Sand from Surplus Quarry Material

Final Report

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Summary

This project was supported by the National Assembly for Wales, via the Aggregates Levy sustainability Fund for Wales. In 2000 the Welsh Assembly acknowledged the need to find a sustainable use for the growing stock piles of crusher fines in Wales, and commissioned research into the use of these fines as a replacement for natural sand. The 2000 study showed that whilst certain crusher dusts were acceptable for use in concrete, they still needed to be blended with natural sands to satisfy the required fine aggregate specifications and desired fresh concrete properties. The report highlighted the need for sand products of consistent quality and acceptable grading and suggested that the manufacturing and screening processes were fundamental to achieving these attributes. It is now believed that this technology has been developed and improved to the point where reprocessed crusher dusts can completely replace natural sand in concrete.

An extensive Cardiff University led laboratory programme, together with information from literature and input from industrial project partners form the basis for the evaluation of the primary aim of this project which was to examine the potential for Kayasand to completely replace natural sand in concrete. The results obtained from the laboratory testing of a range of samples collected for this project provide additional data on grading characteristics and pre and post-processing physical properties of the Kayasand product. Additional investigation into the chemical properties of the Kayasand products is considered in a separate study in order to assess the suitability of the use of the fines in agricultural applications.

Four different rock types were considered in the present study, gritstone (sandstone), limestone, basalt and granite and all appear to varying extents in the geology of South Wales In order to evaluate the use of Kayasand in concrete a suite of physical characterisation tests were performed which were used to identify the effect of the physical sand properties on the fresh and hardened properties of concrete. Mix proportions were established for each individual rock type and a w/c ratio selected to achieve a fresh concrete slump of 50-90mm.

Additional laboratory tests were performed in order to observe the performance of the various Kayasand concrete mixes with the use of plasticisers at a fixed water/cement (w/c) ratio. These mixes allowed the potential for cement savings to be addressed.

The test results demonstrate that with appropriate adjustment to the mix proportions it is possible to replace marine sand in concrete with 100% Kayasand with no detrimental effects on the development of workability as measured by the slump test, compressive or tensile strength. Moreover, there was no apparent relationship between fines content and 28-day compressive strength in any of the Kayasand concretes. This suggests that there are no negative effects of higher fines contents on the compressive strength for the given mix compositions and range of fines contents investigated in the study. An increase in the fines content of the Kayasand mixes generally resulted in a small reduction in the slump of the mix, however only 1 of the 16 Kayasand mixes fell outside of the S2 slump range with some evidence of the fines acting as lubricants in Kayasand concretes with medium fines contents.

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1. Introduction

In 2000 the Welsh Assembly acknowledged the need to find a sustainable use for the growing stock piles of crusher fines in Wales, and commissioned research into the use of these fines as a replacement for natural sand. The 2000 study showed that whilst certain crusher dusts were acceptable for use in concrete, they still needed to be blended with natural sands to satisfy the required fine aggregate specifications and desired fresh concrete properties. The report highlighted the need for sand products of consistent quality and acceptable grading and suggested that the manufacturing and screening processes were fundamental to achieving these attributes.

Wider environmental concerns regarding the depletion of natural aggregate resources have highlighted the need to find alternative sources of fine aggregate. One such source is crushed rock material from stone quarries. However, the material produced differs in characteristics from natural sands. The major differences being its shape and texture, grading and amount of fine filler. These characteristics can detrimentally affect concrete; therefore Manufactured Fine Aggregates (MFAs) are only reluctantly accepted within the industry (Harrison et al., 2000).

The MFA shape is typically highly angular, elongated or flaky. This characteristic greatly influences the fresh and subsequent hardened properties of concrete. MFA shape depends on the parent rock and to large extent on the crushing method (Ahn et al., 2001 and Manning, 2004).

Typical particle size distribution of MFA or “quarry dust” rarely conforms to the requirements of national standards. These types of aggregate can produce “harsh” mixes with bleeding problems if it is washed and screened to fall within the prescribed limits (Harrison et al., 2000). This is mainly due to an excess of fine particles passing the 63 micron sieve and a deficiency of particles in the size range 0.3mm to 1mm. Thus manufactured sands are commonly used in blends with fine natural sands to overcome these shortcomings and minimise the negative effects on fresh and hardened concrete properties.

An alternative to washing and blending is reprocessing the quarry fines by employing another crusher to refine the particle shape and size distribution. Furthermore, if the classification process of the product employs a dry instead of a wet system then environmental benefits can be gained. New methods of manufacturing sand are now available which can more accurately control the sand particle size, shape and gradation including particles in the usually deficient range. Indeed, it is now believed that this technology has improved to the point where reprocessed crusher dusts can completely replace natural sand in concrete.

The aim of this study is to explore the potential for the use of Kayasand, an MFA produced from reprocessing quarry fines, in concrete applications in Wales and the UK as a 100% replacement for natural marine dredged sand.

The motivation for this project is to address the increasing miss balance between the need for aggregates in society and the availability of traditionally suitable geologic sources. A strong need is realised for developing and implementing technology that can enable the use of alternative resources, reduce the need for transport and present zero waste concepts for the aggregate and concrete industry. With small changes in gradations, cement contents in concrete can be minimised in a way never envisaged before. It is also well known that consistency in sand is a key consideration when deciding upon the amount of cement to be used in a mix. Savings in excess of 10% in the cement content have been commonplace in recent tests, but a great deal of test work needs to be done to formulate a model to find the ideal sand gradation for each stone type, including the highest tolerable level of filler content to minimise waste. The results of such an analysis could well lead to specification changes, if significant reductions in cement use generally are to be made, although this is outside the scope of this particular study.

The core objectives of this study are:

- to establish the physical properties of a range of Kayasands of differing mineralogy and fines contents, through a series of standard characterisation tests;
- to determine the effectiveness of the Grace Rapid Methylene Blue Test in comparison with the standard Methylene Blue Test;
- to determine the w/c ratio and mix proportions required for a range of 100% Kayasand mixes of differing mineralogy and fines contents to achieve a slump within a specified range (50-90mm);
- to determine for the same range of 100% Kayasand mixes, the plasticiser content to achieve a slump within a specified range of 50-90mm at a fixed w/c ratio of 0.55;
- to compare the fresh and hardened concrete performance of 100% Kayasand mixes to that of a natural marine dredged sand mix;
- to evaluate the potential for cement savings in the Kayasand mixes to achieve equal performance to a natural marine dredge sand concrete mix.

2. Literature Review

In Wales approximately half of all aggregates for concrete applications are from marine dredged sources, with fine aggregate comprising the majority of this figure (Mankelow et al., 2011). The other half, predominantly comprising coarse aggregates, are from land-base resources. The processing of these coarse aggregates produces crushed quarry fines as a bi-product, which usually represents up to 40% of the quarry output. The crushed quarry fines do find markets as partial fine aggregate replacement materials, but they are generally lower value products, and often a percentage can be classified as surplus or even waste products. The UK has significant reserves of crushed quarry fines in its quarries, which could undergo further processing to provide the majority of the sand required by the construction industry, using the same sales and delivery channels as it does now for its coarse aggregates. The advantage of this being in the ability to specify aggregates from quarries close to their place of end-use, thereby shortening transport distances, followed by less pollution and increased employment opportunities for the local population. However the problem currently lies in the quality of the crushed quarry fines, particularly in their shape, surface texture and grading. Conventional impact crushing techniques have been employed for a number of years as a method by which crushed quarry fines are reprocessed to form sands which are more suitable for concreting applications. However, these MFAs are still deficient in their grading and need to be blended with natural sand before use in concrete. Advances in crushing techniques over the last decade have resulted in technology that produces well-graded MFAs with accurate control over the volume of fines that are returned to the sand after processing.

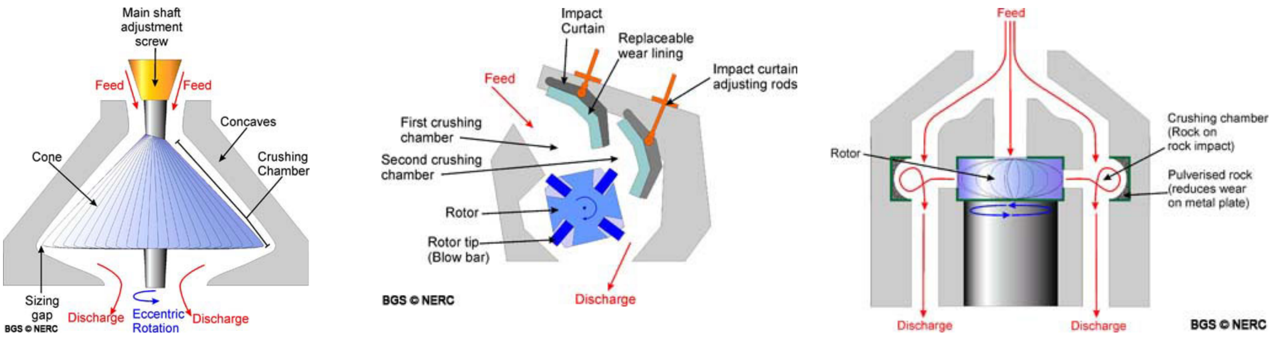
All sands and indeed crushed rocks break differently under impact which results in various gradations and particle shapes. As a result different sand gradation specification “envelopes” generally based on natural sand gradations are provided by construction industry standards worldwide. It is apparent that the best performing sands have good shape and an even gradation, but very little work has been done on actual concrete performance using MFAs.

In order for the complete replacement of natural sand in concrete with MFA it is necessary to understand the influence of the physical and mineralogical properties on the fresh and hardened properties of concrete. This summary of the literature will look at various properties of aggregates, their effects on concrete performance and compile the views expressed in scientific papers. It will present the requirements and recommended tests for MFA in European Standards, published documents and research reports.

2.1 Shape and Texture

Particle shape is influenced by the physical properties of the parent rock and by the method of production. The consistency, flow, yield, air content, water requirement, bleeding and finishability of concrete are all influenced by the particle shape of the fine aggregate (Ahn, 2001). Crushed aggregates contain more angular particles with rougher surface textures and flatter faces than natural sands that are more rounded as a result of weathering experienced over time (Ahn, 2001).

It is very difficult to describe the shape of three-dimensional bodies such as aggregate particles, therefore, it normally proves convenient to define certain geometrical characteristics of such bodies, and the terms used are sphericity, roundness and form. Sphericity is defined as a function of the ratio of the surface area of the particle to its volume. Sphericity is influenced by the type of crushing equipment (examples given in Figure 1) and is related to the bedding and cleavage of the parent rock. Particles with a high ratio of surface area to volume are of particular interest because they increase the water demand for a given consistency of the concrete mixture (Neville, 1995). Roundness measures angularity or relative sharpness of the edges and corners of a particle. Roundness is greatly controlled by the strength and abrasion resistance of the parent rock as well as the wear to which the particle has been subjected. In case of the particle shape of crushed aggregate, it also depends on the type of crusher and its reduction ratio, i.e. the ratio of the size of material fed into the crusher to the size of the finished product. Impact crushers break rock by "hitting" the material, which causes the rock to break along natural zones of weakness along grain interfaces (Marek, 1995) generally producing particles with good cubical shape. Gyratory and cone crushers break rock by compression. Size and shape can be controlled within relatively wide limits with such crushers. Product shape is influenced by (i) the reduction ratio and (ii) the degree to which the crushing chamber is filled with rock. The "best" particle shape is obtained when the crusher chamber is full because a large part of the crushing work is accomplished by interparticle contact. Flat or elongated particles are readily broken into more cubical shapes. Jaw crushers and large gyratories generally produce particles with poor (non-cubical) shape due to the fact that the crushing chamber is rarely full to permit interparticle crushing, and the degree of reduction is high (Marek 1995). Horizontal Shaft Impact (HSI) and Vertical Shaft Impact (VSI) crushers are widely used to crush a range of soft to hard rocks such as basalt, granite, hard limestone. The loading conditions of VSIs typically leads to a higher probability of fracture of either weak or flaky particles, with fracture occurring by cleavage, with a marked contribution from surface attrition. The result is that particles with greater integrity and more isometric shapes are produced by this crushing process in comparison to other techniques, such as cone, jaw and roll crushers.



Cone Crusher   Horizontal Shaft Impact Crusher   Vertical Shaft Impact Crusher

Figure 1. Different forms of crusher (BGS, 2011)

Equidimensional particles are generally preferred to flat and elongated particles for use as concrete aggregates because they present less surface area per unit volume and generally produce tighter packing when consolidated (Marek, 1995). Equidimensional particles of a given grading require a minimum of cement paste for a given degree of consistency of concrete (Marek, 1995). Cubical particles tend to decrease consistency and thus require more cement and water unless the grading (sub 75µm) of the fine aggregate is increased to reduce the void content of the aggregate combination used. Decreasing roundness or increasing angularity directly affects the percentage of voids in the aggregate, and this in turn affects consistency or the mix proportions required. Concrete made with non-spherical aggregates will have higher strength than concrete made with spherical aggregate particles, since the former have a larger surface area, and therefore, greater adhesive forces develop between aggregate particles and the cement matrix (Marek, 1995).

Several different methods have been developed and used to evaluate particle shape or produce a particle shape index (Marek, 1995). These methods include, but are not limited to:

i. Visual comparison of particle silhouettes with standard shapes
ii. Measurement of percentage of voids of individual size fractions, or of standard gradings of fine particles
iii. Measurement of the time of flow required for the material to pass through an orifice, as outlined in BS EN 933 part 6, with reference to the New Zealand flow cone.
iv. Measurement of critical particle dimensions using laser technology or from photographs

Most methods are based on the principle that the volume of voids in the fine aggregate is a function of particle shape and therefore packing ability. Research by Ahn (2001) shows a correlation between flow rate and particle shape and presents a relationship between the average 28-day compressive strength and the orifice flow rate. He noticed that the variations in strength meant that the orifice flow rate could not be used to predict the compressive strength, but there was a general improvement in the compressive strength as the orifice flow rate decreased. Sands with more angular shaped particles took longer to flow due to the interlocking of particles, as opposed to rounded sands which moved past each other much more easily.

The classification of the surface texture is based on the degree to which the particles surfaces are polished or dull, smooth or rough. The surface texture of an aggregate depends on the grain size, hardness and pore characteristics of the parent material, as well as the result of external forces acting on the aggregate surface. There is no recognised method of measuring the surface roughness, however, engineers tend to use a range of approaches to tackle this problem, the most popular is Wright's method: the interface is magnified between the particle and a resin in which it is set, the difference between the length of the profile and the length of an unevenness line drawn as a series of chords is determined and taken as a measure of roughness (Neville, 1995). Additionally, the NZFC has been used as an indirect measure of surface texture.

In summary it is well documented that it is difficult to accurately quantify the shape of an aggregate and determine the exact relationship between its shape and performance in a concrete mix. However, it is apparent that without external influence in the form of superplasticisers there is a compromise between an aggregate's performance in the fresh concrete state and the resulting hardened concrete properties. Whilst angular particles have a detrimental effect on slump and flow, they provide enhanced compressive strength due to greater particle interlock and cement paste bonding. Conversely rounded particles, which tend to have a smoother surface texture, have better flow properties, yet result in lower compressive strength due to weaker interface bonds between the aggregates and cement paste. It seems therefore that manufactured sands, with their isometric shapes may prove beneficial in achieving high compressive strengths if measures are taken to manage their performance in fresh concrete.

2.2 Grading

The suitability of a sand for concrete-making is governed by knowledge of its grading and its void content (Marek, 1995). Aggregate grading has a significant influence on water requirement, consistency, bleeding, segregation and finishing quality of concrete. Current grading specifications for fine aggregate for use in concrete, however, may not define a sand that is suitable for use in concrete. Some sands that comply with existing specifications produce concrete that is harsh and unworkable, prone to bleeding and segregation, and difficult to finish, whilst sands which do not meet present grading specifications may produce concrete with satisfactory fresh and hardened concrete properties. Hewlett (1998) reported that the particle size distribution of the fine aggregate was found to have a greater influence on the properties of concrete than that of the coarse aggregate, if working within permitted standard limits. This is confirmed by Teranishi and Tanigawa (2007) who report that it is the fluidity and segregation resistance in particular that are most affected by the fine aggregate grading. Gonçalves et al (2007) recognised that the crushing processes can also be used to influence the grading of the MFA, particularly the proportion of filler (sub 75µm material). This signifies that through careful selection of crushing and classification techniques it will be possible to produce a sand, from virtually any rock type to meet almost any desired specification.

According to Neville (1995) grading requirements should depend on shape and surface texture of the aggregates. For sharp and angular particles slightly finer grading should be employed to reduce the interlocking possibility and compensate for the high friction between particles. Furthermore, a higher volume of fine aggregate should be used if a crushed and angular coarse aggregate is present in the mix. It follows that for a fine grading of fine aggregate the fine to coarse aggregate ratio should be decreased.

Conventional crushed rock sands typically have a significant number of large particles (~4mm) and an abundance of filler material (<75µm) however, this is normally accompanied by a lack of particles in the 1mm-150µm range (as indicated schematically in Figure 2). Whilst these crushed rock sands can be blended with natural sands there are several factors to address: (i) BS-EN 12620 limits blends of crushed rock fines with natural sand to 50% and (ii) the grading of crushed rock fines are highly inconsistent and therefore it is difficult to establish "standard" mix designs using aggregate from a designated source.

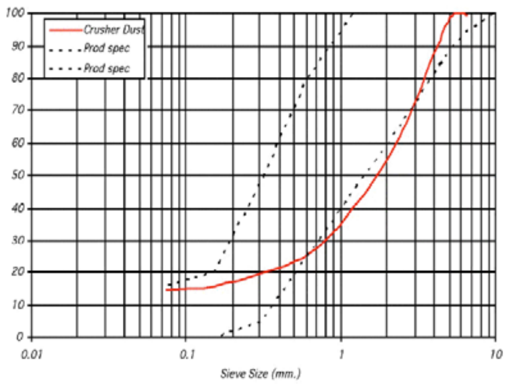


Figure 2. Schematic representation of crushed rock fine grading compared to standard grading envelopes

In summary it appears that there are general guidelines for grading of aggregates, however, the exact grading and combination of aggregates should be estimated based on the properties of aggregates such as shape, texture and packing density as well as on the experience of a particular aggregate's performance in concrete. The influence of aggregate grading on the performance of a concrete mix appears to be the same regardless of the origin of the aggregate (i.e. natural or manufactured) and the concrete industry state that achieving consistency in aggregate grading is one of the most important factors in controlling and potentially reducing cement contents in concretes. Numerous studies indicate that it is the fines (<75µm) component (content and nature) of the fine aggregate that has a greater influence on the fresh and hardened properties of the concrete than the grading alone and therefore this will be explored in more detail in the next section.

2.3 Fines

Fines are defined as the material passing a 75µm sieve (BS EN 12620:2002). In European standards sand and fines are separated at 63µm. These particles may be very fine sand, silt, clay or dust. The presence of a limited quantity of fines is beneficial in a concrete mix as it fulfils a void-filling role, and aids cohesion and finishability. Nevertheless, an excess of fines, especially fines comprising clays, may harm the concrete properties as they increase water demand and reduce the aggregate-cement paste bond both of which result in a reduction in hardened concrete strength (Newman and Choo, 2003).

Research by Celik and Marar (1996) concluded that, as the percentage of fines in the concrete increases, the consistency of the mix decreases, and this was observed via slump measurement with the addition of fines. They also stated that as the fines content of fresh concrete increases, the average air content of the fresh concrete decreases. This indicates that air entrainment can effectively be used as a measurement of void content. The addition of dust also improves the impermeability of concrete due to its pore blocking ability which impedes the movement of moisture and gas through the matrix.

The quantity of filler or "dust" of crushed aggregate used in concrete mixes appears to be relatively similar throughout a vast majority of the studies examined, which is of the order of 10-15%. Celik and Marar (1996) showed in their research that a dust content of 0% to 5% resulted in a number of voids between the cement paste and the aggregate particles, yielding lower compressive strength values than specimens with 10% dust content. As the dust content exceeds 10%, the amount of fines in the concrete increases until there is insufficient cement paste to coat all of the coarse and fine aggregate particles, leading to a decrease in compressive strength. Similar results were also reported by Li et al. (2009) as presented in Figure 3.

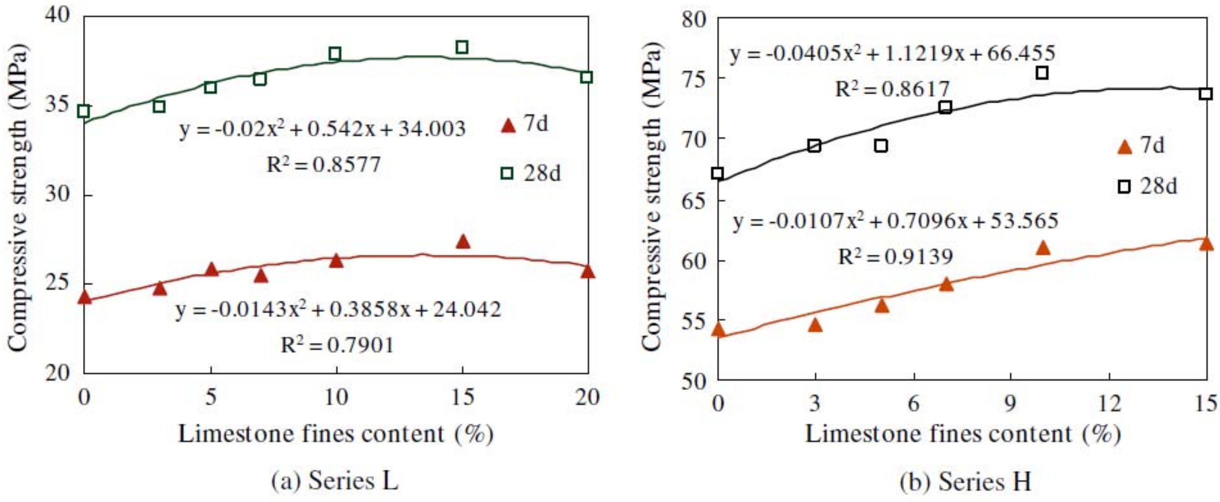


Figure 3. Effect of fines addition on a) low strength concrete and b) high strength concrete (figure reproduced from Li et al., 2009)

Malhotra and Carette (1985) found that at a given water/cement ratio, concrete made with MFA containing up to 7% microfines achieved compressive strengths equal to or higher than concrete made with natural sand, reducing the void content of the aggregate, thereby lubricating the aggregate system without increasing the water requirement of the mix.

In the case of natural sands, the requirements regarding the maximum amount of sub 75µm particles are strictly related to controlling the presence of clays, but for MFAs/quarry fines, the significance is quite different (Dumitru et al., 1999). The sub 75µm fraction resulting from the crushing process of the quarry rocks is likely to have comparable composition with the parent rock. For good quality hard rocks, the fines have the same mineralogy as the parent rocks, whereas for softer rocks, there may be a certain tendency for "segregation" in which the "soft"/alteration components of the rocks would be preferentially concentrated in the fines during the crushing process. It would seem therefore that the type of processing and the rock mineralogy determines the level of fines which may contain clays. Indeed Dumitru et al. (1999) stated that it is advisable to source supply of MFAs from well established sources of aggregate and employ tests such as Methylene Blue Value (MBV) for its performance. This also indicates that a high sub 75µm fraction for good quality manufactured sands does not have to be restricted, and that mineralogical data is essential in assessing the suitability of different aggregates and evaluating actual or potential durability problems (Dumitru et al., 1999). Additionally Dumitru et al. recognised that fines levels up to 15% were possible and more importantly that conventional concrete mixes may need some alterations to achieve the full benefits of incorporating MFAs. These changes may be in the aggregate to sand ratio or admixture dosage.

It has been repeatedly demonstrated in the literature that it is possible to include a high level of filler material within a mix, although it is understood that mix proportions may have to be changed and the use of admixtures explored to compensate for the loss of consistency due to the higher particle surface area and water demand associated with high fines contents.

2.4 Effects of absorption and water content of aggregate

Studies regarding the effect of water absorption of MFA on the fresh properties of a concrete mix appear to focus exclusively on the use of coarse aggregates. However, it is suggested by the authors that the findings of such studies can be equally applied to the use of manufactured fine aggregate in concrete.

The water absorption of aggregate represents the water contained in aggregate in a saturated surface-dry condition. Water content and water absorption are important for concrete mix design as they influence the w/c ratio of concrete which, in turn, affects the consistency of the mix. Normally, it is assumed that the aggregate is in a saturated and surface-dry state at the time of mixing concrete. For aggregate which is in the air-dry or oven-dried condition, it is assumed that some water will be absorbed from the concrete mix to bring the aggregate to a saturated state, decreasing the concrete consistency in the process, therefore additional water is required to provide the necessary w/c ratio. Moreover, when dry aggregate is used, the particles quickly become coated with cement paste forming a barrier to the ingress of any mix water specifically added to the mix to ensure aggregate saturation (Neville, 1995).

According to Poon et al. (2004) the moisture states of aggregate affect the change in slump of the concrete in fresh condition. Oven-dried aggregates led to a higher initial slump than the aggregates in the air-dried and saturated surface-dried state, as indicated in Figure 4. This was attributed to the time dependent nature of aggregate absorption, resulting in mix water designated for absorption remaining within the mix leading to higher values of consistency.

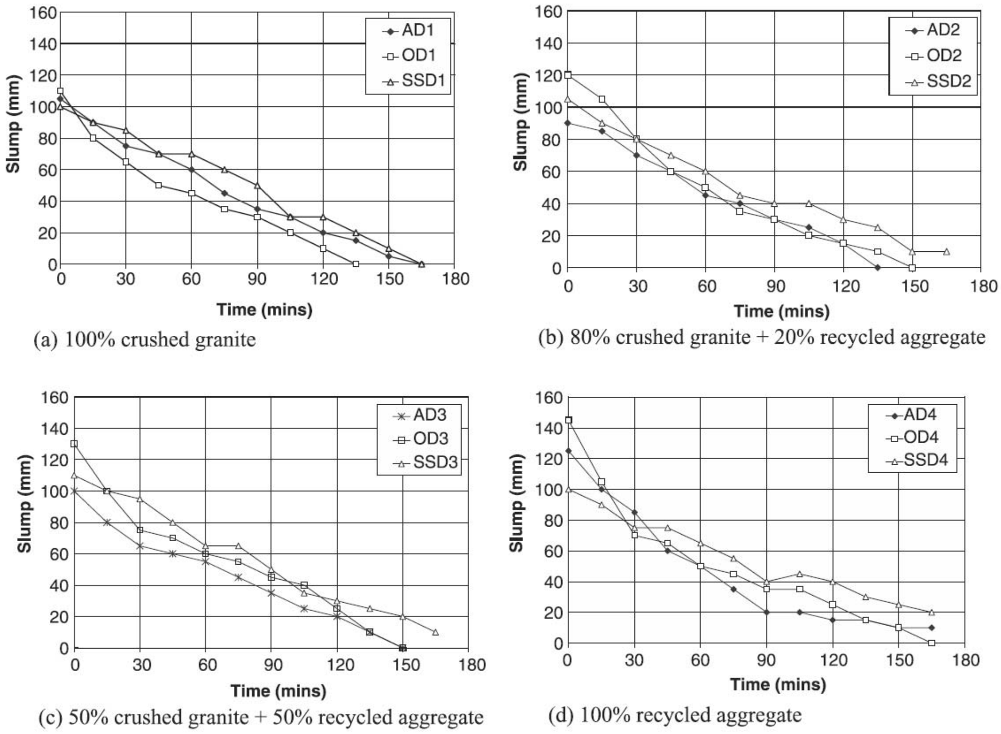


Figure 4. Changes of slump of concrete mixes with different type of coarse aggregate in different moisture conditions (figure reproduced from Poon et al. 2004)

Typically, the absorption capacity between natural sand and MFA is different. This is due to the higher specific surface area of the MFA which tends to be more angular with a rougher surface texture, therefore more water is required to cover all particles in a concrete mixture. Also, the higher absorption of MFA can be related to the process of its production, whereby as a result of the crushing process particles may contain a high percentage of microcracks/fissures, therefore allowing additional water to penetrate inside and, in turn, increase the total water content of the aggregate.

2.5 Aggregate Mineralogy

Aggregates with different mineralogy can produce concrete with various properties. The type of the parent rock will influence the physical and chemical properties of the aggregate as well as particle shape and texture if a crusher is employed to reduce its size. The mineralogical description of the aggregates cannot be used alone to estimate whether it will produce a good concrete or not (Neville 1995). However, the chemical and mineralogical composition can be used as a tool to identify minerals which might interfere with the hydration of cement or cause alkali-silica and alkali-carbonate reactions. It can also be used to identify presence of clay minerals.

Aggregate particles might be covered by clay, silt or crushing dust coatings. These can inhibit the bond between the aggregates and cement paste as well as increase the water demand. However, if the coatings are physically and chemically stable and do not pose a threat to concrete properties, there is no objection to using such aggregate (Neville 1995).

The effect of rock mineralogy upon concrete strength was examined in detail by Donza et al. (2002). The study used granite, limestone and dolomite crushed sand with similar gradings at equal cement content and water cement ratio in concrete mixes. They found that the compressive strength of limestone and dolomite concretes was lower than concretes made with granite sand. This behaviour was attributed to individual particle strength and to the different surface textures and shapes of granite sand particles.

Results by Donza et al. (2002) also showed that concrete with crushed sand required an increase of superplasticiser to obtain the same slump. It also presented a higher strength than the corresponding natural sand concrete at all test ages, while its elastic modulus was lower at 28 days and was the same after that. Studies on the development of hydration and mortar phase of concrete showed that the increase of strength could be attributed to the improvement of the paste–fine aggregate transition zone.

2.6 Specifications and tests for manufactured sands in UK

The current British European standard BS EN 12620:2002 for aggregate properties requires the producer of the fine aggregate to declare the relevant aggregate test values and grading in prescribed categories. This allows the customer to select aggregate for a particular application on the basis of its physical characteristics. However, there are few specified limits included in the standard and as a result PD 6682-1:2009 provides recommended limits for aggregates depending on the end use of concrete in the UK.

Relevant tests for fine aggregates specified in BS EN 12620:2002 and recommended by PD6682-1:2009 for use in UK are:

- Grading (BS EN 933-1).
- Fines content (BS EN 933-1).
- Particle density and water absorption (BS EN 1097-6).
- Bulk density (BS EN 1097-3).
- Chemical requirements (BS EN 1744-1).

Sand Equivalency (SE) provides an indication of the percentage of fines (sub 63µm) contained within a material whilst the Methylene Blue Test (MBV) gives an indication of the clay content of these fines.

BS EN 12620:2002 specifies a number of methods by which fines can be assessed within fine aggregate to be considered as non-harmful for use in concrete. Firstly, the total fines content of the fine aggregate is less than 3 % or another predefined value according to the provisions valid in the place of use of the aggregate. Secondly, the equivalence of performance with known satisfactory aggregate is established or there is evidence of satisfactory use with no experience of problems. Lastly there are country specific limits on the Sand Equivalent (SE) value and Methylene Blue test value (MBV) when tested in accordance with their relevant BS EN standard. Additionally, PD 6682-1:2009 recommends that crushed rock sands could contain up to 16% of fines and be considered non-harmful provided that the materials have been processed. Another recommended option is evidence of satisfactory use. No limits for SE and MBV are provided for the UK as these tests and their interpretation are considered inaccurate.

With respect to grading there is no distinction between crushed and natural sand. Another point to note is that there are no specifications for fine aggregate shape and texture in BS EN 12620:2002, although limited provision is made in BS EN 933-6 for testing these characteristics. As discussed in previous sections, these characteristics can influence the performance of concrete and some guidelines would be beneficial in allowing quantitative evaluation of fine aggregate for expected performance in a concrete mix.

3. Kayasand

In an attempt to reduce the undesirable and detrimental characteristics of MFA Japanese-based KEMCO (Kotobuki Engineering & Manufacturing Co) have developed a new dry sand manufacturing system. The KEMCO V7, illustrated in Figure 5, plant merges the conventional VSI crusher with a centrifugal attrition chamber in order to produce Kayasand; a better shaped and graded fine aggregate with controllable amounts of filler dust. There are two elements of the KEMCO V7 that make it unique in comparison to other crushing machine available on the market. Firstly, the quarry waste material is fed into a crusher chamber, containing a milling function designed so that all particles are subjected to multiple impacts and to help ensure that particles within the normally deficient range of 150µm-1mm are produced. The particles then move to a classifying system using fans to separate particles based on their weight, which allows oversize particles to be

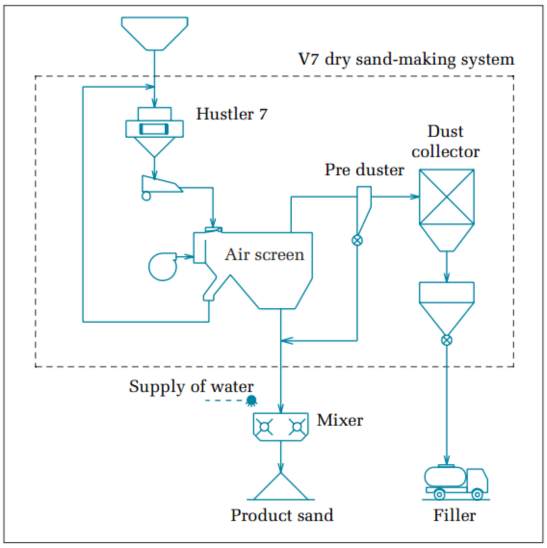


Figure 5. V7 Dry Sand-Making System

(Figure reproduced from Pettingell 2008)

recirculated back to the crusher to undergo further processing. This facility also allows accurate control of the particle grading, particularly of the larger particles at the top end of the grading curve. From the air screen the particles are moved either to the mixer (finished product) or to the dust collector unit, with the potential to return a proportion of fillers, of varying gradations back to the mixer to create the final Kayasand product. By altering various parameters, it is possible to produce a consistent sand product to any reasonable specification.

Compared to the product of conventional sand manufacturing processes, Kayasand is, according to the company, in the position of completely substituting natural sea or river bed dredged sand in concrete and mortar, yielding similar or even higher mechanical properties (Pettingell, 2008). A number of studies have been completed at Cardiff University that support this view for a range of different concrete products, including mortar, self compacting concrete and extrudable concrete (Parton 2012, Chiew 2012, Volodskojs 2012 and Kroh 2010). Furthermore, these studies demonstrated that concretes made with Kayasand also had similar durability indices. According to Pilegis et al. (2012) Kayasand MFA can be used as a replacement for natural sand in concrete. In this study Kayasand has successfully replaced granite and basalt sands in concrete giving higher compressive strength at the same water/cement ratio as natural sand but with a reduction in concrete consistency.

4. Laboratory Testing Programme

A description of the experimental procedures adopted for the studies is reported in this section. The quality and preparation of the main materials used for each concrete mix, the mixing and casting details and the curing regimes used during these studies are also described. Details of trial mixes are reported in quarterly reports 1-4 which have been reproduced in Appendix 1. Industrial input was sought when developing mix proportions and target slump ranges. The laboratory testing programme is divided into two stages. The first stage uses a consistent w/c ratio for each sand which was selected on the basis of obtaining an S2 slump in the –B (approximately 3%) Kayasand grading. The second stage employs a consistent w/c ratio of 0.55 for all sands and achieving an S2 slump through the use of a water reducing admixture.

4.1 Materials

The cement used was CEM I 52.5 N conforming to EN 197-1, supplied by CEMEX. The coarse aggregate used was crushed limestone 4/20mm. In this study marine dredged natural sand was used as a control and it is denoted by the letter N in the tables and figures in this report. The Kayasand sand was processed from 0/8 mm crusher dusts (FEED) taken from four quarries located in the UK, these were: Taff's Well Limestone (L), Gilfach Gritstone (S), Duntilland Basalt (B) and Glensanda Granite (G). Properties of the 0/4mm parts of the crusher dusts were determined via fine aggregate classification tests. The crusher dust, or feed material, is referred to as X-FEED in this report where X is the rock aggregate identifier previously given. From the crusher dusts a number of sands with different particle size distributions (gradings) were produced. These gradings for each rock type are denoted -A to -D (or -E where appropriate) depending on the sub 63 μm particle content. For example, B-A is a basalt sand with the least fines content, whereas B-D is a basalt sand with the highest fines content. The fines content of each of the mixes is reported in Table 1.

4.2 Fine aggregate classification tests

A series of characterisation tests were performed on the fine aggregate as outlined in the following sections of this report.

