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

Final Report

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Background

- River sand is a widely used construction material in Hong Kong, especially in the production of concrete and cement-sand mortar

- The Construction Industry Council has launched 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
  - **The first phase (Phase One)** of the research aims to identify suitable river sand substitutes for practical applications in the local construction industry
  - **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.

Objectives as Stated in the Brief

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

- To review the uses of river sand imported from the Mainland and/or overseas countries in the construction industry
- To review and explore the most widely used river sand substitutes in both local and overseas construction industry
- To explore any river sand substitutes for concrete production and cement sand mortar production
- 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
- To identify suitable river sand substitutes for practical use in concrete production and cement sand mortar production
- 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

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.
- 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.
- The characteristics of river sand would improve the workability of concrete and mortar compared to the use of alternatives such as crushed rock fine.
- 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.
- 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.

Overview of River Sand and River Sand Substitutes

- 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.

Overview of River Sand and River Sand Substitutes

- 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.

- 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.

Overview of 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.

- 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 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.

Review of Current Standards

The following standards on aggregates have been reviewed:

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

Review of Current Standards

- 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.

- The sieve sizes and demarcation between coarse and fine aggregates in the European Standards are totally different from those in the British Standards.

- The British Standards will gradually be replaced by the European Standards.

- 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.

Review of Current 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:
  - The presence of any harmful substances,
  - Since the fines content has very large specific surface area, the presence of high fines content would increase the water and/or superplasticizer demands
  - The presence of high fines content would render the concrete/mortar mix more cohesive.

Review of Current Standards

- 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.

- 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.

Review of Current Standards

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%

Review of Current Standards

Table 1 Limits on fines content in fine aggregates for concrete

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%

Review of Current Standards

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

Review of Current 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: to be reduced from the current value of 16% stipulated in the BS 882 to a lower value of, say, 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): to be set at 10%.

Review of Current Standards

- 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 $\leq$ 3% for floor screeds and repair mortars
  - Category 2 with fines content $\leq$ 5% for rendering and plastering
  - Category 3 with fines content $\leq$ 8% for masonry mortar

Interview with Stakeholders

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

- Interview with Chairman of Working Group for Drafting of CS3
- Interview with General Building Contractors Association
- Interview with Institute of Quarrying Hong Kong Branch
- Interview with Concrete Producers Association
- Interview with Import Aggregates Suppliers Association
- 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
- Interview with China Light and Power Hong Kong Ltd on Bottom Ash
- Interview with K. Wah Construction Products Ltd on Waste Glass
- Interview with Environmental Protection Department on Recycling of Waste Glass
- Consultation with K. Wah Construction Products Ltd on Granulated Slag

Interview with Stakeholders

Suitability of crushed rock fine as fine aggregate for concrete:

- 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.

- Nevertheless, some concrete producers still prefer to use river sand as fine aggregate in concrete of grade $\geq$ 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.

Interview with Stakeholders

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

- They are 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.

- 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.

Interview with Stakeholders

Suitability of manufactured sand as aggregates for concrete and mortar:

- There are two major types of manufactured sand by
  - water washing (wet process) and
  - 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.

- 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.

Interview with Stakeholders

Suitability of manufactured sand as aggregates for concrete and mortar:

- 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.

Interview with Stakeholders

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.

- 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.

- 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.

Interview with Stakeholders

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.

Interview with Stakeholders

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.

- 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.

Interview with Stakeholders

Granulated blastfurnace slag as river sand substitute:

- Theoretically, it is possible to grind granulated blastfurnace slag to sand size for use as river sand substitute.
- However, granulated blastfurnace slag could be ground to cement size to be sold as a supplementary cementitious material at a price close to that of cement (about 90% of the price of cement). Hence, even ground to just sand size, the price is likely to be much higher than the other river sand substitutes.
- Unlikely to be economically viable.

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)

- 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.

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

On May 10, 2012

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

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

1. MS1 was found to have the right consistence for plastering.
   - It was applied onto a vertical concrete wall. 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. There was no problem with building up to a thickness of 10 mm in one layer.
   - Overall, the results were satisfactory.

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

2. MS2 was found to be slightly too wet for plastering.
   - When applied onto a vertical concrete wall, the mortar tended to drip downwards. 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. The mortar could not be applied to the ceiling.
   - Overall, the results were marginally satisfactory.

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

3. 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,
- It appeared to have sufficient wetness.
- 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.
- 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.

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

On May 22, 2012,

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

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

1. 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.

2. CRF2 was found to be slightly too dry and a bit un-cohesive.
   - When applied onto a vertical concrete wall. The mortar could stay on the wall but a small portion of the mortar fell downwards.
   - It could be built up to a thickness of 20 mm in one layer, though with slight difficulties.
   - It was found that due to the apparent dryness, the mortar could not be applied to the ceiling at all.
   - Overall, the results were marginally satisfactory.

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

3. CRF3 was found to be slightly too wet for plastering.
   - When applied onto a vertical concrete wall. The mortar could stay on the wall but a small portion of the mortar fell downwards.
   - 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.
   - 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.

