Standing Committee on Concrete Technology
Annual Concrete Seminar 2019

HONG KONG CONSTRUCTION MATERIALS ASSOCIATION LIMITED

A Review on Technical Aspect of Aggregate Used in Concrete and Mortar Production – River Sand, Crushed Rock Fines & M-Sand

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2 April 2019

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A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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- River sand and crushed rock fines (CRF) have been commonly used as fine aggregates in the construction industry in Hong Kong.
- River sand
  - Commonly used in production of mortar due to its round particle shape and smoother surfaces
  - Less fines content (defined as particles finer than 75μm) compared to CRF
  - Mineralogy may have higher variations and salinity of the river water leads to different chemical properties such as the chloride content.
- Crushed rock fines (CRF)
  - Mainly used as fine aggregate for concrete production in Hong Kong
  - Possess more angular particles and fines content than river sand
  - Not good for production of mortar, which should be cohesive, smooth for troweling with suitable consistence.

A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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- Use of river sand is limited due to a series of adverse environmental impacts caused by dredging river sand.

Impacts caused by dredging river bed	
Biodiversity	Impacts on related ecosystems
Land losses	Both inland and coastal through erosion
Hydrological function	Change in water flows, flood regulation and marine currents
Water supply	Through lowering of the water table and pollution
Landscape	Coastal erosion, changes in deltaic structures
Extreme events	Loss of protection against flood, drought, etc.

- To stay in line with the National Policy of protecting natural resources, the Central Government announced in 2009 to gradually reduce the annual export quota of river sand to Hong Kong and other places.

A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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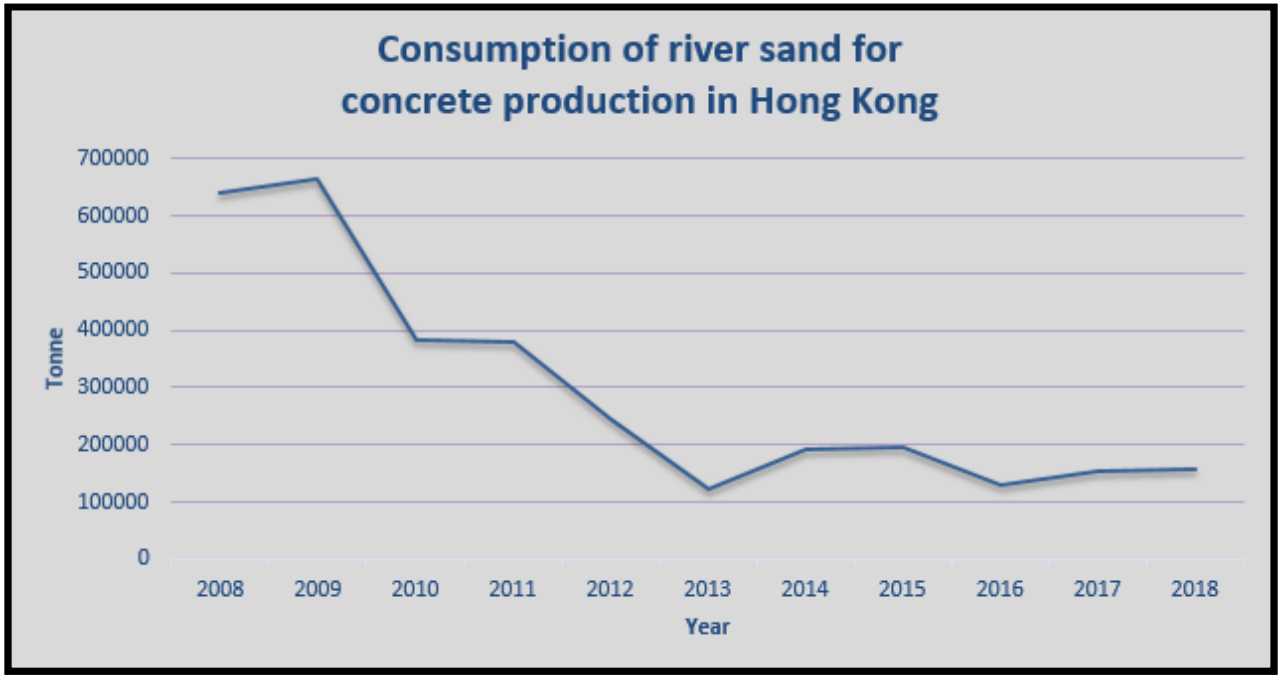
- According to the data provided by CEDD, the consumption of river sand for concrete production in Hong Kong decreased from 640,000T in 2008 to 160,000T in 2018 which is about 75% drop.



(The Quantity of Natural Sand from Mainland used in Construction Industry, CEDD)

A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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- Forbiddance of use of river sand for concrete production to government projects:
  - General Specification for Building 2017 (Cl. 6.33)

    "*Natural sand shall not be used in production of concrete unless otherwise agreed by the SO.*"
  - General Specification for Civil Engineering Works 2006 (Cl. 16.08(2))

    "*Natural sand shall not be used unless with the prior agreement of the Engineer.*"
  - Hong Kong Housing Authority Specification 2018 (CON1.M240.A)

    "*Do not use natural sand unless with prior agreement of the CM.*"

A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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- M-Sand, which is defined as crushed fine aggregates processed to improve the particle shape and grading for enhancing the performance of the material, has been recognized as a suitable substitute for river sand.
- The performance of using manufactured sand (M-Sand) as fine aggregates with comparison to river sand and CRF in the production of concrete and mortar has been widely studied for years.
- It possesses intermediate angular particles and fines content in between those of river sand and crushed rock fines in general.

