CONSTRUCTION INDUSTRY COUNCIL
建造業議會

Research on River Sand Substitutes for Concrete Production and Cement Sand Mortar Production (Phase One) Final Report

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Executive Summary

Excessive dredging of river sand could cause adverse environmental impacts and instability of river banks. For this reason, there is a global trend to limit the dredging of river sand. Locally, due to limitation of river sand export from Mainland, there is an acute shortage of river sand, which has been commonly used as fine aggregate in concrete and mortar. In view of such situation, the Construction Industry Council has launched this research project to explore possible river sand substitutes for concrete and mortar production.

Right at the start of the research, it was found that fine aggregate for concrete and fine aggregate for mortar should be treated separately because they have different effects on the performance of concrete/mortar and are subjected to different requirements. In fact, their standards are usually separated.

From literature review of the British Standards, European Standards, Chinese Standards and Hong Kong Construction Standards on aggregates for concrete and mortar, it is seen that the sieve sizes and demarcation between coarse and fine aggregates in the European Standards are totally different from those in the British Standards being used in Hong Kong. Since those in the Chinese Standards are very similar and some quarries are supplying aggregates to both Hong Kong and Mainland markets, it is better from the market operation point of view to stay with the sieve sizes and demarcation between coarse and fine aggregates given in the British Standards. For this purpose, the government has drafted a self-contained local construction standard CS3 on aggregates for concrete, which follows basically the current British Standards.

The major issues in the various standards are the limits to be imposed on the fines content and the assessment of the harmfulness of the fines content. Since there are still no established methods for assessing the harmfulness of the fines in aggregate and no established acceptance criteria for the non-harmfulness of fines, the usual practice is to impose limits on the fines content so as to reduce the risk of having harmful substances in the aggregate. In this regard, it should be noted that in general, river sand, which has been subjected to washing by flowing water, has lower fines content whereas crushed rock fine has higher fines content. Another major issue is that since the requirements are different, the construction standard CS3 on aggregates for concrete is not applicable to aggregates for mortar and therefore a new construction standard (CS4?) on aggregates for mortar is needed. More importantly, since the high fines content in crushed rock fine has been causing problems in mortar works, the limits to be imposed on the fines content in aggregate for mortar have to be set lower than those imposed on aggregate for concrete.

From interview with stakeholders, it is evident that crushed rock fine has already substituted river sand as fine aggregate for concrete but crushed rock fine is not a suitable river sand substitute as aggregate for mortar because of its excessively high fines content. Even when used in concrete, the high fines content may cause problem. It is better to process the crushed rock fine to reduce and control the fines content to suit different applications. The crushed

rock fine may also be processed to improve particle shape and grading for enhanced performance. Such processed material, called manufactured sand, may be a better alternative to both river sand and crushed rock fine as aggregates for concrete and mortar. However, manufactured sand for mortar and manufactured sand for concrete are not the same and research studies are needed to determine the separate requirements for them. Regarding the other possible river sand substitutes, furnace bottom ash and granulated blastfurnace slag are not viable options whereas crushed waste glass has a high potential.

Field trials on the uses of river sand, crushed rock fine and manufactured sand as aggregate in mortar for plastering have been carried out. The trials revealed that the manufactured sand used, which has a fines content of 2.5%, was suitable as aggregate in mortar for plastering onto both walls and ceilings. Apart from the presence of particles larger than 2.36 mm, which caused certain difficulties in trowelling, the manufactured sand appeared to be easier to apply than the river sand, which has a fines content of 0.6%. On the other hand, the crushed rock fine, which has a fines content of 8.6% and a relatively high water demand, was apparently not as suitable as manufactured sand or river sand for use as fine aggregate in mortar for plastering.

From the above studies and Prof. Albert Kwan's own analysis, the following possible river sand substitutes are identified: (1) manufactured sand; (2) crushed waste glass; and (3) recycled aggregate. Manufactured sand that mimics river sand is already available in the market. However, it is not known what the optimum fines content should be and whether the material should be manufactured to different specification requirements for classification into different categories to suit different applications. Further research is needed to determine the required properties of manufactured sand products for different applications so that specifications of manufactured sand could be developed. Regarding crushed waste glass, about 120,000 tons of waste glass is produced every year in Hong Kong but only a small amount is recycled. In theory, it should be possible to crush waste glass into sand size for use as aggregate in mortar. Trial production and application need to be carried out to evaluate the feasibility of this possible river sand substitute. As the cost of production is quite high, more government support to the recycling industry is required. Regarding recycled aggregate, it is envisaged that the manufactured sand technology may also be applied to recycled aggregate to remove the hardened cement paste on particle surfaces and reduce the fines content to an acceptable level. This has not been done before but should be worthy of trying.

Finally, for Phase Two of the overall study, it is recommended to pursue the following tasks, which are listed in descending order of priority:

- Task 1: Research to help draft a construction standard on aggregates for mortar.
- Task 2: Research on effects of fines content on concrete to determine the optimum and allowable fines contents.
- Task 3: Specifications and classification of manufactured sand.
- Task 4: Research on crushed waste glass as aggregate for mortar.
- Task 5: Research on recycled aggregate as aggregate for mortar.

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1. Background

River sand is a widely used construction material in Hong Kong, especially in the production of concrete and cement-sand mortar. However, it has come to the knowledge of the Construction Industry Council that research into river sand substitutes may warrant consideration in view of a growing concern about potential shortage of river sand in Hong Kong and limited supply from the Mainland. Consequently, the Construction Industry Council commissioned Professor Albert Kwan, Department of Civil Engineering, The University of Hong Kong to launch a research project entitled "Research on River Sand Substitutes for Concrete Production and Cement Sand Mortar Production".

To identify alternative materials to supplement river sand, the research will go through two phases with the ultimate aim of developing a set of practical guidelines and specifications on river sand substitutes for the production of concrete and cement-sand mortar for adoption in both public and private works projects in Hong Kong. The first phase (Phase One) of the research aims to identify suitable river sand substitutes for practical applications in the local construction industry, while the second phase (Phase Two) will focus on formulating practical solutions for using river sand substitutes in Hong Kong and the development of standards or specifications. This report is on the research outcomes of Phase One.

2. Objectives as Stated in the Brief

The objectives as stated in the Outline Brief of the study are:

(1) To review the uses of river sand imported from the Mainland and/or overseas countries in the construction industry in Hong Kong;

(2) To review and explore the most widely used river sand substitutes in both local and overseas construction industry;

(3) To explore any river sand substitutes for concrete production and cement sand mortar production and to evaluate their possible uses for local applications;

(4) To review the specifications of river sand substitute(s) for concrete production and cement sand mortar production currently adopted in construction works in Hong Kong;

(5) To identify suitable river sand substitutes for practical use in concrete production and cement sand mortar production; and

(6) To propose a series of laboratory and on-site testing required in the second phase of the research to validate the technical feasibility of river sand substitutes for concrete production and cement sand mortar production.

3. Overview of River Sand and River Sand Substitutes

River sand is used in the construction industry mainly for concrete production and cement-sand mortar production. In concrete production, it is used as the fine aggregate whereas in mortar production, it is used as the sole aggregate. Basically, river sand is obtained by dredging from river beds. It has the major characteristics that since it has been subjected to years of abrasion, its particle shape is more or less rounded and smooth, and since it has been subjected to years of washing, it has very low silt and clay contents.

Both these two characteristics of river sand would improve the workability of concrete and mortar compared to the use of alternatives such as crushed rock fine. For this reason, the use of river sand would, for a given workability requirement, reduce the water demand and/or superplasticizer demand, and thus allow a lower water content and a lower cement content to be adopted in the mix design. In addition, with lower silt and clay contents, the use of river sand would improve the quality control of the concrete/mortar production because the presence of too much silt and/or clay would adversely affect the workability and strength of the concrete/mortar produced.

However, there could be two major shortcomings with the use of river sand. First, since river sand is brought down by river water from upstream, it could be of widely different mineralogy and, as a result, it is generally difficult to ascertain whether its use would lead to any deleterious alkali-aggregate reaction. Second, river sand dredged from river estuaries close to the sea may be contaminated with salt thus causing the concrete/mortar produced to have high chloride content.

Nevertheless, the local construction industry in Hong Kong, like many other places, has been using river sand for many decades. In fact, the experience of most concrete/mortar producers in Hong Kong is based mainly on the use of river sand. With river sand changed to river sand substitutes, which may have very different characteristics, it takes time for the local construction industry to adapt. Hence, apart from identifying suitable river sand substitutes to supplement river sand, it is important also to evaluate the characteristics of the identified substitutes and the possible effects of using the identified substitutes on the performance of the concrete/mortar produced so that the potential users of the substitutes would better understand the major differences between river sand and river sand substitutes.

The opportunity may be taken to develop a river sand substitute that is not just a substitute but is actually a better material than river sand. For instance, by sieving and blending to control the particle size distribution, it should be possible to optimize the particle size distribution for best overall performance of the concrete/mortar produced. It should also be possible to grind the aggregate particles so that they would become rounded and smooth for improving the packing density of the fine aggregate (a higher packing density would allow the use of a smaller cement paste volume for reducing the cement consumption and carbon footprint, and improving the dimensional stability) and for increasing the workability of the concrete/mortar produced. Such engineered fine aggregate, called “manufactured sand”, would allow the production of much greener and higher performance concrete or mortar than with the use of ordinary river sand.

4. Review of Current Standards

The following standards on aggregates have been reviewed:

(1) British Standard BS 882: 1992 – Specification for aggregates from natural sources for concrete
(2) British Standards BS 1199 and 1200: 1976 – Specifications for building sands from natural sources
(3) British Standard BS EN 12620: 2002 – Aggregates for concrete
(4) British Standard BS EN 13139: 2002 – Aggregates for mortar
(5) BSI PD 6682-1: 2009 Aggregates – Part 1: Aggregates for concrete – Guidance on the use of BS EN 12620
(6) BSI PD 6682-3: 2003 Aggregates – Part 3: Aggregates for mortar – Guidance on the use of BS EN 13139
(7) Chinese Standard GB/T 14684 – 2001 Sand for building
(8) Chinese Standard JGJ 52 – 2006 Standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete
(9) Hong Kong Construction Standard CS3: 2012 – Aggregates for concrete (draft)

A detailed literature review report is attached in Appendix A. For conciseness, only a brief summary is presented in the following.

From the literature review, it is seen that the standard sieve sizes and demarcation between coarse and fine aggregates vary from one standard to another standard. Particularly, the sieve sizes and demarcation between coarse and fine aggregates in the European Standards are totally different from those in the British Standards. As the sieve sizes and demarcation between coarse and fine aggregates in the British Standards that have been in use in Hong Kong for a long time are almost the same as those in the Chinese Standards and some of the quarries are supplying aggregates to both the Hong Kong market and the Mainland market, it is better from the market operation point of view to stay with the sieve sizes and demarcation between coarse and fine aggregates stipulated in the British Standards, although in Hong Kong, the British Standards will gradually be replaced by the European Standards. This will also avoid the trouble of changing from an established practice to a totally new practice, save the cost of buying new equipment and help to preserve our previous experience with aggregate for future use. For this reason, the Hong Kong SAR Government has drafted a self-contained local construction standard CS3 on aggregates for concrete to avoid reliance on the phasing out British Standards.

In general, different requirements are imposed on aggregates for concrete and aggregates for mortar. This is because concrete and mortar have different performance attributes and the quality of fine aggregate has different effects on concrete and mortar. Hence, aggregates for concrete and aggregates for mortar should be clearly differentiated.

For both aggregates for concrete and aggregates for mortar, the major issues seem to be the limits to be imposed on the fines content and the assessment of the harmfulness of the fines content. The fines content needs to be limited for the following reasons:

(1) The presence of any harmful substances, such as clay or silt, in the fines would adversely affect the abrasive resistance, maximum achievable strength and durability of the concrete/mortar.
(2) Since the fines content has very large specific surface area, the presence of high fines content would increase the water and/or superplasticizer demands and thus adversely affect the workability of the concrete/mortar.
(3) The presence of high fines content would render the concrete/mortar mix more cohesive. The increase in cohesiveness due to the presence of high fines content has little effect on the concreting operations. However, this would render the mortar too sticky to be properly trowelled smooth and flat because the mortar tends to stick to the trowel rather than to the substrate.

On the other hand, there are still no established methods for assessing the harmfulness of the fines in aggregate and no established acceptance criteria for the non-harmfulness of fines. The BSI PD 6682-1 recommends that aggregates should better be assessed for non-harmfulness using either a fines content limit or evidence of satisfactory use. This seems to be a pragmatic way of avoiding the controversies regarding the methods of assessment and acceptance criteria. Hence, another reason for limiting the fines content is to reduce the risk of having harmful substance in the aggregate.

The limits imposed on the fines content in the various standards are compared in Table 1 for aggregates for concrete and in Table 2 for aggregates for mortar. From these tables, it can be seen that on the whole the limits imposed on the fines content are more lenient in the British Standards and European Standards and a lot more stringent in the Chinese Standards.

Based on the above, it is recommended that the limits to be imposed on the fines content in fine aggregate for concrete in the draft CS3 could be revised as follows:

(1) Maximum fines content in fine aggregate for use in ordinary concrete (i.e. for general use): to be reduced from the current value of 16% stipulated in the BS 882 to a lower value of, say, 14%.
(2) Maximum fines content in fine aggregate for use in marine concrete (in marine environment), high-strength concrete (concrete grade > 60 MPa), high-durability concrete (design life ≥ 100 years) and high-abrasive resistance concrete (in heavy duty floors): to be set at 10%.

The standards on aggregates for concrete, such as the draft CS3, are not applicable to aggregates for mortar because the respective requirements are not the same. It is recommended that in the longer term, a local construction standard on aggregates for mortar (CS4?) should be produced. In the mean time, fine aggregates for mortar should be classified into Category 1 with fines content ≤ 3% for floor screeds and repair mortars, Category 2 with fines content ≤ 5% for rendering and plastering, and Category 3 with fines content ≤ 8% for masonry mortar.