4.2.1 Grading

Dry sieving was performed in the laboratories at Cardiff University according to standard BS EN 933-1 (2012) and the results compared to the KEMCO output reports. Dry sieving was also completed for the coarse aggregates employed in the study. Research by Hudson (2011) indicates that it is best to perform a wet sieve analysis for fine aggregates. Most specifications call for rigid tolerances on the finest size fractions. If these size fractions are indeed important, which they are with respect to sub 63um and the amount of deleterious fines, then wet sieve analysis has been shown to better quantify this material in the sample. Therefore, additional wet sieving was performed at the Hanson laboratories.

4.2.2 Methylene Blue Test, Rapid Methylene Blue Test and Sand Equivalence Test

MBV and SE tests were used to assess the presence of potentially deleterious fines e.g. clays in the fine aggregate which could adversely affect the fresh and hardened properties of the concrete. The MBV and SE tests were performed on the 0/2mm fine aggregate fraction according to BS EN 933-9 and BS EN 933-8 respectively, however a brief overview of the tests is provided in the following paragraphs.

The MBV test was undertaken by adding methylene blue dye to a sample of sand in suspension and measuring the quantity of dye absorbed via observing the excess released from the particle surface when in contact with filter paper. The principle of the test is that clay minerals adsorb basic dyes from aqueous solutions, therefore the greater the quantity of dye absorbed the greater the quantity of potentially harmful fines present. However the interpretation of the test results is often subjective and as a result significant variation in the results may be observed within the same sample set when examined by a number of different researchers. The RMBV test, developed by Grace Construction Products eliminates this problem as well as reducing the testing time. The test sample was mixed with a methylene blue solution of known concentration, shaken for a fixed time and an aliquot of the suspension was filtered. Afterwards a known volume of the filtrate was diluted with a set amount of water and a pre-calibrated colorimeter was used to estimate the concentration of the solution. This allowed direct estimation of the absorbed amount of methylene blue solution eliminating possible errors due to human judgement. The RMBV test was used in this study to compare the results obtained by the two methods and evaluate the feasibility of the new method.

The SE test provides a rapid assessment of the proportion of clay or plastic fines in the 0/2 mm fraction of a fine aggregate. A small quantity of flocculating solution and a measured volume of oven dried fine aggregate are poured into a measuring cylinder. Agitation loosens the clay like coatings from the coarser particles and irrigation with an additional flocculating agent forces the clay-like material into suspension above the fine aggregate. The sample is allowed to settle for a twenty-minute period and the heights of the columns of clay and sand are measured. The sand equivalent is reported as the ratio of the height of the sediment expressed as a percentage of the total height.

4.2.3 New Zealand Flow Cone (NZFC)

The NZFC (NZS 3111 Section 19) test evaluates sand flow and un-compacted voids ratio. It is widely used within New Zealand and, to a lesser extent, in other countries as a measure of sand characteristics. It involves a fixed volume of sand passing through a cone which is collected in a container of known volume whilst the flow time is measured. Using the density of the sand particles the un-compacted voids ratio can be calculated. The test result is affected by the grading of the sample, by the particle shape and by the surface texture of the particles. The flow of the material is mostly affected by the shape and surface texture of the particles while the voids result is mostly influenced by their grading and shape (Thomas et al. 2007). As such it is an indirect measure of shape and texture and a standard envelope has been developed for natural sands based on the experiences of the New Zealand authorities regarding the performance of various natural sands in concrete. Although the British European Standards EN 933-6 and BS EN 1097-6 evaluate the flow time and un-compacted voids ratio, they do not provide the opportunity to do that simultaneously, as found in the NZFC test.

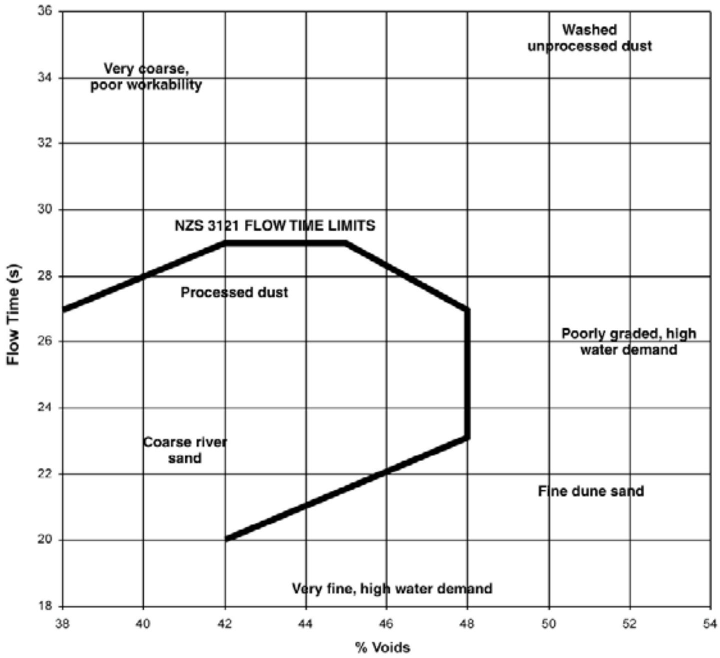


Figure 6. NZFC Flow time envelope (Figure reproduced from Goldsworthy, 2005)

The NZFC is a rapid test that does not require sophisticated equipment and experienced operator as opposed to visual shape and texture estimation techniques. The results are plotted on the diagram shown in Figure 6 with reference to a standard envelope developed in the 1980s by the New Zealand Ministry of Works who tested a variety of sands and measured their influence on the properties of fresh concrete. It was concluded that sand that lies within the prescribed envelope consistently produces good results.

4.3 Mix Proportions

4.3.1 Mix proportions Stage 1

Mix proportions were established after a number of trial mixes and with consultation with industrial collaborators. For each quarry a trial mix using 100% Kayasand with a fines content of 2.8% (X-B) was made adjusting the water content to reach a slump of 50-90mm (industry designated S2 Slump). Other mixes comprising the same quarry material were then made using the established w/c ratio and the resulting slump for each mix recorded. Acknowledging the fact that the natural sand has a significantly different water demand to the Kayasand for each quarry there were two control mixes, the first with a 70±20mm slump and the second with the same w/c ratio as used in the Kayasand mixtures. The slump control mixture in this report is denoted as N whereas the other controls are N-X, where X again represents the aggregate identifier. Mixes were also cast using the FEED material from each quarry. These mixes were again proportioned such that only the w/c ratio was adjusted to obtain an S2 slump. The FEED mixes used 100% of the crusher dust as the replacement for natural sand and therefore it should be highlighted that whilst this has been performed in this study to demonstrate the benefits of the Kayasand processing technique the usual practice is to blend the crusher dust material with natural sand for use in concrete. The mix proportions used in the first stage of this study are presented in Table 1.

It is recognised that the cement content of 350kg/m^3 is towards the upper end of the limits generally used in industry. To maintain the same mix proportions throughout the study required this level of cement together with a coarse to fine aggregate ratio of 1:0.72 in order to achieve workable mixes in each of the different concrete mixes. Parallel work undertaken by industrial collaborators has used a range of cement contents to demonstrate the effectiveness of Kayasand as a 100% replacement for natural sand in concrete and the reader is directed to their investigations for further information.

Table 1. Stage 1 concrete mix proportions at SSD conditions

MIX	CEM kg/m^3	CA[+] kg/m^3	FA[*] kg/m^3	WATER kg/m^3	W/C	FA/ CA	FINES CONTENT % of FA
N	350	1040	753	167	0.48	0.42	1.0
G-FEED	350	1040	753	231	0.66	0.42	10.0
N-G	350	1040	753	202	0.58	0.42	1.0
G-A	350	1040	753	202	0.58	0.42	2.0
G-B	350	1040	753	202	0.58	0.42	2.8
G-C	350	1040	753	202	0.58	0.42	5.1
G-D	350	1040	753	202	0.58	0.42	6.5
G-E	350	1040	753	202	0.58	0.42	9.0
B-FEED	350	1040	753	260	0.87	0.42	13
N-B	350	1040	753	234	0.67	0.42	1.0
B-A	350	1040	753	234	0.67	0.42	1.0
B-B	350	1040	753	234	0.67	0.42	2.9
B-C	350	1040	753	234	0.67	0.42	5.1
B-D	350	1040	753	234	0.67	0.42	7.4
L-FEED	350	1040	753	215	0.61	0.42	12
N-L	350	1040	753	194	0.55	0.42	1.0
L-A	350	1040	753	194	0.55	0.42	2.8
L-B	350	1040	753	194	0.55	0.42	4.9
L-C	350	1040	753	194	0.55	0.42	7.1
L-D	350	1040	753	194	0.55	0.42	9.0
S-FEED	350	1040	753	262	0.748	0.42	18
N-S	350	1040	753	235	0.67	0.42	1.0
S-A	350	1040	753	235	0.67	0.42	3.5
S-B	350	1040	753	235	0.67	0.42	5.0
S-C	350	1040	753	235	0.67	0.42	7.0
S-D	350	1040	753	235	0.67	0.42	9.0

[+]CA – coarse aggregate; [*]FA – fine aggregate

4.3.2 Mix proportions Stage 2

In the second stage the w/c ratios were limited to 0.55 based on the maximum water cement ratio recommend in BS EN 206-1 for a range of typical exposure classes for normal strength concrete (in the range 30-60N/mm^2). A mid-range water reducing admixture (WRDA 90 plasticiser) was then used in the mix to target a 70mm slump (in the S2 slump range). Stage one demonstrated that the limestone Kayasand mixes could achieve an S2 slump at 0.55 water/cement ratio without the use of plasticiser, therefore in the second stage a lower water/cement ratio of 0.50 was employed for this rock type alone. No mixes were cast using the FEED material in this stage and the natural sand control was also made with a 0.55 water/cement ratio. The mix proportions used in the second stage are presented in Table 2. Volumes of plasticiser were limited by the maximum dosage recommended by the admixture manufacturer of 800ml per 100kg of cement (2.75l/m^3). In some instances this was exceeded in order to achieve an S2 slump. Again the reader is directed to the industrial collaborators' investigations for additional mixes made with plasticiser.

Table 2. Stage 2 Table 2. Concrete mix proportions at SSD conditions

MIX	CEM kg/m^3	CA$^+$ kg/m^3	FA* kg/m^3	WATER kg/m^3	W/C	FA/ CA	PLASTICISER l/m^3	FINES CONTENT % of FA
N	350	1040	753	192.5	0.55	0.42	0	1.0
G-A	350	1040	753	192.5	0.55	0.42	0	2.0
G-B	350	1040	753	192.5	0.55	0.42	0	2.8
G-C	350	1040	753	192.5	0.55	0.42	1.25	5.1
G-D	350	1040	753	192.5	0.55	0.42	0.62	6.5
G-E	350	1040	753	192.5	0.55	0.42	1	9.0
B-A	350	1040	753	192.5	0.55	0.42	2.75	1.0
B-B	350	1040	753	192.5	0.55	0.42	2.75	2.9
B-C	350	1040	753	192.5	0.55	0.42	3.3	5.1
B-D	350	1040	753	192.5	0.55	0.42	3.3	7.4
L-A	350	1040	753	175	0.50	0.42	1.63	2.8
L-B	350	1040	753	175	0.50	0.42	1.1	4.9
L-C	350	1040	753	175	0.50	0.42	1.35	7.1
L-D	350	1040	753	175	0.50	0.42	1.1	9.0
S-A	350	1040	753	192.5	0.55	0.42	0.45	3.5
S-B	350	1040	753	192.5	0.55	0.42	2.75	5.0
S-C	350	1040	753	192.5	0.55	0.42	2.75	7.0
S-D	350	1040	753	192.5	0.55	0.42	2.75	9.0

$^+$CA – coarse aggregate; *FA – fine aggregate

4.4 Fresh Concrete Tests

Fresh concrete was tested for slump according to BS EN 12350-2:2009, air entrapment (BS1881: Part 106) and plastic density, although this was limited to the Kayasand and natural mixes and not the FEED mixes.

4.5 Hardened Concrete Specimen Numbers and Tests

In order to perform compressive strength tests ten 100mm cubes were cast in each mix (six for the FEED mixes). These cubes were tested at 1, 7 and 28 days according to BS EN 12390-3:2009. For flexural strength three 100mm x 100mm x 500mm beams were cast from each mix and tested at 28 days according to BS EN 12390-5:2009. The concrete specimens were de-moulded 16 to 20 hours after casting and placed in water tanks at a constant temperature of 20°C until the test age was reached.

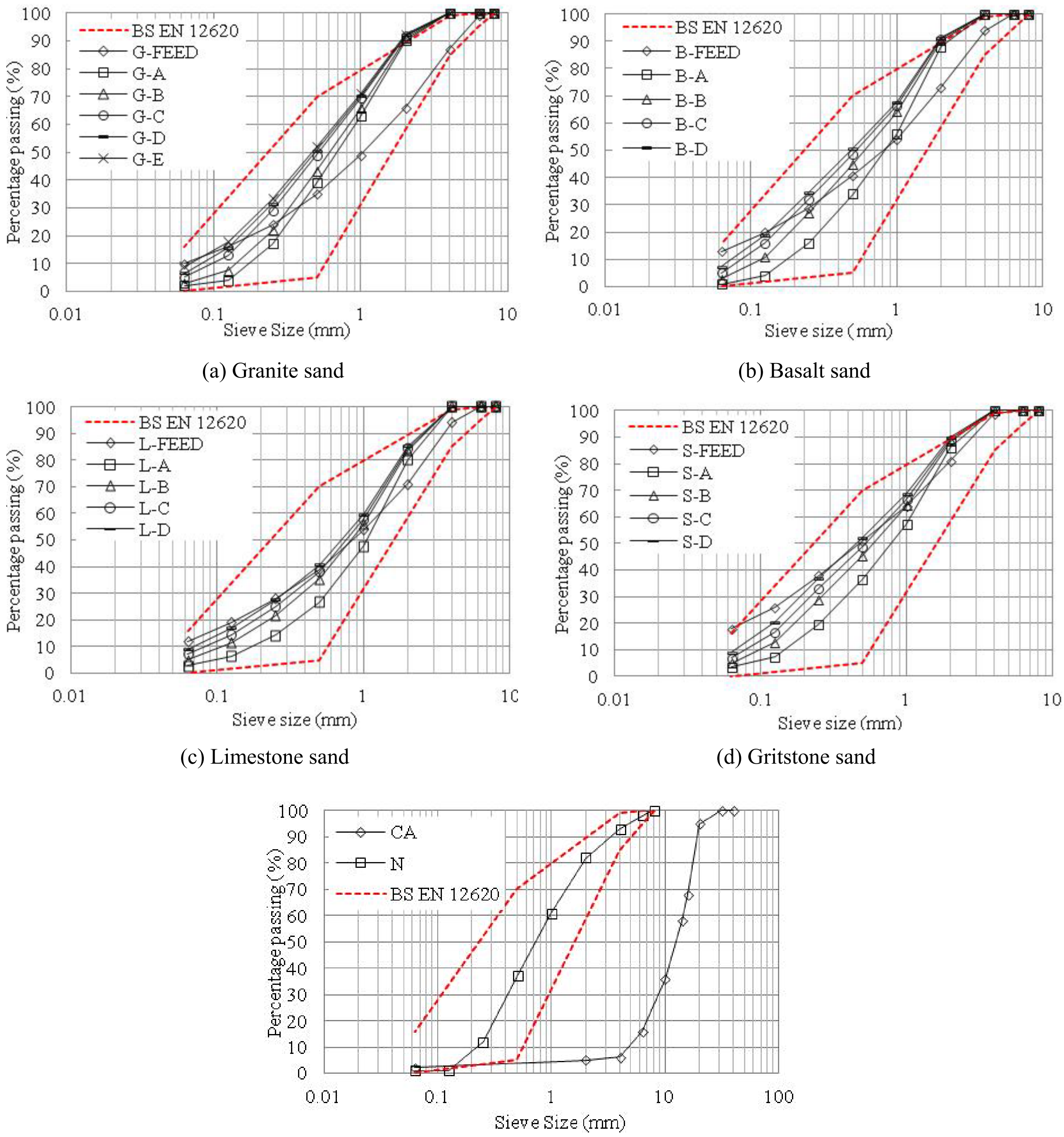
5. Results and Discussion

5.1 Classification tests

5.1.1 Grading

Figure 7 (a) to (d) show the particle size distributions for manufactured sands and corresponding crusher dust 0-4 mm fractions used in the sand production. It can be seen that all manufactured sands irrespective of the parent rock yield similar particle size distributions with sub 63 µm particle content ranging from 1% to 9 % and all fall within the grading envelope specified by BS EN 12620. Furthermore, gradings that contain higher levels of fines have a greater number of particles in the 0.3mm to 1 mm range than the feed crusher dust fractions as indicated by steeper gradients of the particle size distribution curves in that region. The 0.3mm to 1mm fraction is usually deemed to be deficient in crusher dusts, therefore, requiring a blend with natural sand to comply with standards and perform adequately in concrete mixtures, as identified previously in Section 2.2. The particle size distribution results for the FEED materials indicate that the crusher dust gradings generally lie towards the lower limit of the grading envelope. It should be highlighted here that these results were obtained from small samples of crusher dust obtained from stockpiles at each of the quarries at a different time to when the raw material was selected for shipment and due to this direct improvements in grading as a result of the processing technique cannot be readily identified between this material and the final product produced by KEMCO. However, during the processing of the sand KEMCO did perform a series of grading tests on the FEED and resulting Kayasand and these tests clearly showed an improvement in size distribution such that all results conformed to the BS EN 12620 grading envelope. KEMCO's results will not be discussed further in this report but for completeness, extracts of their test report results are provided in Appendix 2. Particle size distribution tests were also performed in the Cardiff University laboratory for the coarse aggregate and natural control sand as indicated in Figure 7(e).

The Kayasand product yield from the crushing processes is between 66% to 87% depending on the rock mineralogy and level of fines (higher yield occurs when more fines are included in the final sand product) and therefore significant levels of filler are still produced alongside the final Kayasand product. The use of this filler in geoenvironmental applications is the subject of a parallel study being undertaken in the Cardiff School of Engineering.



(a) Granite sand

(b) Basalt sand

(c) Limestone sand

(d) Gritstone sand

(e) Coarse aggregate and natural sand

Figure 7. Particle size distribution curves for Kayasand material

5.1.2 Methylene Blue and Sand Equivalence Test Results

Standard and rapid methylene blue results and sand equivalent results are presented in Table 3. Marine dredged sand had the lowest MBV and highest SE value indicating a very clean sand. This is as expected since natural sand from a dredged source typically has less than 1% fines as a result of them being washed out of the sand during the dredging and screening process. The limestone has consistently low MBV across all sand gradings and FEED material, indicating a clean sand with insignificant levels of deleterious fines.

Table 1 also demonstrates a distinct difference in the MBV between the FEED material and the final Kayasand products, with the processing procedure reducing the MBV value by over 50% for the granite, basalt and sandstone aggregates. It can therefore be concluded that during the processing a proportion of clay sized particles (<2 μm) has been removed from the material as part of the filler component lowering the MBV value of the sand, as previously reported by Dumitru et al. (1999). This is beneficial for the Kayasand product and its potential use as 100% replacement for natural sand particularly in instances in which there are limits placed on the MBV that may be met through the Kayasand processing system. However, further investigation is recommended if the Kayasand filler component of certain rock types is intended for use in concrete, especially since the MBV associated with the filler may still be at elevated levels.

Table 3. Fine aggregate classification results

<table>
<tr><th>SAMPLE</th><th>MBV
(g MB sol^n/kg sand)</th><th>GMBV
(g MB sol^n/kg sand)</th><th>SE</th><th>NZFC Voids
(%)</th><th>NZFC Flow time
(s)</th><th>WA_{24}
(%)</th><th>ρ_{ssd}
(Mg/m^3)</th><th>ρ_{od}
(Mg/m^3)</th><th>ρ_a
(Mg/m^3)</th></tr>
<tr><td>N</td><td>0.24</td><td>0.35</td><td>94</td><td>37.9</td><td>20.9</td><td>1.04</td><td>2.66</td><td>2.63</td><td>2.71</td></tr>
<tr><td>G-FEED</td><td>0.77</td><td>0.94</td><td>50</td><td>42.4</td><td>29.1</td><td>0.58</td><td>2.64</td><td>2.62</td><td>2.66</td></tr>
<tr><td>G-A</td><td>0.39</td><td>0.42</td><td>80</td><td>45.2</td><td>25.3</td><td rowspan="5">0.58</td><td rowspan="5">2.63</td><td rowspan="5">2.61</td><td rowspan="5">2.65</td></tr>
<tr><td>G-B</td><td>0.40</td><td>0.5</td><td>74</td><td>44.6</td><td>24.4</td></tr>
<tr><td>G-C</td><td>0.47</td><td>0.71</td><td>71</td><td>43.7</td><td>23.9</td></tr>
<tr><td>G-D</td><td>0.50</td><td>0.88</td><td>70</td><td>43.6</td><td>23.4</td></tr>
<tr><td>G-E</td><td>0.63</td><td>0.9</td><td>69</td><td>42.7</td><td>23.9</td></tr>
<tr><td>B-FEED</td><td>5.36</td><td>6.16</td><td>48</td><td>45.7</td><td>36.7</td><td>1.92</td><td>2.89</td><td>2.83</td><td>3</td></tr>
<tr><td>B-A</td><td>2.10</td><td>2.3</td><td>73</td><td>45.8</td><td>25.7</td><td rowspan="4">1.67</td><td rowspan="4">2.91</td><td rowspan="4">2.87</td><td rowspan="4">3.01</td></tr>
<tr><td>B-B</td><td>2.29</td><td>2.54</td><td>61</td><td>44.5</td><td>23.2</td></tr>
<tr><td>B-C</td><td>2.64</td><td>2.97</td><td>60</td><td>43.7</td><td>22.5</td></tr>
<tr><td>B-D</td><td>2.90</td><td>3.75</td><td>58</td><td>43.7</td><td>22.3</td></tr>
<tr><td>L-FEED</td><td>0.40</td><td>0.65</td><td>65</td><td>42.4</td><td>32.4</td><td>0.62</td><td>2.90</td><td>2.85</td><td>2.87</td></tr>
<tr><td>L-A</td><td>0.47</td><td>0.44</td><td>72</td><td>43.6</td><td>26.3</td><td rowspan="4">0.45</td><td rowspan="4">2.89</td><td rowspan="4">2.85</td><td rowspan="4">2.86</td></tr>
<tr><td>L-B</td><td>0.40</td><td>0.44</td><td>71</td><td>42.1</td><td>23.9</td></tr>
<tr><td>L-C</td><td>0.40</td><td>0.44</td><td>71</td><td>41.9</td><td>23.4</td></tr>
<tr><td>L-D</td><td>0.37</td><td>0.45</td><td>67</td><td>41.0</td><td>23.0</td></tr>
<tr><td>S-FEED</td><td>3.19</td><td>4.05</td><td>27</td><td>45.9</td><td>28.6</td><td>1.53</td><td>2.76</td><td>2.64</td><td>2.68</td></tr>
<tr><td>S-A</td><td>1.40</td><td>1.73</td><td>31</td><td>41.8</td><td>23.3</td><td rowspan="4">0.98</td><td rowspan="4">2.64</td><td rowspan="4">2.57</td><td rowspan="4">2.60</td></tr>
<tr><td>S-B</td><td>1.48</td><td>1.84</td><td>30</td><td>41.6</td><td>22.3</td></tr>
<tr><td>S-C</td><td>1.50</td><td>1.86</td><td>28</td><td>40.8</td><td>21.3</td></tr>
<tr><td>S-D</td><td>1.63</td><td>2.07</td><td>27</td><td>40.1</td><td>20.7</td></tr>
</table>

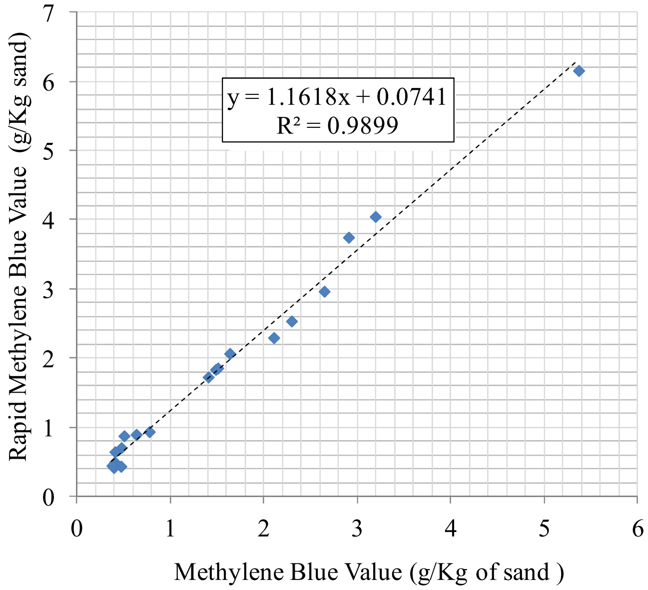


Figure 8. Correlation between RMBV and MBV values for all samples

It can be seen in Table 3 that the sand equivalent (SE) values have increased for the processed quarry dusts. The SE values are the highest for manufactured sands with the least fines and gradually decrease with increasing fines content, a similar inverse trend to that observed in the MBV values, which can be attributed to the removal of clay sized particles during the manufacturing process.

One objective of the project was to compare the Grace RMBV test with the MBV standard test. This was done for each of the four rock mineralogies for all Kayasand gradations and crusher dust material. It can be seen in Figure 8 that the test results obtained using the Rapid test have an excellent correlation (R^2 = 0.99) to the test results obtained via the standard method. The use of the RMBV is therefore recommended for use in all future tests as it eliminates any inconsistency associated with the interpretation of the end point of the standard test.

5.1.3 NZFC Test Results

Figure 9 and Table 3 presents the results from the NZFC test. New Zealand specification NZS 3121 has been used as the envelope as justified in Section 4.2.3. The control sand falls comfortably within the specification envelope as anticipated. The FEED material for each aggregate type lies either on or outside of the envelope suggesting that it suffers from either poor shape and/or grading physical properties. The flow time has been greatly reduced for the Kayasands; at least 4 seconds for granite sands, 11 seconds for basalt sands, 6 seconds for limestone sands and 5 seconds for sandstone sands. This suggests that the particle shape for all aggregates has been modified and after processing it is less angular and flaky. Visual inspection suggested that the basalt and sandstone crusher dust particles were mostly angular and flaky whereas the Kayasand particles were mostly rounded without sharp edges, yielding a reduction in flow time and in voids content. Similarly granite and limestone FEED particles were highly angular and flaky, however the Kayasand particles were mostly cubical with sharp edges but without flaky particles, which resulted in a reduction in flow time although there was associated reduction in voids content.

The general trends that can be observed in Figure 9 are (i) the voids content decreases as the quantity of fines increases due to an increased degree of particle packing and (ii) the flow time decreases with increasing fines content. The latter is an interesting result and it is suggested that this is due to the lubricating effect of the fine particles, as reported previously by Jackson and Brown (1996).

In summary the processing of the sand *via* the KEMCO system has optimised the grading and shape of the Kayasand particles and provides additional justification for their use as 100% natural sand replacement in concrete.

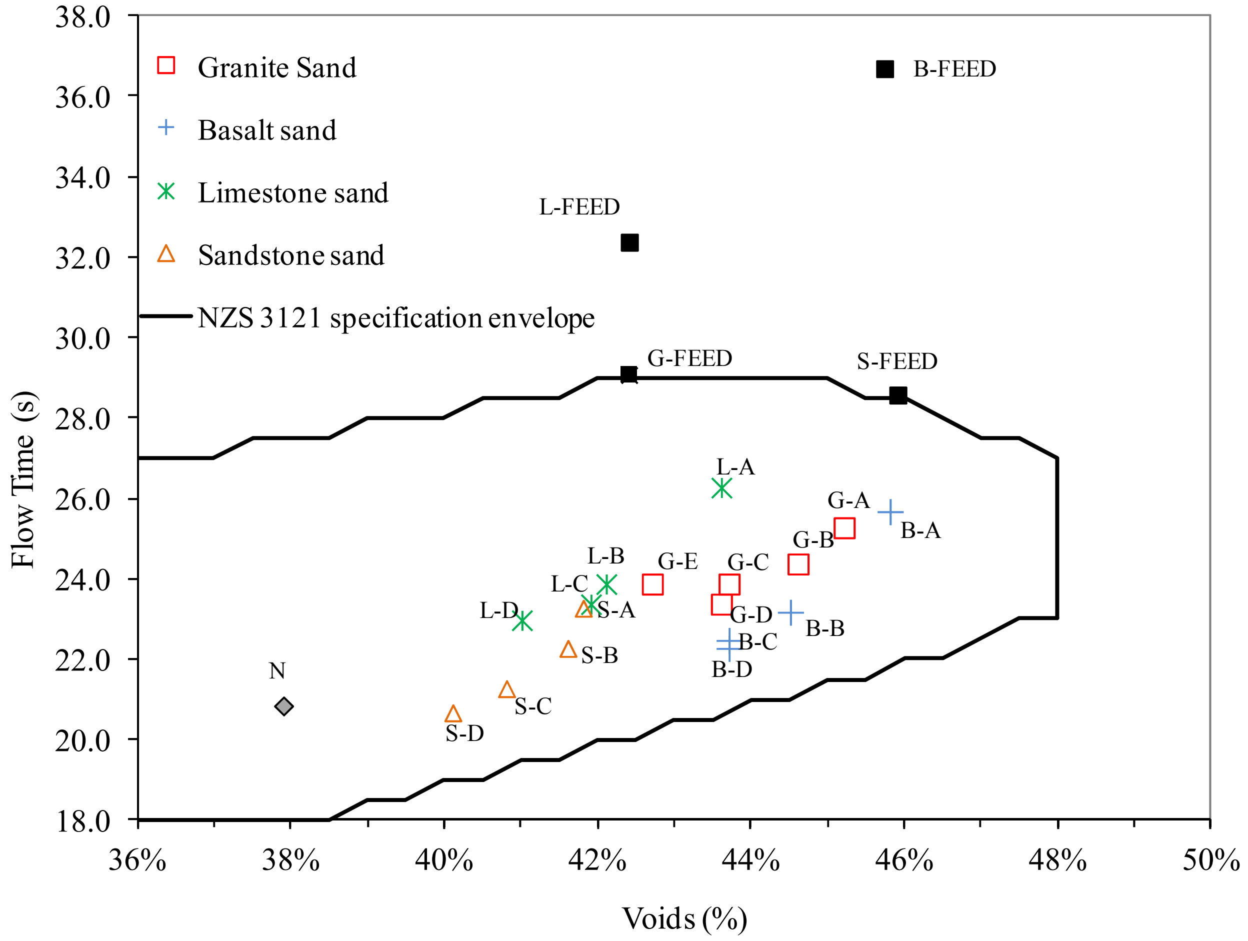


Figure 9. NZFC voids and flow time results for all FEED and Kayasand material

5.1.4 Water Absorption Results and Particle Density

The results from the water absorption tests are reported in Table 3. The test was performed on the 4mm to 63µm fraction of the sand and therefore any differences in the water absorption between the FEED material and the Kayasand product are unlikely to be due to the difference in mass of the sub 63µm particles in the sample. It is acknowledged by the authors that although the FEED material was washed over a 63µm sieve this may not have separated all of the sub 63µm particles from the sand and therefore the FEED material for all aggregate may have contained sufficient levels of fines, some containing clays, to influence the water absorption level. The water absorption tests on Kayasand were performed on the product prior to incorporation of the preduster (additional filler) and therefore the quantity of sub 63µm particles fines in the sand is significantly lower than that of the FEED material. This alone may be responsible for the lower water absorption levels reported for the Kayasand sands. Additionally, the V7 process may influence the water absorption in the following ways (i) it air-scrubs the particles as well as rounds them therefore removing clay coatings and reducing the specific surface area and that in turn yields lower absorption values and (ii) the crushing process breaks particles via areas of weakness (internal pores and cracks) therefore reducing the volume in the sand particles which can be occupied by water.

The basalt and sandstone aggregates had the highest water absorption values of all of the aggregates due to the presence of water absorbing deleterious fines (clays etc) in the fines proportion of the aggregate. The Granite aggregate had the lowest and most consistent water absorption between the FEED and Kayasand materials perhaps due to the inherently low absorption of the parent rock and the greater removal of the fines component during the processing procedure.

5.2 Fresh and Hardened Concrete Tests

5.2.1 Fresh Concrete Properties

The slump test was employed to give an idea of concrete consistency, i.e. its ability to be mixed, placed and compacted. The results presented in Figure 10 and in Table 4 demonstrate a general trend of decreasing slump as the fines content increases as a result of an associated increase in the specific surface area of the sands. However, there are a number of exceptions to this trend, namely mixes B-B, S-C and L-C in particular, where the slump values are higher than the expected trend. This may be due to a lubricating effect of the fines, as observed previously by Malhotra and Carette (1985) in fresh concrete mixes, that occurs as a result of the achievement of optimum void packing with additional fines providing lubrication before a further addition of fines results in an excessive water demand and insufficient paste coverage and an associated reduction in slump. This effect may only be apparent in some of the aggregate types due to their particle shape and gradation.

Natural sand required the least water to cement ratio (0.48) to reach the S2 slump, as a result of the intrinsic roundness of the sand particles as well as lack of fines which have usually been washed out during the dredging process. Basalt and sandstone sands required higher w/c ratio (0.67) than granite and limestone sands (0.58 and 0.55 respectively) to achieve an S2 slump. This was due to presence of clay particles in the sands as indicated by the MBV test discussed previously.

As a result of controlling the w/c ratio for each aggregate via the Kayasand grading –B several mixes fell outside of the S2 slump range. This is not envisaged to be a concern however, and compressive strength results will be reported with reference to the values of slump in the following section.

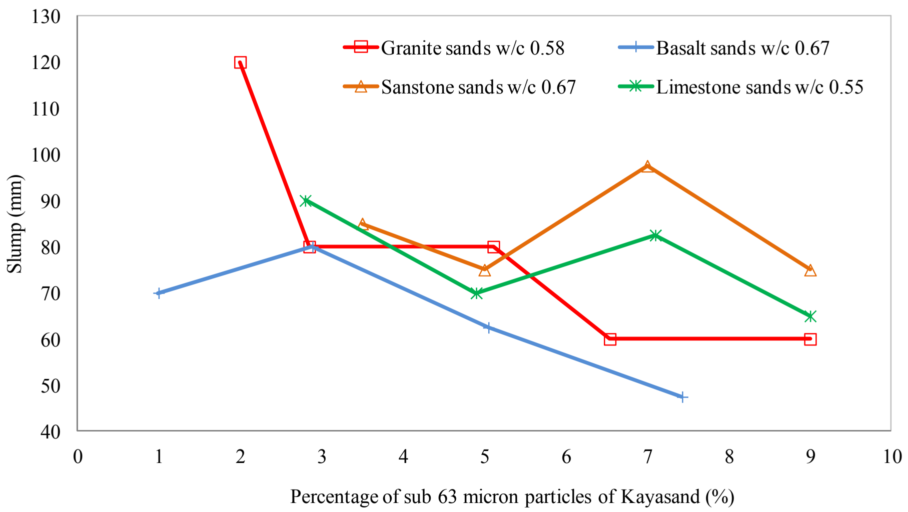


Figure 10. Influence of fines content on concrete consistency

Table 4. Stage 1 and stage 2 fresh and hardened concrete results

	Stage 1						Stage 2					
Mix	w/c ratio	Slump (mm)	Compressive strength (N/mm^2)			Flexural strength N/mm^2	w/c ratio	Slump (mm)	Compressive strength (N/mm^2)			Flexural strength N/mm^2
			1 day	7 day	28 day	28 day			1 day	7 day	28 day	28 day
N	0.48	95	23.8	48.0	58.9	6.1	0.55	Collapse	13.2	39	50.5	5.3
G-FEED	0.66	80	12.5	30.3	39.1	-	-	-	-	-	-	-
N-G	0.58	Collapse	13.5	36.0	48.7	5.4	-	-	-	-	-	-
G-A	0.58	120	17.6	43.5	52.2	5.6	0.55	65	16.4	44.4	53	5.7
G-B	0.58	80	17.0	40.2	49.9	5.6	0.55	67.5	20.1	46.1	59.2	5.8
G-C	0.58	80	17.9	40.4	50.1	6.0	0.55	70	20.7	46.1	55.2	5.9
G-D	0.58	60	19.3	42.2	52.3	5.8	0.55	60	19.4	48.3	58.6	5.5
G-E	0.58	60	16.6	40.6	48.1	5.4	0.55	85	16.6	47.8	59.2	4.7
B-FEED	0.72	70	9.3	25.8	35.5	-	-	-	-	-	-	-
N-B	0.67	Collapse	9.6	26.2	35.9	4.6	-	-	-	-	-	-
B-A	0.67	70	11.8	30.4	41.7	5.3	0.55	60	14.5	48.2	57.6	6.1
B-B	0.67	80	12.9	31.3	43.7	5.5	0.55	30	14.6	49.2	60.5	6.4
B-C	0.67	62.5	13.0	33.1	42.7	5.4	0.55	30	17.9	48.4	59.4	6.1
B-D	0.67	47.5	13.2	35.2	45.6	5.6	0.55	25	16.5	48.3	58.5	5.9
L-FEED	0.61	60	18.5	38.0	50.2	-	-	-	-	-	-	-
N-L	0.55	Collapse	13.2	39	50.5	5.3	-	-	-	-	-	-
L-A	0.55	90	18.0	44.3	55.7	6.6	0.50	90	23.9	52.5	64.3	6.1
L-B	0.55	70	21.2	47.8	58.0	6.7	0.50	90	20	49.7	61.1	6.4
L-C	0.55	82.5	22.7	46.2	56.2	6.1	0.50	75	23.2	51.1	63	6.1
L-D	0.55	65	21.4	46.9	56.6	6.0	0.50	65	20	47.1	59.9	6.8
S-FEED	0.75	80	8.2	23.3	31.3	-	-	-	-	-	-	-
N-S	0.67	Collapse	8.1	24.4	34.9	4.6	-	-	-	-	-	-
S-A	0.67	85	12.7	34.5	41.4	5.2	0.55	60	14.8	44.3	55	5.4
S-B	0.67	75	14.9	31.4	43.3	5.6	0.55	50	19.8	43.8	55.3	6
S-C	0.67	97.5	14.7	32.8	42.8	5.5	0.55	50	18.4	43.2	55.6	5.4
S-D	0.67	75	12.1	30.5	39.9	5.2	0.55	45	17.2	41.7	53	5.9

Several qualitative observations were recorded during the laboratory investigations. For the Kayasand mixes with the lowest fines contents (-A mixes) and the lower water cement ratios (0.55 and 0.58) the concretes were particularly harsh and difficult to finish, primarily due to the lack of fines. For the limestone and granite Kayasands the mixes became easier to finish and work with an increasing fines content (–B and –C gradings). The basalt and sandstone mixes were easy to finish, but tended to be very cohesive at the high fines contents.