A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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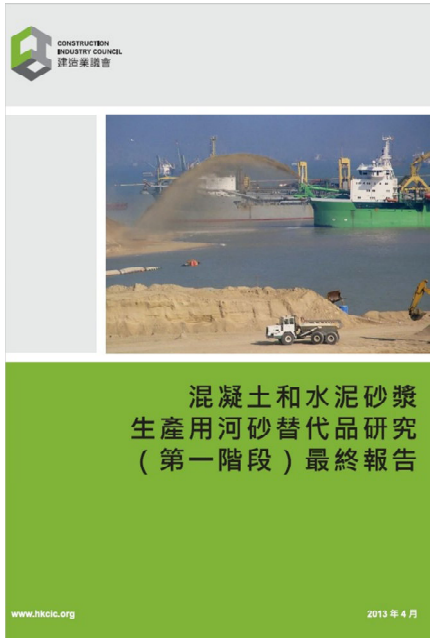
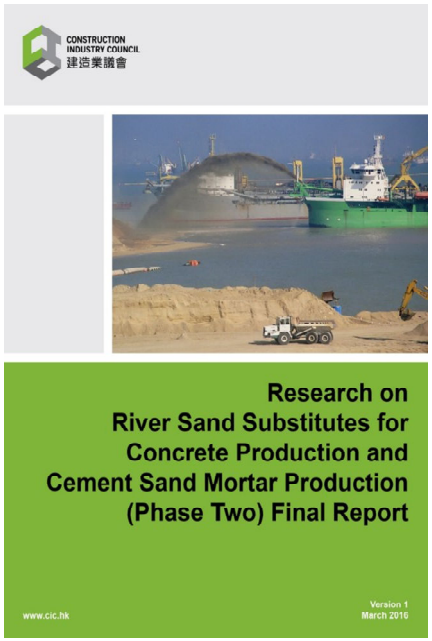
- "Research on River Sand Substitutes for Concrete Production and Cement Sand Mortar Production" was launched by the Construction Industry Council (CIC).

- The final reports of phase one, aimed to identify natural and recycled materials which might be processed to become suitable river sand substitutes and phase two, conducted laboratory tests and field trials and to draft a recommended specifications, were issued in April 2013 and March 2016 respectively.





A Review on Fine Aggregates Used in Hong Kong for Concrete and Mortar Production

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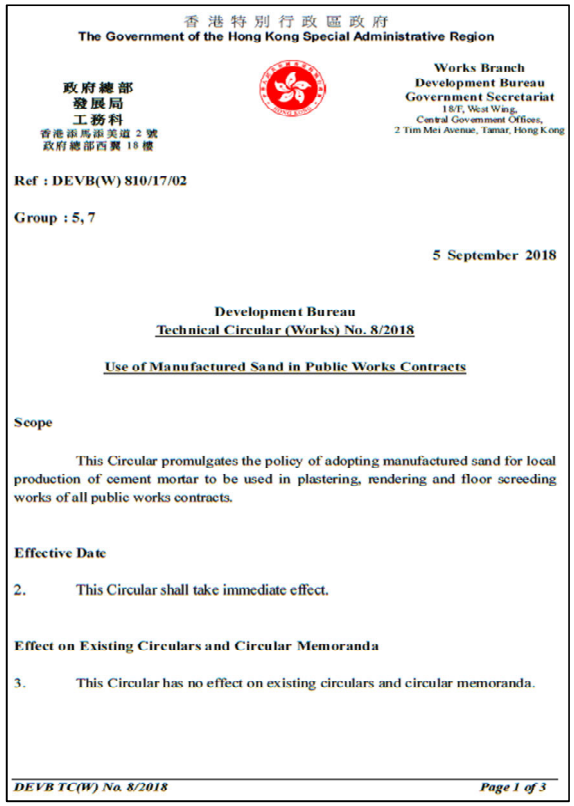
- A Technical Circular (Works) No. 8/2018 for Use of Manufactured Sand in Public Works Contracts has been issued by the Development Bureau in September 2018.
- *Scope: Promulgate the policy of **adopting manufactured sand for local production of cement mortar** to be used in plastering, rendering and floor screeding works of all public works contracts.*
- *Policy: All public works contracts, including design and build contracts and term contracts, the tender invitations of which are issued **on or after 1 October 2018**, shall adopt M-sand for local production of cement mortar to be used in plaster, rendering and floor screeding works through incorporation of the Particular Specification at Appendices A and B*



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Ref : DEVB(W) 810/17/02

Group : 5, 7

5 September 2018

Development Bureau
Technical Circular (Works) No. 8/2018

Use of Manufactured Sand in Public Works Contracts

Scope

This Circular promulgates the policy of adopting manufactured sand for local production of cement mortar to be used in plastering, rendering and floor screeding works of all public works contracts.