Table 1 Limits on fines content in fine aggregates for concrete

Standard	Limits on fines content
BS 882 and BSI PD 6682-1	16% for general use; 9% for use in heavy duty floor finishes
BS EN 12620	No limits applied
GB/T 14684	Natural sand: for high strength concrete: < 1.0% for medium strength concrete: < 3.0% for low strength concrete: < 5.0%
	Manufactured sand: If the methylene blue test passes, for high strength concrete: < 3.0% for medium strength concrete: < 5.0% for low strength concrete: < 7.0%
	Manufactured sand: If the methylene blue test fails, for high strength concrete: < 1.0% for medium strength concrete: < 3.0% for low strength concrete: < 5.0%
JGJ 52	Natural sand: for high strength concrete: ≤ 2.0% for medium strength concrete: ≤ 3.0% for low strength concrete: ≤ 5.0%
	Manufactured sand: If the methylene blue test passes, for high strength concrete: ≤ 5.0% for medium strength concrete: ≤ 7.0% for low strength concrete: ≤ 10.0%
	Manufactured sand: If the methylene blue test fails, for high strength concrete: ≤ 2.0% for medium strength concrete: ≤ 3.0% for low strength concrete: ≤ 5.0%
Draft CS3	10%; if methylene blue test passes, may be increased to 14%

Table 2 Limits on fines content in fine aggregates for mortar

Standard	Limits on fines content
BS 1199 and BS 1200	Crushed rock sand for rendering and plastering: 5% Type S sand for masonry mortar: 10% Type G sand for masonry mortar: 12%
BS EN 13139	Cat. 1 (floor screeds, sprayed, repair mortars): ≤ 3% Cat. 2 (rendering and plastering): ≤ 5% Cat. 3 (masonry with non-crushed aggregate): ≤ 8% Cat. 4 (masonry with crushed aggregate): ≤ 30%
BSI PD 6682-3	Levelling screed: ≤ 3% Rendering and plastering: ≤ 5% Masonry with type S sand: ≤ 5% Masonry with type G sand: ≤ 8%
GB/T 14684	Natural sand: < 5.0%
	Manufactured sand: If the methylene blue test passes: < 7.0% If the methylene blue test fails: < 5.0%
JGJ 52	No recommendation

5. Interview with Stakeholders

The following interviews have been conducted by Prof. Albert K.H. Kwan (AKHK).

(1) Interview with Chairman of Working Group for Drafting of CS3
(2) Interview with General Building Contractors Association
(3) Interview with Institute of Quarrying Hong Kong Branch
(4) Interview with Concrete Producers Association
(5) Interview with Import Aggregates Suppliers Association
(6) Interview with Hong Kong Construction Sub-contractors Association, Plastering Sub-contractors Association, Registered Minor Works Contractor Employees Association and Brick-laying & Construction Trade Workers' Union
(7) Interview with China Light and Power Hong Kong Ltd on Bottom Ash
(8) Interview with K. Wah Construction Products Ltd on Waste Glass
(9) Interview with Environmental Protection Department on Recycling of Waste Glass
(10) Consultation with K. Wah Construction Products Ltd on Granulated Blastfurnace Slag

A detailed interview report is attached in Appendix B. For conciseness, only a brief summary is presented in the following.

<u>Suitability of crushed rock fine as fine aggregate for concrete</u>:
The concrete producers in Hong Kong had already started using crushed rock fine in place of river sand in concrete production a few years back. There is no major problem with the use of crushed rock fine as fine aggregate in normal-strength concrete. The use of crushed rock fine in place of river sand has some effects on the workability and strength of the concrete mixes produced but these can be dealt with by adding a bit more cement and water. Nevertheless, some concrete producers still prefer to use river sand as fine aggregate in concrete of grade ≥ 80 MPa. Some interviewees said that the crushed rock fine can be processed to become manufactured sand with improved particle shape and particle size distribution as a better substitute of both river sand and crushed rock fine. Two quarry operators have already started producing manufactured sand but there is still no standard for manufactured sand. Further research is needed to find out the optimum ranges of particle size distribution and fines content for different applications.

<u>Suitability of crushed rock fine as aggregate for mortar</u>:
The interviewees are generally of the view that fine aggregates for concrete may not be suitable for use as fine aggregates for mortar due to their different effects on concrete and mortar. They are particularly concerned that crushed rock fine is not a suitable river sand substitute for mortar because mortar made with crushed rock fine is very sticky and thus difficult to trowel. It also has a higher water demand, a higher tendency to drip downwards after trowelling and a higher risk of shrinkage cracking after hardening. Furthermore, there is the problem of the presence of particles larger than 2 mm in the crushed rock fine, which makes the mortar surfaces rather rough and difficult to trowel.

They insisted that river sand is an indispensable material for rendering, plastering and masonry mortar. Nevertheless, if the so called manufactured sand is processed to have the fines content reduced to a level similar to that of river sand and the particles larger than 2 mm removed, they would welcome. Since the manufactured sand has different characteristics, re-training of the workers may be needed.

Suitability of manufactured sand as aggregates for concrete and mortar:
There are two major types of manufactured sand, one produced by water washing (wet process) and the other produced by air classification (dry process). The wet and dry processes are to reduce the fines content of the manufactured sand. In addition, some manufactured sands have been ground to certain extent during size reduction to improve the roundness of the particles. Depending on the actual production processes, manufactured sands from different sources may have different fines content, particle size distribution and particle roundness. There is however no established standard for manufactured sand. Two quarry operators have already started producing manufactured sand for the Hong Kong market. According to them, the manufactured sands are currently produced to mimic river sand so as to be used as direct river sand substitute. However, whilst the properties of river sand could fluctuate with the location and depth of dredging, the manufactured sand is produced in a factory under controlled conditions and thus should be more consistent in quality. Moreover, by engineering the various properties of the rock aggregate, manufactured sand could be tailor-made to suit different applications as better substitutes of both river sand and crushed rock fine for concrete and mortar. Further research is needed to determine the required properties of manufactured sand for different applications so that standards or specifications of manufactured sand could be developed.

Need of a separate standard on aggregates for mortar:
Since the standard on aggregates for concrete is not really applicable to aggregates for mortar, a separate standard on aggregates for mortar is needed. In the standard on aggregates for mortar, the imposed limits on the fines content should be lower than those in the standard on aggregates for concrete. Apart from setting relatively low fines content limits, it may also be necessary to classify the aggregates for mortar into different categories with different characteristics for different applications. Research studies and tests are needed to determine the fines content limits and particle size distribution requirements for aggregates to be used in floor screeds, rendering and plastering, and masonry. It may take a long time to develop a local standard on aggregates for mortar. In the mean time, trials using aggregates with different fines contents should be carried out so that fines content limits for aggregates to be used in floor screeds, rendering and plastering, and masonry could be tentatively set as general guidelines for the aggregate suppliers to follow.

Furnace bottom ash as river sand substitute:
According to China Light and Power, furnace bottom ash generated from burning coal for electricity is being used as one of the raw materials for cement production. There is at the moment no disposal problem for furnace

bottom ash. Hence, crushing and sieving furnace bottom ash for use as river sand substitute in concrete or mortar is not a viable option.

Crushed waste glass as river sand substitute:
We are producing about 120,000 tons of waste glass in Hong Kong every year but only about 4% to 5% is being recycled as aggregate in precast concrete paving blocks. The Environmental Protection Department is very keen in increasing the recycling rate to at least 50%. Crushing the waste glass to sand size for use as river sand substitute in mortar could be one good way of increasing the recycling rate. Since there is the concern of alkali-silica reaction, the use of crushed waste glass as aggregate in concrete should be limited to non-structural applications at this stage. Research studies on the use of crushed waste glass as aggregate in mortar and potential alkali-silica reaction of crushed waste glass aggregate are recommended. However, for the option of using crushed waste glass as river sand substitute to be viable, government support is needed.

Granulated blastfurnace slag as river sand substitute:
According to K. Wah Construction Products Ltd, the price of ground granulated blastfurnace slag (ground to fineness similar to that of cement) is about 90% of the price of cement and thus the producers would prefer to grind the granulated blastfurnace slag to a higher fineness so as to sell the material at a higher price rather than to grind the granulated blastfurnace slag to sand size for use as a river sand substitute. Granulated blastfurnace slag is not a waste anymore because of its great demand for grinding to become a supplementary cementitious material that can improve the performance of concrete. Hence, the use of ground granulated blastfurnace slag as a river sand substitute is not considered a viable option.

6. Field Trials on the Uses of River Sand, Crushed Rock Fine and Manufactured Sand in Plastering

Field trials on the uses of river sand (RS), crushed rock fine (CRF) and manufactured sand (MS) in plastering have been carried out. The plastering trials were carried out at the training centre of Hop Yuen Building Materials Ltd in Kowloon Bay on May 10, 2012 and May 22, 2012.

On May 10, 2012, three trials were carried out. In the first two trials, MS tested to have a maximum particle size of 5.0 mm and a fines content of 2.5% was used. Two mortar mixes, designated as MS1 and MS2, were produced. Their mix proportions were:
MS1 – water: cement: sand = 0.4: 1.0: 2.5 by weight
MS2 – water: cement: sand = 0.5: 1.0: 2.5 by weight

MS1 was found to have the right consistence for plastering (i.e. neither too dry nor too wet). It was applied onto a vertical concrete wall, which was pre-wetted with water and then wiped dry before plastering. There was no problem with building up to a thickness of 20 mm in one layer. It was also applied to the ceiling of a concrete slab, which was also pre-wetted with water and then wiped dry before plastering. There was no problem with building up to a thickness of 10 mm in one layer. Overall, the results were satisfactory.

MS2 was found to be slightly too wet for plastering. When applied onto a vertical concrete wall, which was pre-wetted with water and then wiped dry before plastering, the mortar tended to drip downwards. Nevertheless, it could be built up to a thickness of 20 mm in one layer. An attempt was also made to apply the mortar to the ceiling of a concrete slab, which was also pre-wetted with water and then wiped dry before plastering. It was found that due to the high water content and the apparent wetness, the mortar could not be applied to the ceiling (the mortar kept falling down during application). Overall, the results were marginally satisfactory.

In the third trial, RS tested to have a maximum particle size of 2.36 mm and a fines content of 0.6% was used. One mortar mixes, designated as RS1, was produced. Its mix proportions are:
RS1 – water: cement: sand = 0.4: 1.0: 2.5 by weight

RS1 was found to be rather un-cohesive when held in hand, although it appeared to have sufficient wetness. Nevertheless, it could be applied without any difficulties onto a vertical concrete wall, which was pre-wetted with water and then wiped dry before plastering, up to a thickness of 20 mm in one layer. Moreover, it could be applied to the ceiling up to thickness of 10 mm in one layer, though with certain difficulties because a significant portion of the mortar adhered to the ceiling fell downwards during application. Overall, the results were satisfactory, but not as good as MS1.

<u>On May 22, 2012</u>, three trials were carried out. CRF tested to have a maximum particle size of 5.0 mm and a fines content of 8.6% was used. The mortar mixes, designated as CRF1, CRF2 and CRF3, were produced. Their mix proportions were:
CRF1 – water: cement: sand = 0.40: 1.0: 2.5 by weight
CRF2 – water: cement: sand = 0.45: 1.0: 2.5 by weight
CRF3 – water: cement: sand = 0.55: 1.0: 2.5 by weight

CRF1 was found to be too dry and un-cohesive. It could not be applied to any concrete wall or ceiling up to any thickness. The results were unsatisfactory.

CRF2 was found to be slightly too dry and a bit un-cohesive. When applied onto a vertical concrete wall, which was pre-wetted with water and then wiped dry before plastering, the mortar could stay on the wall but a small portion of the mortar fell downwards. Nevertheless, it could be built up to a thickness of 20 mm in one layer, though with slight difficulties. An attempt was also made to apply the mortar onto the ceiling of a concrete slab, which was also pre-wetted with water and then wiped dry before plastering. It was found that due to the apparent dryness, the mortar could not be applied to the ceiling at all (the mortar kept falling down from the ceiling). Overall, the results were marginally satisfactory.

CRF3 was found to be slightly too wet for plastering. When applied onto a vertical concrete wall, which was pre-wetted with water and then wiped dry before plastering, the mortar could stay on the wall but a small portion of the mortar fell downwards. Nevertheless, it could be built up to a thickness of 20 mm in one layer, though with slight difficulties. It was also applied to the ceiling of a concrete slab, which was also pre-wetted with water and then wiped dry before plastering. It could be built up to a thickness of 10 mm but with great difficulties because some of the mortar did not adhere well to the concrete surface and kept falling down during application. Overall, the results were marginally satisfactory.

Summing up, the following conclusions may be drawn from the plastering trials:

(1) The MS seems to be suitable for use as fine aggregate in mortar for plastering works. With MS used as fine aggregate, the mortar should be designed to have a water/cement ratio of within 0.40 to 0.50. At a water/cement ratio of 0.40 (or any water/cement ratio giving the right consistence), the mortar could be applied to both concrete walls and ceilings. At a water/cement ratio of 0.50 (or a relatively high water/cement ratio), the mortar might become too wet and could be applied only to concrete walls but not ceilings. However, during the plastering trials, it was observed that the relatively coarse particles (particles of size 3 to 4 mm) had caused certain difficulties in the trowelling. Hence, it might be better to limit the maximum particle size of MS to 2.36 mm.

(2) The RS, which is quite commonly used in the industry, is also suitable for use as fine aggregate in mortar for plastering works. With RS used, the mortar should be designed to have a water/cement ratio of around 0.40. With an appropriate water/cement ratio adopted, the mortar could be applied to both concrete walls and ceilings. However, during the plastering trials, it was found that mortar made with RS tended to be less cohesive and more difficult to apply than mortar made with MS. Moreover, according to the worker, who claimed to have more than 30 years of experience, the characteristics (mainly the fineness and moisture content) of RS fluctuate a lot and thus the exact amount of water to be added has to be judged during mixing and good experience and skill are needed in producing a mortar mix with the right wetness (or more scientifically, the right consistence).

(3) The CRF is apparently not as suitable as MS or RS for use as fine aggregate in mortar for plastering works. With CRF used, the mortar would require more water to give the right consistence and should be designed to have a water/cement ratio of within 0.45 to 0.55. With an appropriate water/cement ratio adopted, the mortar could be applied to vertical concrete walls with slight difficulties. However, regardless of the water/cement ratio, it would generally be quite difficult to apply the mortar to ceilings. After the plastering trials, the worker said that based on his own experience, the main difficult in the use of CRF in mortar is the very narrow range of suitable water content for making the mortar and quite often after mixing the mortar is found to be either too dry or too

wet. Since the characteristics of CRF also fluctuate a lot, the exact amount of water to be added has to be judged during mixing.

7. Possible River Sand Substitutes

From the above studies and Prof. Albert K.H. Kwan's own analysis, the following possible river sand substitutes have been identified.