5.2.2 Hardened Concrete Properties

5.2.2.1 Stage 1 results

The compressive strength results presented in Table 4 are the mean of either 3 or 4 specimens. The results are given in full in Appendix 3, along with the coefficient of variation for the mean results. This coefficient of variation was a maximum of 4.5% for the 1 and 7 day Kayasand tests and 7.4% for the 28 day Kayasand tests (7.4% is associated with the L-D result, else a maximum of 3.9%). The coefficients of variation associated with the Kayasand tensile strength results did not exceed 8.2%. These levels of variation are generally within the accepted limits for such tests.

The natural sand mix has the highest compressive strength of all mixes at all ages, as reported in Table 4. It should be recognised that this mix is made of high quality fine aggregate, which has not been blended with crusher dust as is usual practice in industry. Therefore, whilst it will be used as the control mix in this study to which other mixes will be benchmarked, the focus will be on achieving viable concrete mixes that can be mixed, placed, compacted and finished adequately through 100% replacement of natural sand with Kayasand. On this note, the fact that the natural sand mix had the lowest w/c ratio of all mixes then it is not surprising that this mix yielded the highest compressive strength. Further control mixes made using the fixed w/c ratio for each aggregate assist in confirming the performance of the Kayasand mixes. However, many of these control mixes suffered from a collapse of slump due to the combination of spherical natural sand particles and higher water contents (up to 40% higher in the most extreme case compared to the S2 natural sand mix) required to achieve S2 slump in the –B Kayasand sands. These aggregate specific control mixes were still cast in order to determine the compressive and tensile strengths, although the mixes performed only marginally better than the FEED mixes in each instance and would in fact be discarded in industry due to non compliance with consistency specifications with accompanying visual observations of segregation and bleeding.

Granite Kayasand concretes at 28 days reached compressive strength of 48.1 to 52.3 N/mm^2, lower than the natural sand mix but still acceptable as viable normal strength concrete mixes. The G-D and G-A mixes achieved the highest compressive strengths. This can be attributed to the moderately high level of fines (6.5%) fines in the former and the good consistency (120mm) and dispersion of mix components in the latter. However, if the granite sands are considered as one data set, the resulting coefficient of variation is 3.5% which reflects the typical variation inherent in compressive strength testing. Therefore, in this instance the evidence suggests that all granite Kayasand gradings perform equally well although it would seem prudent in light of what has been reported in the literature (Celik and Marar 1996) to recommend sands with higher fines contents (G-D and G–E) to aid a reduction in permeability and enhance the durability properties of a concrete. The performance of the granite Kayasand sands exceeds that of the G-FEED mix and demonstrates an improvement in particle shape and size via the V7 process, enabling the use of lower w/c ratios to achieve the same consistency. Comparable compressive strength was achieved by the N-G mix, although as noted previously this result should be treated with caution as a result of slump collapse and segregation of the mix during casting.

The compressive strength of the basalt Kayasand concretes was in the range of 41.7 N/mm^2 for B-A to 45.6 N/mm^2 for the B-D mix. All basalt mixes surpassed the strength of the w/c ratio control N-B mix and B-FEED mix, the latter having a w/c ratio 7% higher than the basalt Kayasand concretes but a compressive strength 22% lower than the mean strength of the basalt Kayasand concretes. This again provides a clear indication of the improvements afforded to the Kayasand from the V7 process, allowing reductions in water content to compensate for improved particle shape and grading with an associated enhancement in compressive strength. As reported for the granite Kayasands, the basalt Kayasands, when considered as one data set have a compressive strength mean of 43.4N/mm^2 and a coefficient of variation of 3.8%. This is again within the 5% limit normally quoted as an acceptable level of variation in the compressive strength of concrete. The basalt Kayasand concretes have compressive strengths 35% lower than the natural sand mix and this can be attributed to the higher w/c ratio required by the basalt mixes to achieve an S2 slump. There is again no clear evidence of higher fines contents resulting in higher compressive strength values at 28 days. Whilst this may imply that a basalt sand with any of the gradations may be suitable for a concrete mix, caution should be exercised when recommending basalt Kayasands with high levels of fines. This is due to the deterioration in the level of slump as a result of the increased water demand from the fines and the associated detrimental effect the clay content of these fines may have on the hardened concrete. Such an effect may explain the lower rate of gain in compressive strength between 1 and 7 days compared to the other Kayasand concretes. However, careful attention to mix proportioning together with admixtures that address the presence of clays may be employed to achieve specified fresh and hardened concrete properties.

Limestone Kayasand concretes yielded compressive strengths from 55.7 to 58.0 N/mm^2 which are comparable to the natural sand control mix with a strength of 58.9 N/mm^2 and a 12% lower w/c ratio. Furthermore, the limestone Kayasand concretes also performed better than the L-FEED and N-L mixes again indicating that the shape of the Kayasand particles positively affects the compressive strength of the concrete. When considered as one set of data the mean compressive strength of the limestone Kayasand concretes is 56.6N/mm^2 with a coefficient of variation of just 1.7%. Although the slump values decrease with increasing fines content, they still lie within the S2 range and therefore there are no apparent limitations in specifying the Kayasand mix with the highest fines content (L-D). The results of the limestone Kayasand concretes provide encouraging evidence that at the same w/c ratio and with the addition of consistency aids that the compressive strength of a limestone Kayasand concrete mix could easily surpass that of a natural sand mix. Conversely to target the same 28 day strength at equal w/c ratio, there is evidence that potential reductions in cement content could be made in the Kayasand mix, the magnitude of which is suggested as an area worthy of future investigation. It is believed that such conclusions can also be extended to the other Kayasands employed in this study.

The concretes containing sandstone Kayasand had compressive strengths in the range 39.9-43.3 N/mm^2, which is similar to the basalt Kayasand concretes. Such a result is not surprising since both Kayasands had high MBV values, yielding a mix with a high water demand and a subsequent reduction in compressive strength as a result of the need to provide sufficient water to meet the slump range requirement. All Kayasand sandstone concretes surpassed the strength of the w/c ratio control N-S mix and S-FEED mix, with the latter having a w/c ratio approximately 12% higher and a compressive strength 34% lower than that of the sandstone Kayasand concretes. As observed in the other mixes there was no significant influence of fines content on the compressive strength. Moreover, there was no deterioration in consistency between the S-B mix, on which the water cement ratio was based, and the S-D mix with 9% fines. The same concerns that were raised for the basalt mixes regarding the potential presence of clays particles equally applies to the sandstone sands, particularly as the fines content increases.

5.2.2.2 Stage 2 Results

The compressive strength results for stage 2 presented in Table 4 are again the mean of either 3 or 4 specimens. The results are given in full in Appendix 4, along with the coefficient of variation for the mean results. This coefficient of variation was a maximum of 6.4% for the 1 and 7 day Kayasand tests and 5.5% (L-A result) for the 28 day Kayasand tests. The coefficients of variation associated with the Kayasand tensile strength results did not exceed 6.8%. These levels of variation are generally within the accepted limits for such tests.

The granite Kayasand concretes at 28 days reached compressive strengths in excess of the Stage 2 natural sand control, although it is acknowledged that at w/c ratio of 0.55 the slump of the control mixed was recorded as a collapse. However, the granite Kayasand concretes with higher levels of fines (G-D and G-E) performed as well as the natural sand control mix for Stage 1 which did record an S2 slump. This supports the use of Kayasands with the maximum level of fines as suggested in the stage 1 results. The level of plasticiser used within these mixes is within the manufacturer's stated dosage limits, and therefore there may be potential to enhance the compressive strength further by reducing the w/c ratio, or maintain the compressive strength level by reducing both the w/c ratio and cement content in the mix.

Regarding the basalt Kayasand concretes, only the mix with the lowest quantity of fines satisfied the slump requirement within the plasticiser dosage limits. The compressive strength of this mix was higher than the Stage 2 control mix and comparable to the Stage 1 control mix. An increase in the fines contents of the basalt Kayasand concretes had a detrimental effect on the slump of the mix, even when the plasticiser dosage was exceeded by 20%. This indicates the clay absorbing characteristics of the fines content of the Kayasand resulted in lower quantities of free water in the mix, which could not be compensated for by the addition of plasticiser. In spite of this the compressive strength of the basalt Kayasand concretes remained reasonably constant demonstrating sufficient water for cement hydration in the mix and the potential to reduce cement contents to match the compressive strength of the natural sand control mixes..

Limestone Kayasand concretes with a w/c ratio of 0.50 yielded compressive strengths in excess of the control mix from stage 2. Although a deterioration in slump was observed with increasing fines content, the slump values were still within the S2 slump range and the plasticiser dosage limits. When compared to the compressive strength of the natural sand control in Stage 1 it is apparent that the limestone Kayasand concretes performed better, even at a higher w/c ratio. This indicates the potential to reduce the w/c ratio further, whilst increasing the plasticiser dosage or reduce the cement content at the same w/c ratio and plasticiser dosage to match the performance of the stage 1 control mix.

Sandstone Kayasand concretes performed better than their stage 1 counterparts as a result of the lower w/c ratio, and better than the stage 2 natural sand control, even though the slump collapse for this mix is acknowledged. Slump values in the S2 slump range were achieved in the majority of the sandstone Kayasand mixes, although S-D fell just below the lower S2 slump boundary. However, unlike the basalt mixes the plasticiser dosage was kept within the manufacturers limits indicating that absorption of the water from the mix by the fines was lower and this is perhaps a reflection of the lower MBV values of the sandstone Kayasands when compared to basalt mixes with equal fines content. Nevertheless, it has been demonstrated that viable mixes can be made with sandstone Kayasands with the same cautionary statements related to the clay contents of the higher fines mixes being made here. It is more difficult to suggest savings in cement for the sandstone Kayasand mixes due to the compressive strength results being lower than a natural sand control mix with similar slump characteristics. However, there are a number of structural applications which require lower strength (C30/37 and C35/45) concretes that could be satisfied using sandstone Kayasand at a w/c ratio and plasticiser dosage similar to that used in stage 2 but with a lower cement content.

Lastly, it should be acknowledged here that there is little variation difference between stage 1 and stage 2 tensile strength results, with only marginal increases seen with the reduction of w/c ratio and introduction of plasticiser.

6. Conclusions

The aim of this study was to explore the use of Kayasand as a complete replacement for natural sand in concrete mixes. The results shown in Section 5 prove that while great care is required to ensure that the mix design used is appropriate for the type and properties of the feed material, it is feasible to produce workable concretes with satisfactory 28 day compressive and flexural strengths using Kayasand as a complete replacement for natural marine dredged sand in concrete.

The fine aggregate test results showed the following:

- The processing of the FEED material improved the shape and grading as well as having removed some deleterious clay sized particles as indicated by the MBV and SE tests. In cases of high MBV in the FEED material the V7 process can reduce the MBV by up to 50%, although this will be reliant on the level of fines considered in the range of Kayasand gradations compared to the FEED material.

- The test results also suggest that the RMBV test could be used as an alternative to the standard MBV test in order to rapidly assess the presence of potentially deleterious fines.
- The enhanced shape and grading of Kayasand is indicated by the reduced flow times in the NZFC results with a visual inspection revealing particles that were less angular and flaky than the FEED material.

For the direct replacement of natural sand with Kayasand, with a target of an S2 slump range the following conclusions can be drawn:

- The increase of fines content in the Kayasand mixes generally resulted in a reduction in the slump of the mix. However, in the Stage 1 study only the B-D mix fell outside of the S2 slump range. There was some evidence of the fines acting as lubricants in Kayasand concretes with medium fines contents.
- There was no apparent relationship between fines content and 28-day compressive strength in any of the Kayasand concretes. This suggests that there are no negative effects of higher fines contents on the compressive strength for the given mix compositions and range of fines contents investigated in the study. However, it is important to assess the presence of clays in the fines portion of the mix as it can dramatically affect the water demand for the same consistency, as shown by the basalt sands in comparison to the granite sands.
- The 28 day flexural strength for all mixes is in the range 4.6 to 6.1 N/mm2 and seems to follow the trends of compressive strength, with higher compressive strength resulting in higher flexural strength.
- Only the 28 day compressive strengths of the limestone Kayasand concretes approached the compressive strength of the natural sand control mix. This is encouraging because it would seem possible to achieve comparable strength concrete using Kayasand at higher w/c ratios.
- Basalt and sandstone Kayasand concretes required higher w/c ratios than limestone and granite Kayasand concretes to meet the S2 slump range due to the high MBV and the probable presence of clay absorbing particles in the fines component of the former. Nevertheless, these w/c ratios were smaller than those required for the respective FEED material and yielded higher compressive strength values at all ages.

For the direct replacement of natural sand with Kayasand, with a target of an S2 slump range achieved through a fixed w/c ratio and the use of a plasticiser the following conclusions can be drawn:

- Use of plasticiser in limestone and granite mixes with w/c ratios of 0.5 and 0.55 respectively, enabled compressive strengths in excess of the control mixes whilst still satisfying the slump range and plasticiser dosage levels.
- For limestone and granite Kayasand concretes there is the potential to enhance the compressive strength further by reducing the w/c ratio, or maintain the compressive strength level by reducing both the w/c ratio and cement content in the mix. The exact reduction in cement content cannot be quantified here.
- For all basalt Kayasand concretes the compressive strength was equivalent to that of the stage 1 control mix, although the S2 slump range could only be satisfied in the mix with the lowest fines content. In the remaining mixes the S2 slump could not be achieved, even when plasticiser dosages 20% higher than those recommended were used.
- For all sandstone Kayasand concretes the compressive strength was less than that of the stage 1 control but higher than that of the stage 2 control, although the latter reported a slump collapse at the w/c ratio of 0.55. The S2 slump could not be satisfied in the mix with the highest fines content whilst using the maximum plasticiser dosage recommended. It is apparent that whilst improvements are seen between stages 1 and 2 sandstone Kayasand concretes, further adjustment to the mix design is required to match the performance of the other Kayasand rock types and this may include amending the w/c ratio, plasticiser type and dosage.
- There was little difference in the flexural strength results between stage 1 and stage 2, even though improvements in compressive strength for all Kayasand concretes was observed when lowering the w/c ratio and introducing a plasticiser into the mix.

In summary, there is sufficient experimental evidence to justify the use of Kayasand as a 100% replacement for natural sand in concrete. When considering sands with low MBV and SE values there is the potential for the concrete mixes to outperform natural concrete mixes through further reductions in w/c ratio. This may not hold true however, if the natural sand mixes are optimised further through the use of plasticisers. With sands containing high MBV and SE values the V7 manufacturing process can significantly reduce the levels of deleterious fines in the sand to make them acceptable for use in concrete. However, prudence is still required in controlling the fines portion in the resultant concrete mix, whether it be by minimising the fines content or using a chemical admixture to deactivate the component of the fines that may be detrimental to the fresh and hardened properties of concrete. Further work is suggested in this area to fully encompass the range of rock mineralogies that are present in the UK. Moreover, there are numerous other properties that would require further investigation in order to have full confidence in the use of Kayasand, namely durability properties, chemical and chloride resistance and creep and shrinkage characteristics.

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Appendix 1. Quarterly Reports produced by Cardiff University

Sand from Surplus Quarry Material

Quarterly Report 1

November 2010
Report no: 0QR1- SC9086-CF

1.0 Introduction

The motivation for this project is the increasing miss balance between the need for aggregates in society and the availability of traditionally suitable geologic sources. A strong need is realised for developing and implementing technology that can enable the use of alternative resources, reduce the need for transport and present zero waste concepts for the aggregate and concrete industry. Aggregate producers are faced with constant demands for higher quality aggregates and, at the same time, have to take environmental issues into account. The most pressing issues being the excess amounts of fines (< 63μm) following the crushing process for manufactured aggregates and the depletion of natural aggregate resources. Excess fines were, and in many countries still are, considered waste and are disposed of accordingly, at great costs and with risk of contamination. Producers have identified an opportunity to develop a manufactured sand from gravel and crushed rock. One advantage is that the sand has a smoother surface texture than most conventional crusher dust products and the Particle Size Distribution (PSD) curve can be accurately adjusted when the material is manufactured therefore making it much more suitable for use in concrete. A second advantage is the ability to source both fine and coarse aggregates from the same quarry, and with knowledge of the effect of the mineralogical composition of such aggregates on the fresh and hardened properties of concrete, quarries can be kept in the near vicinity to their place of end-use, thereby shortening transport distances, followed by less pollution and increased employment opportunities for the local population.

Numerous research programmes have been performed, examining the physical properties of manufactured sand in the context of its use in concrete. The results have in general been in favour of using manufactured sand, given the right conditions concerning parent rock type and production process. However, design parameters for manufactured sand are different from those used for natural sand. It is anticipated that in the future aggregate production from crushed rock will increase and production from natural sand and gravel deposits will decrease.

The project will explore the feasibility of using Kayasand as a complete replacement for natural sand in cementitious materials and then go on to develop a specification for the material. This will be achieved by making up mixes of Kayasand (manufactured sand) at various replacement levels, to determine the optimum mix of Kayasand replacement in terms of workability, compression & tensile strength. The mixes that will be used are: 100% Natural Sand concrete (control); 100% Kayasand concrete; 100% Kayasand with Pre Duster A; 100% Kayasand with Pre Duster B; 100% Kayasand with Pre Duster C; 50% Natural 50% Kayasand; 50% Natural 50% Kayasand with Pre Duster A; 50% Natural 50% Kayasand with Pre Duster B and Natural 50% Kayasand with Pre Duster C.

Kayasand manufactured from 6 different quarries across the UK will be used in the experimental programme. Rock types obtained from these quarries include Greywacke, Limestone, Andersite, Gritstone, Basalt, Granite and Slate. The mineralogy of the parent rock will be taken into consideration when trying to establish the optimum mix proportions and particle gradation for various concrete applications. The following tests are planned for the different Kayasand blends to determine their mineralogy and strength:

- Methylene Blue Test
- XRD and elemental analysis
- Sand Equivalency Test
- Cube Compression Test
- Cylinder Tensile Test

2.0 Work performed to date

In this last quarter the main thrust of work has been concentrated on establishing the correct batching and mixing methods to be used in the remainder of the study, as well as performing some preliminary trials on a limestone Kayasand originating from Rathmolyon Quarry in Southern Ireland. The details of the mixes cast to date are given in Table 2.1. For each mix, 3 cubes were cast to establish their compressive strength at 24 hours, 3 for 7 days and 3 for 28 days. The remaining 2 cubes were kept for potential 56 day compressive strength tests.

Table 2.1. Mixes cast to date

Mix Reference	Date	Rock Type	Replacement level (%)		Preduster Type	No. Cube s	No. Cylinders
			Kayasand	Natural Sand			
CR-N1	14/10/10	Limestone	-	100	-	11	1
CR-K1	14/10/10	Limestone	100	-	-	11	2
CR-K2	21/10/10	Limestone	100	-	A	11	1
CR-K3	21/10/10	Limestone	100	-	B	11	1
CR-K4	21/10/10	Limestone	100	-	C	11	1
CR-N2	21/10/10	Limestone	-	100	-	11	1
CR-K5	21/10/10	Limestone	50	50	-	11	1
CR-K6	28/10/10	Limestone	50	50	-	11	1
CR-K7	28/10/10	Limestone	50	50	A	11	1
CF-K8	28/10/10	Limestone	50	50	C	11	1
CR-N3	28/10/10	Limestone	-	100	-	11	1

Based on the preliminary laboratory work 5 mixes are scheduled for each week, from October 20101 to April 2011. The 5 mixes each week comprise 4 Kayasand mix designs and 1 control mix, to monitor the consistency of the casting process and any natural sand resource variation between mixes performed on consecutive weeks. The preliminary investigations have demonstrated that this level of laboratory work is achievable. However, initial setbacks have meant that the first Kayasand blend has taken a month to complete all of the mix designs (discussed in more detailed below).

3.0 Tests performed to date - number and type

Compression strength tests have been performed so far on 24hr and 7 day cubes of the mixes detailed in Table 2.1 above. A Methylene Blue trial test has been conducted on the Rathmolyon limestone, achieving a successful result. Slump retention and bleed tests have also been performed on the mixes cast to date, but due to delays during the mixing process neither test has yielded any useful data. These tests however, are still being considered for the next stage of casting. The results of the compressive strength tests will be available in the next Quarterly Report.

4.0 Observations/issues

4.1. Slump

In order to make best use of laboratory time the mixing procedure chosen used two pan mixtures running concurrently with two different mix designs. However, whilst the one mix was being tested and subsequently cast, the other remained in the pan and started to stiffen. In the case of the latter, an extra 10mins in the mixer resulted in a 5mm loss in slump, which then signified that additional water was added to the mix to achieve the desired slump. However, in doing so the water/cement ratio of the mix was compromised, leaving a comparison of compression strength results between mixes difficult to complete. The desired slump for all the mixes was set at 70 ±5 mm. However it soon became apparent that such a tolerance for a 70mm slump was unrealistic. The tolerance compounded the length of time to mix and the observations of the mix stiffening made earlier.

After consultation with an industry specialist, it was determined that a tolerance of 40mm (min) to 90mm (max) slump was used widely throughout the concrete industry, and the mix only needed to be in the mixer for approximately 2mins after the water content of the mix design had been added. After realising this information, two concurrent mixes were discontinued in favour of one mix, although this was not done until the 3rd week of casting (28/10/10). Consequently only mixes CR-K6 and CR-K8 have been mixed according to the mix design sheets. All the other mixes (CR – K1 through CR-K5 and CR-K7) had excess water added because the mix was left in the mixers for too long whilst the 70mm slump was targeted. For all future mixes cast after 28/10/10, only the water content outlined in the mix design will be used and the slump value will be recorded for that mix. If the slump is not within 40mm – 90mm then excess water will be added and noted down on the mix design sheet.

4.2 Mould preparation and Demoulding

There have been a number of issues with the cast iron 100mm concrete cube moulds. The first issue concerns the bolts holding the cube moulds on its platform, which had a tendency to unscrew themselves when placed on the vibrating table. This problem was enhanced by surplus oil applied to the steel moulds. The mould bolts have been replaced and this has alleviated the problem. The second issue experienced with these mould was during de-moulding. An internal screw in the moulds made demoulding and rejoining the moulds difficult, delaying the de-

moulding process. The internal screws inside all of the new moulds have now been removed which has helped speed up the de-moulding process.

4.3 Fresh property measurements

Currently air entrapment tests have not been performed on the fresh concrete. It is recognised that this is something that can be done at a later stage rather than delay the missing programme that has currently been established.

Sand from Surplus Quarry Material

Quarterly Report 2

February 2011
Report no: 0QR2- SC9086-CF

1.0 Introduction

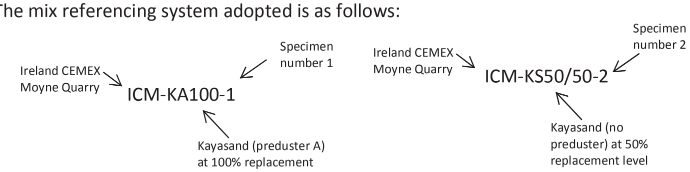
This quarterly report covers the period of November 2010 to January 2011. It reports the work that has been performed to date and presents preliminary results from a series of trial mixes cast in the period of October to November 2010.

2.0 Work performed to date

In this last quarter the main thrust of work has been concentrated on establishing data reporting and recording procedures, mix references and standard operating procedures for all of the anticipated tests. Furthermore, consultation with an industry specialist has been undertaken and is reported in more detail in section 2.2. An additional two mixes were cast during the reporting procedure, namely a 100% Kayasand mix and a Control mix. This was primarily done to trial the new air entrainment device; however, the mixes also served the purpose of providing additional compressive strength results. Compressive strength tests have also been completed on all material cast to date, the results of which are discussed in section 3.

2.1 Mix Referencing System

The mix referencing system adopted is as follows:



Reference back to the data sheets will be required to determine the age of the specimen. Control mixes (100% natural sand) are designated “Control” and have a casting date attached. This is because a number of control mixes are to be cast throughout the duration of the project. The mix references for the preliminary work are reported in Table A.1 of Appendix A, along with the original mix reference given in the first quarterly report.

2.2 Industry specialist consultation

A meeting was set up with Dr Konstantinos Koutselas at the Aggregate Industries research and development concrete laboratory in Derbyshire was arranged in December 2010 to discuss the direction of the project, along with the issues with certain elements of the project as identified by the two students. The following conclusions have been drawn from the meeting:

- There is no need to conduct Tensile Strength Tests on the hardened concrete, as the result bears no significance unless tests to determine the elastic modulus are also performed. To do the latter would significantly increase the number of tests required and in light of the demanding workload from the project as currently scheduled it has therefore been decided that the introduction of further tests is unnecessary. This will allow the researchers to focus on the core aims of the project.
- The Flexural Strength Test (4 point testing) will replace the Tensile Strength test, and should indicate better packing in Kayasand samples.
- There is no need to test for shrinkage of fresh/hardened concrete. This is because the result will have little impact with the overall aims of the project. Furthermore, the BS EN standard written for this test outlines apparatus that simply cannot be found anywhere in the UK.
- The elemental analysis of Kayasand was questioned, as this would have a very small impact on hardened concrete results. However, this test is needed to fully characterize the sand, the results of which will be of beneficial use to the PhD students and the future direction of this work after this current project has been completed.
- Bleeding Tests will be carried out qualitatively as the mixes are being cast. Photos will be taken using a digital camera, and notes will be made on any bleeding that occurs from each mix.
- There is a need to measure Fresh (Plastic) Density as well as Cured Density, as this could give some reasoning to results obtained. The method of how this is measured will need to be examined further.
- We are going to keep to an S2 slump (40mm-90mm), a value commonly used in the concrete industry.
- It is important to source the cement direct from the manufacturer. This project was outlined as using CEM I, however, there have been problems

sourcing CEM I from Cardiff University's cement suppliers. It is now envisaged that the CEM I cement will be sourced from a CEMEX quarry just outside of Cardiff. This is important because up to 5% of fines can be included in the cement which may not be declared to the buyer. It is the level of fines in the cement which could have an impact on the compressive strength results with regards to the use of Pre dusters.

- The water/cement ratio must stay the same for all of the mixes. The current industry w/c ratio is around 0.59, and therefore the aim is to maintain the same w/c ratio for all of the mixes, giving an even platform on which to compare the results. It was noticed from the results of the first mixes that the w/c ratio was very different for all of the mixes, and this undoubtedly affected the compressive strength results that were obtained. It is now very hard to compare these results without having a constant on which to base the theories.
- The mixer will be kept damp for every mix. Dr Koutselas stated that every time a mix is cast in the Aggregate Industries laboratory, an initial mix is cast to dampen the mixer which is subsequently thrown away. The mixes are then started in earnest. The full scientific reasoning behind this practise is not known, but from years of experience in concrete mixing, Dr Koutselas has noticed that there is a difference between using a damp (already mixed) mixer and a dry clean mixer.

Following the discussion with Dr Koutselas a list of Aggregate testing, Fresh Concrete testing and Hardened Concrete testing has been drawn up which will be conducted on all of the research material. This can be seen in Table 2.1.

From this, a schedule of testing has been drawn up over the next 9 months. When the material comes back from Japan 1 week will be spent on aggregate testing. This will give an indication of how the aggregate will behave in the mix, and what properties it possesses, so as to explain the results from any of the mixes. The fresh concrete tests will be conducted when casting the mixes and it will take one day to test all of the hardened concrete

Table 2.1. Proposed aggregate, fresh and hardened concrete testing

Aggregate Testing	Fresh Concrete Testing	Hardened Concrete Testing
Grading	Air Entrainment	Density
Water Absorption	Slump	Compressive Strength
Methylene Blue	Fresh (plastic) Density	Flexural Strength Test (4-point testing)
Sand Equivalency	Bleeding	
New Zealand Flow Cone		
% Water Content (before mixing)		

3.0 Experimental Results and Discussion

It is important to note that the target compressive strengths of the specimens cast in this project are 25N/mm^2 after 7 days of curing and 30N/mm^2 after 28 days of curing. The average compressive strength results, together with the coefficients of variation for the specimens cast in the preliminary study are presented in Table 3.1. The raw data, as collected from the laboratory is provided in Appendix B. It should be noted here that all tests were performed in triplicate, unless stated otherwise. It is observed that both control mixes satisfy the target compressive strength requirements. However, only two Kayasand mixes (ICM-KS50/50 and ICRKS100) approach the requirements, with the remaining Kayasand mixes falling below both 7 and 28 day target strengths. The coefficients of variation are generally within the 5% limit used in the laboratory when considering compressive strength results of concrete.

From the data it is apparent that for the Kayasand mixes with the ICM mix reference, the difference between the 7 and 28 day compressive strength results is unusually small. The control mix cast on the 18th November indicates that the 7 day compressive strength is approximately 75% of the 28-day compressive strength, and this ratio between the compressive strength at the two ages is generally accepted as the standard when working with normal strength concrete mixes in the laboratory at Cardiff University. The reasons for the slow strength gain of Kayasand will be explored fully during the testing programme and it is merely highlighted here as an interesting outcome of the preliminary study. Although the results from the preliminary study give an indication of the expected performance of concrete made

form Kayasand, the main focus was to establish correct working procedures and mix calculation procedures to use in the full study. Indeed, it is important to note here that the water/cement ratios for the ICM and first two control mixes were not kept constant and therefore this may help to explain the variation in compressive strength observed between mixes.

Table 3.1. Compressive Strength results from preliminary tests

	Compressive Strength (N/mm^2) / Coefficient of Variation (%)		
Age (Days)	1	7	28
Mix Reference			
ICM-Control-14/10	6.10	24.49	-
	5.87	0.74	-
ICM-Control-21/10	7.44	27.05	-
	6.17	1.40	-
ICM-KS100	5.45	20.36	22.41
	2.92	3.07	0.77
ICM-KA100	5.32	18.38	21.08
	6.04	1.07	0.60
ICM-KB100	4.76	19.66	21.87
	4.89	0.75	0.95
ICM-KC100	6.02	21.68	22.87
	0.38	1.09	0.16
ICM-KS50/50	6.68	25.29	28.01
	4.12	3.06	0.79
ICM-KA50/50	-	21.58	23.23
	-	0.623	1.422
ICM-KB50/50	-	20.74	23.14
	-	3.42	2.40
ICR-Control – 18/11	-	23.99	32.80
	-	N/A[1]	N/A[2]
ICR-KS100	-	14.87	30.07
	-	N/A[1]	N/A[2]

[1]One specimen only [2]Average of 2 specimens

The results from the control mix cast on the 18th Nov 2011 and the ICR Kayasand mix reflect improvements that were made to the mix-calculations (w/c and densities) as a result of the ICM studies. Similar 28 day strength compressive results were achieved for these mixes although the Kayasand ICR-KS100 mix failed to meet the 7 day compressive strength target. This initially shows that 100% Kayasand can replace traditional marine dredged sand in concrete mixes because it can achieve the 28 day compressive strength target set out by the mix design.

It is interesting to note here that 100% marine dredged sand, which is used as a control in the study, is considered unrepresentative of industry practice. This is because the use of 100% marine sand in a mix is not cost effective and therefore a blend of marine sand and (limestone) filler is commonly used, the filler content generally comprising 10% of the total sand content. The main difference between natural and Kayasand is the shape of the sand particles, and this is believed to be the reason why the 100% natural sand achieves such a higher compressive strength. It is anticipated that if a more realistic control had been used in the preliminary study then the differences between the Kayasand and the Control after 28 days curing would be less pronounced. However, the main goal of this project is to prove that Kayasand can replace natural dredged sand in concrete, without a detrimental effect on the compressive strength. The achievement of this goal will be of particular importance to industry, not only because Kayasand has significant environmental benefits, but because consistent particle shape and gradation can be achieved and according to a number of industry contracts, it is this consistency in material properties which is much desired in the concrete industry.