Effective Date

2. This Circular shall take immediate effect.

Effect on Existing Circulars and Circular Memoranda

3. This Circular has no effect on existing circulars and circular memoranda.

DEVB TC(W) No. 8/2018 Page 1 of 3

Manufacture of M-Sand

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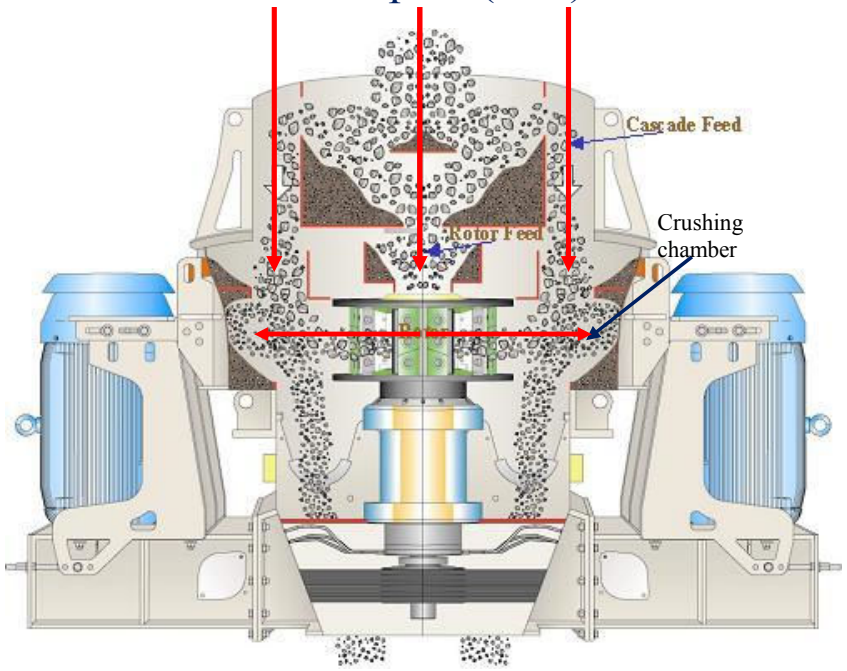
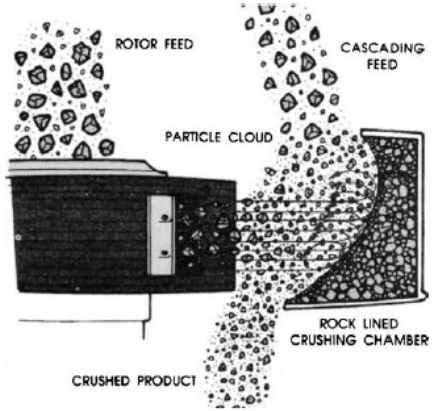
- The facilities and processes of quarries for the production of aggregates may vary significantly, producing aggregates with quite different characteristics.

- Vertical Shaft Impact (VSI) crusher



- Use rotor feed and cascade feed systems to introduce a stream of aggregate.
- Aggregates are propelled out from the rotor to the crush chamber at high speed which can be up to 90m/s. Collison between particles with rock-on-rock crushing action takes place.
- The repeated impact from energy conditioned crushing causes the sharp corners of the particles to break off.



Manufacture of M-Sand

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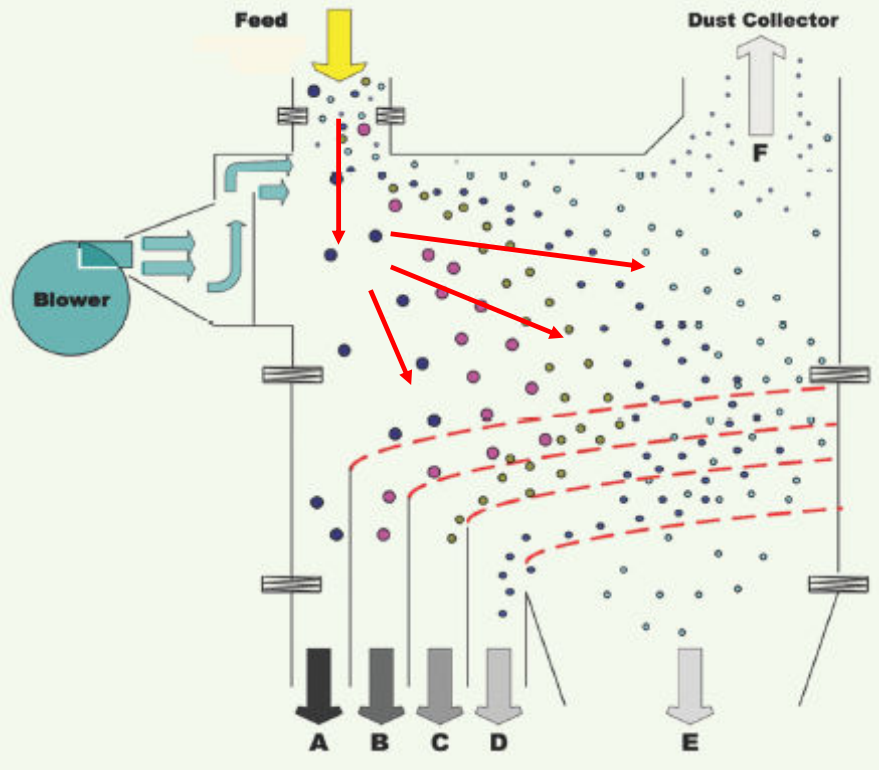
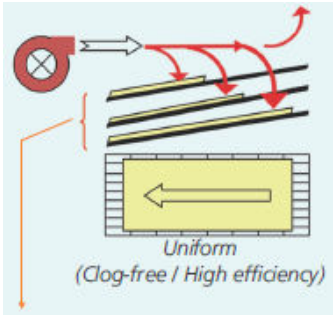
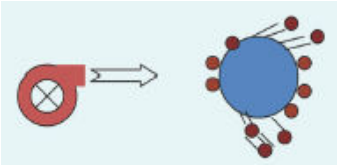
➢ Screening and Dedusting System