7.1 River Sand Substitutes for Concrete

The concrete producers in Hong Kong have already adapted to the use of crushed rock fine as river sand substitute in the production of concrete. For production of normal concrete, the use of unprocessed crushed rock fine (crushed rock fine not processed to control fines content and grading or to improve particle shape) as fine aggregate is generally acceptable, except that the water content, cementitious materials content and superplasticizer dosage may need to be adjusted upwards. For production of high-performance concrete, such as high-strength concrete, high-flowability concrete and high-durability concrete, processed crushed rock fine (crushed rock fine processed to control fines content and grading and to improve particle shape), which is also called manufactured sand, may be preferred (the issue of manufactured sand will be discussed later).

A draft of Construction Standard CS3: 2012 - Aggregates for Concrete has already been completed by the Standing Committee on Concrete Technology and sent out to stakeholders for consultation. It is based largely on the existing British Standard and thus there should be no major difficulties for the quarry operators and concrete producers to comply with. Product certification of aggregate has been included in the draft CS3. It may take one or two years for the quarry operators to obtain product certification but after then the quality of aggregate for concrete in Hong Kong would be significantly improved.

As in the British Standard, three fineness grades of fine aggregate are allowed in the draft CS3. Generally, for making high-strength concrete and high-flowability concrete, which tend to contain high cementitious materials contents, the use of medium to coarse graded fine aggregate may be advantageous. On the other hand, for making pumped concrete and self-consolidating concrete, which require high passing ability and high cohesiveness, the use of fine to medium graded fine aggregate may be advantageous. The selection of the fineness grade is the concrete producer's free choice, but the quarry operator should be required to declare the fineness grade of the fine aggregate being supplied and comply with the relevant grading limits. Proper or optimum grading and proportioning of aggregates for different concretes are good topics for research and should be encouraged or even supported. Provided the performance of the concrete produced meets with the specification requirements, we should not impose unnecessarily restrictive grading limits on the aggregates.

Another issue that has today remained controversial is the fines content limit. Different standards impose widely different limits on the fines content. The fines content has large surface area and thus would significantly affect the water demand and superplasticizer demand of the concrete mix. It may also contain clay or other harmful materials that could adversely affect the quality of the concrete produced. Hence, some limits on the fines content and clay content need to be imposed. The limits on fines content stipulated in the draft CS3 are relatively loose compared to those in the Chinese Standards. Provided the fines content does not contain clay, such relatively loose limits would allow the quarry operators greater freedom in the production of crushed rock fine aggregate. However, if the fines content contains a significant amount of clay, the relatively loose limits on fines content may cause problem with concrete production. It is only that in actual practice, it is not easy to distinguish clay from fines. Although the European Standards and Chinese Standards recommend the use of the methylene blue test for measuring the clay content, this test actually measures only the content of certain chemicals in the fines and is thus not a direct measurement of the clay content. A suitable test for direct measurement of clay content is yet to be developed. Some research on this issue is recommended.

7.2 River Sand Substitutes for Mortar

A major problem with the use of unprocessed crushed rock fine in mortar is that the unprocessed crushed rock fine often contains a substantial amount of fines, which renders the mortar produced rather sticky and difficult to trowel. In fact, the General Building Contractors Association insisted that crushed rock fine (actually what they meant is unprocessed crushed rock fine) is not a suitable substitute for river sand in mortar. As the draft CS3 stipulates fairly high limits on the fines content and rather loose grading limits for the fine aggregate, even crushed rock fine complying with the draft CS3 may not be suitable for use in mortar. In other words, the future CS3 - Aggregates for Concrete is not applicable to aggregates for mortar. A separate standard on aggregates for mortar is needed but it takes a long time, probably two to three years (it should be borne in mind that the consultation itself may last more than one year), to develop a new standard.

An urgent solution for river sand substitutes to be used in mortar has to be worked out as soon as possible. One possible solution is to process the crushed rock fine to reduce the fines content and perhaps also to improve the grading at the quarry before supplying to the market. The effectiveness of such possible solution is yet to be verified on site by trial applications and therefore some experimental works on the performance of processed crushed rock fine with different fines content and grading need to be carried out. If this is proven to be a workable solution, it is recommended that in the mean time, fine aggregates for mortar should be classified into Category 1 with fines content ≤ 3% for floor screeds and repair mortars, Category 2 with fines content ≤ 5% for rendering and plastering, and Category 3 with fines content ≤ 8% for masonry mortar. In the longer term, manufactured sands tailor-made for use in different types of mortar may be a better solution (this issue of manufactured sand will be discussed later). Since mortar works are generally non-structural, the possibility of using crushed waste glass as aggregates for mortar, which helps to solve the environment problem of waste glass disposal, should also be considered (this issue of waste glass will be discussed later).

7.3 Manufactured Sand

Apart from using crushed rock fine directly from the crusher in the quarry without further processing as river sand substitute, a better alternative is to process the crushed rock fine to improve its properties so as to produce a better fine aggregate than unprocessed crushed rock fine and river sand. Such processed crushed rock fine is called "manufactured sand". The processing applied to the crushed rock fine may include grinding to change the shape of the aggregate particles from angular to sub-angular or sub-rounded, screening and blending to optimize the fines content and particle size distribution for best overall performance of the concrete/mortar produced, and cleaning to remove all the harmful substances such as clay in the crushed rock fine. The technology and equipment to produce manufactured sand are already available. It is now a matter of whether there is a big enough market to attract investment on the production of this material.

When used in concrete, the better shape and grading of the manufactured sand would improve the packing density of the fine aggregate and thereby reduce the volume of voids to be filled with cement paste. At a given workability requirement, this would reduce the cement consumption and carbon footprint, and increase the dimensional stability of the concrete. At a given cement paste volume, this would improve the flowability and pumpability of the concrete. The better cleanliness would also allow the attainment of higher strength for the production of high-strength concrete.

When used in mortar, the lower fines content of the manufactured sand would render the mortar produced less cohesive and thus easier to trowel. The better shape and grading of the manufactured sand would improve the packing density and thus allow the use of a smaller paste volume to reduce the drying shrinkage and thus mitigate the shrinkage cracking of mortar. Manufactured sand may also have applications in pre-packed plastering, rendering, screeding and repair mortar.

However, there is at the moment no standard or specification for manufactured sand. Without a recognized standard or specification, it is difficult for quarry operators to market manufactured sand, which will be more expensive than unprocessed crushed rock fine. It may take a few years to develop a standard or specification for manufactured sand. In the mean time, some samples of manufactured sand can be obtained for testing and evaluation.

7.4 Crushed Waste Glass

More than one hundred thousand tons of waste glass (mostly used bottles) are generated as inert solid waste every year in Hong Kong. Only a small quantity (about 4%) of the waste glass is crushed and used as aggregates for the production of precast concrete paving blocks. Most of the waste glass is just dumped to landfills as waste.

One major problem with the use of crushed waste glass as aggregate in concrete is the risk of having alkali-silica reaction, which may affect the durability of the concrete. Another major problem is the high brittleness of glass, which makes the concrete unsuitable for structural applications.

Nevertheless, crushed waste glass may be used as fine and coarse aggregates in concrete paving blocks, concrete blocks for non-structural walls, concrete blocks for pervious pavement and in-situ concrete for minor works.

In theory, crushed waste glass may also be used as aggregate in mortar for plastering, rendering, screeding and masonry. Such possible use of crushed waste glass as river sand substitute for mortar should be explored because if feasible, this will greatly increase the rate of recycling to 50% or more. However, due to the high collection and transportation cost, the cost of producing crushed waste glass is rather high. More support to the recycling industry (such as helping to do research, helping to collect more waste glass for recycling, and promoting the use of crushed waste glass for sustainable development) needs to be provided or otherwise, the production of crushed waste glass to be used as aggregate in mortar will have no market.

7.5 Recycled Aggregate

Millions of tonnes of old concrete are generated as inert solid waste every year in Hong Kong. The government has been promoting the crushing of old concrete to produce recycled aggregate for reuse in new concrete construction. However, the recycled aggregate, especially the fine portion, tends to have old cement paste adhered onto the particle surfaces that may adversely affect the quality of the concrete produced. Hence, many engineers hesitate to use recycled aggregate and for many years, recycled aggregate has been used only in non-structural concrete and low grade structural concrete. Currently, the usage of recycled aggregate is very low and most of the old concrete is just dumped as waste or shipped to other places at a certain cost.

Even when recycled aggregate is used, only the coarse portion is used as coarse aggregate in concrete construction. The fine portion, which contains a lot of fines comprising partly of the fines in the original fine aggregate and partly of old cement paste, is not used and therefore has to be dumped as waste. Without processing, the fine portion of recycled aggregate is not a suitable river sand substitute for use in concrete or mortar. However, there is now the processing technology of reducing the fines content by air classification, which is being used to produce manufactured sand from crushed rock fine. Whether this processing technology could also be applied to improve the quality of the fine portion of recycled aggregate so that after processing, the fine portion is good enough to be used as a river sand substitute in concrete or mortar should be worthy of investigating.

To promote greater use of recycled aggregate, more government initiatives are required. Recycling of old concrete as aggregate has to be done locally and thus perhaps the government should consider providing affordable land for the production of recycled aggregate. The government could also mandate the use of recycled aggregate in certain public works projects. However, there remains the technical issue of the general lack of confidence in the quality of the recycled aggregate. Most research on recycled aggregate concrete are on the properties of concrete made with clean recycled aggregate. No researcher seems to be interested in measuring the cleanliness of recycled aggregate and establishing a quality system for recycled aggregate. Until the time that a product certification scheme is enacted for quality assurance of recycled aggregate, most engineers would not dare to use recycled aggregate at all.

7.6 Furnace Bottom Ash

The burning of coal for electricity generation produces not only fly ash, but also furnace bottom ash. The furnace bottom ash is much coarser and contains more impurities than the fly ash. Hence, the furnace bottom ash cannot be used directly as a cementitious material like the fly ash. It has been suggested that the furnace bottom ash may be crushed and processed to become suitable fine aggregate for concrete or mortar. However, according to China Light and Powers, all the furnace bottom ash in Hong Kong has already been used up as one of the raw materials for cement production and thus there is no un-used furnace bottom ash in Hong Kong that may be employed to produce fine aggregate. The possible use of bottom ash as river sand substitute for concrete and mortar is thus ruled out and no further study in this aspect is warranted.

7.7 Granulated Blastfurnace Slag

In theory, it is possible to grind granulated blastfurnace slag to sand size for use as river sand substitute in concrete and mortar. However, granulated blastfurnace slag can be ground to a higher fineness similar to that of cement for use as a supplementary cementitious material. According to a major slag supplier in Hong Kong, the price of ground granulated blastfurnace slag for use as a supplementary cementitious material is about 90% of the price of cement. This is because ground granulated blastfurnace slag can be used to improve the performance and durability of concrete and is therefore in great demand. Because of the possibility of grinding to a higher fineness for selling at almost the price of cement, the price of raw slag is quite high and thus the price of sand size ground granulated blastfurnace slag is not expected to be competitive compared to other river sand substitutes. Hence, the use of ground granulated blastfurnace slag as a river sand substitute is not a viable option.

8. The Way Forward - Recommendations for Phase Two Research

This study is only Phase One and the overall study on river sand substitutes will continue after completion of this study. To facilitate continuation of the overall study, it is recommended to pursue the following tasks in Phase Two, which are presented below in the order of higher priority (more urgent issue) to lower priority (longer term issue).

8.1 Priority 1 – Construction Standard for Aggregates for Mortar

The most urgent issue of finding river sand substitutes for concrete and mortar is the identification and production of suitable river sand substitutes for mortar (river sand for concrete has already been substituted by crushed rock fine and so far the use of crushed rock fine as fine aggregate for concrete is found to be acceptable, though not ideal). Since unprocessed crushed rock fine is not a suitable river sand substitute for mortar and the newly drafted Construction Standard CS3 is not applicable to aggregates for mortar, a new construction standard on aggregates for mortar (CS4?) is needed. It is the government's jurisdiction to draft construction standards, but the Construction Industry Council may contribute by helping to study the applicability of relevant international standards to Hong Kong, conduct laboratory tests/field trials on the effects of fines content and grading on the performance of mortar in different applications, and draft preliminary guidelines that may form a basis for discussions with stakeholders and drafting of a construction standard on aggregates for mortar by the government.

The British Standard BS EN 13139: 2002 – Aggregates for mortar (actually an English version of the European Standard) is a good starting point for formulating preliminary guidelines for aggregates for mortar. The standard sieve sizes, demarcation between fine and coarse aggregates, and definition of fines in this European Standard are totally different from those in the British Standards being used in Hong Kong. As for the Construction Standard CS3 – Aggregates for concrete, it is recommended to stay with the standard sieve sizes, demarcation between fine and coarse aggregates, and definition of fines given in the British Standards. The fines content limits and grading limits given in the European Standard will then have to be converted into equivalent limits for use with the standard sieve sizes given in the British Standards.

For the laboratory tests/field trials, an extensive testing program, in which the fines content varies from a very low value of say 2% to a relatively high value of say 10%, the maximum aggregate size varies among 1.18 mm, 2.36 mm and 5.0 mm, and the grading varies among coarse graded, medium graded and fine graded (as defined in the European Standard or redefined to suit the use of standard sieve sizes given in the British Standards) should be carried out. For the field trials, it should be a good idea to get an industrial partner with good experience in mortar works involved.

From the laboratory tests/field trials, we should be able to draw fines content limits and grading limits on the aggregates to be used for various kinds of mortar works. These limits will then form guidelines for the processing of crushed rock fine to become suitable river sand substitutes for mortar. Since the definition of fines as particles smaller than 63 μm in the European Standard is not too different from the definition of fines as particles smaller than 75 μm in the British Standards, it is expected that the fines content limits should be similar to those given in the European Standard, namely, fines content ≤ 3% for floor screeds and repair mortars, fines content ≤ 5% for rendering and plastering, and fines content ≤ 8% for masonry mortar.

8.2 Priority 2 – Research on Effects of Fines Content on Concrete

Although unprocessed crushed rock fine with fines content up to more than 10% has been satisfactorily used as river sand substitute for concrete, it remains a controversial issue regarding the allowable fines content or optimum fines content for crushed rock fine aggregate in concrete. Among the existing standards, the limits imposed on the fines content are more lenient in the British Standards and European Standards and a lot more stringent in the Chinese Standards, indicating that there is no general agreement on the limits to be imposed on the fines content. In actual practice, there is the difficulty of controlling the fines content in unprocessed crushed rock fine. Hence, it is not recommended to impose stringent limits on the fines content in unprocessed crushed rock fine. The proposed fines content limit of 14% in the draft CS3 – Aggregates for concrete is already an acceptable compromise between quality and practicality.