Quarterly Report 2 January 2011

Appendix A. Updated Mix Referencing System

Table A1. Revised mix referencing system

Mix Reference adopted in Quarterly Report 1	**Mix Reference adopted in the laboratory and presentation of results (to be used in all future work)**
CR-N1	ICM-Control-14/10
CR-K1	ICM-KS100
CR-K2	ICM-KA100
CR-K3	ICM-KB100
CR-K4	ICM-KC100
CR-N2	ICM-Control-21/10
CR-K5	ICM-KS50/50
CR-K6	ICM-KA50/50
CR-K7	ICM-KB50/50
CF-K8	ICM-KC50/50
CR-N3	ICM-Control-04/11

Appendix B. Concrete Mix and Data Sheets

Concrete Trial Mix Worksheet
Cemex ICM

Date of Trial :	14-Oct-10
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Control
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	Material Details			
	S.G	Type	Supplier	Material Sourse
Cement		PC		
Replacement				
Coarse Aggregate (1)		4/20mm Gravel		
Coarse Aggregate (2)				
Fine Aggregate (1)		0/4mm Natural Sand	Tarmac	
Fine Aggregate (2)				
Admixture (1)				
Admixture (2)				
Solids (kg)				

Admixture Dosage (ml/50kg) or Solid Materials (kg)
0 ml
0 ml
0 ml

MATERIALS	Trial Mix	Aggregate Moisture Total %	Free %	Mix Design Figures S.S.D. kg/m³	Moisture Correctio	Corrected kg/m³	Trial Target	Trial Actual	
Cement				300		7.5	7.50	15.00	
Replacement				0		0	0.00	0.00	
Coarse Aggregate (1)		0.2		1073	0.0	26.8	26.83	53.66	
Coarse Aggregate (2)				0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		1.0		780		19.5	19.50	39.00	
Fine Aggregate (2)				0	0.0	0.0	0.00	0.00	Admix
Water				176	0.4	4.4	4.40	9.20	weight
Admixture (1)				0.00		0.00	0.00	0.00	0.00
Admixture (2)				0.00		0.00	0.00	0.00	0.00
Solids (kg)				0.00		0.00	0.00	0.00	
Comments:			TOTALS	2329.00	0.40	58.23	58.23	116.86	

	SSD	Actual
W/C	0.2	
Fines (%) =		

Corrected Weights (kg/m³) =	0.00
Corrected Water (L/m³) =	0.00
Difference from Target (Litres) =	0.00
Difference from Target (%) =	0.00
Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	Mode	Value(mm)
1	Normal	75
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²	Failure Mode	Density (kg/m³)	Tested By
ICM-Control-14/10-1	1	1	15-Oct-10	60.1				
ICM-Control-14/10-2	2	1	15-Oct-10	64.9				
ICM-Control-14/10-3	3	1	15-Oct-10	57.9				
ICM-Control-14/10-4	4	7	21-Oct-10	246.6				
ICM-Control-14/10-5	5	7	21-Oct-10	245.2				
ICM-Control-14/10-6	6	7	21-Oct-10	243				
ICM-Control-14/10-7	7	28						
ICM-Control-14/10-8	8	28						
ICM-Control-14/10-9	9	28						
ICM-Control-14/10-10	10	56						
ICM-Control-14/10-11	11	56						
ICM-Control-14/10-12		56						

Worked Carried Out By :- ____________

Date :- ____________

Worked Checked Out By :- ____________

Date :- ____________

KAYASAND

Concrete Trial Mix Worksheet
Cemex ICM

Date of Trial :	21-Oct-10
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Control
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		0/4mm Natural Sand	Tarmac		
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Trial Mix	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300			7.50	7.50	
Replacement				0			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		1.00%		780	0.2	7.8	19.50	19.31	
Fine Aggregate (2)				0	0.0	0.0	0.00	0.00	
Water				176	0.5	20.0	4.40	5.15	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			TOTALS	2329.00	0.75	29.95	58.23	58.73	

	SSD	Actual
W/C	0.2	
Fines (%) =		

Corrected Weights (kg/m³) =	0.00
Corrected Water (L/m³) =	0.00
Difference from Target (Litres) =	0.00
Difference from Target (%) =	0.00
Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test

Test	Mode	Value(mm)
1	Normal	85
2	Normal	
Mean Slump Test		

Air Test

Air Meter Number	
Air Content (%)	

Plastic Density

Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-Control-21/10-1	1	1	22-Oct-10	79.6				
ICM-Control-21/10-2	2	1	22-Oct-10	70.8				
ICM-Control-21/10-3	3	1	22-Oct-10	72.9				
ICM-Control-21/10-4	4	7	28-Oct-10	266.1				
ICM-Control-21/10-5	5	7	28-Oct-10	272.5				
ICM-Control-21/10-6	6	7	28-Oct-10	272.8				
ICM-Control-21/10-7	7	28						
ICM-Control-21/10-8	8	28						
ICM-Control-21/10-9	9	28						
ICM-Control-21/10-10	10	56						
ICM-Control-21/10-11	11	56						
ICM-Control-14/10-12		56						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

KAYASAND

Concrete Trial Mix Worksheet
Cemex ICM

Date of Trial :	14-Oct-10
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Kayasand 100%
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300			7.50	7.50	
Replacement				0			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		3.10%		780	0.6	24.2	19.50	18.90	
Fine Aggregate (2)				0	0.0	0.0	0.00	0.00	
Water				176	0.5	20.0	4.40	5.56	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			TOTALS	2329.00	1.16	46.33	58.23	58.73	

	SSD	Actual
W/C	0	0
Fines (%) =	0	

Corrected Weights (kg/m³) =	0.00
Corrected Water (L/m³) =	0.00
Difference from Target (Litres) =	0.00
Difference from Target (%) =	0.00
Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test

Test	Mode	Value(mm)
1	Normal	65
2	Normal	
Mean Slump Test		

Air Test

Air Meter Number	
Air Content (%)	

Plastic Density

Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-KS100-1	1	1	15-Oct-10	56.3				
ICM-KS100-2	2	1	15-Oct-10	53.6				
ICM-KS100-3	3	1	15-Oct-10	53.5				
ICM-KS100-4	4	7	21-Oct-10	196.4				
ICM-KS100-5	5	7	21-Oct-10	207.7				
ICM-KS100-6	6	7	21-Oct-10	206.7				
ICM-KS100-7	7	28		226.1				
ICM-KS100-8	8	28		223				
ICM-KS100-9	9	28		223.2				
ICM-KS100-10	10	56						
ICM-KS100-11	11	56						
ICM-KS100-12	12	56						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

Concrete Trial Mix Worksheet
Cemex ICM

Date of Trial :	14-Oct-10		**Mix Description :**	Kayasand + Perduster A 100%
Material Code :			**Cement (kg/m³) :**	300
Trial Mix Ref :			**Replacement (%) :**	
Batch Time :			**Laboratory Name :**	
Batch Size (litres) :			**Target Consistence :**	

Basic Material Types	**Material Details**				**Admixture Dosage (ml/50kg) or Solid Materials (kg)**
	S.G	**Type**	**Supplier**	**Material Sourse**	
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		Preduster A	ICM		
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	**Aggregate Absorption %**	**Aggregate Moisture**		**Mix Design Figures**					
		Total %	**Free %**	**S.S.D. kg/m³**	**Moisture Correctio**	**Corrected**	**Trial Target**	**Trial Actual**	**Admix weight**
Cement				300.00			7.50	7.50	
Replacement				0.00			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073.00	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0.00	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		3.80%		748.02	0.7	28.4	18.70	17.99	
Fine Aggregate (2)		3.40%		31.98	0.0	1.1	0.80	0.77	
Water				176.00	0.5	20.0	4.40	5.69	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			**TOTALS**	2329.00	1.29	51.66	58.23	58.73	

			Corrected Weights (kg/m³) =	0.00
			Corrected Water (L/m³) =	0.00
	SSD	**Actual**	**Difference from Target (Litres) =**	0.00
W/C	0	0	**Difference from Target (%) =**	0.00
Fines (%) =	0		**Yield (%) =**	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	**Mode**	**Value(mm)**
1	Normal	74
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	**Concrete Mass (g)**	**Density (kg/m³)**
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	**Mould Number**	**Age at Test**	**Test Date**	**Max Load (KN)**	**Strength (N/mm²)**	**Failure Mode**	**Density (kg/m³)**	**Tested By**
ICM-KA100-1	1	1	15-Oct-10	56.9				
ICM-KA100-2	2	1	15-Oct-10	50.9				
ICM-KA100-3	3	1	15-Oct-10	51.9				
ICM-KA100-4	4	7	21-Oct-10	185.9				
ICM-KA100-5	5	7	21-Oct-10	183.5				
ICM-KA100-6	6	7	21-Oct-10	182				
ICM-KA100-7	7	28		212.2				
ICM-KA100-8	8	28		210.3				
ICM-KA100-9	9	28		209.8				
ICM-KA100-10	10	56						
ICM-KA100-11	11	56						
ICM-KA100-12	12	56						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

Concrete Trial Mix Worksheet
Cemex ICM

Date of Trial :	14-Oct-10		**Mix Description :**	Kayasand + Perduster B 100%
Material Code :			**Cement (kg/m³) :**	300
Trial Mix Ref :			**Replacement (%) :**	
Batch Time :			**Laboratory Name :**	
Batch Size (litres) :			**Target Consistence :**	

Basic Material Types	**Material Details**				**Admixture Dosage (ml/50kg) or Solid Materials (kg)**
	S.G	**Type**	**Supplier**	**Material Sourse**	
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		Preduster B	ICM		
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	**Aggregate Absorption %**	**Aggregate Moisture**		**Mix Design Figures**					
		Total %	**Free %**	**S.S.D. kg/m³**	**Moisture Correctio**	**Corrected**	**Trial Target**	**Trial Actual**	**Admix weight**
Cement				300.00			7.50	7.50	
Replacement				0.00			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073.00	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0.00	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		3.70%		748.02	0.7	27.7	18.70	18.01	
Fine Aggregate (2)		0.90%		31.98	0.0	0.3	0.80	0.79	
Water				176.00	0.5	20.0	4.40	5.65	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			**TOTALS**	2329.00	1.25	50.11	58.23	58.73	

			Corrected Weights (kg/m³) =	0.00
			Corrected Water (L/m³) =	0.00
	SSD	**Actual**	**Difference from Target (Litres) =**	0.00
W/C	0	0	**Difference from Target (%) =**	0.00
Fines (%) =	0		**Yield (%) =**	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	**Mode**	**Value(mm)**
1	Normal	68
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	**Concrete Mass (g)**	**Density (kg/m³)**
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	**Mould Number**	**Age at Test**	**Test Date**	**Max Load (KN)**	**Strength (N/mm²)**	**Failure Mode**	**Density (kg/m³)**	**Tested By**
ICM-KB100-1	1	1	15-Oct-10	50.1				
ICM-KB100-2	2	1	15-Oct-10	47.2				
ICM-KB100-3	3	1	15-Oct-10	45.5				
ICM-KB100-4	4	7	21-Oct-10	197.1				
ICM-KB100-5	5	7	21-Oct-10	197.7				
ICM-KB100-6	6	7	21-Oct-10	194.9				
ICM-KB100-7	7	28		220				
ICM-KB100-8	8	28		216.3				
ICM-KB100-9	9	28		219.8				
ICM-KB100-10	10	56						
ICM-KB100-11	11	56						
ICM-KB100-12	12	56						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

Concrete Trial Mix Worksheet
Cemex ICM

KAYASAND

Date of Trial :	21-Oct-10
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Kayasand + Perduster C 100%
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		Preduster C	ICM		
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300.00			7.50	7.50	
Replacement				0.00			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073.00	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0.00	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		4.20%		748.02	0.8	31.4	18.70	17.92	
Fine Aggregate (2)		3.80%		31.98	0.0	1.2	0.80	0.77	
Water				176.00	0.45	18.0	4.40	5.72	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			TOTALS	2329.00	1.32	52.78	58.23	58.68	

	SSD	Actual		
			Corrected Weights (kg/m³) =	0.00
			Corrected Water (L/m³) =	0.00
			Difference from Target (Litres) =	0.00
W/C	0	0	Difference from Target (%) =	0.00
Fines (%) =	0		Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	Mode	Value(mm)
1	Normal	65
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-KC100-1	1	1	22-Oct-10	60.3				
ICM-KC100-2	2	1	22-Oct-10	59.9				
ICM-KC100-3	3	1	22-Oct-10	60.3				
ICM-KC100-4	4	7	28-Oct-10	216.2				
ICM-KC100-5	5	7	28-Oct-10	214.8				
ICM-KC100-6	6	7	28-Oct-10	219.4				
ICM-KC100-7	7	28		228.6				
ICM-KC100-8	8	28		228.4				
ICM-KC100-9	9	28		229.1				
ICM-KC100-10	10	56						
ICM-KC100-11	11	56						
ICM-KC100-12	12	56						

Worked Carried Out By :-

Worked Checked Out By :-

Date :-

Date :-

Concrete Trial Mix Worksheet
Cemex ICM

KAYASAND

Date of Trial :	21-Oct-10
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Kayasand/Natural Sand Blend 50
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		0/4mm Natural Sand	Tarmac		
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300			7.50	7.50	
Replacement				0			0.00	0.00	
Coarse Aggregate (1)				1073	0.0	0.0	26.83	26.83	
Coarse Aggregate (2)				0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		4.20%		390	0.4	16.4	9.75	9.34	
Fine Aggregate (2)		1.00%		390	0.1	3.9	9.75	9.65	
Water				176		0.0	4.40	4.91	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			TOTALS	2329.00	0.51	20.28	58.23	58.23	

	SSD	Actual		
			Corrected Weights (kg/m³) =	0.00
			Corrected Water (L/m³) =	0.00
			Difference from Target (Litres) =	0.00
W/C	0	0	Difference from Target (%) =	0.00
Fines (%) =	0		Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	Mode	Value(mm)
1	Normal	70
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-KS50/50-1	1	1	22-Oct-10	64.1				
ICM-KS50/50-2	2	1	22-Oct-10	66.7				
ICM-KS50/50-3	3	1	22-Oct-10	69.6				
ICM-KS50/50-4	4	7	28-Oct-10	247.2				
ICM-KS50/50-5	5	7	28-Oct-10	249.8				
ICM-KS50/50-6	6	7	28-Oct-10	261.7				
ICM-KS50/50-7	7	28		279.3				
ICM-KS50/50-8	8	28		278.4				
ICM-KS50/50-9	9	28		282.6				
ICM-KS50/50-10	10	56						
ICM-KS50/50-11	11	56						
ICM-KS50/50-12	12	28						

Worked Carried Out By :-

Worked Checked Out By :-

Date :-

Date :-

Concrete Trial Mix Worksheet
Cemex ICM

KAYASAND

Date of Trial :	
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Kayasand + Preduster A/Natural Sand Blend 50
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		Preduster A	ICM		
Fine Aggregate (3)		0/4mm Natural Sand			
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	Mix Design Figures S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300			7.50	7.50	
Replacement				0			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)				374	0.0	0.0	9.35	9.35	
Fine Aggregate (2)				16	0.0	0.0	0.40	0.40	
Fine Aggregate (3)				390	0.0	0.0	9.75	9.75	
Water				176			4.40	4.45	
Admixture (1)				0.00			0.00	0.00	0.00
Admixture (2)				0.00			0.00	0.00	0.00
Solids (kg)				0.00			0.00	0.00	
Comments:			TOTALS	2329.00	0.05	2.15	58.23	58.23	

	SSD	Actual
W/C	0	0
Fines (%) =	0	

Corrected Weights (kg/m³) =	0.00
Corrected Water (L/m³) =	0.00
Difference from Target (Litres) =	0.00
Difference from Target (%) =	0.00
Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	Mode	Value(mm)
1	Normal	
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-KA50/50-1	1	1						
ICM-KA50/50-2	2	1						
ICM-KA50/50-3	3	1						
ICM-KA50/50-4	4	7		216.2				
ICM-KA50/50-5	5	7		216.9				
ICM-KA50/50-6	6	7		214.3				
ICM-KA50/50-7	7	28		228.9				
ICM-KA50/50-8	8	28		232.4				
ICM-KA50/50-9	9	28		235.5				
ICM-KA50/50-10	10	56						
ICM-KA50/50-11	11	56						
ICM-KA50/50-12	12	28						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

Concrete Trial Mix Worksheet
Cemex ICM

KAYASAND

Date of Trial :	
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Kayasand + Preduster B/Natural Sand Blend 50
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		Preduster B	ICM		
Fine Aggregate (3)		0/4mm Natural Sand			
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	Mix Design Figures S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300.0			7.50	7.50	
Replacement				0.0			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073.0	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0.0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)				364.4	0.0	0.0	9.11	9.11	
Fine Aggregate (2)				25.6	0.0	0.0	0.64	0.64	
Fine Aggregate (3)				390.0	0.0	0.0	9.75	9.75	
Water				176.0			4.40	4.45	
Admixture (1)				0.0			0.00	0.00	0.00
Admixture (2)				0.0			0.00	0.00	0.00
Solids (kg)				0.0			0.00	0.00	
Comments:			TOTALS	2329.00	0.05	2.15	58.23	58.23	

	SSD	Actual
W/C	0	0
Fines (%) =	0	

Corrected Weights (kg/m³) =	0.00
Corrected Water (L/m³) =	0.00
Difference from Target (Litres) =	0.00
Difference from Target (%) =	0.00
Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test		
Test	Mode	Value(mm)
1	Normal	
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density		
Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-KB50/50-1	1	1						
ICM-KB50/50-2	2	1						
ICM-KB50/50-3	3	1						
ICM-KB50/50-4	4	7		208.2				
ICM-KB50/50-5	5	7		214				
ICM-KB50/50-6	6	7		199.9				
ICM-KB50/50-7	7	28		225				
ICM-KB50/50-8	8	28		234				
ICM-KB50/50-9	9	28		235.1				
ICM-KB50/50-10	10	56						
ICM-KB50/50-11	11	56						
ICM-KB50/50-12	12	28						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

KAYASAND

Concrete Trial Mix Worksheet
Cemex ICM

Date of Trial :	
Material Code :	
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	

Mix Description :	Kayasand + Preduster C/Natural Sand Blend 50
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	
Target Consistence :	

Basic Material Types	Material Details: S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	ICM		
Fine Aggregate (2)		Preduster C	ICM		
Fine Aggregate (3)		0/4mm Natural Sand			
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture: Total %	Free %	Mix Design Figures: S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300.0			7.50	7.50	
Replacement				0.0			0.00	0.00	
Coarse Aggregate (1)		0.20%		1073.0	0.1	2.1	26.83	26.77	
Coarse Aggregate (2)				0.0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)				354.4	0.0	0.0	8.86	8.86	
Fine Aggregate (2)				35.6	0.0	0.0	0.89	0.89	
Fine Aggregate (3)				390.0	0.0	0.0	9.75	9.75	
Water				176.0			4.40	4.45	
Admixture (1)				0.0			0.00	0.00	0.00
Admixture (2)				0.0			0.00	0.00	0.00
Solids (kg)				0.0			0.00	0.00	
Comments:			TOTALS	2329.00	0.05	2.15	58.23	58.23	

	SSD	Actual
W/C	0	0
Fines (%) =	0	

Corrected Weights (kg/m³) =	0.00
Corrected Water (L/m³) =	0.00
Difference from Target (Litres) =	0.00
Difference from Target (%) =	0.00
Yield (%) =	0.00

Concrete Appearance: Sandy / Normal / Stoney

Slump Test: Test	Mode	Value(mm)
1	Normal	
2	Normal	
Mean Slump Test		

Air Test	
Air Meter Number	
Air Content (%)	

Plastic Density: Test	Concrete Mass (g)	Density (kg/m³)
1		
2		
Pot Volume (litres) :		
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
ICM-KC50/50-1	1	1						
ICM-KC50/50-2	2	1						
ICM-KC50/50-3	3	1						
ICM-KC50/50-4	4	7						
ICM-KC50/50-5	5	7						
ICM-KC50/50-6	6	7						
ICM-KC50/50-7	7	28						
ICM-KC50/50-8	8	28						
ICM-KC50/50-9	9	28						
ICM-KC50/50-10	10	56						
ICM-KC50/50-11	11	56						
ICM-KC50/50-12	12	28						

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

KAYASAND
BREAKS THE SAND BARRIER

V7 Mix Proportions

Quarry: ICA

Quantity Of Fine Aggregate:*** 780

V7 Product (with Pre-Dusters):

V7 Product (Before Pre-Duster):	68.00%
V7 Product A (With Pre-Duster A)	73.60%
V7 Product B (With Pre-Duster B)	75.60%
V7 Product C (With Pre-Duster C)	79.70%

Mix (kgs)

With Pre Duster A:

Kayasand:	720.65
Pre-Duster	59.35

With Pre Duster B:

Kayasand:	701.59
Pre-Duster	78.41

With Pre Duster C:

Kayasand:	665.50
Pre-Duster	114.50

KAYASAND

Concrete Trial Mix Worksheet
Cemex ICR-Air Tests

Date of Trial :		Mix Description :	Control
Material Code :		Cement (kg/m³) :	300
Trial Mix Ref :		Replacement (%) :	
Batch Time :		Laboratory Name :	Cardiff University
Batch Size (litres) :	10	Target Consistence :	S2

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		0/4mm Natural Sand	Tarmac		
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correction	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300		300.0	3.00	3.00	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)		0.20	0.2	1073	2.1	1075.1	10.75	10.75	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		1.00	1.0	780	7.8	787.8	7.88	7.88	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				176		166.1	1.66	1.95	
Admixture (1)				0.00		0.0	0.00	0.00	0.00
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
Comments:			TOTALS	2329.00	9.95	2329.00	23.29	23.58	

	SSD	Actual
W/C Ratio	0.587	0.682
Fines (%) =	42.1	

Corrected Weights (kg/m³) =	2357.75
Corrected Water (L/m³) =	204.75
Difference from Target (Litres) =	28.75
Difference from Target (%) =	16.33
Yeild (%) =	101.63

Concrete Appearance: Sandy / Normal / Stoney

Slump Test

Test	Mode	Value(mm)
1	Normal	60
2	Normal	
Mean Slump Test		60

Slump Retention

Test	Mode	Value(mm)
1 Hour	Normal	
2 Hours	Normal	
Initial Slump		60

Plastic Density

Test	Concrete Mass (kg)	Density (kg/m³)
Actual	23.2	2320
Calculated		2357.746
Pot Volume (litres) :		10
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		2320

Air Test

Meter Number	Kaya
Air Content (%)	0.38%

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²)	Failure Mode	Density (kg/m³)	Tested By
	1	1	19-Nov-10	45.8			2390	DL
	2	7	25-Nov-10	239.9			2240	MP
	3	28	16-Dec-10	332.5			2420	DL
	4	28	16-Dec-10	323.5			2410	DL

Worked Carried Out By :- ______________________ Worked Checked Out By :- ______________________

Date :- ______________________ Date :- ______________________

KAYASAND

Concrete Trial Mix Worksheet
Cemex ICR-air tests

Date of Trial :	18-Nov-10	Mix Description :	Kayasand 100%
Material Code :		Cement (kg/m³) :	300
Trial Mix Ref :		Replacement (%) :	
Batch Time :		Laboratory Name :	
Batch Size (litres) :	10	Target Consistence :	

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand	CR-C-BS		
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correctio	Corrected	Trial Target	Trial Actual	Admix weight
Cement				300		300.0	3.00	3.00	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)		0.20	0.2	1073	2.1	1075.1	10.75	10.75	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)		3.00	3.0	780	23.4	803.4	8.03	8.03	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				176		150.5	1.50	1.80	
Admixture (1)				0.00		0.0	0.00	0.00	0.00
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
Comments:			TOTALS	2329.00	25.55	2329.00	23.29	23.58	

	SSD	Actual
W/C Ratio	0.587	0.683
Fines (%) =	42.1	

Corrected Weights (kg/m³) =	2358.05
Corrected Water (L/m³) =	205.05
Difference from Target (Litres) =	29.05
Difference from Target (%) =	16.50
Yeild (%) =	101.64

Concrete Appearance: Sandy / Normal / Stoney

Slump Test

Test	Mode	Value(mm)
1	Normal	65
2	Normal	
Mean Slump Test		65

Slump Retention

Test	Mode	Value(mm)
1 Hour	Normal	
2 Hours	Normal	
Initial Slump		65

Plastic Density

Test	Concrete Mass (kg)	Density (kg/m³)
Actual	23.2	2320
Calculated		2358.046
Pot Volume (litres) :		10
Pot Number :		
Balance Number :		
Mean Density (kg/m³) :		2320

Air Test

Meter Number	Kaya
Air Content (%)	0.29%

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength (N/mm²)	Failure Mode	Density (kg/m³)	Tested By
	1	1	19-Nov-10	44.7			2420	DL
	2	7	25-Nov-10	148.7			2280	MP
	3	28	16-Dec-10	305.8			2440	DL
	4	28	16-Dec-10	295.5			2440	DL

Worked Carried Out By :- ______________________ Worked Checked Out By :- ______________________

Date :- ______________________ Date :- ______________________

Sand from Surplus Quarry Material

Quarterly Report 3

May 2011
Report no: 0QR3- SC9086-CF

1.0 Introduction

This quarterly report covers the period of February 2011 to April 2011. It reports the work that has been performed to date and presents results from a series of mixes cast using V7 feed material in the same period.

2.0 Work performed to date

In this last quarter the main thrust of work has been concentrated on establishing and performing characterization procedures for the fine aggregate. Trial tests have been performed on existing Kayasand samples and formal tests have been performed on a range of the crusher dust samples from the quarries participating in the project. The crusher dust material represents V7 feed material and the purpose of using the feed material is to identify the effect the manufacturing process has on the fresh and hardened properties of concrete. The activities performed in this period are outlined in further detail below.

2.1 New coarse and fine aggregate

New stocks of coarse and fine aggregate were delivered and stored in the School of Engineering to ensure the availablility of sufficient quantities of aggregate from the same source for the duration of the whole project. This reduces, where possible, any variation in the controlled parameters. The coarse aggregate is crushed limestone 4/14 mm with grading provided in Appendix A. It is supplied by Tarmac, the same supplier as the one used previously in the trial mixes detailed in Quarterly Reports 1 and 2. The fine aggregate is 0/4mm dredged natural sand from the same supplier as the aggregate previously used in trial mixes. However, the grading of the sand has changed since the trial mixes, probably due to the change in dredging site. The new sand is coarser than the one used previously and its grading is also provided in Appendix A.

2.2 New cement

The cement used in previous trial mixes was bagged 32.5N CEM II with up to 7% of fly ash addition manufactured by Lafarge. The concern was that the fly ash content could be variable therefore affecting the hardened and fresh properties of concrete. It was decided that in order to eliminate this potential variation CEM I should be used. An agreement with CEMEX was made for CEM I 52.5N cement deliveries in sealed buckets in shipments of 150kg according to the cement demand for the project.

2.3 Control trials with new aggregate and cement

Forty litre control mixes were made with the new aggregate, cement and Taff's Well crusher dust. It was observed that the usage of CEM I and new coarse aggregate in the control mix yielded a slump of 50 mm instead of 70mm as expected from the slump values obsevred during the previous trial mixes. The crusher dust concrete had 0mm slump and was unworkable. Two potential causes were identified:

1. Higher fineness and lack of fly ash particles in the CEM I cement increased water demand and decreased workability,
2. The absorption capacity and moisture content of coarse aggregate was not taken into account in mix design.

In order to address the first point, the impact of the change in cement on the fresh concrete properties was verified using two 10 litre mixes. The CEM II cement mix yielded a slightly higher slump value than the CEM I cement mix. However, it was evident that the loss in the workability of the mix could not be attributed solely to the change in cement type.

In the trial mixes the water content and absorption capacity of coarse aggregate was not accounted for. Due to the storage of the coarse aggregate in the concrete laboratory where it is warm and with sufficient air circulation the aggregate had become extremely dry. Therefore, during mixing a significant amount of water was absorbed by the aggregate from the mix, lowering the effective w/c ratio. This was identified as the cause of the unexpectedly low workability. Thus, it was decided to keep the aggregate moist and covered with a jute cloth as well as determine the water content of the aggregates before mixing and account for the moisture content

and the absorption capacity of the aggregate by adjusting the amount of water to be added to the mix.

2.4 Aggregate characterization tests

As the processed material from Japan has not yet been delivered, it was decided to use crusher dusts (0/4mm feed for V7 process) from the quarries involved in the project. These would serve as controls to compare the material before and after processing as well as build up a database of various materials and their corresponding characteristics. The crusher dusts and control sand tested with their corresponding mix designations/codes are shown below.

Table 2.1. Source and material with corresponding code.

Source	**Code**
Tarmac, Control dredged sand	Control
Cemex, Taff's Well crusher dust	CT-BS-C
Cemex, Gilfach crusher dust	CG-BS-C
AI, Duntilland crusher dust	AD-BS-C
AI, Glensanda crusher dust	AG-BS-C

The following tests were performed on the crusher dusts and control sand, the results of which are given in Table 2.2:

1. Wet sieving –(performed in the Hanson laboratory) (graphical results in Appendix A)
2. Sand Equivalent test
3. Absorption capacity and density
4. Methylene Blue test according to BS EN 933-9
5. Methylene Blue test – method developed by GRACE
6. New Zealand flow cone (graphical results in Appendix A)

The MBV test is a test indicating the presence of clay mineralogy in a given sample. There are two different MBV tests. One is a European Standard test, the other has been developed by GRACE admixtures. The principle of how they work is similar – measuring the methylene blue dye absorption on a material surface. However, the way in which this measurement is performed is different. The standard test uses titration and human judgement is involved in the determination of the test's endpoint, whereas the GRACE test calorimetrically determines the concentration of methylene blue dye which is left after the particle surface has absorbed it. A comparison of the results from the two methods will made at the end of the project.

Table 2.2 Summary of characterization test results

Grading	Control	CT-BS-C	AG-BS-C	CG-BS-C	AD-BS-C	Coarse
Sieve size (mm)	(% passing)	(% passing)	(% passing)	(% passing)	(% passing)	(% passing)
31.5	100	100	100	100	100	100
20	100	100	100	100	100	100
16	100	100	100	100	100	100
14	100	100	100	100	100	100
10	100	100	100	100	100	91
8	100	100	100	100	100	37
6.3	99	100	99	100	100	8
4	93	94	87	99	94	3
2	80	71	66	81	73	2
1	60	54	49	64	54	2
0.5	37	39	35	51	41	2
0.25	13	28	24	38	29	1
0.125	1	19	16	26	20	1
0.063	0	12	10	18	13	1
Sample	**Control**	**CT-BS-C**	**AG-BS-C**	**CG-BS-C**	**AD-BS-C**	**Coarse**
Sand Equivalent test	Awaiting result	65	50	27	48	-
Sample	**Control**	**CT-BS-C**	**AG-BS-C**	**CG-BS-C**	**AD-BS-C**	**Coarse**
Water absorption WA24, %	1.04	1.09	0.58	1.53	1.92	0.79
Particle density on SSD basis, Mg/m^3	2.66	2.83	2.64	2.68	2.89	2.70
Particle density on an oven-dried basis, Mg/m^3	2.63	2.79	2.62	2.64	2.83	2.68
Apparant particle density, Mg/m^3	2.71	2.88	2.66	2.76	3.00	2.73
NZ Flow Cone	**Control**	**CT-BS-C**	**AG-BS-C**	**CG-BS-C**	**AD-BS-C**	**Coarse**
Voids, %	37.89%	41.19%	42.40%	45.94%	45.73%	-
Flow time, sec	20.9	32.4	29.1	28.6	36.7	-
Sample	**Control**	**CT-BS-C**	**AG-BS-C**	**CG-BS-C**	**AD-BS-C**	**Coarse**
BS EN 933-9 MB value, grams of dye per kilogram of the 0/2 mm fraction	0.34	0.43	0.77	2.58	5.36	-
GRACE MBV TEST RESULT 0/2 mm fraction	0.35	0.67	0.94	3.9	6.16	-

2.5 Control mixes with crusher dust

Concrete made with crusher dust as a replacement for natural sand resulted in unworkable and zero slump mixtures. Therefore, it was decided to prepare mixtures with additional water which would give 70 ±10 mm slump, the same as for the control natural sand mixture.

The additional water requirement was determined in small 10 litre mixes to avoid the longer mixing times associated with the 40 litre batches. In these mixtures the water content and absorption capacity of fine and coarse aggregate was taken into account, allowing w/c ratios to be precisely calculated. This signified that a time consuiming trial and error approach to prepare 40 litre batches with the same w/c ratios and workability could be avoided.

The acquired data will be used later to compare and evaluate the influence of the V7 process on specific rock types. Mix designs and corresponding fresh and hardened properties can be found in Appendix B. The following tests were/will be carried out on fresh and hardened concrete properties:

1. Slump
2. Air entrapment
3. Fresh density
4. Compressive strength – 1,7,28 days
5. Flexural strength – 28 days.

Three mixes have been performed using the crusher dust from Taffs Well (CT-BS-C), Glensanda (AG-BS-C) and Duntiland (AD-BS-C) quarries. All three mixes are awaiting final results and an additional two mixes will be cast in near future to include the control mix and the Gilfach quarry. The mix proportions used in the mixes, along with the results obtained to date are provided in full in Appendix B. It is difficult at this stage to draw any comparisons between the results from the mixes as in order to control the workability of the mix, the water/cement ratio is altered for each crusher dust material. The magnitude of this alteration will be highly dependent on the absorption characterisics of the crusher dust, the grading of the crusher dust and on the shape of the crusher dust particles which in turn is highly dependent on the behaviour of individual rock types during the quarry crushing process. The most useful comparison to make will be between the crusher dust mix results and the results from the mixes made with the same rock type V7 product. This will only be possible once the V7 material for each quarry has been delivered and processed in the Cardiff School of Engineering.

3. Future work

The plan for the next quarter is to carry out all the crusher dust testing before the Kayasand V7 material arrives. Once the V7 material has arrived it will be processed in the School of Engineering using the characterisation tests that have been established and mixed using constant w/c ratios as identified in the preliminary mixes.