- The processed aggregates are fed into the screening and dedusting system.
- Aggregates fall into different decks of screens depending on their particle sizes.
- Residual dust of particles are blown away by air





Quality Requirement and Properties Comparison of Different Fine Aggregates

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- Technical Circular (Works) No. 8/2018

Items	Requirement	Test Standard
Oven-dried particle density	≥2000kg/m^3	CS3: 2013 Section 17
Fines content	≤5% (passing 75μm test sieve)	CS3: 2013 Section 10
Drying shrinkage	≤0.75%	CS3: 2013 Section 20
Alkali-silica reactivity	Not classified as "Reactive"	CS1: 2010 Section 22 or 23
Total chloride ion content	≤0.03%	CS3: 2013 Section 21
Acid-soluble sulphate content	≤0.8%	CS3: 2013 Section 21
Total sulphur content	≤1.0%	CS3: 2013 Section 21
Angularity	Sub-angular, sub-rounded or rounded	N/A
Foreign materials content	≤0.5% (wood and other material less dense than water)	N/A
	≤1.0% (other foreign materials)	

Quality Requirement and Properties Comparison of Different Fine Aggregates

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- Drying shrinkage

It should be pointed out that according to CS3 Section 20 Method for Determination of Drying Shrinkage, the test prisms shall be cast using the following amount of cement, aggregates and water:

Ordinary Portland cement	550±5g
Coarse aggregate (10mm to 20mm)	1466±5g
Coarse aggregate (5mm to 10mm)	734±5g
Fine aggregate	1100±5g
Water	330±5g

The drying shrinkage of aggregate is calculated as the average change in length of the prisms that are subjected to wetting followed by drying at 105±5^{o}C.

Quality Requirement and Properties Comparison of Different Fine Aggregates

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- Declare the grading for fine aggregates of size 0/5.0mm and 0/2.36mm

Size 0/5.0mm (for cement mortar not incorporating lime)

Sieve size	Percentage by mass passing test sieve (%)			
	Overall limits	Limits for declared grading		
		C	M	F
10mm	100	-	-	-
5mm	89-100	-	-	-
2.36mm	60-100	60-100	65-100	80-100
1.18mm	30-100	30-90	45-100	70-100
600µm	15-100	15-54	25-80	55-100
300µm	5-70	5-40	5-48	5-70
150µm	0-20	-	-	-

Size 0/2.36mm (for cement mortar incorporating lime)

Sieve size	Percentage by mass passing test sieve (%)			
	Overall limits	Limits for declared grading		
		C	M	F
5mm	100	-	-	-
2.36mm	89-100	-	-	-
1.18mm	60-100	60-100	65-100	80-100
600µm	30-100	30-90	45-100	70-100
300µm	15-100	15-54	25-80	55-100
150µm	5-70	5-40	5-48	5-70
75µm	0-14	-	-	-

- *Manufactured sand of grading C (coarse graded) shall not be used unless prior approval from the Engineer is obtained.*

Quality Requirement and Properties Comparison of Different Fine Aggregates

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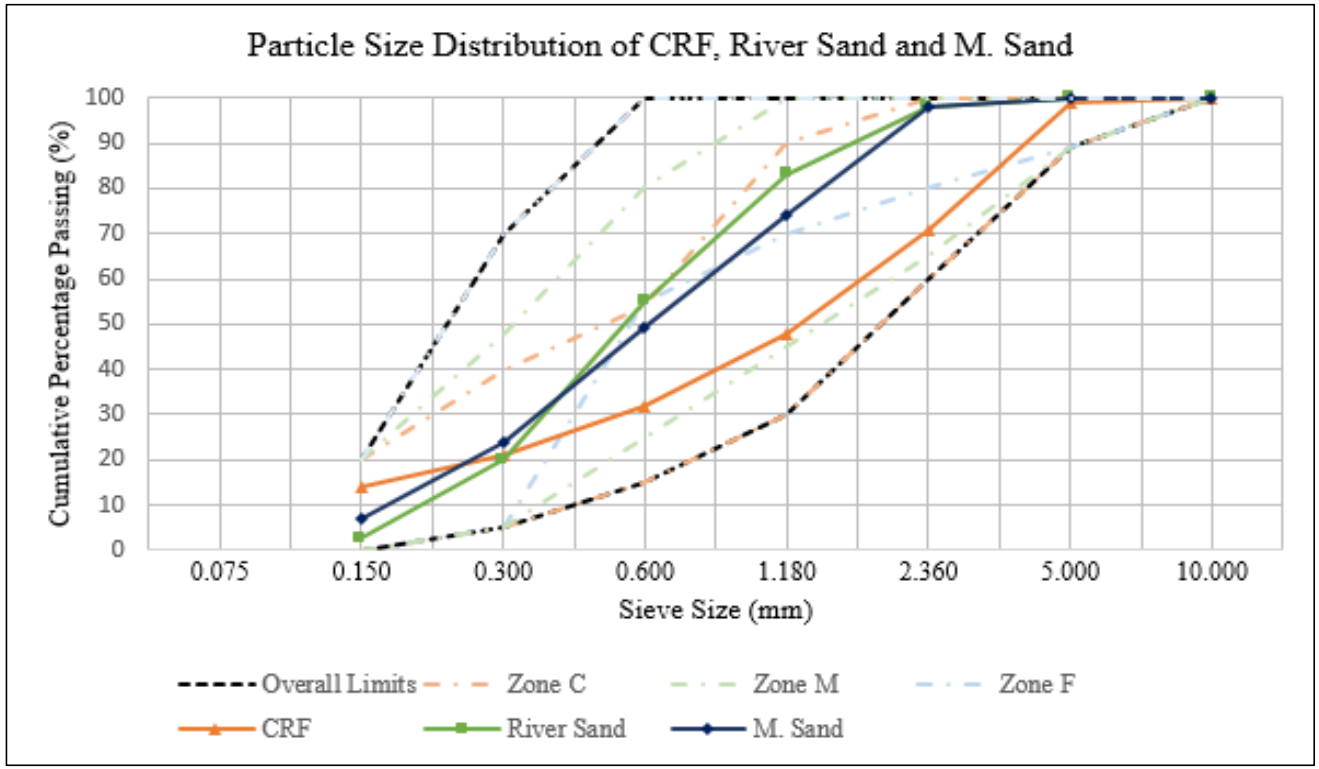