However, there is still the need to conduct research on the effects of fines content in fine aggregate on the overall performance of concrete, such as water demand, superplasticizer demand, workability, cohesiveness and strength of concrete. The effects of fines content on the packing density and surface area of the total aggregate should also be studied in order to find out whether the changes in performance of concrete are due to the corresponding changes in packing density or surface area. It is believed that at each set of water/cement ratio and cement paste volume, there is an optimum fines content for best overall performance of concrete. The optimum fines contents at different water/cement ratios and cement paste volumes can be determined by testing trial concrete mixes with water/cement ratio varying from 0.30 to 0.60, cement paste volume varying from 25% to 35%, and fines content varying from 6% to 14%.

Preferably, the crushed rock fine should be processed to have fines content close to the optimum fines content or within a certain recommended range encompassing the optimum fines content. Such knowledge of the optimum fines content would help the quarry operators process the crushed rock fine to produce manufactured sand. These recommended ranges of fines content will form guidelines or specifications for different categories of manufactured sand to be used in different applications. With manufactured sand marketed as a material complying with certain recognized specifications, it is then up to the design engineers or concrete producers to specify ordinary crushed rock fine (unprocessed crushed rock fine), which is cheaper and should be good enough for normal concrete, or manufactured sand (processed crushed rock fine), which is more expensive but should be a better choice for high-performance concrete.

In the longer term, there is a need to draft a standard for manufactured sand.

8.3 Priority 3 – Specifications and Classification of Manufactured Sand

Manufactured sand for mortar and manufactured sand for concrete are not the same because their requirements are different. Basically, manufactured sand for mortar should have lower fines content (3% to 8% depending on expected usage) while manufactured sand for concrete should have higher fines content (6% to 10% depending on concrete mix design). Nevertheless, it is suggested to develop just one general specification of manufactured sand for both concrete and mortar with manufactured sand classified into several categories according to fines content, maximum aggregate size and particle shape. As the fines content limits given in the European Standard BS EN 13139 are: fines content ≤ 3% for floor screeds and repair mortars, fines content ≤ 5% for rendering and plastering, and fines content ≤ 8% for masonry mortar, and the fines content limit given in the Construction Standard CS3 for unprocessed crushed rock fine is 14%, it is proposed that manufactured sand may be classified into the following categories:
Category 1: fines content ≤ 3%; maximum aggregate size = 2.36 mm
Category 2: fines content ≤ 5%; maximum aggregate size = 2.36 mm
Category 3: fines content ≤ 8%; maximum aggregate size = 2.36 mm
Category 4: fines content ≤ 6%; maximum aggregate size = 5.0 mm
Category 5: fines content ≤ 10%; maximum aggregate size = 5.0 mm

The above proposed classification is very preliminary. It is suggested that consultation with stakeholders and field trials of the different categories of manufactured sand should be conducted in Phase Two before deciding on the exact fines content limits and maximum aggregate size limits to be adopted in the classification. It is hoped that in the longer term, after some years of usage, the general specification so developed would become a standard.

8.4 Priority 4 – Research on Crushed Waste Glass as Aggregate for Mortar

One major problem with the recycling of waste glass is the high cost of collection and transportation to the recycling factory. According to a recycling company, the main reason is that the waste glass, mostly in the form of bottles occupying a large bulk volume, has to be transported as whole bottles back to the recycling factory for cleaning before crushing. However, it is felt that there may be a possibility of crushing the bottles in the lorry at the collection point for easier transportation and then cleaning the crushed glass in the factory. Cleaning after crushing of the bottles is inevitably more difficult but the saving in transportation cost should more than compensate the higher cost of cleaning after crushing. More government support to the collection of waste glass bottles would also reduce the cost and provide more incentives for the recycling industry to increase the rate of recycling.

For crushed waste glass to be used as river sand substitute for mortar, research is needed. Glass is a brittle and fairly uniform material (uniform in the sense that there should be little weak minerals, or clay-like materials, in the glass), and thus it is expected that after crushing, the fines content should be on the low side. The expected low fines content would render the crushed waste glass a good substitute of river sand as aggregate for mortar. To do this kind of research, it is recommended to get the waste glass recycling companies involved. The recycling companies should be asked to produce samples of crushed waste glass for testing. The testing should include measurement of fines content, particle size distribution, packing density and water demand, and field trials to assess the suitability of the crushed waste glass as aggregate in mortar for different applications such as floor screeds, rendering, plastering and masonry mortar.

8.5 Priority 5 – Research on Recycled Aggregate as Aggregate for Mortar

The fine portion of recycled aggregate, which is usually dumped as waste, tends to have a significant amount of old cement paste adhered to the particle surfaces and very high fines content. Hence, without processing, recycled aggregate is not suitable as a river sand substitute for mortar. It is envisaged that the old cement paste could be removed by grinding using the grinding technology adopted in the production of manufactured sand to improve particle roundness and the fines content could be reduced by the air classification employed in the production of manufactured sand. In other words, the processing currently applied to crushed rock fine to produce manufactured sand may also be applied to recycled aggregate to produce a suitable river sand substitute for mortar. This has not been done before but some field trials to investigate the feasibility of applying the manufactured sand technology to convert raw recycled aggregate to a suitable aggregate for mortar seem warranted. Again, to do this kind of research, it is recommended to get the manufactured sand producers involved.

- End of Report -

Appendix A

Literature Review of Current Standards on Aggregates for Concrete and Mortar

1. Current Standards on Aggregates for Concrete and Mortar

As part of the study on river sand substitutes, a literature review of current standards on aggregates for concrete and mortar has been carried out. The standards gathered for review are:

(1) British Standard BS 882: 1992 – Specification for aggregates from natural sources for concrete
(2) British Standards BS 1199 and 1200: 1976 – Specifications for building sands from natural sources
(3) British Standard BS EN 12620: 2002 – Aggregates for concrete
(4) British Standard BS EN 13139: 2002 – Aggregates for mortar
(5) BSI PD 6682-1: 2009 Aggregates – Part 1: Aggregates for concrete – Guidance on the use of BS EN 12620
(6) BSI PD 6682-3: 2003 Aggregates – Part 3: Aggregates for mortar – Guidance on the use of BS EN 13139
(7) Chinese Standard GB/T 14684 – 2001 Sand for building
(8) Chinese Standard JGJ 52 – 2006 Standard for technical requirements and test method of sand and crushed stone (or gravel) for ordinary concrete
(9) Hong Kong Construction Standard CS3: 2012 – Aggregates for concrete (draft)

2. British Standard BS 882: 1992 – Specification for Aggregates from Natural Sources for Concrete

This is the British Standard on aggregates for concrete that has been used in Hong Kong for a long time. Until the time that it is replaced by the new Hong Kong Construction Standard CS3, it will remain effective in Hong Kong.

The standard sieve sizes are: 75 µm, 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 5.00 mm, 10.00 mm, 20.00 mm, 37.50 mm and 50.00 mm. Particles finer than 75 µm (passing the 75 µm sieve) are called fines. Limits on the fines content in crushed rock sand are imposed as follows: for general use: 16%; for use in heavy duty floor finishes: 9%.

The grading limits for sand are as given in Table 1. Two sets of grading limits are stipulated, namely: the overall limits; and the additional limits for gradings C (coarse), M (medium) and F (fine). The overall limits are very loose; two sands with very different particle size distributions could both satisfy the overall grading limits. In addition to satisfying the overall limits, the sand has to fall within either one of the additional limits for C, M or F. The additional limits for C, M or F are relatively tighter. Basically, sands of grading C may have 15% finer than 600 µm and 85% coarser than 600 µm, sands of grading M may have 25% finer than 600 µm and 75% coarser than 600 µm, and sands of grading F may have 55% finer than 600 µm and 45% coarser than 600 µm. For sands satisfying the overall limits but not falling within any one of the additional limits C, M or F, an agreed grading envelope may also be used provided the supplier can satisfy the purchaser that such material can produce concrete of the required quality.

Table 1 Grading limits for sand given in BS 882: 1992

Sieve size	Percentage passing by mass			
	Overall limits	Additional limits for grading		
		C	M	F
10.00 mm	100	100	100	100
5.00 mm	89 – 100	89 – 100	89 – 100	89 – 100
2.36 mm	60 – 100	60 – 100	65 – 100	80 – 100
1.18 mm	30 – 100	30 – 90	45 – 100	70 – 100
600 µm	15 – 100	15 – 54	25 – 80	55 – 100
300 µm	5 – 70	5 – 40	5 – 48	5 – 70
150 µm	0 – 15[a]	0 – 15[a]	0 – 15[a]	0 – 15[a]
Note 1: For sands satisfying the overall limits but not falling within any one of the additional limits C, M or F, an agreed grading envelope may also be used provided the supplier can satisfy the purchaser that such material can produce concrete of the required quality.				
Note 2: [a] Increased to 20% for crushed rock fines except when used in heavy duty floors.				

3. British Standards BS 1199 and 1200: 1976 – Specifications for Building Sands from Natural Sources

This is the British Standard on aggregates for mortar that has been used in Hong Kong for a long time. It is rather old and overly simplistic. No distinction is made between natural sand (such as river sand) and crushed rock sand in the requirements to be applied except for the fines content limits.

The standard sieve sizes are: 75 µm, 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 5.00 mm and 6.30 mm.

For sands to be used for external renderings, and internal cement and lime plastering, the sands shall be of type A or type B, whose grading limits are as given in Table 2. Type A is relatively coarser while type B is relatively finer. Their grading zones overlap with each other and thus individual sands may comply with the requirements of more than one type.

Table 2 Sands for external renderings, and internal cement and lime plastering given in BS 1199: 1976

Sieve size	Percentage passing by mass	
	Type A	Type B
6.30 mm	100	100
5.00 mm	95 – 100	95 – 100
2.36 mm	60 – 100	80 – 100
1.18 mm	30 – 100	70 – 100
600 µm	15 – 80	55 – 100
300 µm	5 – 50	5 – 75
150 µm	0 – 15	0 – 20
75 µm	0 – 5	0 – 5

For sands to be used for mortar for plain and reinforced brickwork, blockwalling and masonry, the sands shall be of type S or type G, whose grading limits are as given in Table 3. Type S is relatively coarser while type G is relatively finer. Their grading zones overlap with each other and thus individual sands may comply with the requirements of more than one type.

Table 3 Sands for mortar for plain and reinforced brickwork, blockwalling and masonry given in BS 1200: 1976

Sieve size	Percentage passing by mass	
	Type S	Type G
6.30 mm	100	100
5.00 mm	98 – 100	98 – 100
2.36 mm	90 – 100	90 – 100
1.18 mm	70 – 100	70 – 100
600 µm	40 – 100	40 – 100
300 µm	5 – 70	20 – 90
150 µm	0 – 15	0 – 25
75 µm	0 – 5[a]	0 – 8[b]
Notes: [a] 0 – 10 for crushed rock sands; [b] 0 – 12 for crushed rock sands		

Comparing the grading limits for sand for mortar in BS 1199 and 1200 and the grading limits for sand for concrete in BS 882, it is noted that sand for mortar is generally finer and has to contain a much lower fines (materials passing the 75 µm sieve) content. Hence, the standard for sand for concrete should not be applied to sand for mortar.

4. British Standard BS EN 12620: 2002 – Aggregates for Concrete

This is the new European Standard on aggregates for concrete. It has recently replaced the British Standard BS 882: 1992 in the UK, but may not be applied in Hong Kong.

In the European Standard, the standard sieve sizes are changed to 63 µm, 125 µm, 250 µm, 0.5 mm, 1 mm, 2 mm, 4 mm, 8 mm, 16 mm, 32 mm and 63 mm, which are totally different from those in the British Standards being used in Hong Kong. The demarcation between coarse aggregate and fine aggregate is changed to 4 mm particle size (in other words, coarse aggregate is defined as particles larger than 4 mm whereas fine aggregate is defined as particles smaller than 4 mm). Moreover, the definition of fines is changed to particles finer than 63 µm (passing the 63 µm sieve). The term “sand”, which means fine aggregate in the old British Standards, is not used anymore.

For fine aggregate with a declared maximum size of *D*, the following general grading requirements apply: 100% passing sieve of size 2*D*, at least 95% passing sieve of size 1.4*D*, and 85 to 99 % passing sieve of size *D*. So, up to 15% of the fine aggregate is allowed to be larger than the declared maximum size. Apart from these requirements, there are no additional requirements on the grading of fine aggregate.

The aggregate producer is allowed to declare the typical grading for each fine aggregate size produced but tolerance limits are applied to control the variability of the fine aggregate. The tolerance limits to be applied for general use fine aggregate are as given in Table 4.

Table 4 Tolerances on producer's declared typical grading for general use fine aggregate given in BS EN 12620: 2002

Sieve size	Tolerance in percentage passing by mass		
	0/4 (4 mm max size)	0/2 (2 mm max size)	0/1 (1 mm max size)
4 mm	± 5[a]	–	–
2 mm	–	± 5[a]	–
1 mm	± 20	± 20	± 5[a]
250 µm	± 20	± 25	± 25
63 µm[b]	± 3	± 5	± 5

[a] Tolerance further limited by the requirements for percentage passing *D*.
[b] Tolerance further limited by the maximum allowed fines content.

Where specifiers wish to additionally describe the coarseness or fineness of the fine aggregate, so as to impose certain grading limits, the fine aggregate may be described as *C* (coarse graded), *M* (medium graded) or *F* (fine graded). For such descriptions of the fine aggregate, either Table 5 or Table 6, but not both, may be used.

Table 5 Coarseness/fineness based on percentage passing in BS EN 12620

Percentage passing 0.5 mm sieve by mass		
CP	*MP*	*FP*
5 to 45	30 to 70	55 to 100

Table 6 Coarseness/fineness based on fineness modulus in BS EN 12620

Fineness modulus		
CF	*MF*	*FF*
4.0 to 2.4	2.8 to 1.5	2.1 to 0.6

There are no limits imposed on the fines (passing the 63 µm sieve) contents in the aggregate. The aggregate producer is allowed to declare the maximum fines content in accordance with specified categories. For fine aggregate, the categories for maximum values of fines content are: f_3 – fines content ≤ 3%; f_{10} – fines content ≤ 10%; f_{16} – fines content ≤ 16%; and f_{22} – fines content ≤ 22%. Hence, unlike the British Standards, provided the aggregate producer declares the maximum fines content in the aggregate and exercise tight control of the fines content, fairly high fines contents are allowed.