Appendix A – Characterisation Results

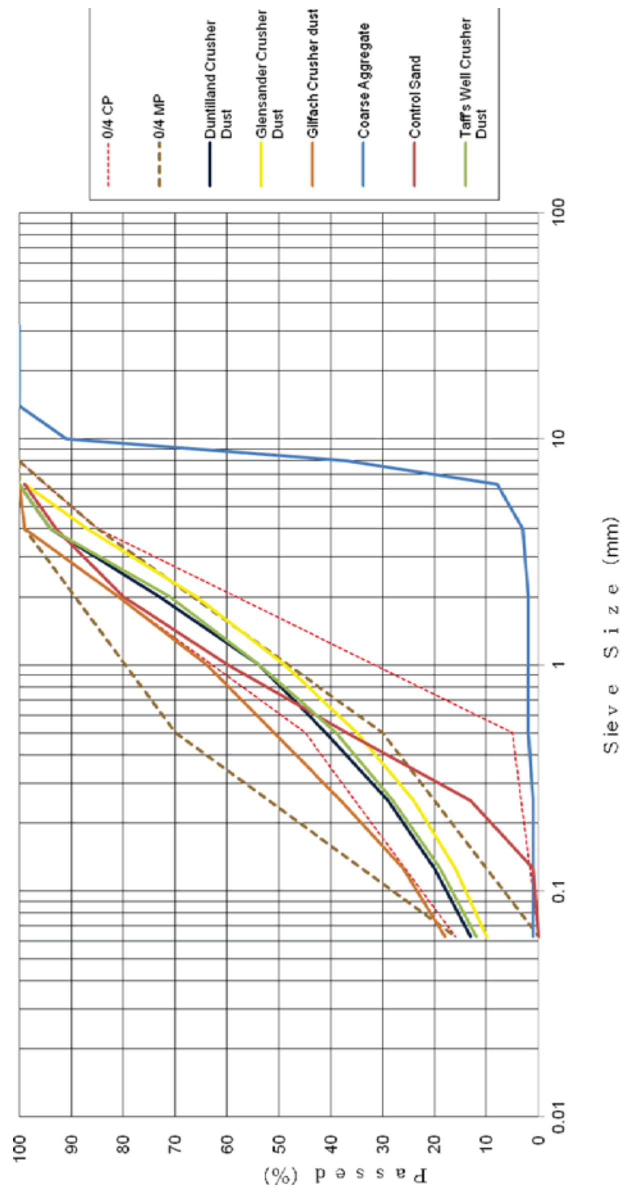


Figure A1. Aggregate particle size distribution and recommended grading envelopes for UK by PD 6682-1:2009 in GF85 category

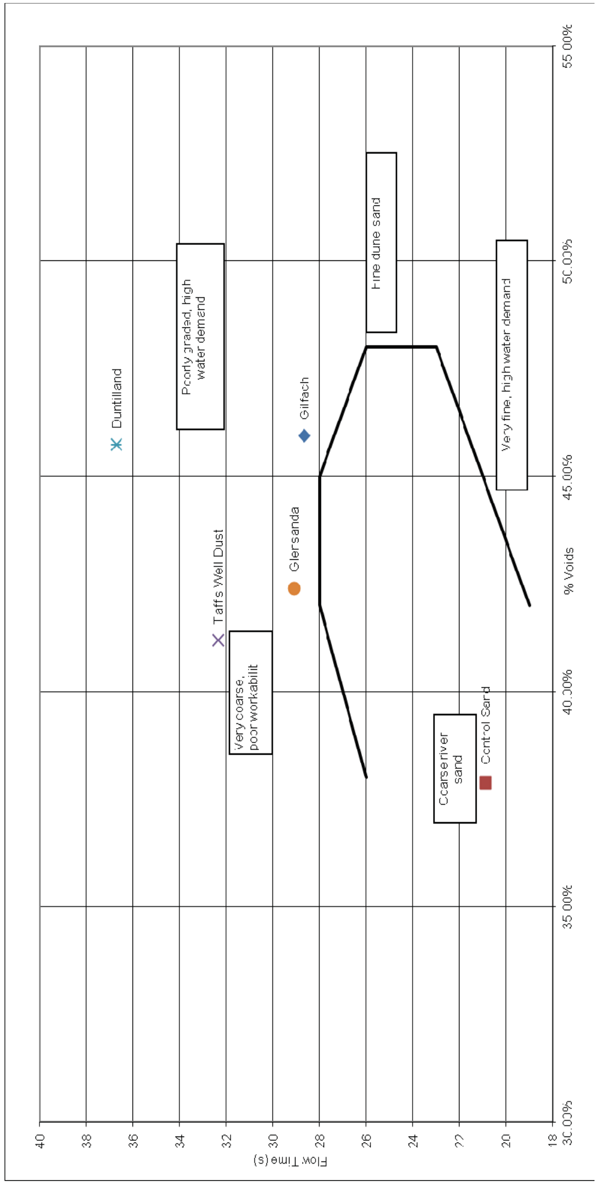


Figure A2. NZ Flow cone results and specification envelope

Appendix B Mix Details and Compressive Strength Results

KAYASAND

Concrete Mix Worksheet

Date of Trial :	19-May-11	Mix Description :	Crusher Dust 100%
Material Code :	AD-BS-C	Cement (kg/m³) :	300
Trial Mix Ref :		Replacement (%) :	
Batch Time :		Laboratory Name :	Cardiff University
Batch Size (litres) :	40	Target Consistence :	S2

Basic Material Types	Material Details S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Crusher Dust	AI	Duntiland	
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	Mix Design Figures S.S.D. kg/m³	Moisture Correction	Corrected kg/m³	Trial Target	Trial Actual	Admix weight
Cement				300		300.0	12.00	12.00	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)	0.79	1.70	0.9	1073	9.8	1082.8	43.31	43.31	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)	1.92	3.50	1.6	780	12.3	792.3	31.69	31.69	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				176		153.9	6.16	9.53	
Admixture (1)				0.00		0.0	0.00	0.00	0.00
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
Comments: High water demand			TOTALS	2329.00	22.09	2329.00	93.16	96.53	

	SSD	Actual
W/C Ratio	0.587	0.869
Fines (%) =	42.1	

Corrected Weights (kg/m³) =	2413.34
Corrected Water (L/m³) =	260.34
Difference from Target (Litres) =	84.34
Difference from Target (%) =	47.92
Yield (%) =	98.21

Concrete Appearance:

Slump Test

Test	Mode	Value(mm)
1	Normal	60
2	Normal	60
Mean Slump Test		60

Plastic Density

Test	Concrete Mass (kg)	Density (kg/m³)	Pot + concrete (kg)
Actual	18.9615	2370.188	22.904
Calculated	19.31	2413.338	
Pot Volume (litres) :		8	
Pot Mass :		3.9425	
Mean Density (kg/m³) :		2370.188	

Air Test	
Meter Number	Kaya
Air Content (%)	0.19%

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²	Failure Mode	Density (kg/m³)	Tested By
	1	1	26-May-11	63.2	6.32	Normal	2361	MP
	2	1	26-May-11	64.5	6.45	Normal	2369.5	MP
	3	1	26-May-11	61	6.1	Normal	2353	MP
	4	7						
	5	7						
	6	7						
	7	28						
	8	28						
	9	28						
	10							
	11							
	12							
	13							
	14							
	15							

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

KAYASAND BREAKS THE SAND BARRIER

Concrete Mix Worksheet

Date of Trial :	19-May-11
Material Code :	CT-BS-C
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	40

Mix Description :	Crusher Dust 100%
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	Cardiff University
Target Consistence :	S2

Basic Material Types	S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Crusher Dust	CEMEX	Taff's Well	
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correction	Corrected kg/m³	Trial Target	Trial Actual	Admix weight
Cement				300		300.0	12.00	12.00	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)	0.79	1.15	0.4	1073	3.9	1076.9	43.07	43.07	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)	1.09	1.19	0.1	780	0.8	780.8	31.23	31.23	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				176		171.4	6.85	8.58	
Admixture (1)				0.00		0.0	0.00	0.00	0.00
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
			TOTALS	2329.00	4.64	2329.00	93.16	94.89	

Comments:Mix appears watery, little bleeding in molds, workability ok, finishing well

	SSD	Actual Fre
W/C Ratio	0.587	0.731
Fines (%) =	42.1	

Corrected Weights (kg/m³) =	2372.14
Corrected Water (L/m³) =	219.14
Difference from Target (Litres) =	43.14
Difference from Target (%) =	24.51
Yield (%) =	101.30

Concrete Appearance: Stoney

Slump Test

Test	Mode	Value (mm)
1	Normal	80
2	Normal	80
Mean Slump Test		80

Plastic Density

Test	Concrete Mass (kg)	Density (kg/m³)	Pot + concrete (kg)
Actual	19.224	2403	23.1665
Calculated	18.98	2372.143	
Pot Volume (litres) :		8	
Pot Mass :		3.9425	
Mean Density (kg/m³) :		2403	

Air Test

Meter Number	Kaya
Air Content (%)	0.70%

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²)	Failure Mode	Density (kg/m³)	Tested By
	1	1	20-May-11	105	10.5	Normal	2394	MP
	2	1	20-May-11	100.1	10.01	Normal	2391	MP
	3	1	20-May-11	98.6	9.86	Normal	2383	MP
	4	7	26-May-11	273.2	27.32	Normal	2420	SD
	5	7	26-May-11	266.9	26.69	Normal	2415	SD
	6	7	26-May-11	273.1	27.31	Normal	2421	SD
	7	28						
	8	28						
	9	28						
	10							
	11							
	12							
	13							
	14							
	15							

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

Concrete Mix Worksheet

Date of Trial :	26-May-11
Material Code :	AG-BS-C
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	40

Mix Description :	Crusher Dust 100%
Cement (kg/m³) :	300
Replacement (%) :	
Laboratory Name :	Cardiff University
Target Consistence :	S2

Basic Material Types	S.G	Type	Supplier	Material Sourse	Admixture Dosage (ml/50kg) or Solid Materials (kg)
Cement		PC			
Replacement					
Coarse Aggregate (1)		4/20mm Gravel			
Coarse Aggregate (2)					
Fine Aggregate (1)		Crusher Dust	AI	Glensanda	
Fine Aggregate (2)					
Admixture (1)					0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Moisture Correction	Corrected kg/m³	Trial Target	Trial Actual	Admix weight
Cement				300		300.0	12.00	12.00	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)	0.79	1.70	0.9	1073	9.8	1082.8	43.31	43.31	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)	0.58	2.00	1.4	780	11.1	791.1	31.64	31.64	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				176		155.2	6.21	8.70	
Admixture (1)				0.00		0.0	0.00	0.00	0.00
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
			TOTALS	2329.00	20.84	2329.00	93.16	95.65	

Comments: hard to finish

	SSD	Actual
W/C Ratio	0.587	0.795
Fines (%) =	42.1	

Corrected Weights (kg/m³) =	2391.34
Corrected Water (L/m³) =	238.34
Difference from Target (Litres) =	62.34
Difference from Target (%) =	35.42
Yield (%) =	97.77

Concrete Appearance: Rocky

Slump Test

Test	Mode	Value(mm)
1	Normal	60
2	Normal	70
Mean Slump Test		65

Plastic Density

Test	Concrete Mass (kg)	Density (kg/m³)	Pot + concrete (kg)
Actual	18.705	2338.125	22.6475
Calculated	19.13	2391.34	
Pot Volume (litres) :		8	
Pot Mass :		3.9425	
Mean Density (kg/m³) :		2338.125	

Air Test

Meter Number	Kaya
Air Content (%)	0.50%

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²)	Failure Mode	Density (kg/m³)	Tested By
AG-BS-C 1	1	1	27-May-11	86.4	8.64	Normal	2315.5	MP
AG-BS-C 2	2	1	27-May-11	85	8.5	Normal	2301	MP
AG-BS-C 3	3	1	27-May-11	87.6	8.76	Normal	2297	MP
	4	7						
	5	7						
	6	7						
	7	28						
	8	28						
	9	28						
	10							
	11							
	12							
	13							
	14							
	15							

Worked Carried Out By :-

Date :-

Worked Checked Out By :-

Date :-

Sand from Surplus Quarry Material

Quarterly Report 4

August 2011
Report no: 0QR4- SC9086-CF

1.0 Introduction

This quarterly report covers the period of May 2011 to August 2011. It reports the work that has been performed to date on a series of mixes cast using basalt and granite Kayasand received from Japan during the period of this quarterly report.

2.0 Work performed to date

In this last quarter the main thrust of work has concerned the full scale testing of basalt and granite Kayasand received from Japan. Moreover, crusher dusts from all quarries that form part of this research project have been characterised and cast in concrete to enable the effect of the Kayasand manufacturing process on the fresh and hardened properties of the concrete to be established. All mixes were cast using cement contents of 300 kg/m^3 with constant workability of S2 slump.

The initial delay in Kayasand material delivery to Cardiff University allowed the literature review of usage of manufactured sands in concrete to be completed (see Appendix A). This literature review will form one of the chapters of the PhD thesis.

Upon delivery of Glensanda (granite) and Duntilland (basalt) Kayasands a full range of planned aggregate characterisation tests were performed. Fine aggregate particle size distributions were determined by wet sieving in the Hanson laboratory whereas the remainder of the tests were carried out in Cardiff University's concrete laboratory. The results will be presented in the next quarterly report.

One of the initial objectives of the experimental work was to determine the effect of the use of Kayasand on the strength of concrete whilst maintaining the same mix proportions for all concrete mixes cast. This involved maintaining the same water/cement ratio whilst simply reporting the resulting workability of the concrete. However, after a number of Kayasand and natural sand (control) mixes were made with 300 kg/m3 cement it was quickly evident that the water demand for each of the Kayasands was higher than for natural sand as well as differing between the Kayasands, with basalt sand displaying a the highest water demand of all sands. This suggested that it was going to extremely difficult to obtain workable concrete mixtures maintain the same w/c ratios without introducing some changes in the mix design.

Expert consultation was sought from Al and Grace, who suggested changes in mixture design by increasing the cement content and changing the fine to coarse aggregate ratio. After another set of trial mixes and a visit to the Grace R&D lab in UK the mix design was changed and the existing mostly single sized 14mm coarse aggregate replaced with a continuously graded 4 to 20 mm. The change in aggregates was justified by a trial with plasticizer – the concrete mixture with single sized aggregate resulted in a mixture which was “harsh” and difficult to work with. Therefore, a coarse aggregate of continuous particle size distribution was considered to be more suitable for the programme keeping in mind that the second phase of concrete testing would include admixtures.

The changes in mix design and new coarse aggregate lowered the water demands for all sands, but it was clear that it would be impossible to achieve equal w/c ratios for all sands, therefore, a new approach was considered as summarised below:

1. For each quarry a concrete mixture with 350 kg/m^3 cement content and Kayasand + preduster A (usually 2- 3% fines) is made with target slump of 70 mm. The w/c ratio of that mix is recorded.
2. The rest of the Kayasand mixes for that quarry are mixed with the recorded w/c ratio and tested for fresh and hardened properties.
3. A natural sand mix (control mix 1) with the recorded w/c is made and tested.
4. An additional natural sand mix (control mix 2) with a target slump of 70 mm is made and tested.

3.0 Future work

The plan for the next quarter is to process all of the fresh and hardened concrete results for presentation in a conference paper.

Sand from Surplus Quarry Material

Quarterly Report 5

December 2011

Report no: 0QR5- SC9086-CF

1. Introduction

This quarterly report covers the period of September 2011 to November 2011. It reports the results of the work that has been performed to date on basalt and granite Kayasand received from Japan during the period of QR4.

2. Work performed to date

2.1 Conference Paper

In this last quarter the main thrust of work has been concerned with the processing of the fresh and hardened concrete results from the Granite and Basalt Kaysand mixes. These have been incorporated into a conference paper entitled “Manufactured sand for a low carbon era” to be presented at the 2012 Conference on “Concrete for a low Carbon Era”, one of the largest international concrete conferences hosted by the Concrete Technology Unit at the University of Dundee. The conference paper in Appendix A provides a succinct summary of the testing and results to date.

2.2 Further Laboratory Tests

The differences in the water demand that were highlighted in the last quarterly report have been attributed to the clay content of Duntilland basalt sand as indicated by high MBV values from the aggregate testing results as well as differences in shape of the aggregates. A number of exploratory laboratory tests have been performed to investigate deactivation of the clay content and these are still ongoing.

2.3 Visits to Project Partners

A number of site visits have been conducted since the concrete testing work was completed in August 2011:

- Visit to CEMEX Rugby plant to familiarize with cement manufacturing and meet with people working in the particular field.
- Visit to Aggregate Industries R&D lab in Derby to discuss and share opinions and results on the progress of the project, testing and mixing methods.
- Visit to Grace Construction Products R&D lab in Poland, Poznan. Aimed as an introduction into admixtures and their usage in concrete, testing, quality control, dosages etc.

The knowledge gained from the visit to the Grace laboratory will allow the use of admixtures to be explored within this project. It is evident from the results presented in the conference paper that Kayasand can be successfully used in concrete without the use of admixtures, however, it is rare in practice that concrete would be made without admixtures. It is therefore important for future commercial viability to understand and identify the potential interaction between the sand, admixtures and clay de-activators.

3. Future Plans

The plan for the next quarter is to repeat the established laboratory procedures and tests on the Gilfach and Taffs Well Kayasand samples when they are received mid-January 2012. Further long term plans which will enable additional academic publication of the work also include:

1. Concrete mixes with admixtures: testing all available sands and pre-dusters with w/c ratio of 0.55 with various Water Reducing Agents (WRDA) 90 dosages to obtain S2 slump aiming at 70 mm.
2. Shape and texture study: analysis of different gradings, shapes and textures using optical microscope, New Zealand flow cone, and Mini mortar slump tests with constant w/c ratio.
3. MBV and clay inhibitor study: testing MBV and mini mortar slump of treated and untreated sands.

Appendix A – Conference Paper Dundee 2012

MANUFACTURED SAND FOR A LOW CARBON ERA

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Keywords: manufactured sand, concrete, sand replacement, workability, strength

Abstract

In 2000 the Welsh Assembly acknowledged the need to find a sustainable use for the growing stock piles of crusher fines in Wales, and commissioned research into their use as a replacement for natural sand in concrete. This study concluded that crusher fines were not a suitable replacement for natural sand in concrete due to their inconsistent grading and a lack of particles in the 0.3 to 1 mm range. New methods of manufacturing sand are now available which can more accurately control the sand particle size, shape and gradation including particles in the usually deficient range. Therefore a study has been launched to investigate the suitability of this manufactured sand for use in concrete applications.

Concrete that incorporates sand manufactured from quarry waste is a major development in achieving a sustainable construction material. However, the characteristics of manufactured fine aggregates are different to those of natural sands and their effects on the performance of concrete are not fully understood. The most common issues associated with manufactured sands are poor shape, gradation, and the quantity and quality of filler material. To investigate the effects of these and other parameters a test programme has been undertaken.

Laboratory tests have been used to evaluate the mineralogical and physical characteristics of a range of quarry waste sands. Concrete mixes with 100% replacement of natural sand have been used to compare and correlate the characteristics of these sands with the behaviour of fresh and hardened concrete. This paper describes the methodology of this study, presents the results and discusses the significance of the findings in the context of manufactured sand for a low carbon era.

INTRODUCTION

As natural resources of concrete aggregates are being depleted or a resistance to the usage of dredged sand due to environmental concerns is met, an alternative source of fine aggregate has to be found. One such source is crushed rock material from stone quarries. However, the material produced differs in characteristics from natural sands. The major differences are shape and texture, grading and amount of fine filler. These characteristics can detrimentally affect concrete, therefore manufactured fine aggregates are only reluctantly accepted within the industry [1].

The manufactured fine aggregate (MFA) shape is typically highly angular, elongated or flaky. This characteristic greatly influences the fresh and therefore hardened properties of concrete. MFA shape depends on the parent rock and to large extent on the crushing method [2], [3].
Typical particle size distribution of MFA or “quarry dust” rarely conforms to the requirements of national standards. These types of aggregate can produce “harsh” mixes with bleeding problems if it is washed and screened to fall within the prescribed limits [1]. This is mainly due to an excess of fine particles passing the 63 micron sieve and a deficiency of particles in the size range 0.3mm to 1mm. Thus manufactured sands are commonly used in blends with fine natural sands to overcome these shortcomings and minimise the negative effects on fresh and hardened concrete properties.

An alternative to washing and blending is reprocessing the quarry fines by employing another crusher to refine the particle shape and size distribution. Furthermore, if the classification process of the product employs a dry instead of a wet system then environmental benefits can be gained. Kotobuki Engineering & Manufacturing Company (Kemco), Japanese quarry industry supplier has developed a plant which incorporates these features, known as the V7 dry sand manufacturing system.

According to Lusty, in 2008 there were approximately 50 V7 plants in Japan accounting for 20% of Japan’s sand supply [4]. The sand has been noted as “exhibiting excellent characteristics in concrete as a complete replacement for natural sand. Moreover it has been reported that the shape of the particles is cubicle even in the fine sizes, and the gradation can be adjusted and held at a level within any of the standards set by American Society for Testing and Materials (ASTM), Japanese Standards (JIS) or British Standards (BS).”

In 2000 the Welsh Assembly acknowledged the need to find a sustainable use for the growing stock piles of crusher fines in Wales, and commissioned research into their use as a replacement for natural sand in concrete [1]. This study concluded that crusher fines were not a suitable replacement for natural sand in concrete due to their inconsistent grading and a lack of particles in the 0.3 to 1 mm range. New methods, including Kemco’s V7, of manufacturing sand are now available which can more accurately control the sand particle size, shape and gradation including particles in the usually deficient range. Therefore this study has been launched to investigate the suitability of this manufactured sand for use in concrete applications in Wales and the UK as a 100% replacement for natural sand.

In this study two manufactured sands of different mineralogy produced using the V7 plant were considered. The resulting consistency and compressive strength of concrete when sands were used as 100% replacement for natural sand is presented.

V7 PLANT

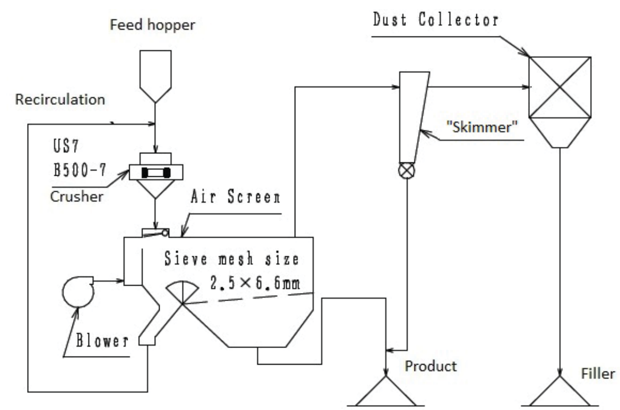

Figure 1 V7 plant simplified diagram

The manufactured sand used in this study was produced using the V7 plant. Figure 1 shows a simplified setup of the plant. The feed material for manufacturing sand is usually a 0/8 mm crusher dust with a water content less than 1.5%. It is fed to a vertical shaft impact (VSI) crusher and afterwards separated using an air screen. Oversize and some coarser particles are re-circulated, while the required particle sizes, are delivered as a product whereas most of the dust is fed to a “skimmer”. The “skimmer” separates coarser particles as well as some filler from the dust. The separated particles known as a pre-duster are added into the final product increasing the yield, allowing control of the fines content as well as providing usually deficient 0.3 to 1 mm particles in the manufactured sand.

For the project at least four sand gradations were produced from each crusher dust. The sands slightly differ with particle size distributions as shown in Tables 2-4.

MATERIALS

Cement

The cement used was CEM I 52.5 N conforming to EN 197-1.

Coarse Aggregate

The coarse aggregate used was crushed limestone 4/20mm and its particle size distribution is shown in Table 4.

Fine Aggregate

In this study marine dredged sand was used as a control and it is denoted by the letter N in the tables and figures in this paper.

The manufactured sand was processed from 0/8 mm crusher dusts taken from two quarries located in UK. One quarry produces basalt whereas the other produces granite aggregate. Properties of the 0/4mm parts of the crusher dusts are included in Tables 1 - 3 for comparison purposes. In all tables and figures the basalt crusher dust is denoted as B-FEED and the granite as G-FEED.

From the crusher dusts four basalt sands and five granite sands with different particle size distributions were produced. Basalt sands are denoted by letter B in the tables and figures whereas granite sands are denoted by letter G. Following the letter B or G indicating the quarry, the sands are further denoted with a letters A to DE (E for granite sand) depending on the sub 63 micron particle content. For example, B-A is a basalt sand with the least fines content, whereas B-D is a basalt sand with the highest fines content. Particle size distributions are shown in Tables 2 and 3.

The fine aggregate used in the study was characterized using the following standard tests:
- Methylene blue test (MBV) according to BS EN 933-9 on 0/2mm fraction
- Sand equivalent test (SE) according to BS EN 933-8 on 0/2mm fraction
- Particle size distribution according to BS EN 933-1
- Particle density and water absorption according to BS EN 1097-6.

MBV and SE tests are intended to assess if there are potentially deleterious fines e.g. clays in the fine aggregate which could adversely affect the fresh and hardened properties of the concrete.

In addition to the abovementioned tests the following fine aggregate tests were also used:
- New Zealand Flow cone (NZFC) according to NZS 3111-1986
- Rapid Methylene blue test (RMBV) developed by Grace on the 0/2mm fraction of the sands.

The NZFC test evaluates sand flow and the un-compacted voids ratio. A fixed volume of sand is passed through a cone and collected in a container of known volume whilst measuring the flow time. Using the density of the sand particles allows the un-compacted voids ratio to be calculated. The test result is affected by the grading of the sample, by the particle shape and by the surface texture of the particles. The flow of the material is mostly affected by the shape and surface texture of the particles while the voids result is mostly influenced by grading and shape [5]. Although the British European Standards EN 933-6 and BS EN 1097-6 evaluate the flow time and un-compacted voids, they do not provide the opportunity to do that simultaneously.

The NZFC is a rapid test that does not require sophisticated equipment and experienced operator as opposed to visual shape and texture estimation techniques. The results are plotted on the diagram shown in Figure 2 with reference to a standard envelope adopted by the New Zealand authorities, therefore, the NZFC test was adopted in the study.

The RMBV test evaluates the same properties as the BS EN 933-9 MBV test, however, using a different approach. The British European standard procedure determines the absorption of methylene blue dye by consecutively adding a drop of the dye and checking for the test's endpoint. The endpoint of the test is determined by dropping a small amount of the suspension on a filter paper until a light blue halo around a central deposit is observed and this endpoint is often open to interpretation.

The RMBV test eliminates this problem as well as reducing the testing time. The test portion is mixed with a methylene blue solution of known concentration, shaken for a fixed time and an aliquot of the suspension is filtered. Afterwards a known volume of the filtrate is diluted with a set amount of water and a pre-calibrated colorimeter is used to estimate the concentration of the solution. This allows direct estimation of the absorbed amount of methylene blue solution eliminating possible errors due to human judgement.

The RMBV test was used in this study to compare the results obtained by the two methods and evaluate the feasibility of the new method.

Table 1 Fine aggregate test results

SAMPLE	MBV, g of MB solution per kg of sand	RMBV, g of MB solution per kg of sand	SE	NZFC VOIDS, %	NZFC FLOW TIME, sec	WA_{24}, %	ρ_{ssd}, Mg/m^3	ρ_{rd}, Mg/m^3	ρ_a, Mg/m^3
N	0.24	0.35	94	37.9	20.9	1.04	2.66	2.63	2.71
G-FEED	0.77	0.94	50	42.4	29.1	0.58	2.64	2.62	2.66
G-A	0.39	0.42	80	45.2	25.3	0.58	2.63	2.61	2.65
G-B	0.40	0.50	74	44.6	24.4				
G-C	0.47	0.71	71	43.7	23.9				
G-D	0.50	0.88	70	43.6	23.4				
G-E	0.63	0.90	69	42.7	23.9				
B-FEED	5.36	6.16	48	45.7	36.7	1.92	2.89	2.83	3.00
B-A	2.10	2.3	73	45.8	25.7	1.67	2.91	2.87	3.01
B-B	2.29	2.54	61	44.5	23.2				
B-C	2.64	2.97	60	43.7	22.5				
B-D	2.90	3.75	58	43.7	22.3				

* BS EN 1097-6 test was carried out only for manufactured sands with the lowest fines content as the sub-63 micron particles are washed out of the sample prior to testing.
** WA_{24} - water absorption
***ρ_{ssd} – particle density on saturated surface dry basis
****ρ_{rd} - particle density on oven dry basis
*****ρ_a- apparent particle density

Table 2 Aggregate particle size distribution

SAMPLE	D-FEED	B-A	B-B	B-C	B-D	N
SIEVE SIZE mm	PERCENT PASSING BY MASS					
8	100.0	100.0	100.0	100.0	100.0	100.0
6.3	100.0	100.0	100.0	100.0	100.0	98.0
4	94.0	100.0	100.0	100.0	100.0	93.0
2.8	86.0	99.0	99.2	99.3	99.3	87.0
2	73.0	88.0	90.3	91.0	91.4	82.0
1	54.0	56.0	64.2	66.4	67.7	61.0
0.5	41.0	34.0	44.9	48.7	50.8	37.0
0.25	29.0	16.0	27.1	32.2	34.7	12.0
0.125	20.0	4.0	10.9	15.9	18.8	1.0
0.063	13.0	1.0	2.9	5.1	7.4	1.0

Table 3 Aggregate particle size distribution continued

SAMPLE	G-FEED	G-A	G-B	G-C	G-D	G-E
SIEVE SIZE mm	PERCENT PASSING BY MASS					
8	100.0	100.0	100.0	100.0	100.0	100.0
6.3	99.0	100.0	100.0	100.0	100.0	100.0
4	87.0	100.0	100.0	100.0	100.0	100.0
2.8	77.0	99.0	99.1	99.2	99.2	99.2
2	66.0	90.0	90.8	91.8	92.1	92.3
1	49.0	63.0	65.7	69.4	70.2	71.1
0.5	35.0	39.0	43.2	48.9	50.6	51.9
0.25	24.0	17.0	21.9	29.1	31.4	33.3
0.125	16.0	4.0	7.5	13.0	15.6	17.8
0.063	10.0	2.0	2.8	5.1	6.5	9.0

Table 4 Aggregate particle size distribution continued

SAMPLE	CA
SIEVE SIZE mm	PERCENT PASSING BY MASS
40	100
31.5	100
20	95
16	68
14	58
10	36
6.3	16
4	6
2	5
0.063	2

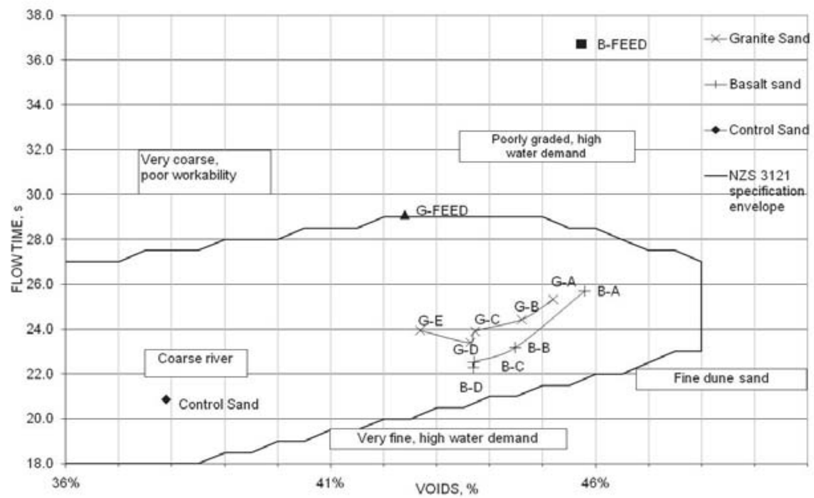

Figure 2 New Zealand Flow Cone results and specification envelope

CONCRETE MIXTURES

For each quarry a trial mix using 100% manufactured sand with a fines content of 2.8% (G-B or B-B) was made adjusting the water content to reach a slump of 80mm. Other mixes of that quarry material were made using the established w/c ratio. Acknowledging the fact that the natural sand has different water demand to the manufactured sand for each quarry there were two control mixes, the first with 80±20mm slump and the second with the same w/c ratio as used in the manufactured sand mixtures. The slump control mixture in this paper is denoted as N whereas the other controls are N-G for the granite quarry and N-B for the basalt quarry mixes.

The absorption capacity and water content of fine and coarse aggregates were taken into consideration and the mixture's water content was adjusted accordingly to maintain the w/c ratio and mixture proportions, as presented in Table 5.

Table 5 Concrete mixture proportions at SSD conditions

MIX	CEM kg/m^3	CA kg/m^3	FA kg/m^3	WATER kg/m^3	W/C	FA/ CA	FINES CONTENT % of FA
N	350	1040	753	167	0.48	0.42	1.0
N-G	350	1040	753	202	0.58	0.42	1.0
G-A	350	1040	753	202	0.58	0.42	2.0
G-B	350	1040	753	202	0.58	0.42	2.8
G-C	350	1040	753	202	0.58	0.42	5.1
G-D	350	1040	753	202	0.58	0.42	6.5
G-E	350	1040	753	202	0.58	0.42	9.0
N-B	350	1040	753	234	0.67	0.42	1.0
B-A	350	1040	753	234	0.67	0.42	1.0
B-B	350	1040	753	234	0.67	0.42	2.9
B-C	350	1040	753	234	0.67	0.42	5.1
B-D	350	1040	753	234	0.67	0.42	7.4

*FA – fine aggregate, CA – coarse aggregate

Fresh Concrete Tests

Fresh concrete was tested for slump according to BS EN 12350-2:2009, plastic density and air entrapment. The results of these tests are presented in Table 6.

Hardened Concrete Tests

Hardened concrete was tested for compressive strength at 1, 7 and 28 days according to BS EN 12390-3:2009, for flexural strength at 28 days according to BS EN 12390-5:2009. The concrete specimens were de-moulded 16 to 20 hours after casting and placed in water tanks at a constant temperature of 20°C until the test age was reached. Results of these tests are presented in Table 6.

RESULTS AND DISCUSSION

In this section fresh and hardened concrete properties are presented and discussed with reference to the fine aggregate properties shown in Tables 1-4 and Figure 2.

Fine Aggregate Test Results

One objective of the project was to compare the RMBV test with the MBV standard test. It can be seen in Figure 3 that the test results obtained using both methods exhibit a very good linear correlation with R^2 = 0.99 suggesting that both test methods evaluate the same property, although providing different numerical values. This suggests that the RMBV test could be used as an alternative test to the standard MBV test.

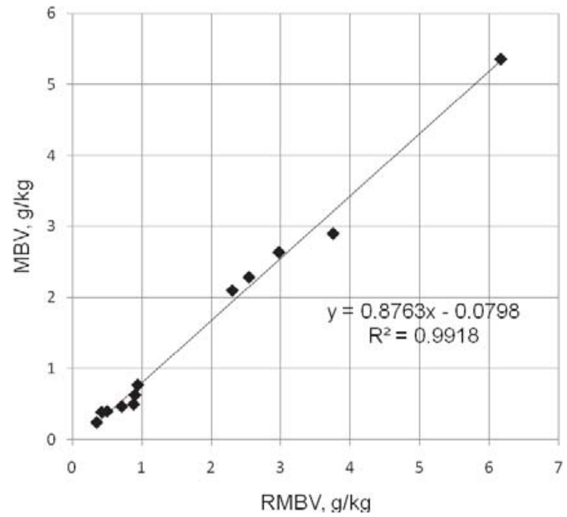

Figure 3 Correlation between RMBV and MBV values for all samples

Table 1 shows that there are differences between the feed material for each quarry and the resulting manufactured sands. B-FEED basalt quarry dust has a high MBV of 5.36 g/kg (RMBV 6.16 g/kg) whereas the highest fines basalt manufactured sand B-D possesses an MBV of 2.90 g/kg (RMBV 3.75 g/kg). A similar trend can be seen with the granite manufactured sands. The G-FEED MBV is 0.77 g/kg whereas the highest fines granite sand G-E MBV is 0.63 g/kg. It can be concluded that during the processing a proportion of clay sized particles (<2 micron) has been removed from the material as part of the filler component lowering the MBV value of the sand.

From Table 1 it can be seen that the sand equivalent (SE) values have increased for the processed quarry dusts. The SE values are the highest for manufactured sands with the least fines and gradually decrease with increasing fines content. A similar inverse trend to that was observed in the MBV values that can be attributed to the removal of clay sized particles during the manufacturing process.

The SE values for granite sands are in range from 80 to 69; for basalt sands they are lower - from 70 to 58. Similarly to the MBV values this suggests that the basalt sands contain some deleterious fines or clays which may adversely affect the water demand of concrete mixtures.

Figure 2 shows the results from NZFC. The processed manufactured sands lie within the New Zealand specification envelope whereas the feed material from both quarries does not conform to the specification. It suggests that the G-FEED and B-FEED are poorly shaped and graded.

The flow time has been greatly reduced for the manufactured sands; at least 4 seconds for granite sands and 11 seconds for basalt sands. This suggests that the particle shape has been modified and after processing it is less angular and flaky. The voids content of the G-FEED is 42.4% whereas for the manufactured sands it ranges from 45.2% for the least fines sand to 42.7% for the highest fines sand G-E, whereas the voids content of the B-FEED is 45.7% and it is decreasing for manufactured sands with more fines. Visual inspection suggests that the basalt crusher dust particles are mostly angular and flaky whereas the manufactured sand particles are mostly rounded without sharp edges. Similarly granite crusher dust particles are highly angular and flaky, however the manufactured sands are mostly cubical with sharp edges but without flaky particles.

These observations suggest that angular and flaky particles result in a higher voids content and flow rate. Similarly cubical particles with sharp edges increase the voids content but to a lesser extent than flaky ones. Rounded particles result in the lowest voids content and flow rates. Increased fines contents lower the voids content and generally improve the flow rate.

Workability

It was expected from the fine aggregate tests that the natural sand would require the least water to achieve the 80 mm slump due to the intrinsic roundness and low amount of fines. The granite sand was expected to have a higher water demand than natural sand due to shape and higher amounts of fines, however, lower than that of the basalt sand due to the lower MBV. The test results proved the expected trend – to reach an 80 mm slump the natural sand mixture (N) required a w/c ratio of 0.48, the granite sand (G-B) 0.58 and the basalt sand (B-B) 0.67.

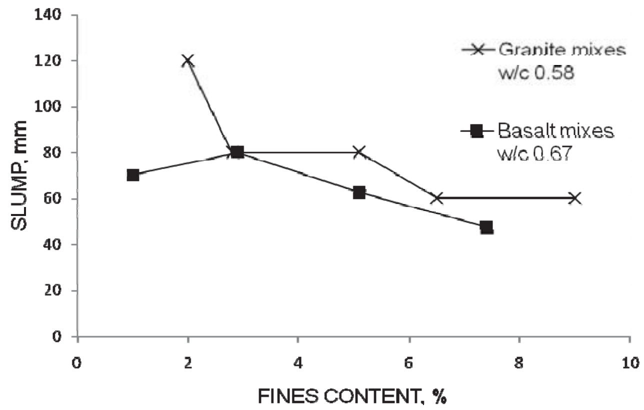

Figure 4 Variation of slump with fines content

Figure 4 shows the slump versus the amount of fines for the granite and basalt mixtures. The general trend is that the higher the amount of fines, the lower the slump of the concrete. However, it has to be noted that the manufactured sand mixtures with the lowest fines content were observed to be hard to work and finish even though the slump was from 70 to 120 mm. Mixtures with higher fines contents B-B, B-C and G-B, G-C, G-D were easier to finish and work even with lower slump values. However, the B-D and G-E mixtures were very cohesive due to the amount of fines.

It was not possible to measure the slump for the natural sand w/c ratio controls for both quarries (N-G and N-B) as the slumps collapsed. During the casting of specimens the mixtures segregated and bleeding was observed.

The natural sand slump control N mix was easy to work and finish.

Hardened Concrete Properties

Table 6 Fresh and hardened concrete properties

MIX	SLUMP mm	AIR %	FRESH DENSITY kg/m^3	COMPRESSIVE STRENGTH, N/mm^2			FLEXURAL STRENGTH, N/mm^2
				1 day	7 day	28 day	28 day
N	95	0.5	2447	23.8	48.0	58.9	6.1
N-G	Collapse	0.3	2405	13.5	36.0	48.7	5.4
G-A	120	0.45	2393	17.6	43.5	52.2	5.6
G-B	80	1.6	2375	17.0	40.2	49.9	5.6
G-C	80	0.9	2378	17.9	40.4	50.1	6.0
G-D	60	0.65	2393	19.3	42.2	52.3	5.8
G-E	60	0.78	2393	16.6	40.6	48.1	5.4
N-B	Collapse	0.35	2363	9.6	26.2	35.9	4.6
B-A	70	0.5	2430	11.8	30.4	41.7	5.3
B-B	80	0.5	2423	12.9	31.3	43.7	5.5
B-C	62.5	0.45	2434	13.0	33.1	42.7	5.4
B-D	47.5	0.65	2410	13.2	35.2	45.6	5.6

Table 6 shows the compressive and flexural strengths of all concrete mixtures. The compressive strength of the control mixture N is the highest at all stages of testing and reaches 58.9 N/mm^2 at 28 days.

The compressive strength of basalt mixes is in range of 41.7 N/mm^2 for B-A to 45.6 N/mm^2 for the B-D mix. All basalt mixtures surpass the strength of the w/c ratio control N-B mixture. Similarly to the basalt sand mixes, the compressive strength of granite sand mixes surpass the w/c ratio control N-G and are in range of 48.1 N/mm^2 to 52.3 N/mm^2. However, it has already been noted that the slump of the N-B and N-G mixtures collapsed and segregated during casting, and therefore it would seem prudent to treat these results with caution.