	CRF	River Sand	M-Sand
Fines content (%)	8.9	0.6	2.0

Quality Requirement and Properties Comparison of Different Fine Aggregates

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Items		CRF	River Sand	M-Sand
Fineness modulus		3.15	2.41	2.48
Particle density (SSD) (Mg/m^3)		2.65	2.64	2.65
Bulk density (kg/m^3)	Uncompacted	1.53	1.45	1.51
	compacted	1.70	1.58	1.66
Void ratio (%)	Uncompacted	42.3	45.1	43.0
	compacted	35.8	40.2	37.4

- CRF possess highest fineness modulus and bulk density with lowest void ratio among them. The properties of M-Sand falls between CRF and river sand in general

Quality Requirement and Properties Comparison of Different Fine Aggregates

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CRF

River Sand

M-Sand

Micrographs of CRF, river sand and M-Sand

(Ross K.K. Chow, Sam W.S. Yip and Alber K.H. Kwan. Processing crushed rock fine to produce manufactured sand for improving overall performance of concrete. HKIE Transaction, 2013, Vol. 20, No. 4, 240-249)

Quality Requirement and Properties Comparison of Different Fine Aggregates

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- Summary of Properties Comparison:

Physical Properties	**CRF**	**River Sand**	**M-Sand**
Angularity	Angular	Rounded to sub-rounded	Sub-angular
Fines content	Higher	Lower	Intermediate
Water absorption	Higher	Lower	Intermediate
Bulk density	Higher	Lower	Intermediate

Quality Requirement and Properties Comparison of Different Fine Aggregates

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Chemical Properties	CRF	River Sand	M-Sand
Total chloride ion content (%)	<0.01	<0.01	<0.01
Acid-soluble sulphate content (%)	0.04	0.03	0.03
Total sulphur content (%)	0.04	0.04	0.05
Alkali-silica reactivity	0.06	0.08	0.07