There is, however, a new requirement on fines quality. It is now required to assess the harmfulness of the fines in the fine aggregate. According to Annex D of BS EN 12620, the fines shall be considered non-harmful when any of the four following conditions apply:

(1) the total fines content of the fine aggregate is less than 3% or other values according to the provisions valid in the place of use of the aggregate;
(2) the sand equivalent test value is higher than a certain lower limit;
(3) the methylene blue test value is less than a certain specified limit; and
(4) equivalence of performance with satisfactory aggregate is established or there is evidence of satisfactory use with no experience of problems.

No precise limits have been given for the total fines content, sand equivalent test value and methylene blue test value. These limits shall be established from experience of existing requirements of materials in local satisfactory use according to the provisions valid in the place of use of the aggregate.

5. British Standard BS EN 13139: 2002 – Aggregates for Mortar

This is the new European Standard on aggregates for mortar. It has recently replaced the British Standards BS 1199 and 1200: 1976 in the UK, but may not be applied in Hong Kong.

The standard sieve sizes, the definition of fine aggregate as particles smaller than 4 mm, and the definition of fines as particles finer than 63 μm are the same as those in BS EN 12620: 2002.

For fine aggregate with a declared maximum size of *D*, the following general grading requirements apply: 100% passing sieve of size 2*D*, at least 95% passing sieve of size 1.4*D*, and 85 to 99 % passing sieve of size *D*. So, up to 15% of the fine aggregate is allowed to be larger than the declared maximum size. Apart from these requirements, there are no additional requirements on the grading of fine aggregate. These requirements are the same as those in BS EN 12620: 2002.

The aggregate producer is allowed to declare the typical grading for each fine aggregate size produced but tolerance limits are applied to control the variability of the fine aggregate. The tolerance limits to be applied for general use fine aggregate are as given in Table 4, i.e. the same as those in BS EN 12620: 2002.

Where specifiers wish to additionally describe the coarseness or fineness of the fine aggregate, so as to impose certain grading limits, the fine aggregate may be described as *C* (coarse graded), *M* (medium graded) or *F* (fine graded). For such descriptions of the fine aggregate, either Table 7 or Table 8, but not both, may be used. Note, however, that while Table 7 is identical to Table 5, Table 8 is slightly different from Table 6. Hence, the description of coarseness or fineness in BS EN 13139 is not exactly the same as that in BS EN 12620.

Table 7 Coarseness/fineness based on percentage passing in BS EN 13139

Percentage passing 0.5 mm sieve by mass		
CP	*MP*	*FP*
5 to 45	30 to 70	55 to 100

Table 8 Coarseness/fineness based on fineness modulus in BS EN 13139

Fineness modulus		
CF	*MF*	*FF*
3.6 to 2.4	2.8 to 1.5	2.1 to 0.6

There are no limits imposed on the fines (passing the 63 µm sieve) contents in the fine aggregate. The aggregate producer is allowed to declare the maximum fines content in accordance with specified categories. The categories for maximum values of fines content are: category 1 – fines content ≤ 3%; category 2 – fines content ≤ 5%; category 3 – fines content ≤ 8%; and category 4 – fines content ≤ 30%. These categories are not the same as those in BS EN 12620: 2002. Examples of end uses for different categories are:
Category 1: floor screeds, sprayed, repair mortars, grouts (all aggregates)
Category 2: rendering and plastering mortars (all aggregates)
Category 3: masonry mortars (excluding crushed rock aggregate)
Category 4: masonry mortars (crushed rock aggregate)

As for BS EN 12620: 2002, there is also a new requirement on fines quality. In BS EN 13139: 2002, it is required to assess the harmfulness of the fines in the fine aggregate in accordance with Annex C of BS EN 13139: 2002, which is very similar to Annex D of BS EN 12620: 2002. According to Annex C of BS EN 13139: 2002, the fines shall be considered non-harmful when any of the four following conditions apply:

(1) the total fines content of the fine aggregate is less than 3% or other values according to the provisions valid in the place of use of the aggregate;
(2) the sand equivalent test value is higher than a certain lower limit;
(3) the sand equivalent test value is lower than a certain lower limit but the methylene blue test value is less than a certain specified limit;
(4) the methylene blue test value is less than a certain specified limit.

Alternatively, when equivalence with satisfactory aggregate is established or there is evidence of satisfactory use with no experience of problems, the fines in the fine aggregate may also be considered as non-harmful. Although the wordings in Annex C of BS EN 13139: 2002 are slightly different from those in Annex D of BS EN 12620: 2002, these two annexes are actually equivalent.

6. BSI PD 6682-1: 2009 Aggregates – Part 1: Aggregates for Concrete – Guidance on the Use of BS EN 12620

The BSI PDs (BSI published documents) are not British Standards, but they do give recommendations on top of the new European Standards for UK practice. Some of the recommendations given therein may be considered for application in Hong Kong, as summarised below.

The fines content categories recommended in the UK are: for crushed rock coarse aggregate: f_4 (fines content ≤ 4%); for crushed rock fine aggregate not to be used in heavy duty floor finishes: f_{16} (fines content ≤ 16%); and for crushed rock fine aggregate to be used in heavy duty floor finishes: f_9 (fines content ≤ 9%). These recommendations are in fact the same as those given in British Standard BS 882: 1992.

Whilst the European Standard BS EN 12620: 2002 specifies requirements to ensure no harmful fines, e.g. swelling clay, are present, the BSI PD 6682-1: 2009 points out that in the UK, fines contents are considered non-harmful provided the aggregates have been processed and conform to the fines content limits given in the previous paragraph. It also points out that the sand equivalent and methylene blue tests are not considered sufficiently precise for the purpose of determining harmful fines content in aggregate in the UK. It is recommended that aggregates and filler aggregates should be assessed for non-harmfulness using either a fines content limit or evidence of satisfactory use.

7. BSI PD 6682-3: 2003 Aggregates – Part 3: Aggregates for Mortar – Guidance on the Use of BS EN 13139

The BSI PDs (BSI published documents) are not British Standards, but they do give recommendations on top of the new European Standards for UK practice. Some of the recommendations given therein may be considered for application in Hong Kong, as summarised below.

The BSI PD 6682-3: 2003 recommends that the choice of which European designation of aggregate size and which European fines content category should be selected can be determined by reference to Annex A of the BSI PD (presented below as Table 9).

Table 9 Aggregate descriptions and recommended European designations in BSI PD 6682-3

Mortar type	British Standard equivalent	Recommended European designation
Rendering or plastering	BS 1199, Type A	0/2 (*CP* or *MP*) Category 2 fines (fines content ≤ 5%)
	BS 1199, Type B	0/2 (*FP* or *MP*) Category 2 fines (fines content ≤ 5%)
Masonry	BS 1200, Type S	0/2 (*FP* or *MP*) Category 2 fines (fines content ≤ 5%)
	BS 1200, Type G	0/2 (*FP* or *MP*) Category 3 fines (fines content ≤ 8%)
Levelling screed	BS 882, finer range of grading C or coarser range of grading M	0/4 (*CP* or *MP*) Category 1 fines (fines content ≤ 3%)

It is noteworthy that for floor screeds, only Category 1 fines (fines content ≤ 3%) is allowed; and for rendering or plastering, only Category 2 fines (fines content ≤ 5%) is allowed. Category 3 fines (fines content ≤ 8%) may be used only in masonry whereas Category 4 fines (fines content ≤ 30%) is not allowed at all.

8. Chinese Standard GB/T 14684 – 2001 Sand for Building

This standard applies to both sand for concrete and sand for mortar. In other words, no distinction is made between sand for concrete and sand for mortar.

The standard sieve sizes are: 75 µm, 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 4.75 mm, 9.50 mm. Hence, except for the sieve sizes 4.75 mm and 9.50 mm, the standard sieve sizes are the same as those in the British Standards currently in use in Hong Kong. The demarcation between coarse aggregate and sand (fine aggregate) is 4.75 mm (i.e. coarse aggregate is defined as particles coarser than 4.75 mm whereas sand is defined as particles finer than 4.75 mm).

In natural sand (sand from nature without crushing), the materials finer than 75 µm are regarded as clay whereas in manufactured sand (sand obtained by crushing rock), the materials finer than 75 µm are regarded as rock fines (it is noteworthy that in most other standards, these materials are just called fines).

Three grading zones, namely: zone 1, zone 2 and zone 3, are specified. Their grading limits are as given in Table 10.

Table 10 Grading limits for sand given in GB/T 14684 – 2001

Sieve size	Percentage retained by mass		
	Grading zone 1	Grading zone 2	Grading zone 3
9.50 mm	0	0	0
4.75 mm	10 – 0	10 – 1	10 – 0
2.36 mm	35 – 5	25 – 0	15 – 0
1.18 mm	65 – 35	50 – 10	25 – 0
600 µm	85 – 71	70 – 41	40 – 16
300 µm	95 – 80	92 – 70	85 – 55
150 µm	100 – 90[a]	100 – 90[b]	100 – 90[c]
Notes: [a] 100 – 85 for manufactured sands; [b] 100 – 80 for manufactured sands; [c] 100 – 75 for manufactured sands			

Three fineness classes, namely: coarse, medium and fine, are specified, as given in Table 11.

Table 11 Fineness classes based on fineness modulus in GB/T 14684 – 2001

Fineness modulus		
Coarse	Medium	Fine
3.7 to 3.1	3.0 to 2.3	2.2 to 1.6

Three usage classes, namely: usage 1, usage 2 and usage 3, are specified. Usage 1 is for high strength concrete of grade higher than C60. Usage 2 is for medium strength concrete of grade from C30 to C60, frost resistance concrete and anti-seepage concrete. Usage 3 is for low strength concrete of grade lower than C30 and cement-sand mortar.

Limits on the clay content in natural sand are imposed as follows: for usage 1, clay content < 1.0%; for usage 2, clay content < 3.0%; and for usage 3, clay content < 5.0%.

Limits on the rock fines content in manufactured sand are imposed as follows: (1) If the methylene blue test passes, then for usage 1, rock fines content < 3.0%; for usage 2, rock fines content < 5.0%; and for usage 3, rock fines content < 7.0%. (2) If the methylene blue test fails, then for usage 1, rock fines content < 1.0%; for usage 2, rock fines content < 3.0%; and for usage 3, rock fines content < 5.0%.

9. Chinese Standard JGJ 52 – 2006 Standard for Technical Requirements and Test Method of Sand and Crushed Stone (or Gravel) for Ordinary Concrete

This is a standard on aggregates for concrete. Fine aggregate is called sand and defined as particles smaller than 5.0 mm whereas coarse aggregate is called crushed stone or gravel and defined as particles larger than 5.0 mm.

The standard sieve sizes are: 80 µm, 160 µm, 315 µm, 630 µm, 1.25 mm, 2.50 mm, 5.00 mm, 10.00 mm. Both sieves with circular apertures and sieves with square apertures may be adopted provided their aperture sizes are as given in Table 12.

Table 12 Sieve sizes in JGJ 52 – 2006

Nominal sieve size	Diameter of circular apertures	Width of square apertures
5.00 mm	5.00 mm	4.75 mm
2.50 mm	2.50 mm	2.36 mm
1.25 mm	1.25 mm	1.18 mm
630 µm	630 µm	600 µm
315 µm	315 µm	300 µm
160 µm	160 µm	150 µm
80 µm	80 µm	75 µm

The demarcation between coarse aggregate and sand (fine aggregate) is 5.00 mm (i.e. coarse aggregate is defined as particles coarser than 5.00 mm whereas sand is defined as particles finer than 5.00 mm).

The materials finer than 80 µm are regarded as dust. In manufactured sand (sand obtained by crushing rock), if the dust has the same mineralogy as the parent rock from which it is obtained, the duct is also called crusher dust.

Three grading zones, namely: zone 1, zone 2 and zone 3, are specified. Their grading limits are as given in Table 13.

Table 13 Grading limits for sand given in JGJ 52 – 2006

Sieve size	Percentage retained by mass		
	Grading zone 1	Grading zone 2	Grading zone 3
5.00 mm	10 – 0	10 – 0	10 – 0
2.50 mm	35 – 5	25 – 0	15 – 0
1.25 mm	65 – 35	50 – 10	25 – 0
630 μm	85 – 71	70 – 41	40 – 16
315 μm	95 – 80	92 – 70	85 – 55
160 μm	100 – 90	100 – 90	100 – 90

Four fineness classes, namely: coarse, medium, fine and superfine, are specified, as given in Table 14.

Table 14 Fineness classes based on fineness modulus in JGJ 52 – 2006

Coarse	Medium	Fine	Superfine
3.7 to 3.1	3.0 to 2.3	2.2 to 1.6	1.5 to 0.7

Limits on the dust content in natural sand are imposed as follows: for use in concrete of grade ≥ C60, dust content ≤ 2.0%; for use in concrete of grade C55 ~ C30, frost resistant concrete and anti-seepage concrete, dust content ≤ 3.0%; and for use in concrete of grade ≤ C25, dust content ≤ 5.0%.

Limits on the crusher dust content in manufactured sand are imposed as follows: (1) If the methylene blue test passes, then for use in concrete of grade ≥ C60, crusher dust content ≤ 5.0%; for use in concrete of grade C55 ~ C30, crusher dust content ≤ 7.0%; and for use in concrete of grade ≤ C25, crusher dust content ≤ 10.0%. (2) If the methylene blue test fails, then for use in concrete of grade ≥ C60, crusher dust content ≤ 2.0%; for use in concrete of grade C55 ~ C30, crusher dust content ≤ 3.0%; and for use in concrete of grade ≤ C25, crusher dust content ≤ 5.0%.

10. Hong Kong Construction Standard CS3: 2012 – Aggregates for Concrete (Draft)

This standard was drafted by a working group of the Standing Committee on Concrete Technology of the Hong Kong SAR Government. It is still in draft form for public consultation. At least in the near future, there will be only one construction standard on aggregates for concrete and no construction standard on aggregates for mortar.

The draft CS3 is based on the British Standard BS 882: 1992 currently in use in Hong Kong. Unlike the new European Standards, fines are defined as particles passing the 75 μm sieve. For natural fine aggregate, the fines content is limited to not higher than 16% (this limit was given in the original draft as per BS 882: 1992; it was later reduced to 14% in the revised draft).