The increase of fines content in manufactured sands did not show a correlation with the compressive strengths at 28 days. It suggests that there are no negative effects of higher fines

contents on the compressive strength for the given mixture composition and range of fines contents investigated in the study.
The 28 day flexural strength for all mixes is in the range 4.6 to 6.1 N/mm^2 and seems to follow the trends of compressive strength, with higher compressive strength resulting in higher flexural strength.

CONCLUSIONS

The results show that the manufactured sand mixtures at the same w/c ratios surpass the strength of natural sand concrete, however, they exhibit lower workability. However the 28 day strength of the slump controlled natural sand concrete surpasses that of the manufactured sand concrete due to the lower w/c ratio.
The fine aggregate test results showed that the processing of crusher dusts improved the shape and grading as well as removed some deleterious clay sized particles as indicated by the MBV and SE tests. The test results also suggest that the RMBV test could be used as an alternative to the standard MBV test in order to rapidly assess the presence of potentially deleterious fines.
It is important to assess the harm of fines in fine aggregates as it can dramatically affect the water demand for the same workability, as shown by the basalt sands in comparison to the granite sands.
During this phase of the study it was observed that it is hard or sometimes impossible to compare the manufactured sands with natural sand at the same w/c ratio and concrete mixture composition due to the shape and texture, and presence of deleterious particles in the manufactured sands. Therefore, the next phase of the study will be aimed at investigating the performance of manufactured sand concrete mixtures containing admixtures.

ACKNOWLEDGEMENTS

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Sand from Surplus Quarry Material

Quarterly Report 6

May 2012
Report no: 0QR6- SC9086-CF

1. Introduction

This quarterly report covers the period of January 2012 to May 2012. It reports the results of the work that has been performed to date on the partial shipment of limestone and gritstone Kayasand received from Japan during the period of QR5 and additional test performed on the granite and basalt Kayasand discussed in previous quarterly reports.

2. Work performed to date

2.1Mixes incorporating admixtures

A series of tests were performed using a clay inhibitor EXP-CM1 admixture provided by GRACE in small Duntilland concrete mixes incorporating WRDA 90 plasticizer. In order to complete these trials a dosage response curve was developed using 100 g sand samples (adjusted for moisture content) and treated with various dosages of EXP-CM1. The dosages were calculated from the mass of single drops, rather than percentage values for the mix based on the available measuring techniques in the lab. However, this had no influence on the final form of the response curve graph. The sand was treated with the EXP-CM1 mixed with water to reach a 10% moisture state in the sand, mixed and after 5 minutes dried in the microwave oven. The dried sand particles had become slightly "cemented"

The dosage chosen for the 10 litre concrete trials was the maximum used in the production of the response curve 24.48%. Two sets of concrete mixes, one with 0.55 w/c ratio and the other with 0.60 w/c ratio. Both were adjusted for moisture content, aggregate absorption and water in the admixtures (Mix design sheets are in Appendix A). The first mix incorporated WRDA 90 without EXP-CM1 to establish initial slump value, the second mix incorporating same amount of water (adjusted for 50% water in the EXP-CM1) and WRDA 90 plus the clay deactivator. The following mixing sequence was followed for all mixes:

1) Sand and Coarse aggregate placed in drum and mixed with half of mixing water + EXP-CM1 for 1 minute

2) Covered and left for 5 minutes

3) mixed for 2 minutes while adding rest of the water and plasticizer

4) Tested slump two times, with brief remixing in between the tests

The compressive strength results at 1 and 7 and 28 days are summarised in Table 2.1.

Table 2.1

			Compressive strength, N/mm^2		
	w/c	Slump, mm	1 day	7 day	28 day
No CM-1	0.55	20	20.08	52.5	65.6
With CM-1	0.55	40	17.23	48.84	62.5
No CM-1	0.6	70	15.36	43.95	53.4
With CM-1	0.6	75	14.11	43.3	54.2

An increase in slump of 20 mm was observed for 0.55 w/c ratio mixes but only 5 mm for 0.6 w/c mix. Furthermore, the mixes incorporating EXP-CM1 seemed wetter and easier to work and finish, however, the increase in slump was only marginal. CM-1 mixes have lower strength at 1 and 7 days, this could be explained by more free water in the mix due to the action of CM-1 but there is very small increase in slump which accompanies it. Discussions with GRACE have revealed that the clay deactivator works better with an S3 consistency concrete incorporating different type of plasticizer (superplasticiser). This may be explored further by Cardiff or by Grace depending on the time available within the project.

From the results it seems that without plasticizer to obtain S2 slump basalt sand with clay requires more water than granite sand, confirming theoretical predictions. This indicates that clay absorbs water, therefore, more water is required to compensate for this absorption and hence the final strength is compromised due to the higher free water/cement ratio if only absorption of the sand and coarse aggregate is taken into account (to test absorption capacity according to the standard, the fines must be washed out of the sample). That means the water absorbed by clays does not contribute to workability, but contributes to the lower strength of the concrete at later stages. This can be confirmed by the second set of results of 0.55 w/c ratio which yields very similar strength at 28 days for all granite and basalt concrete mixes.

2.2 Sand Characterisation tests on Taff's Well and Gilfach Kayasands

Partial shipment of the Taff's Well and Gilfach sands were received in April 2012. The following suite of tests has been performed on the sands and the results presented in Table 2.2:

1) Methylene Blue Value (MBV)
2) Methylene Blue Value using GRACE method (GMBV)
3) Sand Equivalent (SE)
4) New Zealand flow cone (uncompacted voids and flow time) (NZFC)
5) Water absorption (WA), and relative densities: dry (r_{rd}), apparent (r_a) and SSD density(r_{ssd})

Table 2.2 Summary of Characterisation test results

SAMPLE	MBV, g of MB solution per kg of 0/2mm sand	GMBV, g of MB solution per kg of 0/2 mm sand	SE	NZFC Voids, %	NZFC Flow time, sec	WA_{24}, %	r_{ssd}, Mg/m^3	r_{rd}, Mg/m^3	r_a, Mg/m^3
Natural sand	0.24	0.35	94	37.9	20.9	1.04	2.66	2.63	2.71
Taff's Well Feed	0.40	0.65	65	42.4	32.4	0.62	2.90	2.85	2.87
Taff's Well	0.47	0.44	72	43.6	26.3	0.45	2.89	2.85	2.86
Taff's Well PA	0.40	0.44	71	42.1	23.9				
Taff's Well PB	0.40	0.44	71	41.9	23.4				
Taff's Well PC	0.37	0.45	67	41.0	23.0				
Gilfach Feed	3.19	4.05	27	45.9	28.6	1.53	2.76	2.64	2.68
Gilfach	1.40	1.73	31	41.8	23.3	0.98	2.64	2.57	2.60
Gilfach PA	1.48	1.84	30	41.6	22.3				
Gilfach PB	1.50	1.86	28	40.8	21.3				
Gilfach PC	1.63	2.07	27	40.1	20.7				

In order to compare the GMBV test with the MBV standard test, test results from all 4 Kayasands have been considered (Duntilland, Glensanda, Taff's Well and Gilfach). It can be seen in Figure 2.1 that the test results obtained using both methods exhibit a very good linear correlation with R^2 = 0.99 suggesting that both test methods evaluate the same property, although providing different numerical values. This suggests confidence in the RMBV test as an alternative test to the standard MBV test.

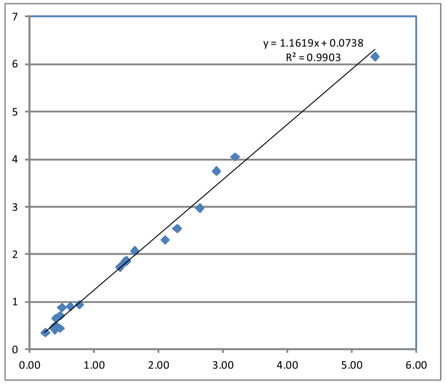


Figure 3 Correlation between GMBV and MBV values for all samples

2.3 Concrete Mixes with Taff's Well and Gilfach Kayasands

Concrete mixes, identical in nature to those reported in 0QR4- SC9086-CF for the Duntilland and Glensanda sands were produced with Taff's Well and Gilfach. The full results are provided in Appendix B although they are summarised here for completeness.

At all ages the Taff's Well limestone concretes show very similar strength results to the natural sand slump control mix even though the w/c ratio for limestone concrete was 0.55 whereas for the control it was 0.48. This implies that it should be possible, with the use of admixtures to develop a Kayasand mix which yields higher compressive strength values when compared to the natural sand slump control mix at equal w/c ratio.

The Gilfach sand performed in a very similar manner to the Duntilland sand, with an S2 slump value being achieved at an identical w/c ratio. Although slightly lower GMBV and MBV values were reported for the former in comparison to the latter this difference had little effect on the observed compressive strength and only marginal effect on the workability of the mix. This confirms previous observations that whilst it is possible to use Duntilland and Gilfach sands in a concrete mix, the use of admixtures may be required to achieve desired fresh and hardened properties.

3. Future Plans

The plan for the next quarter is to complete the full range of tests on the Gilfach and Taff's Well Kayasand samples when the remainder of the Shipment is received in July 2012. These tests mainly concern concrete mixes using w/c ratio of 0.55 including a WRDA 90 plasticizer and a 70mm (S2) slump. Additional activities that are ongoing include:

- Finalise shape and texture study for the sands using New-Zealand flow cone, mini-mortar slump cone and optical microscopy.
- Investigate modelling of concrete properties using Artificial Neural Networks.
- Lastly the results to date will be presented at the international conference "Concrete in the Low Carbon Era" in Dundee, July 2012

Appendix A – Admixture Mix Design Sheets

Concrete Trial Mix Worksheet

Date of Trial :	11-Apr-12
Material Code :	AD-ADM
Trial Mix Ref :	
Batch Time :	
Batch Size (litres) :	10

Mix Description :	Kayasand 100%
Cement (kg/m³) :	350
Replacement (%) :	
Laboratory Name :	Cardiff University
Target Consistence :	

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC	Cemex	Rugby	
Replacement					
Coarse Aggregate (1)		/20mm Crushed Limeston			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand		Duntiland	
Fine Aggregate (2)					
Admixture (1)		WRDA 90 plasticizer	Grace		0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	Mix Design Figures S.S.D. kg/m³	Moisture Correction	Corrected	Trial Target	Trial Actual	Admix weight
Cement				350		350.0	3.50	3.50	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)	0.66	0.14	-0.5	1040	-5.4	1034.6	10.35	10.35	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)	1.67	4.35	2.7	753	20.2	773.2	7.73	7.73	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				192		177.2	1.77	1.76	
Admixture (1)				2.75		2.8	0.03	0.03	0.03
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
Comments:			TOTALS	2337.75	14.77	2337.75	23.38	23.37	

	SSD	Actual
W/C Ratio	0.549	0.551
Fines (%) =	42.0	

Corrected Weights (kg/m³) =	2336.52
Corrected Water (L/m³) =	190.77
Difference from Target (Litres) =	-1.23
Difference from Target (%) =	-0.64
Yield (%) =	-0.21

Concrete Appearance:

Slump Test

Test	Mode	Value(mm)
1	Normal	20
2	Normal	20
Mean Slump Test		20

Air Test

Meter Number	Kaya
Air Content (%)	

Plastic Density

Test	Concrete (kg)	Density (kg/m³)	Pot + concrete (kg)
Actual	-3.9425	-492.813	
Calculated	18.69	2336.522	
Pot Volume (litres) :		8	
Pot Mass :		3.9425	
Mean Density (kg/m³) :		-492.813	

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²	Failure Mode	Density (kg/m³)	Tested By	Average
AD-ADM-1		1			0.00	Normal			
AD-ADM-2		1			0.00	Normal			0.0
AD-ADM-3		1			0.00	Normal			
AD-ADM-4		7			0.00	Normal			
AD-ADM-5		7			0.00	Normal			0.0
AD-ADM-6		7			0.00	Normal			
AD-ADM-7		28			0.00	Normal			
AD-ADM-8		28			0.00	Normal			0.0
AD-ADM-9		28			0.00	Normal			
AD-ADM-10		28			0.00	Normal			

Lab Reference	Mould Number	Age at Test	Test Date	Real Load (kN)	Flexural Strength N/mm²	Failure Mode		Tested By	average
AD-ADM-1		28			0	Normal		MP	
AD-ADM-2		28			0	Normal		MP	0.0
AD-ADM-3		28			0	Normal		MP	

Concrete Trial Mix Worksheet

KAYASAND

Date of Trial :	11-Apr-12	Mix Description :	Kayasand 100%
Material Code :	AD-ADM	Cement (kg/m³) :	350
Trial Mix Ref :		Replacement (%) :	
Batch Time :		Laboratory Name :	Cardiff University
Batch Size (litres) :	10	Target Consistence :	

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC	Cemex	Rugby	
Replacement					
Coarse Aggregate (1)		/20mm Crushed Limeston			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand		Duntiland	
Fine Aggregate (2)					
Admixture (1)		WRDA 90 plasticizer	Grace		0 ml
Admixture (2)					0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Mix Design Figures Moisture Correction	Corrected	Trial Target	Trial Actual	Admix weight
Cement				350		350.0	3.50	3.50	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)	0.66	0.14	-0.5	1040	-5.4	1034.6	10.35	10.35	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)	1.67	4.35	2.7	753	20.2	773.2	7.73	7.73	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				210		195.2	1.95	1.93	
Admixture (1)				2.75		2.8	0.03	0.03	0.03
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
Comments:			TOTALS	2355.75	14.77	2355.75	23.56	23.54	

	SSD	Actual		
			Corrected Weights (kg/m³) =	2353.52
			Corrected Water (L/m³) =	207.77
			Difference from Target (Litres) =	-2.23
W/C Ratio	0.600	0.600	Difference from Target (%) =	-1.06
Fines (%) =	42.0		Yield (%) =	-0.21

Concrete Appearance:

Slump Test		
Test	Mode	Value(mm)
1	Normal	70
2	Normal	70
Mean Slump Test		70

Plastic Density			
Test	Concrete (kg)	Density (kg/m³)	Pot + concrete (kg)
Actual	-3.9425	-492.813	
Calculated	18.83	2353.522	
Pot Volume (litres) :		8	
Pot Mass :		3.9425	
Mean Density (kg/m³) :		-492.813	

Air Test	
Meter Number	Kaya
Air Content (%)	

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²)	Failure Mode	Density (kg/m³)	Tested By	Average
AD-ADM-1		1			0.00	Normal			
AD-ADM-2		1			0.00	Normal			0.0
AD-ADM-3		1			0.00	Normal			
AD-ADM-4		7			0.00	Normal			
AD-ADM-5		7			0.00	Normal			0.0
AD-ADM-6		7			0.00	Normal			
AD-ADM-7		28			0.00	Normal			
AD-ADM-8		28			0.00	Normal			0.0
AD-ADM-9		28			0.00	Normal			
AD-ADM-10		28			0.00	Normal			

Lab Reference	Mould Number	Age at Test	Test Date	Real Load (kN)	Flexural Strength N/mm²)	Failure Mode		Tested By	average
AD-ADM-1		28			0	Normal		MP	
AD-ADM-2		28			0	Normal		MP	0.0
AD-ADM-3		28			0	Normal		MP	

Concrete Trial Mix Worksheet

KAYASAND

Date of Trial :	11-Apr-12	Mix Description :	Kayasand 100%
Material Code :	AD-ADM	Cement (kg/m³) :	350
Trial Mix Ref :		Replacement (%) :	
Batch Time :		Laboratory Name :	Cardiff University
Batch Size (litres) :	10	Target Consistence :	

Basic Material Types	Material Details				Admixture Dosage (ml/50kg) or Solid Materials (kg)
	S.G	Type	Supplier	Material Sourse	
Cement		PC	Cemex	Rugby	
Replacement					
Coarse Aggregate (1)		/20mm Crushed Limeston			
Coarse Aggregate (2)					
Fine Aggregate (1)		Kayasand		Duntiland	
Fine Aggregate (2)					
Admixture (1)		WRDA 90 plasticizer	Grace		0 ml
Admixture (2)		EXP-CM1	Grace		0 ml
Solids (kg)					0 ml

MATERIALS	Aggregate Absorption %	Aggregate Moisture Total %	Aggregate Moisture Free %	S.S.D. kg/m³	Mix Design Figures Moisture Correction	Corrected	Trial Target	Trial Actual	Admix weight
Cement				350		350.0	3.50	3.50	
Replacement				0		0.0	0.00	0.00	
Coarse Aggregate (1)	0.66	0.14	-0.5	1040	-5.4	1034.6	10.35	10.35	
Coarse Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Fine Aggregate (1)	1.67	4.35	2.7	753	20.2	773.2	7.73	7.73	
Fine Aggregate (2)			0.0	0	0.0	0.0	0.00	0.00	
Water				210		195.2	1.95	1.92	
Admixture (1)				2.75		2.8	0.03	0.03	0.03
Admixture (2)				0.00		0.0	0.00	0.00	0.00
Solids (kg)				0.00		0.0	0.00	0.00	
Comments:			TOTALS	2355.75	14.77	2355.75	23.56	23.53	

	SSD	Actual		
			Corrected Weights (kg/m³) =	2352.52
			Corrected Water (L/m³) =	206.77
			Difference from Target (Litres) =	-3.23
W/C Ratio	0.600	0.600	Difference from Target (%) =	-1.54
Fines (%) =	42.0		Yield (%) =	-0.21

Concrete Appearance:

Slump Test		
Test	Mode	Value(mm)
1	Normal	75
2	Normal	75
Mean Slump Test		75

Plastic Density			
Test	Concrete (kg)	Density (kg/m³)	Pot + concrete (kg)
Actual	-3.9425	-492.813	
Calculated	18.82	2352.522	
Pot Volume (litres) :		8	
Pot Mass :		3.9425	
Mean Density (kg/m³) :		-492.813	

Air Test	
Meter Number	Kaya
Air Content (%)	

Lab Reference	Mould Number	Age at Test	Test Date	Max Load (KN)	Strength N/mm²)	Failure Mode	Density (kg/m³)	Tested By	Average
AD-ADM-1		1			0.00	Normal			
AD-ADM-2		1			0.00	Normal			0.0
AD-ADM-3		1			0.00	Normal			
AD-ADM-4		7			0.00	Normal			
AD-ADM-5		7			0.00	Normal			0.0
AD-ADM-6		7			0.00	Normal			
AD-ADM-7		28			0.00	Normal			
AD-ADM-8		28			0.00	Normal			0.0
AD-ADM-9		28			0.00	Normal			
AD-ADM-10		28			0.00	Normal			

Lab Reference	Mould Number	Age at Test	Test Date	Real Load (kN)	Flexural Strength N/mm²)	Failure Mode		Tested By	average
AD-ADM-1		28			0	Normal		MP	
AD-ADM-2		28			0	Normal		MP	0.0
AD-ADM-3		28			0	Normal		MP	

Appendix B – Taffs Well and Gilfach Concrete Results

No admixture mixes

MIX	w/c	Slump, mm	Compressive strength N/mm2: 1day	coefficient of variation	7day	coefficient of variation	28day	coefficient of variation	Flexural strength N/mm2: 28day	coefficient of variation
Control slump	0.48	95	23.8	0.4	48	2.8	58.9	2.9	6.1	4.6
Taff's FEED	0.614	60	18.5	1.6	38	3.9	50.2	0.4	-	-
Control Taff's Well	0.55	collapse	13.2	1.9	39	2.3	50.5	0.6	5.3	10.4
Taff's Well	0.55	90	18	2.5	44.3	2.8	55.7	3.1	6.6	4.3
Taff's Well PA	0.55	70	21.2	1.0	47.8	1.2	58	1.1	6.7	4.3
Taff's Well PB	0.55	82.5	22.7	4.2	46.2	3.2	56.2	3.6	6.1	8.0
Taff's Well PC	0.55	65	21.4	1.5	46.9	2.0	56.6	7.4	6	6.3
Gilfach FEED	0.748	80	8.2	2.4	23.3	1.7	31.3	1.1	-	-
Control Gilfach	0.67	collapse	8.1	5.5	24.4	5.5	34.9	1.9	4.6	3.3
Gilfach	0.67	85	12.7	0.9	34.5	2.9	41.4	3.9	5.2	3.3
Gilfach PA	0.67	75	14.9	1.4	31.4	0.7	43.3	2.6	5.6	8.2
Gilfach PB	0.67	97.5	14.7	1.4	32.8	3.3	42.8	2.2	5.5	4.5
Gilfach PC	0.67	75	12.1	0.9	30.5	2.3	39.9	0.6	5.2	6.3

w/c ratio 0.55 admixture

				Compressive strength N/mm2						Flexural strength N/mm2	
MIX	w/c	Slump, mm	% fines of FA	1day	coefficient of variation	7day	coefficient of variation	28day	coefficient of variation	28day	coefficient of variation
Control	0.55	collapse	1	13.2	1.9	39	2.3	50.5	0.6	5.3	10.4
Taff's Well	0.5	90	2.8	23.9	0.7	52.5	1.8	64.3	5.5	6.1	3.6
Taff's Well PA	0.5	90	4.9	20	1.8	49.7	6.4	61.1	1.9	6.4	16.0
Taff's Well PB	0.5	75	7.1	23.2	0.8	51.1	2.6	63	3.0	6.1	23.1
Taff's Well PC	0.5	65	9	20	0.9	47.1	0.2	59.9	2.1	6.8	14.2
Gilfach	0.55	60	3.5	14.8	1.1	44.3	1.3	55	2.8	5.4	4.1
Gilfach PA	0.55	50	5	19.8	2.0	43.8	1.6	55.3	1.9	6	5.6
Gilfach PB	0.55	50	7	18.4	1.7	43.2	0.8	55.6	2.1	5.4	7.3
Gilfach PC	0.55	45	9	17.2	1.7	41.7	0.4	53	2.6	5.9	10.6

Appendix 2. KEMCO Test Reports

21-Jan-11
Test No.03539

Glensanda Quarry

V7 dry sand making test report

KOTOBUKI ENGINEERING AND MANUFACTURING CO.,LTD.

Takato Kaya
Chief engineer

Yuichi Nagahara
R&D manager

1. Raw material

Dates of tests		4-Jan-11～20-Jan-11
Raw material	Rock type	Granite
	Size (mm)	6.7～0
	Moisture content (%)	1.19
	Bags in total	10
	Total Weight (kg)	7230

2. Required size distribution

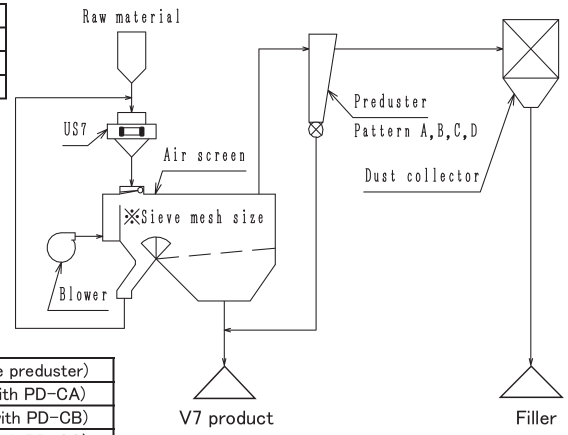
V7 product	Concrete sand	0.063mm and below after decantation test			
		3.0%	5.0%	7.0%	9.0%
	Mortar sand	Masonary Mortar			
Data	Moisture content of feed material Circulating load ratio Yield ratio (%) Particle size distribution (wet siving method)				

3. Flow of test plant

Crusher	US7 (B500)
Air screen	AS800
Preduster	PD200S
Dust collector	150m^3／min

※Sieve mesh size

Concrete sand	2.5×6.6mm
Mortar sand	2.0×3.0mm



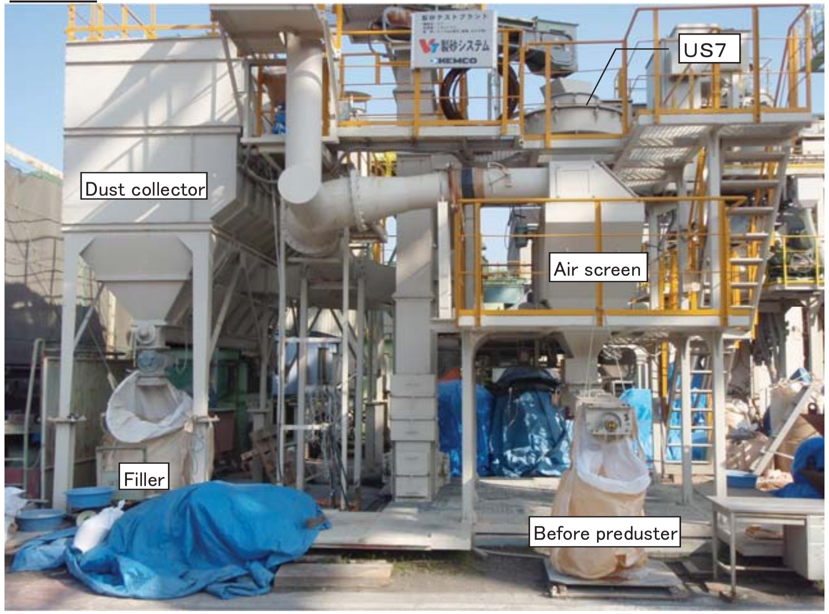
V7 product

Concrete sand	V7－C: V7 product (before preduster)
	V7－CA: V7 product A (with PD-CA)
	V7－CB: V7 product B (with PD-CB)
	V7－CC: V7 product C (with PD-CC)
	V7－CD: V7 product D (with PD-CD)
Mortar sand	V7－M: V7 product (before preduster)
	V7－MA: V7 product A (with PD-MA)
	V7－MB: V7 product B (with PD-MB)
	V7－MC: V7 product C (with PD-MC)

4. Test result

Sample			Size (mm)	Moisture content (%)	Circulating load ratio	Yield ratio (%)	0.063mm and below after decantation test
Raw material			6.7～0	1.19	ー	ー	11.3%
V7 product	Concrete sand	V7－C	4～0	ー	1.42	66.9	1.9%
		V7－CA				72.5	2.8%
		V7－CB				81.9	5.4%
		V7－CC				84.3	6.9%
		V7－CD				86.4	8.4%
	Motar sand	V7－M	2～0	ー	2.03	64.1	2.1%
		V7－MA				70.2	2.8%
		V7－MB				73.2	3.5%
		V7－MC				80.0	5.2%

5. Photo

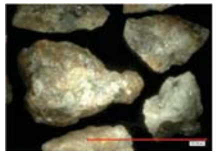
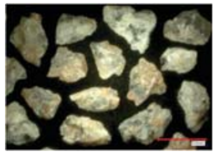
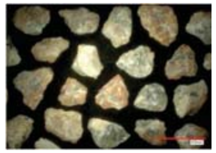
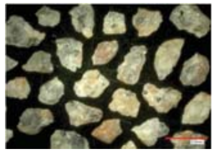
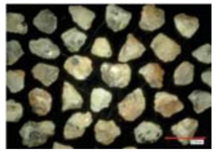
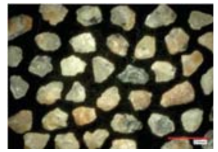
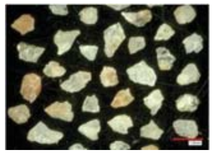
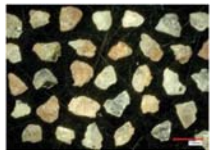
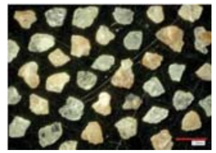
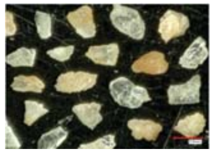
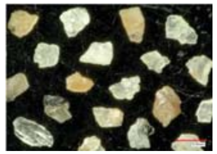
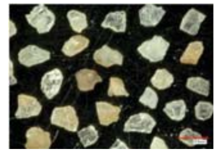
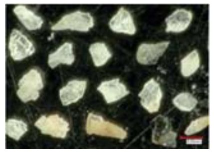
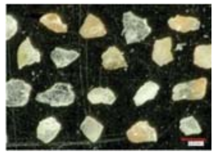
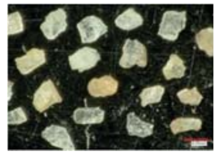
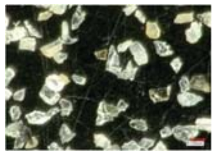
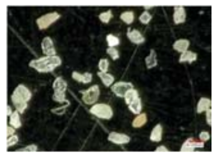
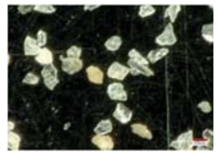


a) V7 test plant


b) Preduster

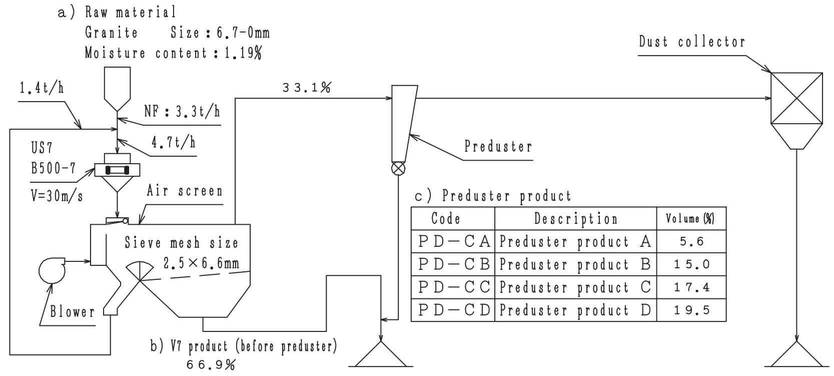

c) Raw material

6. Property

Sample	Raw material	V7 product: Concrete sand	V7 product: Mortar sand
Size (mm)	2.5～1.2		—
Surface dry density (g/cm³)	2.63	2.64	
Oven dry density (g/cm³)	2.62	2.63	
Water absorption ratio (%)	0.54	0.37	
Solid content (%)	53.0	55.5	
Size 9.5–4.0mm		—	—
Size 4.0–2.0mm			—
Size 2.0–1.0mm			
Size 1.0–0.5mm			
Size 0.5–0.25mm			
Size 0.25–0.125mm			
Size 0.125–0.063mm			

7. Test report for concrete

1) Test production flow.



c) Preduster product

Code	Description	Volume (%)
PD−CA	Preduster product A	5.6
PD−CB	Preduster product B	15.0
PD−CC	Preduster product C	17.4
PD−CD	Preduster product D	19.5

d) V7 product (with preduster product)

Code	Description	Yield ratio (%)
V7−C	V7 product (before preduster)	66.9
V7−CA	V7 product A (with PD-A)	72.5
V7−CB	V7 product B (with PD-B)	81.9
V7−CC	V7 product C (with PD-C)	84.3
V7−CD	V7 product D (with PD-CD)	86.4

e) Filler

Code	Description	Volume (%)
F−C	Filler	33.1
F−CA	Filler A	27.5
F−CB	Filler B	18.1
F−CC	Filler C	15.7
F−CD	Filler D	13.6

Circulating load ratio
1.42

2) Grading

a) Raw material

Sieve size (mm)	Raw material	
	Retained (%)	Passed (%)
9.5〜8	0.0	100.0
8〜6.7	0.5	99.5
6.7〜4	9.2	90.3
4〜2	20.6	69.7
2〜1	16.7	53.0
1〜0.5	14.3	38.7
0.5〜0.25	11.9	26.8
0.25〜0.125	9.4	17.4
0.125〜0.063	6.1	11.3
0.063〜0	11.3	
total	100.0	

b) V7 product (before preduster)

Sieve size (mm)	V7−C: V7 product (before preduster)	
	Retained (%)	Passed (%)
9.5〜8	0.0	100.0
8〜6.7	0.0	100.0
6.7〜4	0.0	100.0
4〜2	11.6	88.4
2〜1	26.8	61.6
1〜0.5	25.9	35.7
0.5〜0.25	20.4	15.3
0.25〜0.125	11.3	4.0
0.125〜0.063	2.1	1.9
0.063〜0	1.9	
total	100.0	

c) Preduster product

Sieve size (mm)	PD−CA: Preduster product A		PD−CB: Preduster product B		PD−CC: Preduster product C		PD−CD: Preduster product D	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	0.2	99.8	0.3	99.7	0.4	99.6	0.5	99.5
2〜1	2.5	97.3	2.0	97.7	1.5	98.1	1.1	98.4
1〜0.5	5.3	92.0	4.2	93.5	3.6	94.5	3.0	95.4
0.5〜0.25	11.1	80.9	9.3	84.2	8.2	86.3	7.2	88.2
0.25〜0.125	31.8	49.1	28.6	55.6	26.1	60.2	23.9	64.3
0.125〜0.063	35.2	13.9	34.4	21.2	34.0	26.2	33.5	30.8
0.063〜0	13.9		21.2		26.2		30.8	
total	100.0		100.0		100.0		100.0	

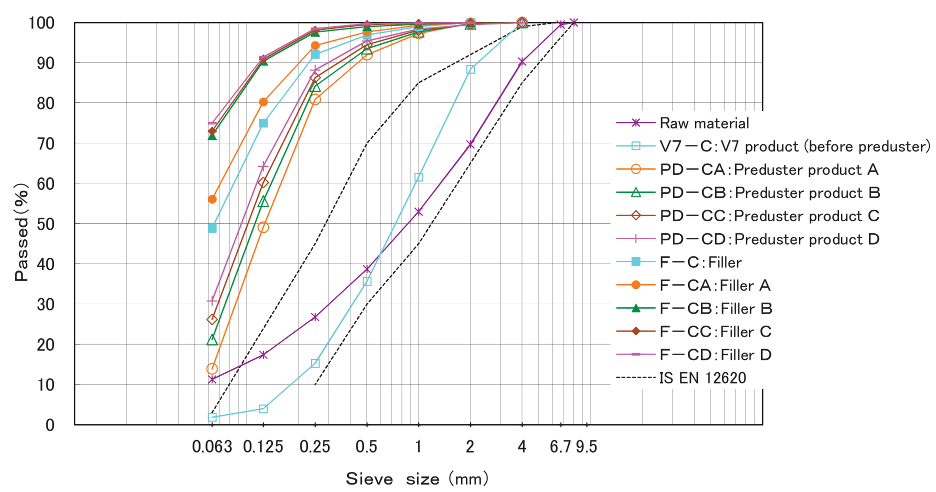
d) V7 product (with preduster product)

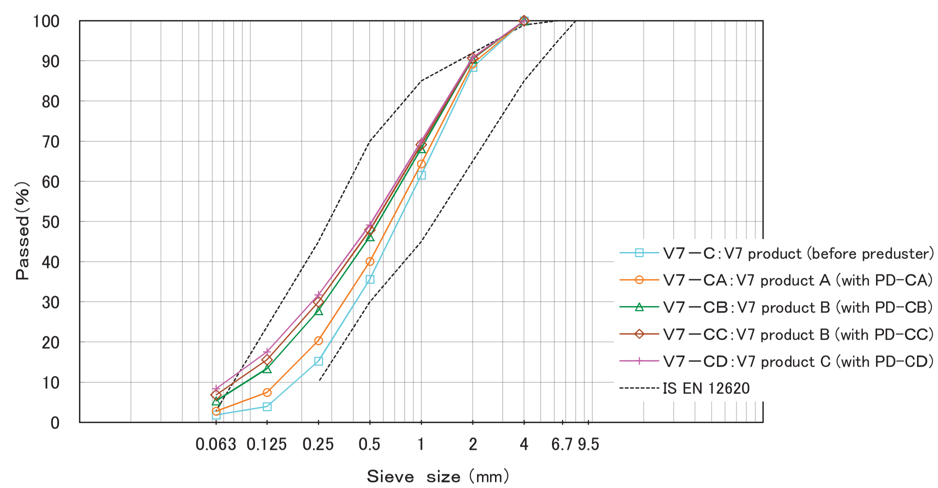
Sieve size (mm)	V7−CA: V7 product A (with PD-CA)		V7−CB: V7 product B (with PD-CB)		V7−CC: V7 product B (with PD-CC)		V7−CD: V7 product C (with PD-CD)	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	10.7	89.3	9.5	90.5	9.3	90.7	9.1	90.9
2〜1	24.9	64.4	22.3	68.2	21.5	69.2	20.9	70.0
1〜0.5	24.3	40.1	21.9	46.3	21.3	47.9	20.8	49.2
0.5〜0.25	19.7	20.4	18.4	27.9	17.9	30.0	17.4	31.8
0.25〜0.125	12.9	7.5	14.5	13.4	14.4	15.6	14.2	17.6
0.125〜0.063	4.7	2.8	8.0	5.4	8.7	6.9	9.2	8.4
0.063〜0	2.8		5.4		6.9		8.4	
total	100.0		100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−C: Filler		F−CA: Filler A		F−CB: Filler B		F−CC: Filler C		F−CD: Filler D	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
2〜1	1.0	99.0	0.7	99.3	0.4	99.6	0.2	99.8	0.1	99.9
1〜0.5	2.1	96.9	1.6	97.7	0.6	99.0	0.3	99.5	0.2	99.7
0.5〜0.25	4.8	92.1	3.4	94.3	1.4	97.6	1.4	98.1	1.2	98.5
0.25〜0.125	17.1	75.0	14.0	80.3	7.2	90.4	7.2	90.9	7.1	91.4
0.125〜0.063	26.1	48.9	24.2	56.1	18.5	71.9	17.9	73.0	16.4	75.0
0.063〜0	48.9		56.1		71.9		73.0		75.0	
total	100.0		100.0		100.0		100.0		100.0	