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

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.

(2) The RS, which is quite commonly used in the industry, is also suitable for use as fine aggregate in mortar for plastering works.

(3) The CRF is apparently not as suitable as MS or RS for use as fine aggregate in mortar for plastering works.

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.
  - River Sand Substitutes for Concrete
  - River Sand Substitutes for Mortar
  - Manufactured Sand
  - Crushed Waste Glass
  - Recycled Aggregate
  - Furnace Bottom Ash

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 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 and high-flowability concrete, processed crushed rock fine, which is also called manufactured sand, may be preferred.

River Sand Substitutes for Concrete

- 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.

River Sand Substitutes for Concrete

- As in the British Standard, three fineness grades of fine aggregate are allowed in the draft CS3.
- 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.
- 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.
- Proper or optimum grading and proportioning of aggregates for different concretes are good topics for research and should be encouraged or even supported.

River Sand Substitutes for Concrete

- Another issue that has today remained controversial is the fines content limit.
- 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.
- 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.
- A suitable test for direct measurement of clay content is yet to be developed. Some research on this issue is recommended.

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
- In fact, the General Building Contractors Association insisted that 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, probably two to three years to develop a new standard.

River Sand Substitutes for Mortar

- 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 if necessary also improve the grading at the quarry before supplying to the market.

- 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 $\leq$ 3% for floor screeds and repair mortars,
  - Category 2 with fines content $\leq$ 5% for rendering and plastering, and
  - Category 3 with fines content $\leq$ 8% for masonry mortar.

- In the longer term, special manufactured sands tailor made for use in different types of mortar may be a better solution.

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.

- The technology and equipment to produce manufactured sand are already available.

Manufactured Sand

- 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.

Manufactured Sand

- 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.

Manufactured Sand

- 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.
- It may take a few years to develop a standard or specification for manufactured sand.
- In the mean time, some samples of manufactured sand could be obtained from the quarry operators for testing and evaluation.

Crushed Waste Glass

- More than one hundred thousand tons of waste glass are generated as inert solid waste every year in Hong Kong. Only a small quantity 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. Another major problem is the high brittleness of glass.

- 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 such as planters and barriers.

Crushed Waste Glass

- In theory, crushed waste glass may also be used as fine aggregate in mortar for plastering, rendering, screeding and masonry.
- Such possible uses of crushed waste glass as river sand substitute for mortar should be explored.
- However, at the moment, due to the high collection and transportation cost, the cost of producing crushed waste glass is about $1000/ton, which is much too high to be economically viable.
- Unless the government has a long-term policy to promote recycling of waste glass and actually provides certain assistance in the collection of waste glass and transportation of the collected waste glass to the recycling factories, the production of crushed waste glass to be used as fine aggregate in mortar will have no market.

Recycled Aggregates

- 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.
- 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.
- 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 dumped as waste. In any case, it does not seem that recycled aggregate is a suitable river sand substitute for use in concrete or mortar.

Recycled Aggregates

- To promote greater use of recycled aggregate, more government initiatives are required.
  1. The government should increase the charge of dumping solid waste to landfills.
  2. The government could provide affordable land for the production of recycled aggregate from old concrete.
  3. The government could mandate the use of recycled aggregate in public works projects.

- However, there remains the technical issue of the general lack of confidence in the quality of the recycled aggregate.

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 to lower priority.

  - Priority 1 – Construction Standard for Aggregates for Mortar
  - Priority 2 – Research on Effects of Fines Content on Concrete
  - Priority 3 – Specifications and Classification of Manufactured Sand
  - Priority 4 – Research on Crushed Waste Glass as Aggregate for Mortar
  - Priority 5 – Research on Recycled Aggregate as Aggregate for Mortar

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.

- 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.

Priority 1 – Construction Standard for Aggregates for Mortar

- The British Standard BS EN 13139: 2002 – Aggregates for mortar 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.

Priority 1 – Construction Standard for Aggregates for Mortar

- 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 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.

Priority 1 – Construction Standard for Aggregates for Mortar

- 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
  - fines content ≤ 3% for floor screeds and repair mortars
  - fines content ≤ 5% for rendering and plastering
  - fines content ≤ 8% for masonry mortar.

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.

Priority 2 – Research on Effects of Fines Content on Concrete

- 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%.

Priority 2 – Research on Effects of Fines Content on Concrete

- 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, which is cheaper and should be good enough for normal concrete, or manufactured sand, 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.

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 while manufactured sand for concrete should have higher fines content.

- 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 $\leq$ 3% for floor screeds and repair mortars
  - fines content $\leq$ 5% for rendering and plastering
  - fines content $\leq$ 8% for masonry mortar
  - fines content limit given in the Construction Standard CS3 for unprocessed crushed rock fine is 14%

Priority 3 – Specifications and Classification of Manufactured Sand

- 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.

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.

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

- For crushed waste glass to be used as river sand substitute for mortar, research is needed.
- Glass is a brittle and fairly uniform material, 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.

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.