As for BS 882: 1992, the overall grading limits for fine aggregate are very loose. Nevertheless, for each fine aggregate, not more than one in ten consecutive samples shall have a grading outside the additional limits for any one of the gradings C, M or F, as in the original British Standard. Hence, for better grading control, the aggregate producer should be required to declare whether the fine aggregate is of grading C, M or F and then the fine aggregate should comply with both the overall grading limits and the relevant tighter additional grading limits (note: the draft CS3 was eventually revised such that the aggregate producers or supplier are required to declare the grading of the fine aggregate in line with the practice of BS EN 12620).

There is no requirement to check the cleanliness or non-harmfulness of the fines in the fine aggregate. Since the fine aggregate in Hong Kong is sometimes found to contain clay, as indicated by the yellowish colour of the fine aggregate when wetted, it may be prudent to impose certain requirements on the cleanliness or non-harmfulness of the fines in the fine aggregate. Alternatively, since it is not easy to check the harmfulness of the fines content and there are still no established acceptance criteria for the various tests on the harmfulness of fines, a lower limit on the maximum fines content may be imposed to reduce the risk of having harmful substance in the aggregate.

In the literature review report submitted in January 2012, it has been recommended that the limits to be imposed on the fines content in fine aggregate for concrete in the draft CS3 could be revised as follows: Maximum fines content in fine aggregate for use in ordinary concrete: 10%. If there is proof that the fines is free of harmful materials or evidence of satisfactory use, the above limits may be relaxed to 16%. These recommendations have been conveyed to the Working Group for Drafting of CS3. Consequently, the draft CS3 was revised to reduce the limit for fines content in fine aggregate for use in ordinary concrete from 16% to 10%. However, the Concrete Producers Association was concerned that the proposed 10% limit might be too stringent and impractical for crushed rock fines and counter proposed to set the maximum limit as 14%. Eventually the draft CS3 was revised such that two classes of natural fine aggregate are allowed, Class I with a maximum fines content of 10% and Class II with a maximum fines content of 14% and a methylene blue value ≤ 1.4 (in other words, the maximum fines content may be relaxed to 14% if the fine aggregate passes the methylene blue test).

11. Overview of Current Standards on Aggregates for Concrete and Mortar

The above standards are compared with regard to the following aspects.

Standard sieve sizes: The standard sieve sizes in the British Standards and Chinese Standards are similar but the standard sieve sizes in the new European Standards are totally different from those in the British Standards that are currently in use in Hong Kong. There is actually nothing wrong with the standard sieve sizes in the British Standards. The standard sieve sizes in the new European Standards are probably compromises between the existing standard sieve sizes of the various European countries. That explains why the Standing Committee on Concrete Technology of the Hong Kong SAR Government is not following the European Standards and prefers to draft a local Construction Standard CS3 on aggregates.

Demarcation between coarse and fine aggregates: The demarcation between coarse and fine aggregates in the British Standards and Chinese Standards are similar but the demarcation in the new European Standards is totally different. Changing the demarcation between coarse and fine aggregates from a particle size of 5.0 mm as in the British Standards to 4.0 mm as in the European standards will lead to difficulties of bringing forward our previous experience with aggregate for future use. This is another reason why Hong Kong is not following the European Standards.

Grading limits for fine aggregate: In the British Standards and Chinese Standards, grading limits for fine aggregates of three different grading classes or zones are specified (the grading zones 1, 2 and 3 in the Chinese Standards are equivalent to the gradings C, M and F in the British Standards). However, in the European Standards, no grading limits are specified. Instead, the aggregate producer is allowed to declare the typical grading for each fine aggregate size produced but required to control the variability of the fine aggregate such that the grading is within certain tolerance limits.

Fines content: The British Standards and Chinese Standards define the fines in aggregate as the materials finer than 75 μm or 80 μm, whereas the European Standards define the fines in aggregate as the materials finer than 63 μm. Such slight difference in the definition of fines is not really significant. However, there are big differences in the maximum allowable limits on the fines content. In BS 882, the fines content in crushed rock sand for concrete is limited to 16% for general use and to 9% for use in heavy duty floor finishes. In BS 1199 and BS 1200, the fines content in crushed rock sand for mortar is limited to 5% for rendering and plastering and to 10% for type S sand for masonry mortar and 12% for type G sand for masonry mortar. In BS EN 12620, no limits are imposed on the fines content in fine aggregates for concrete. In BS EN 13139, it is stipulated that fine aggregates for mortar are to be classified into four categories: category 1 (fines content ≤ 3%), category 2 (fines content ≤ 5%), category 3 (fines content ≤ 8%), and category 4 (fines content ≤ 30%), which are for the following recommended uses: category 1: floor screeds, sprayed, repair mortars, grout; category 2: rendering and plastering; category 3: masonry mortar not using crushed rock aggregate; and category 4; masonry mortar using crushed rock aggregate. In GB/T 14684 and JGJ 52, limits on fines content in fine aggregate are imposed according to source and usage of the fine aggregate. The limits for natural sand in GB/T 14684 (JGJ 52) are: for high strength concrete, fines content < 1.0% (≤ 2.0%); for medium strength concrete, fines content < 3.0% (≤ 3.0%); and for low strength concrete, fines content < 5.0% (≤ 5.0%). The limits for manufactured sand in GB/T 14684 (JGJ 52) are: (1) If the methylene blue test passes, then for high strength concrete, fines content < 3.0% (≤ 5.0%); for medium strength concrete, fines content < 5.0% (≤ 7.0%); and for low strength concrete, fines content < 7.0%

(≤ 10.0%). (2) If the methylene blue test fails, then for high strength concrete, fines content < 1.0% (≤ 2.0%); for medium strength concrete, fines content < 3.0% (≤ 3.0%); and for low strength concrete, fines content < 5.0% (≤ 5.0%).

Assessment of harmfulness of fines: The British Standards do not require any assessment or tests on the harmfulness of the fines in aggregate. The European Standards require tests on the harmfulness of the fines in aggregate but do not give any acceptance criteria for the non-harmfulness of the fines. On the other hand, the Chinese Standards require tests on the harmfulness of the fines in aggregate and specify acceptance criteria for the non-harmfulness of the fines. This is a controversial issue. The BSI PD 6682-1 points out that the sand equivalent and methylene blue tests for assessing the harmfulness of the fines in aggregate are not sufficiently precise for the purpose of determining the harmful fines content in aggregate. It recommends that aggregates and filler aggregates should be assessed for non-harmfulness using either a fines content limit or evidence of satisfactory use and that the fines contents may be considered non-harmful provided the aggregates have been processed and conform to the fines content limits given in the BSI PD 6682-1.

Distinction between aggregates for concrete and aggregates for mortar: In the British Standards and the European Standards, very clear distinction is made between aggregates for concrete and aggregates for mortar but in the two Chinese Standards, aggregates for concrete and aggregates for mortar are not clearly differentiated. Apparently, the Chinese Standards are more for aggregates for concrete rather than for aggregates for mortar. It should be better to clearly differentiate aggregates for concrete and aggregates for mortar because their respective requirements are not the same.

12. Summary and Recommendations

From the above review, it is seen that the standard sieve sizes and demarcation between coarse and fine aggregates vary from one standard to another standard. As the standard sieve sizes and the demarcation between coarse and fine aggregates in the British Standards that have been used in Hong Kong for a long time are almost the same as those in the Chinese Standards and some of the quarries are supplying aggregate to both the Hong Kong market and the Mainland market, it is better from the market operation point of view to stay with the standard sieve sizes and demarcation between coarse and fine aggregates in the British Standards. This will also avoid the trouble of changing from an established practice to a totally new practice, save the cost of buying new equipment and help to preserve our previous experience with aggregate for future use.

In general, different requirements are imposed on aggregates for concrete and aggregates for mortar. This is because concrete and mortar have different performance attributes and the quality of fine aggregate has different effects on concrete and mortar. Hence, aggregates for concrete and aggregates for mortar should be clearly differentiated.

For both aggregates for concrete and aggregates for mortar, the major issues seem to be the limits to be imposed on the fines content and the assessment of the harmfulness of the fines content. The fines content needs to be limited for the following reasons. In concrete, any harmful substances, such as clay, in the fines would affect the abrasive resistance, maximum achievable strength, and durability of the concrete. Moreover, since the fines content has very large specific surface area, its quantity would affect the water and superplasticizer demands and thus also the workability of the concrete. The presence of high fines content in the concrete would render the concrete more cohesive, but this has little effect on the concreting operation. In mortar, the presence of clay or excessive fines would also affect the abrasive resistance, maximum achievable strength and workability of the mortar. More importantly, the increase in cohesiveness due to the presence of excessive fines would render the mortar too sticky to be properly trowelled smooth and flat because the mortar tends to stick to the trowel rather than to the substrate.

On the other hand, there are still no established methods for assessing the harmfulness of fines in aggregate and no established acceptance criteria for the non-harmfulness of fines. The BSI PD 6682-1 recommends that aggregates should better be assessed for non-harmfulness using either a fines content limit or evidence of satisfactory use. This seems to be a pragmatic way of avoiding the controversies regarding the methods of assessment and acceptance criteria. Hence, another reason for limiting the fines content is to reduce the risk of having harmful substance in the aggregate.

Considering aggregates for concrete and aggregates for mortar separately, the limits imposed on the fines content in the above reviewed standards are compared in Table 15 for aggregates for concrete and in Table 16 for aggregates for mortar.

From Tables 15 and 16, it can be seen that the limits imposed on the fines content are more lenient in the British Standards and European Standards and a lot more stringent in the Chinese Standards.

Based on the above, it is recommended that the limits to be imposed on the fines content in fine aggregate for concrete in the draft CS3 could be revised as follows: Maximum fines content in fine aggregate for use in ordinary concrete: 14%. Maximum fines content in fine aggregate for use in marine concrete (in marine environment), high-strength concrete (concrete grade > 60 MPa), high-durability concrete (design life ≥ 100 years) and high-abrasive resistance concrete (in heavy duty floors): 10%.

It is also recommended that in the longer term, a local construction standard on aggregates for mortar (CS4?) should be produced (the construction standard CS3 on aggregates for concrete is not applicable to aggregates for mortar). In the mean time, fine aggregates for mortar should be classified into Category 1 with fines content ≤ 3% for floor screeds and repair mortars, Category 2 with fines content ≤ 5% for rendering and plastering, and Category 3 with fines content ≤ 8% for masonry mortar.

Table 15 Limits on fines content in fine aggregates for concrete

Standard/ document	**Limits on fines content**
BS 882 and BSI PD 6682-1	16% for general use; 9% for use in heavy duty floor finishes
BS EN 12620	No limits applied
GB/T 14684	Natural sand: for high strength concrete: < 1.0% for medium strength concrete: < 3.0% for low strength concrete: < 5.0%
	Manufactured sand: If the methylene blue test passes, for high strength concrete: < 3.0% for medium strength concrete: < 5.0% for low strength concrete: < 7.0%
	Manufactured sand: If the methylene blue test fails, for high strength concrete: < 1.0% for medium strength concrete: < 3.0% for low strength concrete: < 5.0%
JGJ 52	Natural sand: for high strength concrete: ≤ 2.0% for medium strength concrete: ≤ 3.0% for low strength concrete: ≤ 5.0%
	Manufactured sand: If the methylene blue test passes, for high strength concrete: ≤ 5.0% for medium strength concrete: ≤ 7.0% for low strength concrete: ≤ 10.0%
	Manufactured sand: If the methylene blue test fails, for high strength concrete: ≤ 2.0% for medium strength concrete: ≤ 3.0% for low strength concrete: ≤ 5.0%
Draft CS3	10% for general use, and if the methylene blue value ≤ 1.4, may be increased to 14%

Table 16 Limits on fines content in fine aggregates for mortar

Standard/ document	**Limits on fines content**
BS 1199 and BS 1200	Crushed rock sand for rendering and plastering: 5% Type S sand for masonry mortar: 10% Type G sand for masonry mortar: 12%
BS EN 13139	Cat. 1 (floor screeds, sprayed, repair mortars): ≤ 3% Cat. 2 (rendering and plastering): ≤ 5% Cat. 3 (masonry with non-crushed aggregate): ≤ 8% Cat. 4 (masonry with crushed aggregate): ≤ 30%
BSI PD 6682-3	Levelling screed: ≤ 3% Rendering and plastering: ≤ 5% Masonry with type S sand: ≤ 5% Masonry with type G sand: ≤ 8%
GB/T 14684	Natural sand: < 5.0%
	Manufactured sand: If the methylene blue test passes: < 7.0% If the methylene blue test fails: < 5.0%
JGJ 52	No recommendation

- End of Appendix A -

Appendix B

Interview with Suppliers, Producers, Users and Government Officials on Possible River Sand Substitutes

1. Interviews Conducted

As part of the study on river sand substitutes, a number of interviews with suppliers, producers, users and government officials have been conducted by Prof. Albert K.H. Kwan (AKHK). The interviews conducted (in chronological order) are:

(1) Interview with Chairman of Working Group for Drafting of CS3
(2) Interview with General Building Contractors Association
(3) Interview with Institute of Quarrying Hong Kong Branch
(4) Interview with Concrete Producers Association
(5) Interview with Import Aggregates Suppliers Association
(6) Interview with Hong Kong Construction Sub-contractors Association, Plastering Sub-contractors Association, Registered Minor Works Contractor Employees Association and Brick-laying & Construction Trade Workers' Union
(7) Interview with China Light and Power Hong Kong Ltd on Bottom Ash
(8) Interview with K. Wah Construction Products Ltd on Waste Glass
(9) Interview with Environmental Protection Department on Recycling of Waste Glass
(10) Consultation with K. Wah Construction Products Ltd on Granulated Blastfurnace Slag

2. Interview with Chairman of Working Group for Drafting of CS3

The interview with Ir. Peter Leung of Public Works Central Laboratory, who is the Chairman of Working Group for Drafting of CS3 and a member of Standing Committee on Concrete Technology (SCCT), was conducted on November 11, 2011 at Public Works Central Laboratory.

From the interview, AKHK was given to understand that SCCT has already conducted some studies on river sand substitutes. At the moment, most of the ready mixed concrete (probably 99% or more) in Hong Kong are made of crushed rock fine instead of river sand. In fact, an amendment was made to the General Specification for Civil Engineering Works in 2008 to the effect that natural sand shall not be used unless with the prior agreement of the Engineer. River sand is still used only in special applications such as foam concrete and high-strength concrete. Furthermore, a working group under SCCT has drafted a new construction standard CS3: 2012 Aggregates for Concrete, which will be sent out for consultation by the end of November 2011.