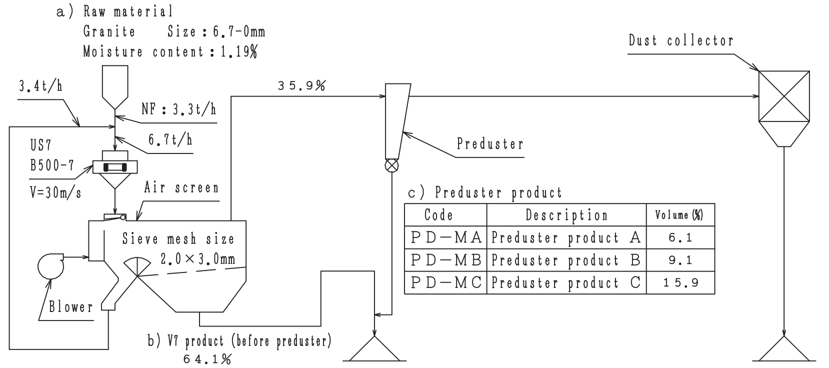
3) Grading curves





8. Test report for mortar

1) Test production flow.



c) Preduster product

Code	Description	Volume (%)
PD−MA	Preduster product A	6.1
PD−MB	Preduster product B	9.1
PD−MC	Preduster product C	15.9

d) V7 product (with preduster product)

Code	Description	Yield ratio (%)
V7−M	V7 product (before preduster)	64.1
V7−MA	V7 product A (with PD-MA)	70.2
V7−MB	V7 product B (with PD-MB)	73.2
V7−MC	V7 product C (with PD-MC)	80.0

e) Filler

Code	Description	Volume (%)
F−M	Filler	35.9
F−MA	Filler A	29.8
F−MB	Filler B	26.8
F−MC	Filler C	20.0

Circulating load ratio
2.03

2) Grading

a) Raw material

Sieve size (mm)	Raw material Retained (%)	Raw material Passed (%)
9.5～8	0.0	100.0
8～6.7	0.4	99.6
6.7～4	8.3	91.3
4～2.8	12.0	79.3
2.8～2	9.9	69.4
2～1	16.3	53.1
1～0.5	14.4	38.7
0.5～0.25	11.9	26.8
0.25～0.125	9.3	17.5
0.125～0.063	6.1	11.4
0.063～0	11.4	
total	100.0	

b) V7 product (before preduster)

Sieve size (mm)	V7−M: V7 product (before preduster) Retained (%)	Passed (%)
9.5～8	0.0	100.0
8～6.7	0.0	100.0
6.7～4	0.0	100.0
4～2.8	0.3	99.7
2.8～2	0.9	98.8
2～1	22.4	76.4
1～0.5	30.2	46.2
0.5～0.25	23.9	22.3
0.25～0.125	14.9	7.4
0.125～0.063	5.3	2.1
0.063～0	2.1	
total	100.0	

c) Preduster product

Sieve size (mm)	PD−MA: Preduster product A		PD−MB: Preduster product B		PD−MC: Preduster product C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7～4	0.0	100.0	0.0	100.0	0.0	100.0
4～2.8	0.3	99.7	0.3	99.7	0.1	99.9
2.8～2	1.7	98.0	1.5	98.2	1.3	98.6
2～1	9.4	88.6	8.8	89.4	7.0	91.6
1～0.5	16.2	72.4	13.5	75.9	10.7	80.9
0.5～0.25	21.8	50.6	19.1	56.8	15.7	65.2
0.25～0.125	26.2	24.4	26.2	30.6	24.3	40.9
0.125～0.063	16.8	7.6	20.0	10.6	23.5	17.4
0.063～0	7.6		10.6		17.4	
total	100.0		100.0		100.0	

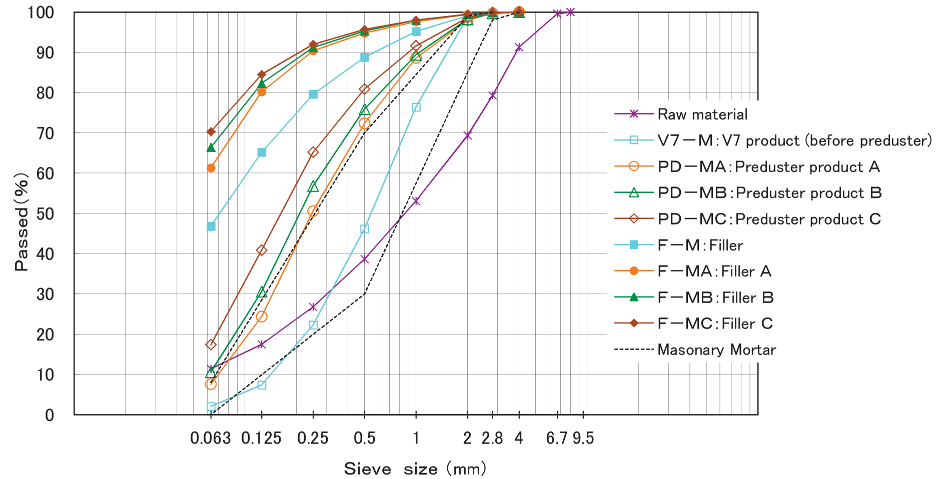
d) V7 product (with preduster product)

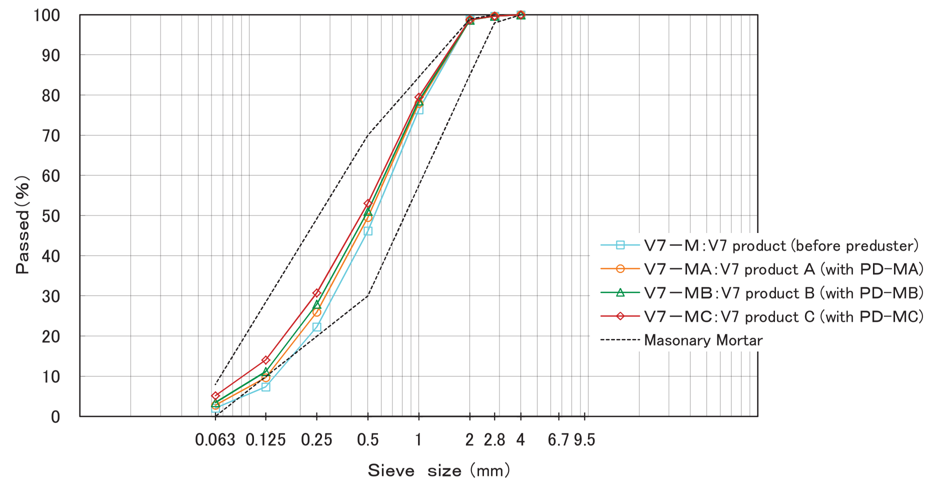
Sieve size (mm)	V7−MA: V7 product A (with PD-MA)		V7−MB: V7 product B (with PD-MB)		V7−MC: V7 product C (with PD-MC)	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7～4	0.0	100.0	0.0	100.0	0.0	100.0
4～2.8	0.3	99.7	0.3	99.7	0.3	99.7
2.8～2	1.0	98.7	1.0	98.7	0.9	98.8
2～1	20.7	78.0	20.1	78.6	19.3	79.5
1～0.5	28.4	49.6	27.5	51.1	26.4	53.1
0.5～0.25	23.6	26.0	23.1	28.0	22.3	30.8
0.25～0.125	16.3	9.7	16.8	11.2	16.7	14.1
0.125～0.063	6.9	2.8	7.7	3.5	8.9	5.2
0.063～0	2.8		3.5		5.2	
total	100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−M: Filler		F−MA: Filler A		F−MB: Filler B		F−MC: Filler C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7～4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4～2.8	0.2	99.8	0.1	99.9	0.1	99.9	0.1	99.9
2.8～2	0.7	99.1	0.5	99.4	0.5	99.4	0.4	99.5
2～1	3.9	95.2	1.8	97.6	1.4	98.0	1.5	98.0
1～0.5	6.4	88.8	2.8	94.8	2.7	95.3	2.3	95.7
0.5～0.25	9.2	79.6	4.4	90.4	4.1	91.2	3.7	92.0
0.25～0.125	14.4	65.2	10.2	80.2	8.9	82.3	7.5	84.5
0.125～0.063	18.4	46.8	18.9	61.3	15.9	66.4	14.2	70.3
0.063～0	46.8		61.3		66.4		70.3	
total	100.0		100.0		100.0		100.0	

3) Grading curves





29-Mar-12
Test No.03605

Cemex Gilfach Quarry

V7 dry sand making test report

KEMCO
KOTOBUKI ENGINEERING AND MANUFACTURING CO.,LTD.
T. Kaya
Takato Kaya
Chief engineer
Y. Nagahara
Yuichi Nagahara
R&D manager

1. Raw material

Dates of tests		9-Mar-12～28-Mar-12
Raw material	Rock type	Gritstone
	Size (mm)	9.5～0
	Moisture content (%)	1.11
	Bags in total	11
	Total Weight (kg)	9290

2. Required size distribution

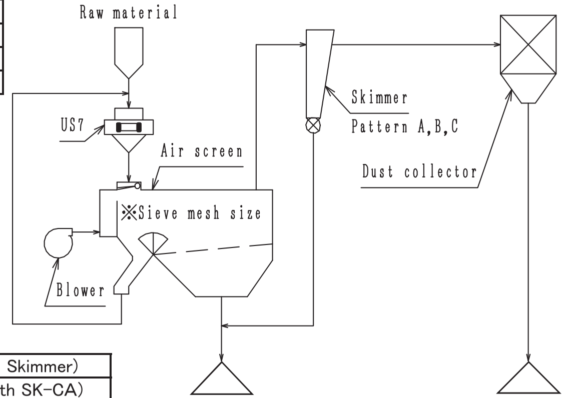
V7 product	Concrete sand	0.063mm and below after decantation test			
		3.0%	5.0%	7.0%	9.0%
	Mortar sand	Masonry Mortar			
Data	Moisture content of feed material Circulating load ratio Yield ratio (%) Particle size distribution (wet siving method)				

3. Flow of test plant

Crusher	US7 (B500)
Air screen	AS800
Skimmer	PD200S
Dust collector	150m³／min

※Sieve mesh size

Concrete sand	2.5×6.6mm
Mortar sand	2.0×3.0mm



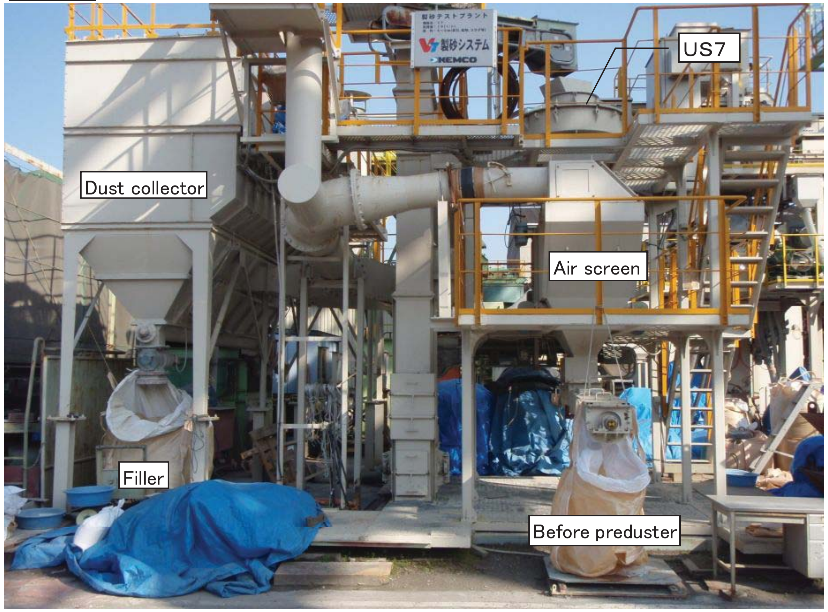
V7 product

Concrete sand	V7－C: V7 product (before Skimmer)
	V7－CA: V7 product A (with SK-CA)
	V7－CB: V7 product B (with SK-CB)
	V7－CC: V7 product C (with SK-CC)
Mortar sand	V7－M: V7 product (before Skimmer)
	V7－MA: V7 product A (with SK-MA)
	V7－MB: V7 product B (with SK-MB)
	V7－MC: V7 product C (with SK-MC)

4. Test result

Sample			Size (mm)	Moisture content (%)	Circulating load ratio	Yield ratio (%)	0.063mm and below after decantation test
Raw material			9.5～0	1.11	—	—	3.9%
V7 product	Concrete sand	V7－C	4～0	—	1.73	64.5	3.5%
		V7－CA				79.8	5.0%
		V7－CB				84.0	7.0%
		V7－CC				88.3	9.0%
	Motar sand	V7－M	2～0	—	2.12	65.2	4.1%
		V7－MA				77.4	4.7%
		V7－MB				79.2	5.3%
		V7－MC				81.3	6.3%

5. Photo

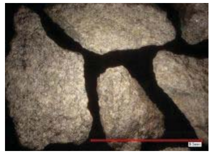
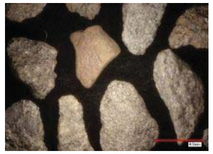
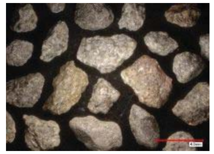
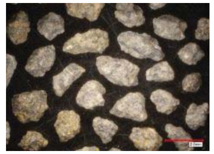
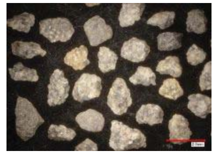
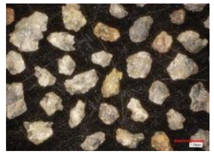
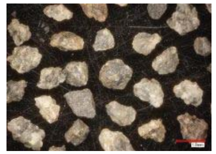
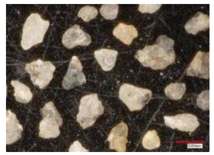
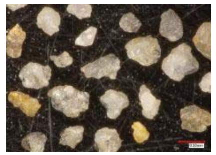
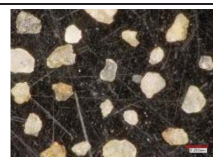
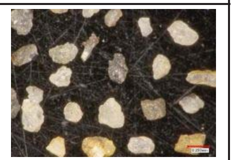
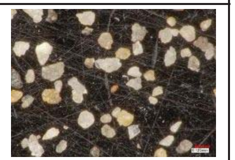


a) V7 test plant

b) Preduster

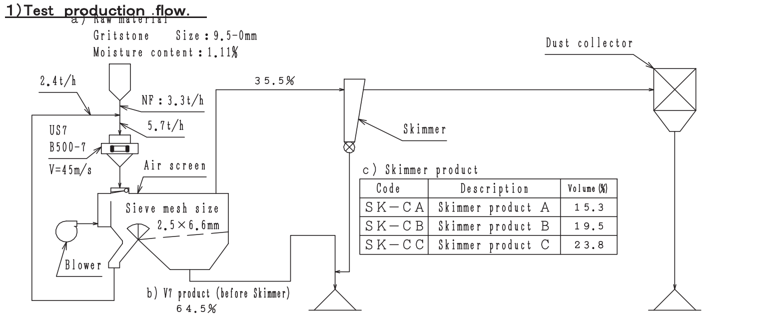
c) Raw material

6. Property

Sample	Raw material	V7 product	
		Concrete sand	Mortar sand
Size (mm)	—	2.5～1.2	—
Surface dry density (g/cm³)		2.65	
Oven dry density (g/cm³)		2.62	
Water absorption ratio (%)		1.37	
Solid content (%)		55.7	
Size 9.5–4.0mm		—	—
Size 4.0–2.0mm			—
Size 2.0–1.0mm	—		
Size 1.0–0.5mm	—		
Size 0.5–0.25mm	—		
Size 0.25–0.125mm	—		
Size 0.125–0.063mm	—		

7. Test report for concrete

1) Test production flow.



c) Skimmer product

Code	Description	Volume (%)
SK−CA	Skimmer product A	15.3
SK−CB	Skimmer product B	19.5
SK−CC	Skimmer product C	23.8

d) V7 product (with Skimmer product)

Code	Description	Yield ratio (%)
V7−C	V7 product (before Skimmer)	64.5
V7−CA	V7 product A (with SK-CA)	79.8
V7−CB	V7 product B (with SK-CB)	84.0
V7−CC	V7 product C (with SK-CC)	88.3

e) Filler

Code	Description	Volume (%)
F−C	Filler	35.5
F−CA	Filler A	20.2
F−CB	Filler B	16.0
F−CC	Filler C	11.7

Circulating load ratio
1.73

2) Grading

a) Raw material

Sieve size (mm)	Raw material	
	Retained (%)	Passed (%)
19∼13.2	0.0	100.0
13.2∼9.5	0.0	100.0
9.5∼6.7	5.9	94.1
6.7∼4	74.4	19.7
4∼2	11.6	8.1
2∼1	1.2	6.9
1∼0.5	0.6	6.3
0.5∼0.25	0.6	5.7
0.25∼0.125	0.8	4.9
0.125∼0.063	1.0	3.9
0.063∼0	3.9	
total	100.0	

b) V7 product (before Skimmer)

Sieve size (mm)	V7−C:V7 product (before Skimmer)	
	Retained (%)	Passed (%)
19∼13.2	0.0	100.0
13.2∼9.5	0.0	100.0
9.5∼6.7	0.0	100.0
6.7∼4	0.0	100.0
4∼2	14.0	86.0
2∼1	28.6	57.4
1∼0.5	20.9	36.5
0.5∼0.25	16.8	19.7
0.25∼0.125	12.5	7.2
0.125∼0.063	3.7	3.5
0.063∼0	3.5	
total	100.0	

c) Skimmer product

Sieve size (mm)	SK−CA:Skimmer product A		SK−CB:Skimmer product B		SK−CC:Skimmer product C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5∼6.7	0.0	100.0	0.0	100.0	0.0	100.0
6.7∼4	0.0	100.0	0.0	100.0	0.0	100.0
4∼2	1.2	98.8	0.9	99.1	0.0	100.0
2∼1	5.4	93.4	2.6	96.5	0.7	99.3
1∼0.5	9.3	84.1	6.6	89.9	4.9	94.4
0.5∼0.25	15.7	68.4	12.9	77.0	10.7	83.7
0.25∼0.125	31.7	36.7	29.1	47.9	27.1	56.6
0.125∼0.063	25.4	11.3	29.4	18.5	32.6	24.0
0.063∼0	11.3		18.5		24.0	
total	100.0		100.0		100.0	

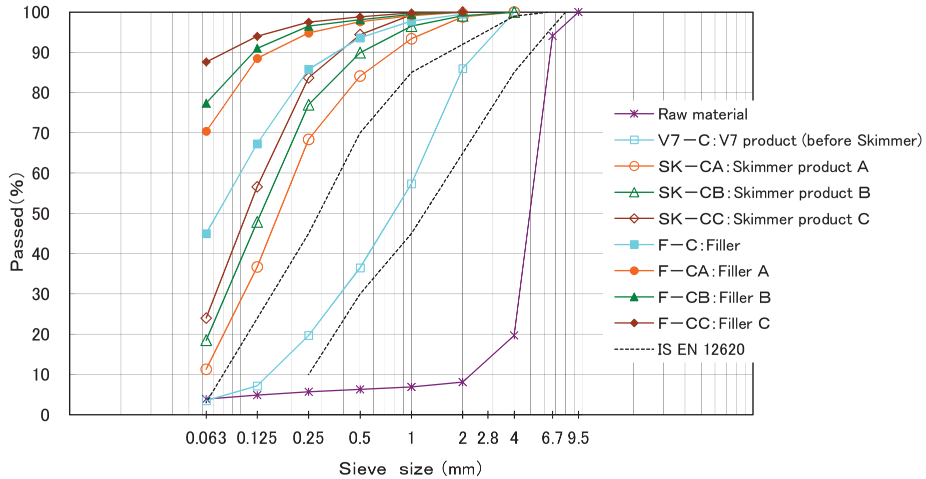
d) V7 product (with Skimmer product)

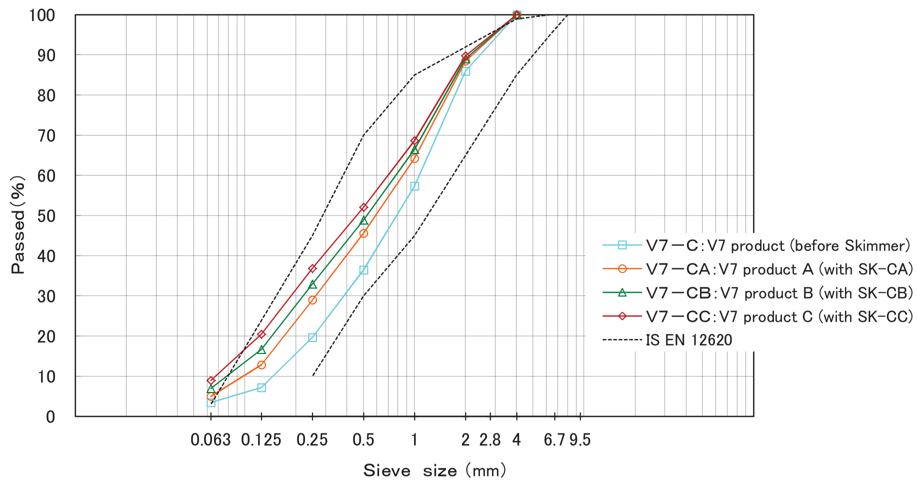
Sieve size (mm)	V7−CA:V7 product A (with SK-CA)		V7−CB:V7 product B (with SK-CB)		V7−CC:V7 product C (with SK-CC)	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5∼6.7	0.0	100.0	0.0	100.0	0.0	100.0
6.7∼4	0.0	100.0	0.0	100.0	0.0	100.0
4∼2	11.5	88.5	10.9	89.1	10.2	89.8
2∼1	24.2	64.3	22.6	66.5	21.1	68.7
1∼0.5	18.7	45.6	17.6	48.9	16.6	52.1
0.5∼0.25	16.6	29.0	15.9	33.0	15.2	36.9
0.25∼0.125	16.1	12.9	16.3	16.7	16.4	20.5
0.125∼0.063	7.9	5.0	9.7	7.0	11.5	9.0
0.063∼0	5.0		7.0		9.0	
total	100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−C:Filler		F−CA:Filler A		F−CB:Filler B		F−CC:Filler C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5∼6.7	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
6.7∼4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4∼2	0.5	99.5	0.0	100.0	0.0	100.0	0.0	100.0
2∼1	1.7	97.8	0.9	99.1	0.6	99.4	0.2	99.8
1∼0.5	4.2	93.6	1.5	97.6	1.3	98.1	1.0	98.8
0.5∼0.25	7.8	85.8	2.8	94.8	1.6	96.5	1.3	97.5
0.25∼0.125	18.5	67.3	6.3	88.5	5.5	91.0	3.5	94.0
0.125∼0.063	22.3	45.0	18.1	70.4	13.6	77.4	6.4	87.6
0.063∼0	45.0		70.4		77.4		87.6	
total	100.0		100.0		100.0		100.0	

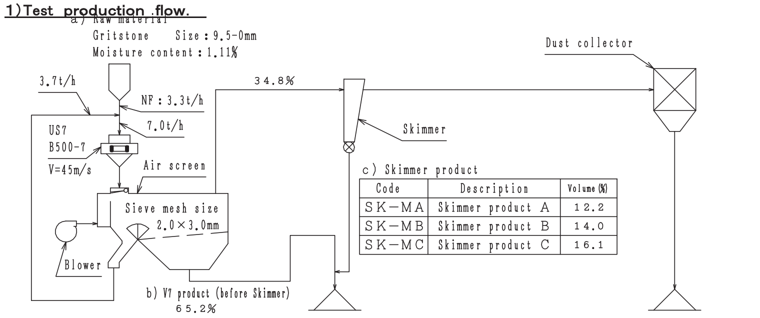
3) Grading curves





8. Test report for mortar

1) Test production flow.



c) Skimmer product

Code	Description	Volume (%)
SK−MA	Skimmer product A	12.2
SK−MB	Skimmer product B	14.0
SK−MC	Skimmer product C	16.1

d) V7 product (with Skimmer product)

Code	Description	Yield ratio (%)
V7−M	V7 product (before Skimmer)	65.2
V7−MA	V7 product A (with SK-MA)	77.4
V7−MB	V7 product B (with SK-MB)	79.2
V7−MC	V7 product C (with SK-MC)	81.3

e) Filler

Code	Description	Volume (%)
F−M	Filler	34.8
F−MA	Filler A	22.6
F−MB	Filler B	20.8
F−MC	Filler C	18.7

Circulating load ratio
2.12

2) Grading

a) Raw material

Sieve size (mm)	Raw material Retained (%)	Raw material Passed (%)
19〜13.2	0.0	100.0
13.2〜9.5	0.0	100.0
9.5〜6.7	5.9	94.1
6.7〜4	74.4	19.7
4〜2	11.6	8.1
2〜1	1.2	6.9
1〜0.5	0.6	6.3
0.5〜0.25	0.6	5.7
0.25〜0.125	0.8	4.9
0.125〜0.063	1.0	3.9
0.063〜0	3.9	
total	100.0	

b) V7 product (before Skimmer)

Sieve size (mm)	V7−M:V7 product (before Skimmer) Retained (%)	Passed (%)
13.2〜9.5	0.0	100.0
9.5〜6.7	0.0	100.0
6.7〜4	0.0	100.0
4〜2.8	0.0	100.0
2.8〜2	0.1	99.9
2〜1	20.9	79.0
1〜0.5	28.3	50.7
0.5〜0.25	23.5	27.2
0.25〜0.125	17.7	9.5
0.125〜0.063	5.4	4.1
0.063〜0	4.1	
total	100.0	

c) Skimmer product

Sieve size (mm)	SK−MA:Skimmer product A		SK−MB:Skimmer product B		SK−MC:Skimmer product C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0
4〜2.8	0.0	100.0	0.0	100.0	0.0	100.0
2.8〜2	0.6	99.4	0.5	99.5	0.4	99.6
2〜1	5.5	93.9	4.7	94.8	4.3	95.3
1〜0.5	11.4	82.5	10.2	84.6	9.3	86.0
0.5〜0.25	18.4	64.1	16.6	68.0	15.5	70.5
0.25〜0.125	32.8	31.3	30.5	37.5	28.9	41.6
0.125〜0.063	23.4	7.9	26.5	11.0	26.0	15.6
0.063〜0	7.9		11.0		15.6	
total	100.0		100.0		100.0	

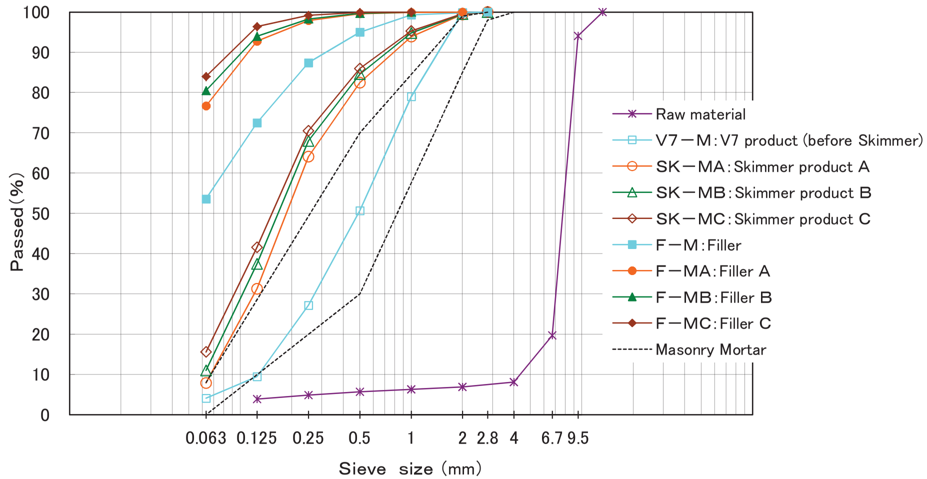
d) V7 product (with Skimmer product)

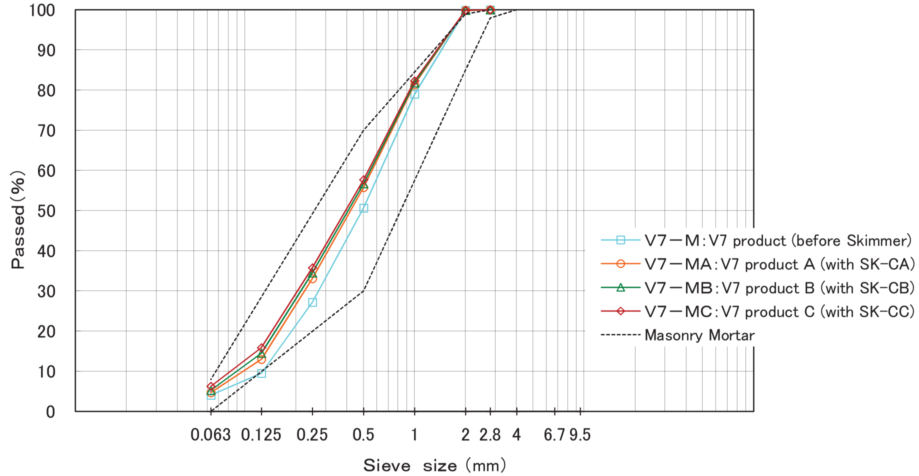
Sieve size (mm)	V7−MA:V7 product A (with SK-CA)		V7−MB:V7 product B (with SK-CB)		V7−MC:V7 product C (with SK-CC)	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0
4〜2.8	0.0	100.0	0.0	100.0	0.0	100.0
2.8〜2	0.1	99.9	0.1	99.9	0.1	99.9
2〜1	18.5	81.4	18.1	81.8	17.6	82.3
1〜0.5	25.6	55.8	25.1	56.7	24.6	57.7
0.5〜0.25	22.7	33.1	22.2	34.5	21.9	35.8
0.25〜0.125	20.1	13.0	20.0	14.5	19.9	15.9
0.125〜0.063	8.3	4.7	9.2	5.3	9.6	6.3
0.063〜0	4.7		5.3		6.3	
total	100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−M:Filler		F−MA:Filler A		F−MB:Filler B		F−MC:Filler C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4〜2.8	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
2.8〜2	0.2	99.8	0.0	100.0	0.0	100.0	0.0	100.0
2〜1	0.5	99.3	0.1	99.9	0.0	100.0	0.0	100.0
1〜0.5	4.3	95.0	0.3	99.6	0.3	99.7	0.1	99.9
0.5〜0.25	7.6	87.4	1.7	97.9	1.4	98.3	0.7	99.2
0.25〜0.125	14.9	72.5	5.1	92.8	4.3	94.0	2.8	96.4
0.125〜0.063	18.9	53.6	16.1	76.7	13.5	80.5	12.4	84.0
0.063〜0	53.6		76.7		80.5		84.0	
total	100.0		100.0		100.0		100.0	

3) Grading curves





13-Mar-12
Test No.03600

Cemex Taff's Well Quarry

V7 dry sand making test report

KOTOBUKI ENGINEERING AND MANUFACTURING CO.,LTD.