Ir. Peter Leung has also shown AKHK some sieve analysis results of crushed rock fine, natural sand and manufactured sand. The results indicated that the crushed rock fine has more than 16% finer than 150 μm but less than 40% finer than 0.6 mm, the natural sand has less than 10% finer than 150 μm but more than 70% finer than 0.6 mm. Comparatively, the manufactured sand has a particle size distribution intermediate between crushed rock fine and natural sand. Samples of the crushed rock fine, natural sand and manufactured sand showed that the crushed rock fine particles are angular, the natural sand particles are rounded, whereas the manufactured sand particles are sub-angular or sub-rounded.

3. Interview with General Building Contractors Association

The interview was conducted on December 15, 2011. Those present included Mr. W.W. Ho, ex-chairman of Hong Kong General Building Contractors Association, Mr. David S.H. Tse, council member of Hong Kong General Building Contractors Association, Mr. K.K. Pun, secretary general of Hong Kong General Building Contractors Association, and Mr. Anthony Y.T. Chan, member of Hong Kong General Building Contractors Association.

The General Building Contractors Association (GBCA) expressed their concern that river sand is an indispensable material for rendering, plastering and masonry mortar but recently, there is a growing trend of acute shortage and soaring price of river sand. GBCA also explained that crushed rock fine is not a suitable substitute for river sand because mortar made with crushed rock fine is very sticky and thus difficult to trowel, and has the tendency to drip downwards leading to reduced built thickness per layer of application. Moreover, mortar made with crushed rock fine often has shrinkage cracks formed. They still prefer to use river sand and hope that the government can help to import river sand for their use. In case only crushed rock fine is available in the future, they hope to have crushed rock fine with the particles finer than 75 μm or 100 μm partially or completely removed because these fine particles tend to cause difficulties with the application of mortar. On the other hand, regarding river sand substitutes for concrete, they have no particular comments.

AKHK promised to reflect their views to the Construction Industry Council and via the Construction Industry Council to the government. He also explained that he will try the use of crushed rock fine with lower fines content and find out whether crushed rock fine with fines content lower than, say, 5% or 10% would be suitable as a river sand substitute for mortar.

4. Interview with Institute of Quarrying Hong Kong Branch

The interview was conducted on December 19, 2011. Those present included Mr. Ross Chow, chairman of Institute of Quarrying Hong Kong Branch, Mr. Sam Yip, member of Institute of Quarrying Hong Kong Branch, and Mr. Andy Kwok, member of Contract Quarry Association.

The Institute of Quarrying Hong Kong Branch (IoQHK) and Contract Quarry Association (CQA) informed that they are well aware of the current situation of shortage in river sand and are very willing to help solve the problem. They were of the general view that fine aggregate for concrete and fine aggregate for mortar are not quite the same because their requirements are different.

For fine aggregates to be used in concrete, they suggested that the fines content could be better controlled but it is not clear what the optimum fines content is because there has been little research on this topic. They also suggested that a low clay content could improve the quality control of the concrete production, which is particularly important in the production of high-strength concrete or high-performance concrete. However, the fines content is not necessarily clay. Some quarry operators have set up the methylene blue test for checking the clay content in crushed rock fine but the methylene blue test is a chemical test that detects only certain types of clay. Moreover, there is no established acceptance criterion for the methylene blue test value. Hence, this methylene blue test is more suitable for checking the variation in clay content in a particular quarry where the same type of rock is being processed all the time.

If there is a market need, they can process the crushed rock fine to improve the particle shape and particle size distribution of the crushed rock fine aggregate (after processing, they prefer to call the product a manufactured sand). Such processing will increase the cost of production and therefore the manufactured sand will be more expensive than ordinary crushed rock fine aggregate. But as the price of natural river sand keeps on increasing, it may eventually be more economical to produce manufactured sand as river sand substitute for concrete. It is only that up to this moment, there are no clear specification requirements for fine aggregate and manufactured sand. There is a need to produce a standard for fine aggregates, in which the fine aggregates are classified into different grades (with different grading limits, different fines contents and perhaps also different particle shapes) for different applications. If all fine aggregates are treated the same, there is no incentive for the quarry operators to produce better fine aggregates for the market.

For fine aggregates to be used in mortar, they explained that this is a different story because fine aggregates for concrete may not be suitable for use as fine aggregates for mortar. The fines content in a fine aggregate for mortar is the main issue because a high fines content often leads to difficulties with the trowelling of the mortar. They have also heard of complaints about the angular shape of crushed rock fine which makes the surface finish of render, plaster and mortar quite uneven. The presence of particles larger 2 mm in the crushed rock fine aggregate may also be a problem. Nevertheless, if there is a market need, they can process the crushed rock fine to produce a better fine aggregate, i.e. a manufactured sand, suitable for use as river sand substitute for mortar. It is only that up to this moment, there are no clear specification requirements for such material. There is a need to produce a standard for fine aggregates for mortar, in which the fine aggregates are classified into different grades (with different grading ranges, different fines contents and perhaps also different particle shapes) for different applications. Alternatively, the contractors, or more specifically the users of such fine aggregates for mortar, should spell out explicitly their specific requirements so that the quarry operators can produce the materials they want.

AKHK thanked IoQHK and CQA for their valuable advices. AKHK said he has no experience with the methylene blue test. Mr. Sam Yip showed AKHK the equipment for the methylene blue test and explained that the methylene blue test is not difficult to carry out. However, Mr. Yip also explained that the methylene blue test value should not be taken as a direct measure of clay content because the test only detects certain chemicals in the fines content. AKHK added that the fines content should not be assumed to be entirely clay because the fines content may contain largely of granular materials. However, he had encountered crushed rock fine, which turned yellowish in colour after being wetted and produced about 10% lower concrete strength when applied to high-strength concrete. AKHK suspected that the crushed rock fine, which turned yellowish in colour upon wetting, contained certain amount of clay. AKHK further explained that his view was to control either the clay content or the fines content in the crushed rock fine aggregate. The production of manufactured sand is a good idea but it may take one or two years to develop a standard for manufactured sand. AKHK suggested that some trial production samples of manufactured sand should be made available for testing. Whether the market would welcome this material is yet to be seen.

5. Interview with Concrete Producers Association

The interview was conducted on December 20, 2011. Those present included Mr. Jaime Yeung, Mr. David Chan, Mr. Sam Yip, Mr. Henry Tai, Mr. C.W. Ko, Mr. Alan Wu and Mr. Y.P. Szeto, all members of Concrete Producers Association.

The Concrete Producers Association (CPA) informed that they had already started using crushed rock fine in place of river sand in concrete production a few years back. They have no major problem with the use of crushed rock fine as fine aggregate in normal-strength concrete. The use of crushed rock fine in place of river sand has some effects on the workability and strength of the concrete mix but these can be dealt with quite easily by adding a bit more cement and water. A slightly more difficult problem is that the effectiveness of some superplasticizers seems to be affected by the quality of the crushed rock fine. Anyway, it is generally acceptable to use crushed rock fine as river sand substitute for concrete. However, some concrete producers still prefer to use river sand as fine aggregate in concrete of grade ≥ 80 MPa.

Regarding the grading limits and fines content of fine aggregate, the CPA would like to see some research conducted on the effects of these parameters on the water demand, rheology and strength of concrete and mortar. Some concrete producers expressed that different concrete producers may have different preferences on the grading of the fine aggregate, depending on the types of concrete they are producing, and therefore the grading limits should not be too restrictive.

They also have different opinions on the control of fines content in the crushed rock fine aggregate. The main issue is that the fines content may not be clay at all and is therefore not necessarily harmful. Exercising an excessively tight control on the fines content will create conflict between the concrete producer and the aggregate supplier, which may require a long time to resolve. Another difference in opinion is whether product certification of aggregate should be required. In any case, it should be borne in mind that it takes at least one year for the industry to develop a product certification scheme and another year for individual quarry operators/concrete producers to obtain product certificates.

Regarding the fine aggregates to be used in mortar, the CPA members reminded that there is another British Standard for fine aggregates to be used in mortar, namely: BS 1199 and 1200: Specifications for Building Sands from Natural Sources. A different type of fine aggregate may be needed for mortar. They have no particular comments on river sand substitutes for mortar.

AKHK thanked CPA for their valuable advices. AKHK said that the Standing Committee on Concrete Technology has produced a draft of Construction Standard CS3: Aggregates for Concrete, which is based largely on the existing British Standard. Product certification of aggregate may be required and the CPA should convey their comments on the draft CS3 directly to the Standing Committee on Concrete Technology. AKHK added that he will, at the end of this study, make a recommendation to the Construction Industry Council to conduct some research on the effects of grading and fines content of the fine aggregate on the various performance attributes of concrete. He himself at The University of Hong Kong will also do some tests in order to help solve the problems.

6. Interview with Import Aggregates Suppliers Association

The interview was conducted on May 18, 2012. Those present included Mr. David Chan, chairman of the Import Aggregates Suppliers Association, Mr. Jason To of Kin Wo Quarry (subsidiary of Man Fai Tai Holdings Ltd.), Mr. Eric Chiu and Mr. Alan Wu of Hong Kong – China Concrete Co. Ltd., and Mr. Ricky Wong and Mr. Jaime Yeung of Yue Xiu Concrete Ltd.

The Import Aggregates Suppliers Association (IASA) explained that fine aggregate for use in concrete and fine aggregate for use in mortar for site works (plastering, rendering and screeding) are not quite the same. They added that in the production of concrete, river sand has already been substituted by crushed rock fine but in the making of mortar for site works, there is still no suitable substitute for river sand (crushed rock fine is not considered a suitable substitute for river sand in the making of mortar). The current consumption of river sand (mainly for the making of mortar) is around 130,000 ton per month or approximately 1.5 million ton per year, which is quite substantial. Moreover, the price of river sand has increased to well above $100 per ton in recent months.

IASA advised that there are now two quarry operators, Kin Wo Quarry and Alliance Construction Materials Ltd, producing manufactured sand, which may be considered as a better river sand substitute than crushed rock fine.

Manufactured sand is produced by a new crushing/grinding technology that not only crushes the rock particles for size reduction but also grinds the rock particles to improve the shape (mainly to increase roundness) of the fine aggregate particles. After crushing/grinding, air classification is carried out to remove the excessive fines content and control the grading of the fine aggregate. The whole process is performed under dry condition and thus would not produce any water pollution. IASA pointed out that manufactured sand is actually more than just a river sand substitute; the manufactured sand can be tailor-made to suite different applications as a better alternative to river sand and crushed rock fine. However, it still needs time to develop manufactured sand for optimum performance.

Regarding the specification requirements for manufactured sand, they do not want strict limits to be imposed; instead, they prefer to classify manufactured sand into different types and grades with different characteristics and/or performance standards, and let the users decide which type and grade to use. AKHK said that when we classify manufactured sand into different types and grades, we are already imposing certain specification requirements onto the different types and grades of manufactured sand. For wider acceptability and fair competition, there still needs to be a standard. However, there is at the moment no established international standard that we can follow.

7. Interview with Hong Kong Construction Sub-contractors Association, Plastering Sub-contractors Association, Registered Minor Works Contractor Employees Association and Brick-laying & Construction Trade Workers' Union

The interview was conducted on June 25, 2012. Those present included Mr. Eric C.Y. Tse of Hong Kong Construction Sub-contractors Association and Plastering Sub-contractors Association, Mr. L.M. Chow of Registered Minor Works Contractor Employees Association, and Mr. L.S. Chow, Mr. P.T. Yeung, Mr. W.H. Tse and Mr. P. Wong of H.K. Brick-laying & Construction Trade Workers' Union. Before the interview started, Mr. Eric Tse thanked AKHK for giving the employees association and workers union this opportunity to express their views and concern on the shortage of river sand and the problems associated with the use of crushed rock fine in mortar.

At the meeting, the following views on the use of crushed rock fine as river sand substitute in plastering and rendering were expressed:

(1) Because of the high fines content, a higher water content is generally needed to produce the mortar, leading to a higher tendency for the mortar to drip downwards while still fresh, a larger drying shrinkage after hardening, and a higher likelihood to have shrinkage cracks formed.
(2) For the crushed rock fine to be used as river sand substitute in mortar, it is better to first sieve away the excessive fines content before use. Some workers have tried this before and found that it works but the sieving of crushed rock fine is very laborious and time consuming.
(3) It is however not known what fines content is appropriate for plastering

and rendering works. To really solve the problems with the use of crushed rock fine in mortar, it was recommended to conduct some tests on the use of crushed rock fine with different fines contents to determine the most appropriate fines content for crushed rock fine to be used in mortar.

In addition, the following views on the use of river sand in plastering and rendering were expressed:

(1) Although in theory, the Mainland has stopped exporting river sand to Hong Kong, it is still possible to buy river sand in Hong Kong but the price of river sand has recently soared to $160/ton.
(2) The annual consumption of river sand for mortar in Hong Kong is estimated to be about 1.0 million ton per year, which could be larger at times of construction booms.
(3) The fineness (particle size) of river sand could vary a lot and thus the water to be added to the mortar has to be adjusted from time to time to suit. Good experience and skill are therefore needed.
(4) Even river sand should preferably be processed to maintain consistent quality.

Regarding the most suitable fine aggregate for mortar, the following views were expressed:

(1) Fine aggregate suitable for concrete may not be suitable for mortar. Fine aggregate for concrete may have a maximum size of 5.0 mm but fine aggregate for mortar should have a maximum size of 2 to 3 mm (or more precisely 2.36 mm). Hence, the crushed rock fine to be used in mortar should be processed to have particles larger than 2.36 mm sieved away.
(2) Although there is nowadays the technology for grinding the fine aggregate particles so that the particles become rounded in shape, this is not strictly necessary because a fine aggregate with angular shape can be trowelled as good as a fine aggregate with rounded shape.

Regarding the possible use of manufactured sand as river sand substitute in mortar, the following views were expressed:

(1) There are actually two types of manufactured sand, one produced under wet condition by washing the fine aggregate to remove the excessive fines content, and the other produced under dry condition by air classifying (also called air screening) the fine aggregate to remove the excessive fines content.
(2) The employees association and workers union have no objection to the use of manufactured sand as river sand substitute in mortar. Some of their members have encountered this material before and have no adverse comments on it.
(3) However, manufactured sand seems to have different characteristics compared to river sand and crushed rock fine. There is a need to re-train the workers to adapt to the use of manufactured sand in mortar. Perhaps CIC and CITA should consider the provision of training courses to workers on the use of manufactured sand in mortar.
(4) Manufactured sand should better be supplied in two different types of

package: bulk (in truck loads each of several tons) and bagged (in bags each about 45 to 50 kg). The bulk supply is more for new works whereas the bagged supply is more for renovation and concrete repair.

Finally, the employees association and workers union expressed the concern that their members are often unjustifiably blamed for bad workmanship whenever debonding failure occurs. They recommended that research should be carried out to study the pull-out strength of plastering/rendering and the deterioration of the pull-out strength under different environmental conditions. A standard or best practice manual should be published after the research so as to provide guidelines for the workers. Particularly, the effects of using river sand, crushed rock fine and manufactured sand on the pull-out strength of mortar should be included in the research. AKHK promised to relay their concern to CIC and the relevant parties.

8. Interview with China Light and Power Hong Kong Ltd on Bottom Ash

An attempt was made to arrange an interview with China Light and Power Hong Kong Ltd (CLP) concerning the possible use of furnace bottom ash (FBA) as river sand substitute. However, instead of arranging an interview, CLP replied to AKHK directly through an email to the various questions raised and thus eventually no interview was conducted.

CLP's replies to the various questions on the possible use of FBA as river sand substitute were as follows:

(1) Are all FBA used up in cement production? Yes, all the FBA generated from CLP are sold to a cement company, which mainly uses the FBA as one of the raw materials for cement production.

(2) Is there any un-used FBA being dumped to ash lagoons or landfills? In general, CLP does not have disposal problem for the FBA. Besides, it is not CLP's normal practice to dump the FBA to Tsang Tsui ash lagoon or any landfill site unless the cement company has problems (e.g. major equipment failure or long plant outage) in consuming the FBA generated.

(3) Would you think that the use of FBA as fine aggregate or filler could help to solve both the ash disposal and shortage of river sand problems? To the best of my understanding, the PRC Government does not really abandon the export of river sand but has imposed a very stringent requirement for the export of it, e.g. export quota and export permit, and it is likely that the quota will be reduced in the coming years. All in all, if there are something that CLP can help on resolving the availability problem of river sand in Hong Kong, CLP is happy to give a hand on it.

9. Interview with K. Wah Construction Products Ltd on Waste Glass

The interview was conducted on July 5, 2012. Those present included Mr. Alex Lam and Mr. Gilbert Lo of K. Wah Construction Products Ltd, and Mr. Andy Kwok of K. Wah Concrete Ltd.

K. Wah started by explaining that currently, about 120,000 tons of waste glass are generated every year in Hong Kong and only 4% of the waste glass are recycled mainly as fine and coarse aggregates in concrete paving blocks. There are only two companies crushing waste glass and producing paving blocks with crushed waste glass used as aggregates. K. Wah added that there are no particular technical difficulties in the use of waste glass in paving blocks. The main difficulty is actually in the collection of waste glass from the various sources. Waste glass is usually in the form of bottles and occupies a large volume during transportation. For this reason, a lorry can carry only one to two tons of waste glass to the recycling factory. The waste glass could not be crushed before transportation because it tends to contain rubbish and once the waste glass is crushed, the rubbish is not easy to remove. Hence, K. Wah is forced to first transport the waste glass to the factory and then remove the rubbish before crushing. If the government, or some social enterprises, could help to collect the waste glass and deliver the waste glass to the recycling factory, more of the waste glass could be recycled.

K. Wah is now exploring the use of crushed waste glass as fine aggregate and 10 mm coarse aggregate to make concrete blocks for the construction of non-structural walls. Adding crushed waste glass to replace 20% of the normal rock aggregate had been tried and the results seem to be very promising. AKHK suggested that since the strength requirement for concrete blocks is not high, perhaps 100% crushed waste glass aggregate may be used. K. Wah is also exploring the use of crushed waste glass as fine and coarse aggregates to make pervious concrete. Some samples have been made and again the results seem to be very promising.

AKHK asked if K. Wah would consider crushing waste glass to produce fine aggregate for mortar to be used in plastering, rendering and screeding. K. Wah replied that in theory, crushed waste glass may be used as fine aggregate in mortar. However, the cost of producing crushed waste glass (including transportation, removal of rubbish, crushing and sieving etc) is about $1000 per ton. With no subsidy, it is difficult to market crushed waste glass as fine aggregate for mortar. Actually, most of the cost goes to transportation. If the government, or some social enterprises, could help to collect the waste glass and deliver to the recycling factory, the cost of producing crushed waste glass could be substantially reduced.

AKHK expressed his concern that dumping waste glass to landfills will use up the valuable and limited capacity of the existing landfills. Although the government is considering the construction of refuse incinerators to burn away the solid waste, waste glass cannot be burnt and thus the construction of refuse incinerators would not help to resolve the waste glass disposal problem. There is at the moment no way out. K. Wah responded that as a caring company, K. Wah is willing to do something to help solve the problem. It is only that the government does not seem to have any long-term policy and thus it is very difficult for K. Wah and the other recycling companies to invest a lot of money for longer term development.

10. Interview with Environmental Protection Department on Recycling of Waste Glass

The Environmental Protection Department (EPD) of the HKSAR Government noted that Prof. A.K.H. Kwan is working on this Construction Industry Council (CIC) research project to identify suitable river sand substitutes and has suggested that crushed waste glass may be considered as a possible river sand substitute for aggregate in mortar and non-structural concrete, and they had arranged an informal meeting with AKHK to exchange views on recycling and reuse of waste glass bottles. The informal meeting was held on September 6, 2012 at The University of Hong Kong. Those present included Dr. Alain Lam (Principal Environmental Protection Officer), Mr. Stephen Siu (Senior Environmental Protection Officer), Mr. Eddie Leung (Senior Engineer) and AKHK.

EPD pointed out that the generation of waste glass bottles in Hong Kong amounts to more than 100,000 tons per year. Currently, only 4% to 5% of the waste glass is recycled for use as aggregate in precast concrete paving blocks. Most of the waste glass bottles are disposed of as solid waste to landfills as there is lack of recycling outlets. They appreciated that AKHK, or the CIC, could help to explore more possible uses of recycled waste glass so as to establish sustainable recycling outlets for waste glass bottles and thus increase their recycling rate in Hong Kong.

AKHK explained that the production of precast paving blocks is quite limited in Hong Kong and therefore the use of recycled waste glass only as aggregate for precast paving blocks would not use up any large volume of waste glass. In some other countries, there are already research studies on crushing waste glass to sand size particles for use as fine aggregate for concrete. There is the concern of alkali-silica reaction but the results obtained so far are not conclusive. Whether alkali-silica reaction would occur seems to be dependent on the type of glass, fineness of the waste glass aggregate and the concrete mix design. In the mean time, it may be better to focus on non-structural applications of crushed waste glass because any aggregate that could cause alkali-silica reaction would not be allowed in structural applications. The most promising application should be the use of crushed waste glass as river sand substitute in mortar for plastering, rendering, screeding and masonry. In Hong Kong, the consumption of sand for mortar is more than one million ton per year. If 10% of the sand for mortar works is crushed waste glass, then most of the waste glass bottles, if not all, could be recycled. EPD welcomed this idea as it could help to increase the recycling rate of waste glass bottles to at least 50% in the not too distant future.

11. Consultation with K. Wah Construction Products Ltd on Granulated Blastfurnace Slag

During the various progress meetings, it had been suggested that granulated blastfurnace slag (GBS), if ground to sand size (0.15 mm to 5.0 mm), may also be a suitable river sand substitute in concrete and mortar. Currently, GBS is mainly ground to a fineness as high as that of cement (around 10 to 20 μm in size) for use as a supplementary cementitious material. Grinding GBS to a high fineness similar to that of cement is quite expensive but for use as a river sand substitute, it is only necessary to grind the GBS to sand size and perhaps the cost of grinding should be much lower.

To study the possible grinding of GBS to sand size for use as aggregates in concrete and mortar, AKHK consulted K. Wah Construction Products Ltd on their views regarding the practicality and commercial viability of producing ground GBS as river sand substitute. K. Wah is a major importer of ground granulated blastfurnace slag (GGBS) to Hong Kong. According to the email replies by Mr. Andy Kwok of K. Wah in December 2012, although GGBS is generally used as a supplementary cementitious material to reduce the cement content in concrete and improve the durability of concrete structures, in theory, GGBS ground to a lower fineness than cement or just GBS can also be used as a fine aggregate. However, the price of GGBS is about 90% of the price of cement. So, GGBS is a fairly expensive material; it is not used as a waste but rather as an additive that can improve the performance of concrete. Although grinding the GBS to a lower fineness would reduce the cost of production, the cost of the raw GBS and the cost of transportation to Hong Kong added together are still quite high and therefore it is very difficult for GBS to compete with the other river sand substitutes. In fact, the GBS suppliers would prefer to grind the GBS to a higher fineness so that they can sell the material as GGBS at a higher price. There may also be other technical problems associated with the continuous pozzolanic reaction of the GBS in the concrete or mortar. Considering these factors, grinding GBS to sand size for use as a river sand substitute is not considered a viable option.

12. Summary and Recommendations

From the interviews conducted, the following points are summarised:

<u>Suitability of crushed rock fine as fine aggregate for concrete</u>:
According to the Public Works Central Laboratory, the Institute of Quarrying Hong Kong Branch, the Concrete Producers Association and the Import Aggregate Suppliers Association, the concrete producers in Hong Kong had already started using crushed rock fine in place of river sand in concrete production a few years back. There is no major problem with the use of crushed rock fine as fine aggregate in normal-strength concrete. The use of crushed rock fine in place of river sand has some effects on the workability and strength of the concrete mixes produced but these can be dealt with by adding a bit more cement and water. Nevertheless, some concrete producers still prefer to use river sand as fine aggregate in concrete of grade ≥ 80 MPa. Some interviewees said that the crushed rock fine can be processed to become manufactured sand with improved particle shape and particle size distribution as a better substitute of both river sand and crushed rock fine. Two quarry operators have already started producing manufactured sand but there is still

no standard for manufactured sand. Further research is needed to find out the optimum ranges of particle size distribution and fines content for different applications.

Suitability of crushed rock fine as aggregate for mortar:
The interviewees are generally of the view that fine aggregates for concrete may not be suitable for use as fine aggregates for mortar due to their different effects on concrete and mortar. The General Building Contractors Association, the Hong Kong Construction Sub-contractors Association, the Plastering Sub-contractors Association, the Registered Minor Works Contractor Employees Association and the Brick-laying & Construction Trade Workers Union are particularly concerned that crushed rock fine is not a suitable river sand substitute for mortar because mortar made with crushed rock fine is very sticky and thus difficult to trowel. It also has a higher water demand, a higher tendency to drip downwards after trowelling and a higher risk of shrinkage cracking after hardening. Furthermore, there is the problem of the presence of particles larger than 2 mm in the crushed rock fine, which makes the mortar surfaces rather rough and difficult to trowel. They insisted that river sand is an indispensable material for rendering, plastering and masonry mortar. Nevertheless, if the so called manufactured sand is processed to have the fines content reduced to a level similar to that of river sand and the particles larger than 2 mm removed, they would welcome. Since the manufactured sand has different characteristics, re-training of the workers may be needed.

Suitability of manufactured sand as aggregates for concrete and mortar:
There are two major types of manufactured sand, one produced by water washing (wet process) and the other produced by air classification (dry process). The wet and dry processes are to reduce the fines content of the manufactured sand. In addition, some manufactured sands have been ground to certain extent during size reduction to improve the roundness of the particles. Depending on the actual production processes, manufactured sands from different sources may have different fines content, particle size distribution and particle roundness. There is however no established standard for manufactured sand. Two quarry operators have already started producing manufactured sand for the Hong Kong market. According to them, the manufactured sands are currently produced to mimic river sand so as to be used as direct river sand substitute. However, whilst the properties of river sand could fluctuate with the location and depth of dredging, the manufactured sand is produced in a factory under controlled conditions and thus should be more consistent in quality. Moreover, by engineering the various properties of the rock aggregate, manufactured sand could be tailor-made to suit different applications as better substitutes of both river sand and crushed rock fine for concrete and mortar. Further research is needed to determine the required properties of manufactured sand for different applications so that standards or specifications of manufactured sand could be developed.

Need of a separate standard on aggregates for mortar:
Since the standard on aggregates for concrete is not really applicable to aggregates for mortar, a separate standard on aggregates for mortar is needed.

In the standard on aggregates for mortar, the imposed limits on the fines content should be lower than those in the standard on aggregates for concrete. Apart from setting relatively low fines content limits, it may also be necessary to classify the aggregates for mortar into different categories with different characteristics for different applications. Research studies and tests are needed to determine the fines content limits and particle size distribution requirements for aggregates to be used in floor screeds, rendering and plastering, and masonry. It may take a long time to develop a local standard on aggregates for mortar. In the mean time, trials using aggregates with different fines contents should be carried out so that fines content limits for aggregates to be used in floor screeds, rendering and plastering, and masonry could be tentatively set as general guidelines for the aggregate suppliers to follow.

Furnace bottom ash as river sand substitute:
According to China Light and Power, furnace bottom ash generated from burning coal for electricity is being used as one of the raw materials for cement production. There is at the moment no disposal problem for furnace bottom ash. Hence, crushing and sieving furnace bottom ash for use as river sand substitute in concrete or mortar is not a viable option.

Crushed waste glass as river sand substitute:
We are producing about 120,000 tons of waste glass in Hong Kong every year but only about 4% to 5% is being recycled as aggregate in precast concrete paving blocks. The Environmental Protection Department is very keen in increasing the recycling rate to at least 50%. Crushing the waste glass to sand size for use as river sand substitute in mortar could be one good way of increasing the recycling rate. Since there is the concern of alkali-silica reaction, the use of crushed waste glass as aggregate in concrete should be limited to non-structural applications at this stage. Research studies on the use of crushed waste glass as aggregate in mortar and potential alkali-silica reaction of crushed waste glass aggregate are recommended. However, for the option of using crushed waste glass as river sand substitute to be viable, more government support is needed.

Granulated blastfurnace slag as river sand substitute:
According to K. Wah Construction Products Ltd, the price of ground granulated blastfurnace slag (ground to fineness similar to that of cement) is about 90% of the price of cement and thus the suppliers would prefer to grind the granulated blastfurnace slag to a higher fineness so as to sell the material at a higher price rather than to grind the granulated blastfurnace slag to sand size for use as a river sand substitute. Granulated blastfurnace slag is not a waste anymore because of its great demand for grinding to become a supplementary cementitious material that can improve the performance of concrete. Hence, the use of ground granulated blastfurnace slag as a river sand substitute is not considered a viable option.

- End of Appendix B -