Takato Kaya
Chief engineer

Yuichi Nagahara
R&D manager

1. Raw material

Dates of tests		1-Feb-12～14-Feb-12
Raw material	Rock type	Limestone
	Size (mm)	6.7～0
	Moisture content (%)	0.58
	Bags in total	5
	Total Weight (kg)	4260

2. Required size distribution

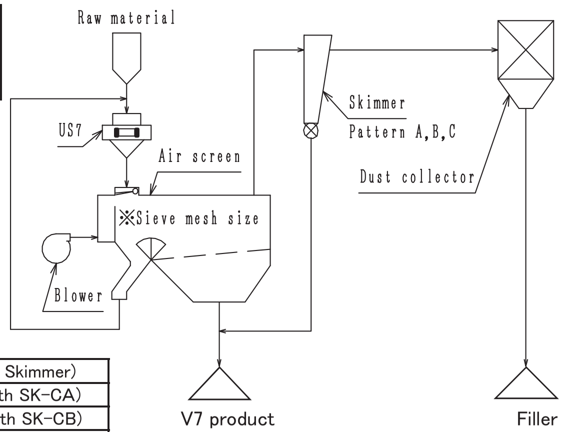
V7 product	Concrete sand	0.063mm and below after decantation test			
		3.0%	5.0%	7.0%	9.0%
Data	Moisture content of feed material Circulating load ratio Yield ratio (%) Particle size distribution (wet siving method)				

3. Flow of test plant

Crusher	US7 (B500)
Air screen	AS800
Skimmer	PD200S
Dust collector	150m^3／min

※Sieve mesh size

Concrete sand	2.5×6.6mm



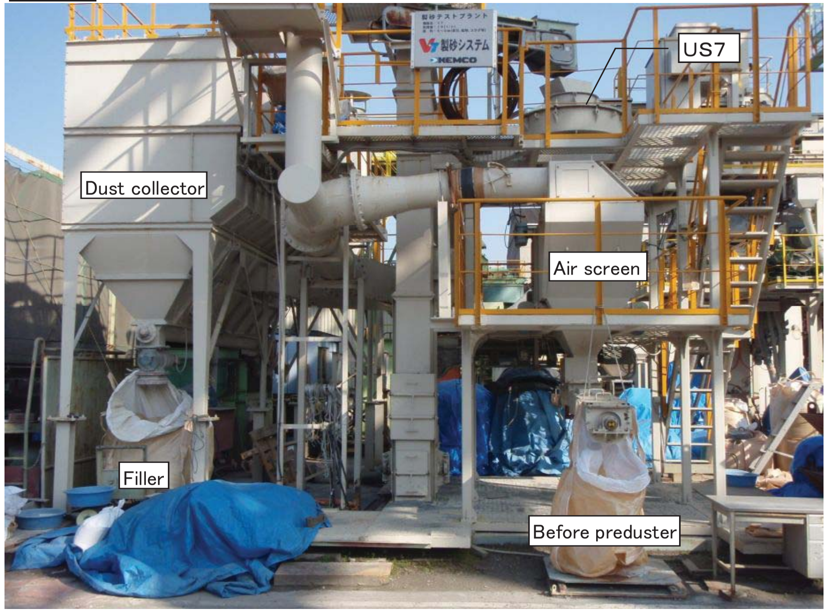
V7 product

Concrete sand	V7－C:V7 product (before Skimmer)
	V7－CA:V7 product A (with SK-CA)
	V7－CB:V7 product B (with SK-CB)
	V7－CC:V7 product C (with SK-CC)

4. Test result

Sample			Size (mm)	Moisture content (%)	Circulating load ratio	Yield ratio (%)	0.063mm and below after decantation test
Raw material			9.5～0	0.58	—	—	8.9%
V7 product	Concrete sand	V7－C	4～0	—	1.58	51.6	2.8%
		V7－CA				66.1	4.9%
		V7－CB				69.5	7.1%
		V7－CC				72.9	9.0%

5. Photo

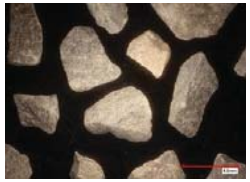
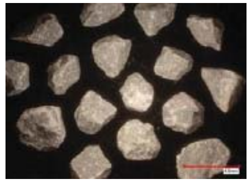
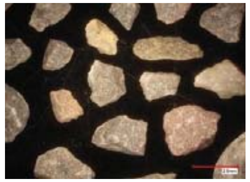
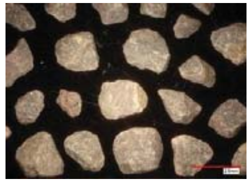
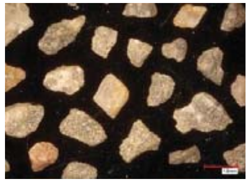
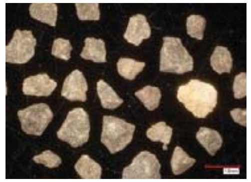
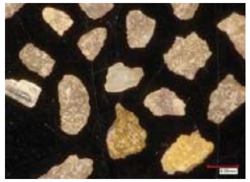
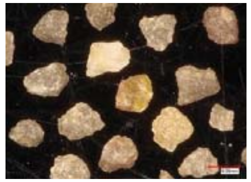
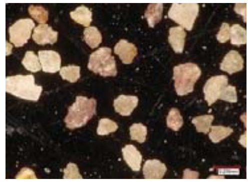
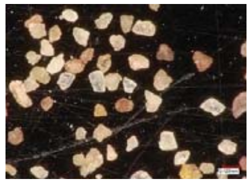


a) V7 test plant

b) Preduster

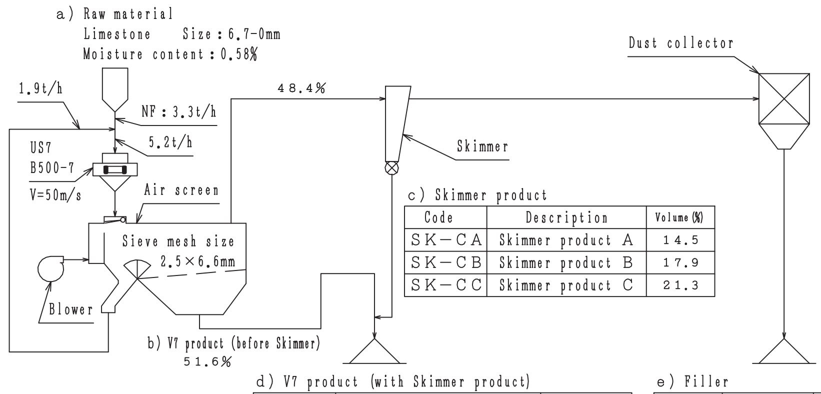
c) Raw material

6. Property

Sample	Raw material	V7 product
Size (mm)	2.36～1.18	
Surface dry density (g/cm³)	2.81	2.81
Oven dry density (g/cm³)	2.79	2.79
Water absorption ratio (%)	0.68	0.65
Solid content (%)	54.7	59.0
Size 4-2 (mm)		
Size 2-1 (mm)		
Size 1-0.5 (mm)		
Size 0.5-0.25 (mm)		
Size 0.25-0.125 (mm)		
Size 0.125-0.063 (mm)		

7. Test report for concrete

1) Test production flow.



c) Skimmer product

Code	Description	Volume (%)
SK−CA	Skimmer product A	14.5
SK−CB	Skimmer product B	17.9
SK−CC	Skimmer product C	21.3

Circulating load ratio
1.58

d) V7 product (with Skimmer product)

Code	Description	Yield ratio (%)
V7−C	V7 product (before Skimmer)	51.6
V7−CA	V7 product A (with SK-CA)	66.1
V7−CB	V7 product B (with SK-CB)	69.5
V7−CC	V7 product C (with SK-CC)	72.9

e) Filler

Code	Description	Volume (%)
F−C	Filler	48.4
F−CA	Filler A	33.9
F−CB	Filler B	30.5
F−CC	Filler C	27.1

2) Grading

a) Raw material

Sieve size (mm)	Raw material Retained (%)	Raw material Passed (%)
19〜13.2	0.0	100.0
13.2〜9.5	0.0	100.0
9.5〜6.7	1.9	98.1
6.7〜4	37.8	60.3
4〜2	20.1	40.2
2〜1	12.8	27.4
1〜0.5	7.8	19.6
0.5〜0.25	5.0	14.6
0.25〜0.125	3.2	11.4
0.125〜0.063	2.5	8.9
0.063〜0	8.9	
total	100.0	

b) V7 product (before Skimmer)

Sieve size (mm)	V7−C:V7 product (before Skimmer) Retained (%)	Passed (%)
19〜13.2	0.0	100.0
13.2〜9.5	0.0	100.0
9.5〜6.7	0.0	100.0
6.7〜4	0.0	100.0
4〜2	20.0	80.0
2〜1	32.3	47.7
1〜0.5	21.0	26.7
0.5〜0.25	12.5	14.2
0.25〜0.125	7.8	6.4
0.125〜0.063	3.6	2.8
0.063〜0	2.8	
total	100.0	

c) Skimmer product

Sieve size (mm)	SK−CA:Skimmer product A		SK−CB:Skimmer product B		SK−CC:Skimmer product C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5〜6.7	0.0	100.0	0.0	100.0	0.0	100.0
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	3.3	96.7	2.6	97.4	2.4	97.6
2〜1	12.1	84.6	10.2	87.2	9.1	88.5
1〜0.5	18.0	66.6	15.2	72.0	13.9	74.6
0.5〜0.25	18.4	48.2	16.0	56.0	14.8	59.8
0.25〜0.125	19.1	29.1	18.2	37.8	16.9	42.9
0.125〜0.063	16.6	12.5	18.2	19.6	18.8	24.1
0.063〜0	12.5		19.6		24.1	
total	100.0		100.0		100.0	

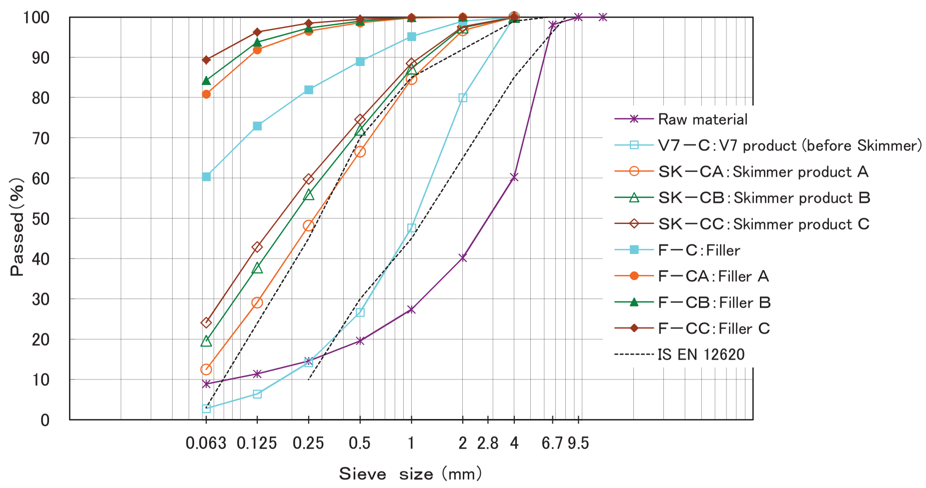
d) V7 product (with Skimmer product)

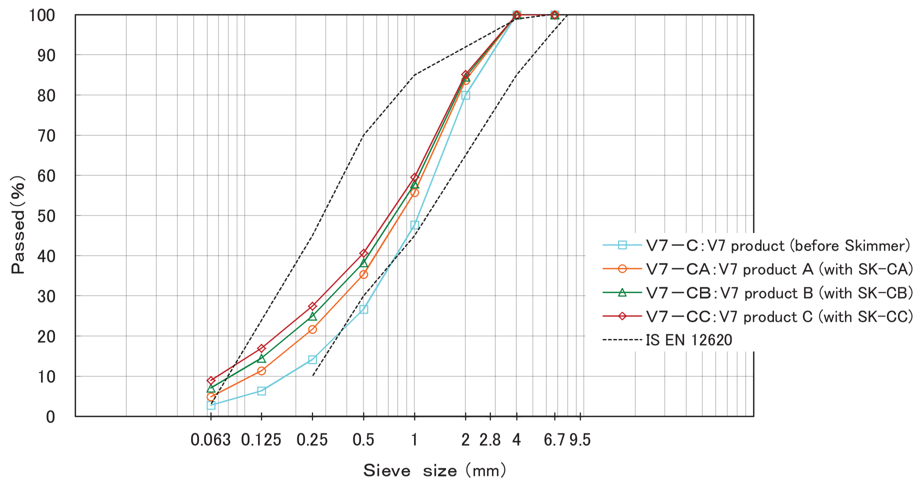
Sieve size (mm)	V7−CA:V7 product A (with SK−CA)		V7−CB:V7 product B (with SK−CB)		V7−CC:V7 product C (with SK−CC)	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5〜6.7	0.0	100.0	0.0	100.0	0.0	100.0
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	16.3	83.7	15.5	84.5	14.8	85.2
2〜1	27.9	55.8	26.6	57.9	25.6	59.6
1〜0.5	20.4	35.4	19.6	38.3	18.9	40.7
0.5〜0.25	13.7	21.7	13.3	25.0	13.2	27.5
0.25〜0.125	10.3	11.4	10.5	14.5	10.5	17.0
0.125〜0.063	6.5	4.9	7.4	7.1	8.0	9.0
0.063〜0	4.9		7.1		9.0	
total	100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−C:Filler		F−CA:Filler A		F−CB:Filler B		F−CC:Filler C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5〜6.7	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	1.0	99.0	0.0	100.0	0.0	100.0	0.0	100.0
2〜1	3.8	95.2	0.2	99.8	0.1	99.9	0.1	99.9
1〜0.5	6.2	89.0	1.2	98.6	0.9	99.0	0.4	99.5
0.5〜0.25	7.0	82.0	2.1	96.5	1.7	97.3	1.0	98.5
0.25〜0.125	9.0	73.0	4.6	91.9	3.5	93.8	2.2	96.3
0.125〜0.063	12.6	60.4	11.0	80.9	9.5	84.3	6.9	89.4
0.063〜0	60.4		80.9		84.3		89.4	
total	100.0		100.0		100.0		100.0	

3) Grading curves





12-Apr-11
Test No.03552

Duntilland Quarry

V7 dry sand making test report

KEMCO
KOTOBUKI ENGINEERING AND MANUFACTURING CO.,LTD.

T. Kaya
Takato Kaya
Chief engineer

Y. Nagahara
Yuichi Nagahara
R&D manager

1. Raw material

Dates of tests		15-Mar-11～25-Mar-11,1-Apr-11～11-Apr-11
Raw material	Rock type	Basalt
	Size (mm)	9.5～0
	Moisture content (%)	3.56
	Bags in total	10
	Total Weight (kg)	10020

2. Required size distribution

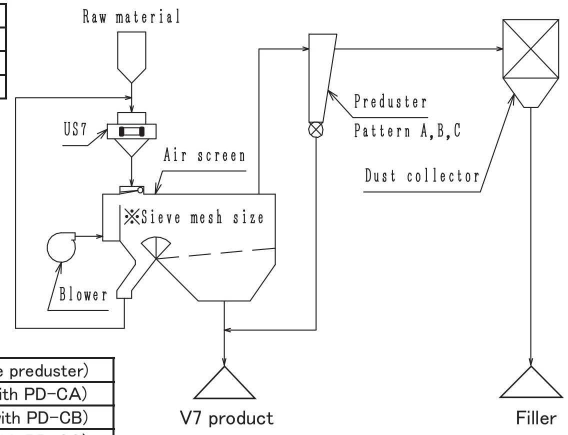
V7 product	Concrete sand	0.063mm and below after decantation test			
		3.0%	5.0%	7.0%	9.0%
	Mortar sand	Masonary Mortar			
Data	Moisture content of feed material Circulating load ratio Yield ratio (%) Particle size distribution (wet siving method)				

3. Flow of test plant

Crusher	US7 (B500)
Air screen	AS800
Preduster	PD200S
Dust collector	150m^3／min

※Sieve mesh size

Concrete sand	2.5×6.6mm
Mortar sand	2.0×3.0mm



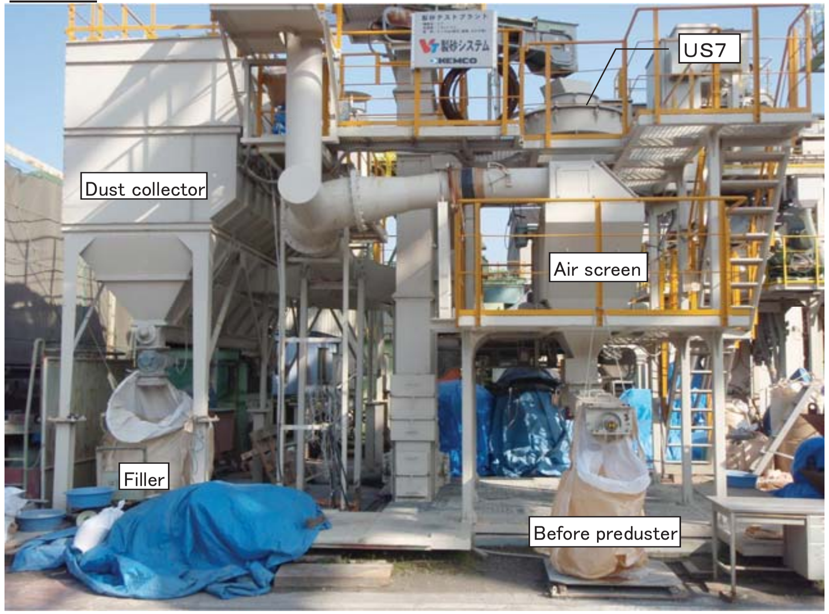
V7 product

Concrete sand	V7－C:V7 product (before preduster)
	V7－CA:V7 product A (with PD-CA)
	V7－CB:V7 product B (with PD-CB)
	V7－CC:V7 product C (with PD-CC)
Mortar sand	V7－M:V7 product (before preduster)
	V7－MA:V7 product A (with PD-MA)
	V7－MB:V7 product B (with PD-MB)
	V7－MC:V7 product C (with PD-MC)

4. Test result

Sample			Size (mm)	Moisture content (%)	Circulating load ratio	Yield ratio (%)	0.063mm and below after decantation test
Raw material			9.5～0	3.56	―	―	11.3%
V7 product	Concrete sand	V7－CA	4～0	―	1.79	60.1	3.7%
		V7－CB				76.1	5.3%
		V7－CC				80.5	7.5%
		V7－CD				83.4	9.3%
	Motar sand	V7－M	2～0	―	2.56	57.6	4.2%
		V7－MA				70.7	4.5%
		V7－MB				75.1	5.7%
		V7－MC				78.5	7.2%

5. Photo



a) V7 test plant

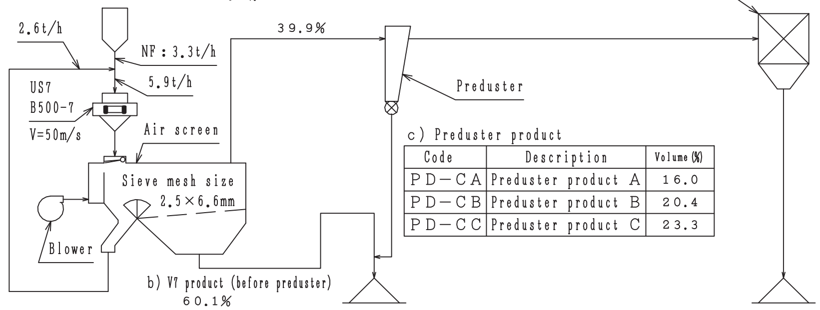

b) Preduster


c) Raw material

6. Test report for concrete

1) Test production flow.

a) Raw material
Basalt Size : 9.5-0mm
Moisture content : 3.56%



c) Preduster product

Code	Description	Volume (%)
PD－CA	Preduster product A	16.0
PD－CB	Preduster product B	20.4
PD－CC	Preduster product C	23.3

Circulating load ratio
1.79

d) V7 product (with preduster product)

Code	Description	Yield ratio (%)
V7－C	V7 product (before preduster)	60.1
V7－CA	V7 product A (with PD-CA)	76.1
V7－CB	V7 product B (with PD-CB)	80.5
V7－CC	V7 product C (with PD-CC)	83.4

e) Filler

Code	Description	Volume (%)
F－C	Filler	39.9
F－CA	Filler A	23.9
F－CB	Filler B	19.5
F－CC	Filler C	16.6

2) Grading

a) Raw material

Sieve size (mm)	Raw material Retained (%)	Raw material Passed (%)
19～13.2	0.0	100.0
13.2～9.5	0.8	99.2
9.5～6.7	5.8	93.4
6.7～4	22.3	71.1
4～2	21.1	50.0
2～1	12.4	37.6
1～0.5	8.5	29.1
0.5～0.25	7.5	21.6
0.25～0.125	6.9	14.7
0.125～0.063	5.0	9.7
0.063～0	9.7	
total	100.0	

b) V7 product (before preduster)

Sieve size (mm)	V7－C:V7 product (before preduster) Retained (%)	Passed (%)
19～13.2	0.0	100.0
13.2～9.5	0.0	100.0
9.5～6.7	0.0	100.0
6.7～4	0.0	100.0
4～2	11.7	88.3
2～1	29.1	59.2
1～0.5	22.8	36.4
0.5～0.25	18.0	18.4
0.25～0.125	12.0	6.4
0.125～0.063	2.7	3.7
0.063～0	3.7	
total	100.0	

c) Preduster product

Sieve size (mm)	PD－CA:Preduster product A		PD－CB:Preduster product B		PD－CC:Preduster product C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5～6.7	0.0	100.0	0.0	100.0	0.0	100.0
6.7～4	0.0	100.0	0.0	100.0	0.0	100.0
4～2	1.7	98.3	1.4	98.6	1.2	98.8
2～1	5.8	92.5	5.2	93.4	4.8	94.0
1～0.5	7.0	85.5	6.2	87.2	6.3	87.7
0.5～0.25	13.7	71.8	10.8	76.4	9.1	78.6
0.25～0.125	34.5	37.3	28.0	48.4	25.3	53.3
0.125～0.063	25.8	11.5	29.8	18.6	29.6	23.7
0.063～0	11.5		18.6		23.7	
total	100.0		100.0		100.0	

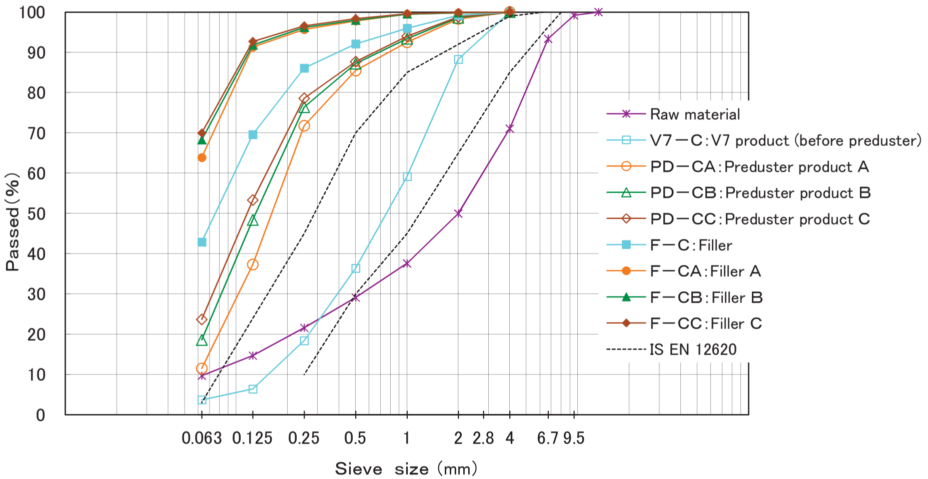
d) V7 product (with preduster product)

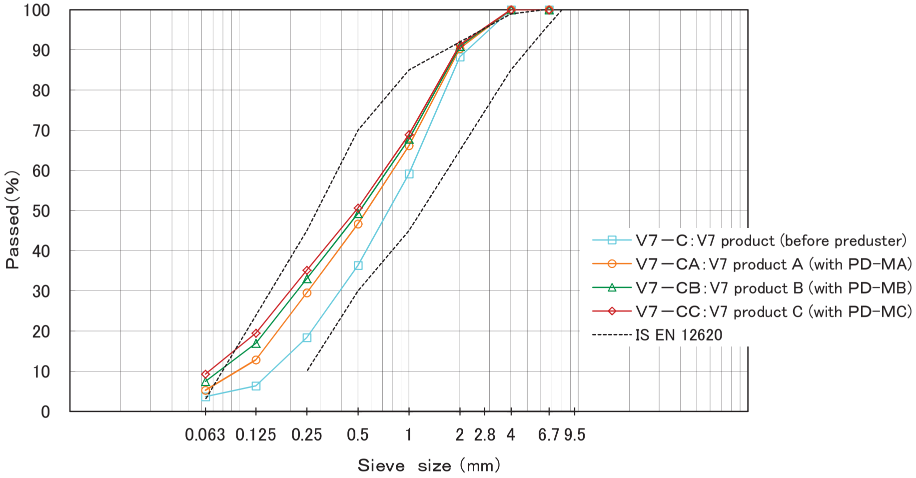
Sieve size (mm)	V7－CA:V7 product A (with PD-MA)		V7－CB:V7 product B (with PD-MB)		V7－CC:V7 product C (with PD-MC)	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
9.5～6.7	0.0	100.0	0.0	100.0	0.0	100.0
6.7～4	0.0	100.0	0.0	100.0	0.0	100.0
4～2	9.6	90.4	9.1	90.9	8.7	91.3
2～1	24.2	66.2	23.1	67.8	22.4	68.9
1～0.5	19.5	46.7	18.5	49.3	18.2	50.7
0.5～0.25	17.1	29.6	16.2	33.1	15.5	35.2
0.25～0.125	16.7	12.9	16.1	17.0	15.7	19.5
0.125～0.063	7.6	5.3	9.5	7.5	10.2	9.3
0.063～0	5.3		7.5		9.3	
total	100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−C:Filler Retained (%)	F−C:Filler Passed (%)	F−CA:Filler A Retained (%)	F−CA:Filler A Passed (%)	F−CB:Filler B Retained (%)	F−CB:Filler B Passed (%)	F−CC:Filler C Retained (%)	F−CC:Filler C Passed (%)
9.5〜6.7	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4〜2	0.8	99.2	0.2	99.8	0.2	99.8	0.1	99.9
2〜1	3.2	96.0	0.3	99.5	0.3	99.5	0.3	99.6
1〜0.5	3.9	92.1	1.7	97.8	1.5	98.0	1.2	98.4
0.5〜0.25	6.0	86.1	2.1	95.7	1.8	96.2	1.8	96.6
0.25〜0.125	16.5	69.6	4.4	91.3	4.4	91.8	3.9	92.7
0.125〜0.063	26.7	42.9	27.4	63.9	23.5	68.3	22.7	70.0
0.063〜0	42.9		63.9		68.3		70.0	
total	100.0		100.0		100.0		100.0	

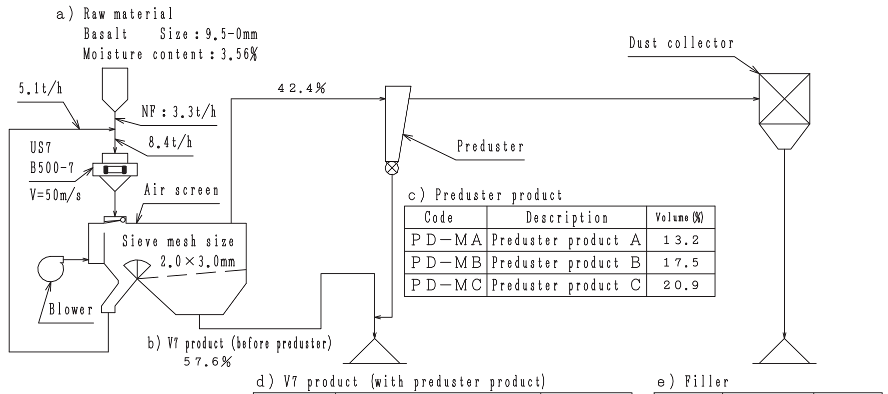
3) Grading curves





7. Test report for mortar

1) Test production flow.



c) Preduster product

Code	Description	Volume (%)
PD−MA	Preduster product A	13.2
PD−MB	Preduster product B	17.5
PD−MC	Preduster product C	20.9

Circulating load ratio
2.55

d) V7 product (with preduster product)

Code	Description	Yield ratio (%)
V7−M	V7 product (before preduster)	57.6
V7−MA	V7 product A (with PD-MA)	70.7
V7−MB	V7 product B (with PD-MB)	75.1
V7−MC	V7 product C (with PD-MC)	78.5

e) Filler

Code	Description	Volume (%)
F−M	Filler	42.4
F−MA	Filler A	29.2
F−MB	Filler B	24.9
F−MC	Filler C	21.5

2) Grading

a) Raw material

Sieve size (mm)	Raw material Retained (%)	Raw material Passed (%)
19〜13.2	0.0	100.0
13.2〜9.5	0.8	99.2
9.5〜6.7	5.8	93.4
6.7〜4	22.3	71.1
4〜2	21.1	50.0
2〜1	12.4	37.6
1〜0.5	8.5	29.1
0.5〜0.25	7.5	21.6
0.25〜0.125	6.9	14.7
0.125〜0.063	5.0	9.7
0.063〜0	9.7	
total	100.0	

b) V7 product (before preduster)

Sieve size (mm)	V7−M:V7 product (before preduster) Retained (%)	Passed (%)
13.2〜9.5	0.0	100.0
9.5〜6.7	0.0	100.0
6.7〜4	0.0	100.0
4〜2.8	0.5	99.5
2.8〜2	0.9	98.6
2〜1	24.9	73.7
1〜0.5	26.7	47.0
0.5〜0.25	21.2	25.8
0.25〜0.125	15.7	10.1
0.125〜0.063	5.9	4.2
0.063〜0	4.2	
total	100.0	

c) Preduster product

Sieve size (mm)	PD−MA:Preduster product A Retained (%)	PD−MA Passed (%)	PD−MB:Preduster product B Retained (%)	PD−MB Passed (%)	PD−MC:Preduster product C Retained (%)	PD−MC Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0
4〜2.8	0.3	99.7	0.2	99.8	0.1	99.9
2.8〜2	2.8	96.9	2.4	97.4	2.1	97.8
2〜1	12.3	84.6	11.1	86.3	10.0	87.8
1〜0.5	15.2	69.4	13.6	72.7	12.7	75.1
0.5〜0.25	21.0	48.4	18.1	54.6	15.7	59.4
0.25〜0.125	27.9	20.5	24.8	29.8	23.2	36.2
0.125〜0.063	14.7	5.8	19.0	10.8	20.5	15.7
0.063〜0	5.8		10.8		15.7	
total	100.0		100.0		100.0	

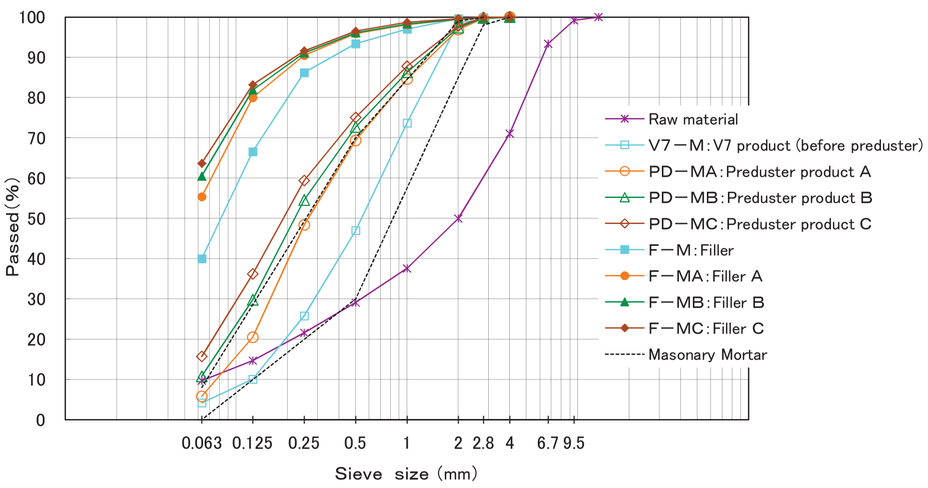
d) V7 product (with preduster product)

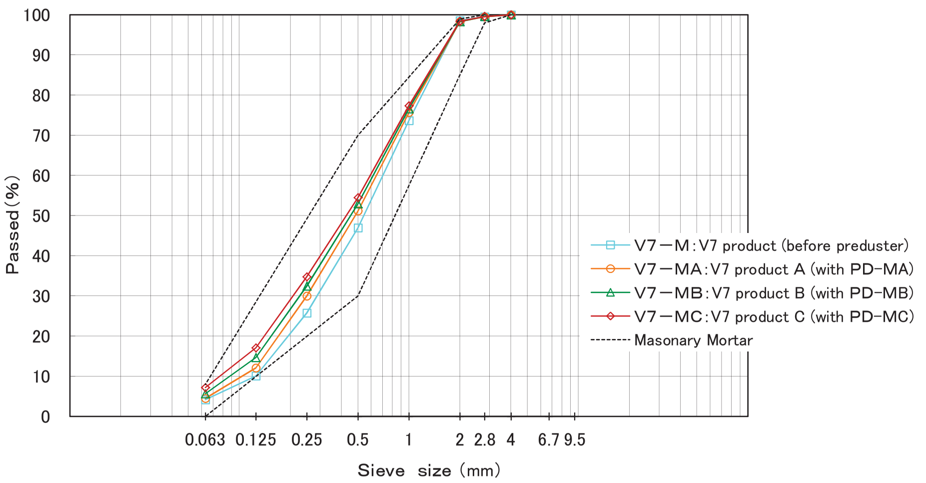
Sieve size (mm)	V7−MA:V7 product A (with PD−MA) Retained (%)	Passed (%)	V7−MB:V7 product B (with PD−MB) Retained (%)	Passed (%)	V7−MC:V7 product C (with PD−MC) Retained (%)	Passed (%)
6.7〜4	0.0	100.0	0.0	100.0	0.0	100.0
4〜2.8	0.5	99.5	0.4	99.6	0.4	99.6
2.8〜2	1.2	98.3	1.3	98.3	1.2	98.4
2〜1	22.6	75.7	21.7	76.6	21.0	77.4
1〜0.5	24.5	51.2	23.6	53.0	22.9	54.5
0.5〜0.25	21.2	30.0	20.5	32.5	19.7	34.8
0.25〜0.125	17.9	12.1	17.8	14.7	17.7	17.1
0.125〜0.063	7.6	4.5	9.0	5.7	9.9	7.2
0.063〜0	4.5		5.7		7.2	
total	100.0		100.0		100.0	

e) Filler

Sieve size (mm)	F−M: Filler		F−MA: Filler A		F−MB: Filler B		F−MC: Filler C	
	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)	Retained (%)	Passed (%)
6.7～4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
4～2.8	0.1	99.9	0.2	99.8	0.2	99.8	0.1	99.9
2.8～2	0.3	99.6	0.3	99.5	0.3	99.5	0.3	99.6
2～1	2.6	97.0	1.4	98.1	1.2	98.3	0.9	98.7
1～0.5	3.6	93.4	2.2	95.9	2.2	96.1	2.2	96.5
0.5～0.25	7.2	86.2	5.4	90.5	5.0	91.1	4.9	91.6
0.25～0.125	19.6	66.6	10.5	80.0	9.2	81.9	8.4	83.2
0.125～0.063	26.6	40.0	24.6	55.4	21.4	60.5	19.5	63.7
0.063～0	40.0		55.4		60.5		63.7	
total	100.0		100.0		100.0		100.0	

3) Grading curves





Appendix 3. Full Stage 1 Results

Table A3.1 Stage 1 full results

MIX	w/c	Slump (mm)	Compressive strength 1 day (N/mm^2)	COV (%)	7 day (N/mm^2)	COV (%)	28 day (N/mm^2)	COV (%)	Flexural strength 28day (N/mm^2)	COV (%)
N	0.48	95	23.8	0.4	48	2.8	58.9	2.9	6.1	4.6
G-FEED	0.66	80	12.5	1.9	30.3	0.0	39.1	3.5	-	-
N-G	0.58	collapse	13.5	4.1	36	2.7	48.7	1.6	5.4	4.4
G-A	0.58	120	17.6	0.6	43.5	1.0	52.2	2.3	5.6	5.3
G-B	0.58	80	17	1.6	40.2	1.6	49.9	1.9	5.6	5.4
G-C	0.58	80	17.9	0.7	40.4	2.0	50.1	1.2	6	5.7
G-D	0.58	60	19.3	1.9	42.2	2.1	52.3	1.4	5.8	7.3
G-E	0.58	60	16.6	0.3	40.6	1.0	48.1	3.6	5.4	5.6
B-FEED	0.72	70	9.3	2.4	25.8	0.4	35.5	0.9	-	-
N-B	0.67	collapse	9.6	0.5	26.2	1.0	35.9	1.3	4.6	0.2
B-A	0.67	70	11.8	1.8	30.4	2.9	41.7	2.2	5.3	4.9
B-B	0.67	80	12.9	2.1	31.3	4.5	43.7	1.7	5.5	5.1
B-C	0.67	62.5	13	2.3	33.1	2.0	42.7	1.8	5.4	7.7
B-D	0.67	47.5	13.2	2.3	35.2	0.4	45.6	2.6	5.6	3.2
L-FEED	0.614	60	18.5	1.6	38	3.9	50.2	0.4	-	-
N-L	0.55	collapse	13.2	1.9	39	2.3	50.5	0.6	5.3	10.4
L-A	0.55	90	18	2.5	44.3	2.8	55.7	3.1	6.6	4.3
L-B	0.55	70	21.2	1.0	47.8	1.2	58	1.1	6.7	4.3
L-C	0.55	82.5	22.7	4.2	46.2	3.2	56.2	3.6	6.1	8.0
L-D	0.55	65	21.4	1.5	46.9	2.0	56.6	7.4	6	6.3
S-FEED	0.748	80	8.2	2.4	23.3	1.7	31.3	1.1	-	-
N-S	0.67	collapse	8.1	5.5	24.4	5.5	34.9	1.9	4.6	3.3
S-A	0.67	85	12.7	0.9	34.5	2.9	41.4	3.9	5.2	3.3
S-B	0.67	75	14.9	1.4	31.4	0.7	43.3	2.6	5.6	8.2
S-C	0.67	97.5	14.7	1.4	32.8	3.3	42.8	2.2	5.5	4.5
S-D	0.67	75	12.1	0.9	30.5	2.3	39.9	0.6	5.2	6.3

Appendix 4. Full Stage 2 Results

Table A4.1 Stage 2 full results

MIX	w/c	Slump (mm)	% fines of FA	Compressive strength 1 day (N/mm^2)	COV (%)	7 day (N/mm^2)	COV (%)	28 day (N/mm^2)	COV (%)	Flexural strength 28day (N/mm^2)	COV (%)
N	0.55	collapse	1	13.2	1.9	39	2.3	50.5	0.6	5.3	10.4
G-A	0.55	65	2	16.4	1.7	44.4	2.7	53	2.7	5.7	5.7
G-B	0.55	67.5	2.85	20.1	1.4	46.1	1.6	59.2	2.2	5.8	9.6
G-C	0.55	70	5.11	20.7	0.9	46.1	1.7	55.2	1.9	5.9	7.1
G-D	0.55	60	6.54	19.4	3.1	48.3	1.3	58.6	1.7	5.5	2.7
G-E	0.55	85	9.0	16.6	2.2	47.8	1.6	59.2	1.7	4.7	12.2
B-A	0.55	60	1.0	14.5	2.8	48.2	1.1	57.6	2.5	6.1	4.2
B-B	0.55	30	2.89	14.6	1.7	49.2	1.1	60.5	1.8	6.4	3.8
B-C	0.55	30	5.05	17.9	2.7	48.4	1.5	59.4	2.4	6.1	1.0
B-D	0.55	25	7.43	16.5	2.8	48.3	2.4	58.5	2.5	5.9	1.4
L-A	0.5	90	2.8	23.9	0.7	52.5	1.8	64.3	5.5	6.1	3.6
L-B	0.5	90	4.9	20	1.8	49.7	6.4	61.1	1.9	6.4	16.0
L-C	0.5	75	7.1	23.2	0.8	51.1	2.6	63	3.0	6.1	23.1
L-D	0.5	65	9.0	20	0.9	47.1	0.2	59.9	2.1	6.8	14.2
S-A	0.55	60	3.5	14.8	1.1	44.3	1.3	55	2.8	5.4	4.1
S-B	0.55	50	5.0	19.8	2.0	43.8	1.6	55.3	1.9	6	5.6
S-C	0.55	50	7.0	18.4	1.7	43.2	0.8	55.6	2.1	5.4	7.3
S-D	0.55	45	9.0	17.2	1.7	41.7	0.4	53	2.6	5.9	10.6