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Laboratory Trial Mix

for

Concrete Mix and Mortar

with

River Sand, Crushed Rock Fines & M-Sand

Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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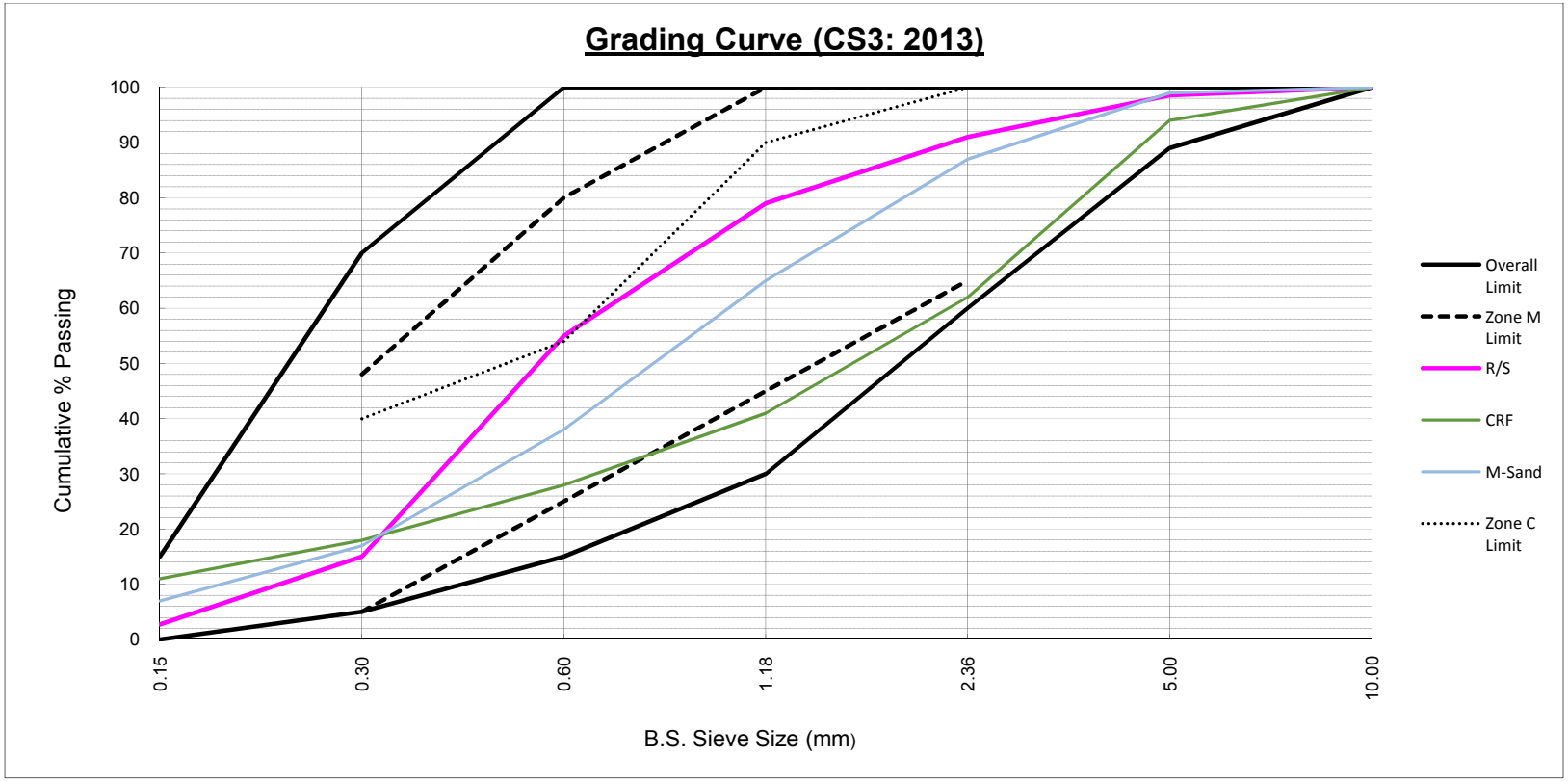
- Fines Aggregate Samples for Trial



Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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➢ Fines Aggregate Samples for Trial

Test Items	CRF	R/S	M-Sand
Fines Content	7.80%	1.50%	3.70%
Oven Dried Particle Density	2640kg/m^3	2620kg/m^3	2610kg/m^3
Water Absorption	0.90%	0.50%	0.80%
Water Soluble Chloride Ion Content (Cl)	<0.01%	<0.01%	< 0.01%
Acid Soluble Sulphate Ion Content (SO_3)	<0.1%	<0.02%	< 0.02%
Total Sulphur Content (S)	<0.1%	< 0.1%	< 0.1%
Presence of Humus	Negative	Negative	Negative
Ultra-accelerated Mortar Bar	<0.1% (Innocuous)	<0.1% (Innocuous)	<0.1% (Innocuous)

Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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➢ Concrete Mix Design River Sand vs Crushed Rock Fines

Ingredients (Proportion per cum. in kg)	30D/20/100		45D/20/125		60D/20+PFA(25%)/200	
	C – RS1	C – CRF1	C – RS2	C – CRF2	C – RS3	C – CRF3
Cement	315	360	385	480	354	412
PFA	---	---	---	---	118	138
20 mm aggregates	820	720	820	640	760	600
10 mm aggregates	330	260	320	255	300	230
River Sand	700	---	670	---	670	---
Crushed Rock Fines	---	770	---	760	---	765
Low-Range Water Reducing Admixture (% per 100kg of cementitious content)	0.70%	0.85%	--	--	--	--
Mid-Range Water Reducing Admixture (% per 100kg of cementitious content)	--	--	0.65%	0.75%	--	--
Superplasticizer (% per 100kg of cementitious content)	--	--	--	--	0.77%	1.20%
Water	172	198	165	205	158	180
Water/Cementitious Content Ratio	0.55	0.55	0.43	0.43	0.33	0.33
Fine Materials Vol. (%) (Cementitious Material + River Sand/ Crushed Rock Fine)	37%	41%	38%	44%	42%	48%

Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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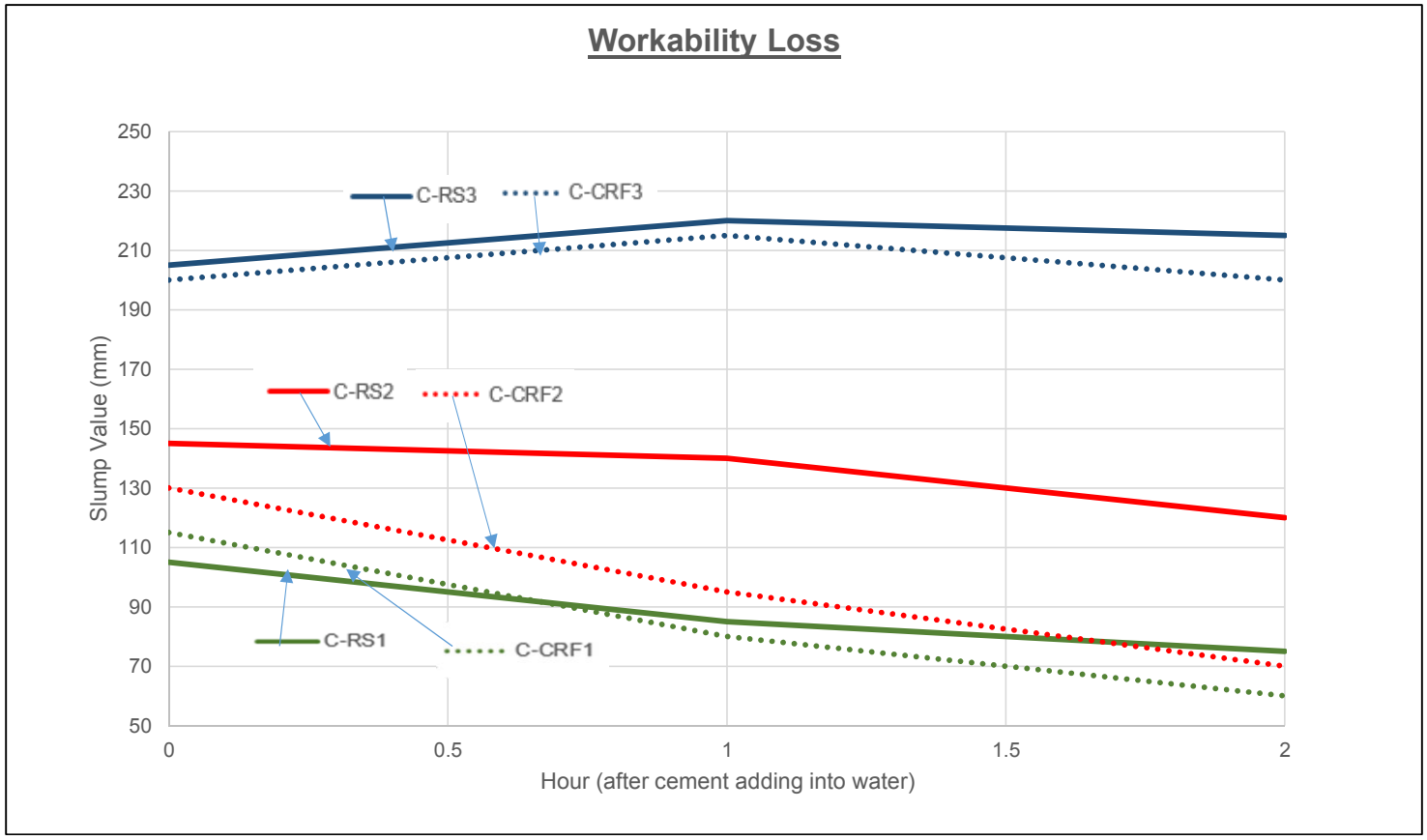
- Performance of Concrete Mix Design with River Sand & Crushed Rock Fines



Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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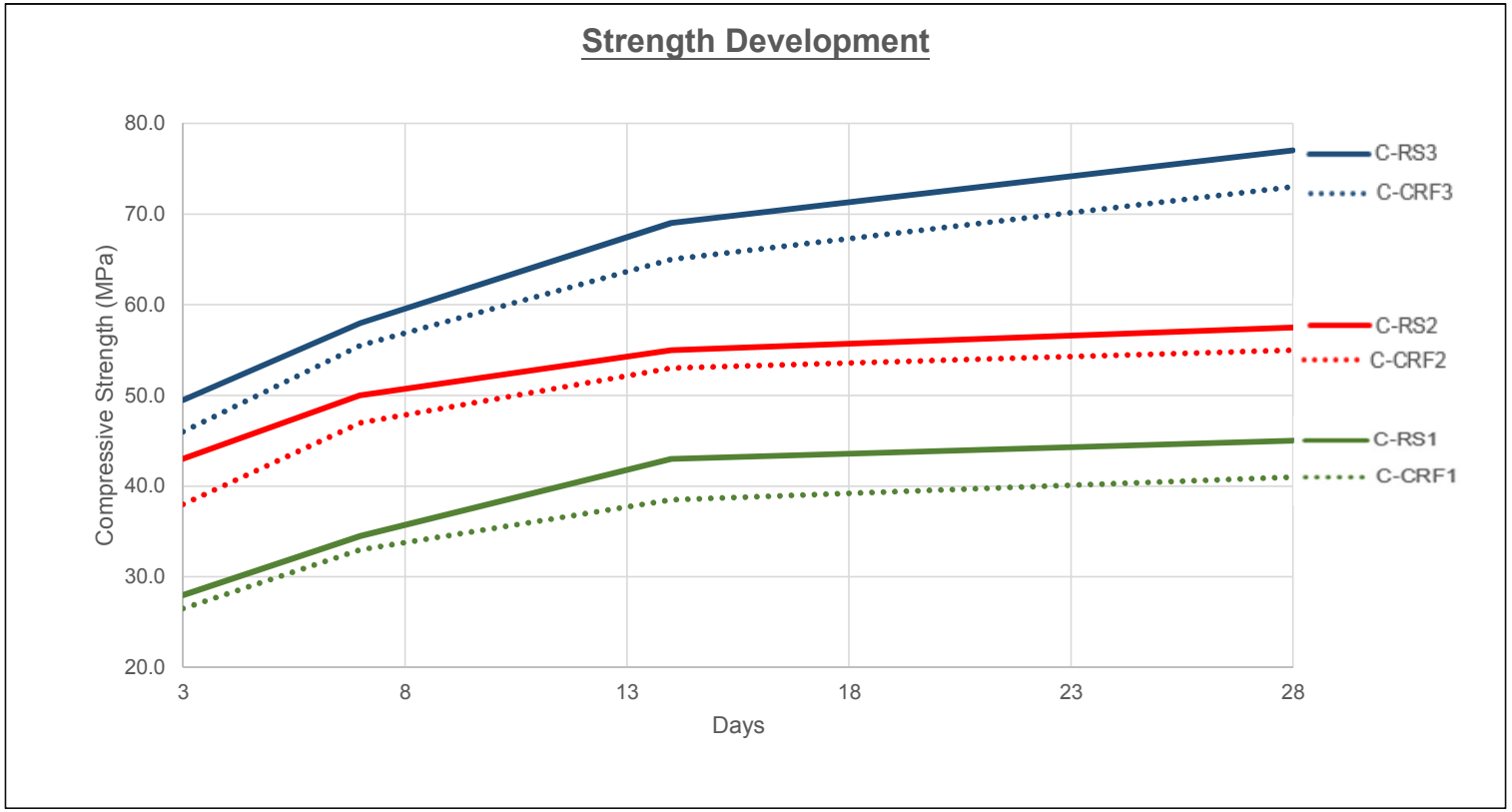
- Performance of Concrete Mix Design with River Sand & Crushed Rock Fines



Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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- Instant Mortar Design River Sand vs M-Sand

Ingredients (Proportion per cum. In kg)	Wall Plaster (1:3)	
	M – RS1	M – MS1
Cement	1 Part	1 Part
River Sand	3 Part	---
M-Sand	---	3 Part
Set Retarding Admixture (% per 100kg of cementitious content)	0.55%	0.70%
Air-entraining Admixture (% per 100kg of cementitious content)	0.25%	0.35%
Flow Table Test (In accordance with BS EN 1015-3)	195mm	200mm
Density (kg/m3)	1750	1790
Workable Life - Initial setting time to achieve 1MPa (hours)	36	30

Laboratory Trial Mix for Concrete Mix and Mortar with River Sand, Crushed Rock Fines & M-Sand

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- Flow Table Test for Mortar (BS EN 1015-3)

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Field Trial Performance

- Field Trial Performance

Wall Plaster (River Sand)

Wall Plaster (M-Sand)

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Comparison of Properties & Performance

Properties of Concrete/Mortar		Types of Fine Aggregate Used		
		River Sand	CRF	M-Sand
Concrete	Water Demand	Lower	Higher	N/A
	Dosage of Water-reducing Admixture	Lower	Higher	N/A
	Cementitious Content	Lower	Higher	N/A
	Workability Retention	Decline smoothly	Decline shapely	N/A
Mortar	Trowelability during plastering	Higher	N/A	Lower
	Smoothness of Finishes	Higher	N/A	Lower
	Dosage of Set Retarding Admixture	Lower	N/A	Higher
	Dosage of Air-entraining Admixture	Lower	N/A	Higher

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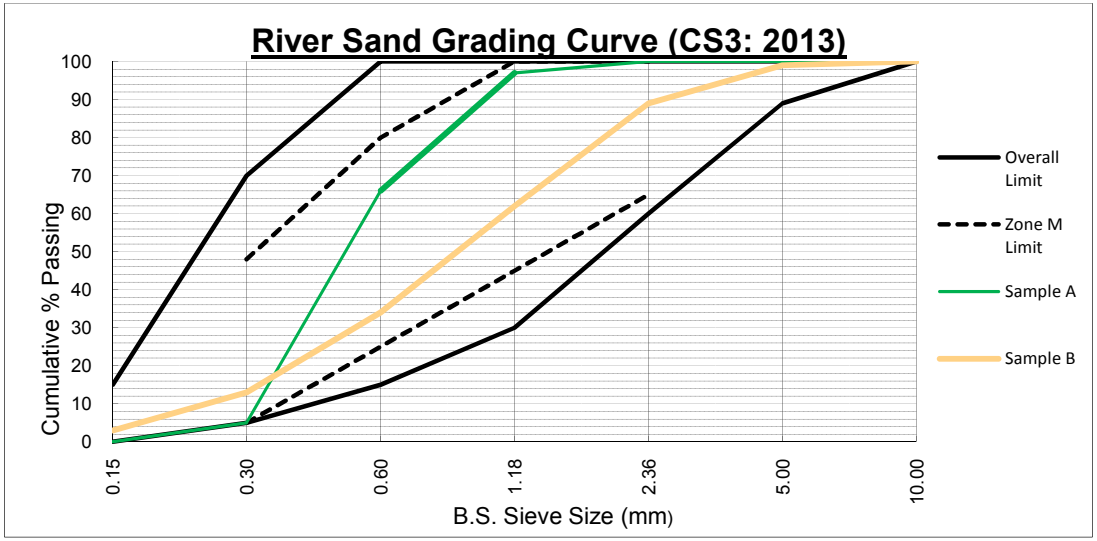
Comparison of Properties & Performance

Supplementary Information (River Sand):

Widely varied characteristics from batch to batch

- Certain amount of pea stone / pebbles might be found
- Varied grading from batch to batch
- Varied performance of mortar
- Complaints from contractors / site workers during plastering/troweling



Comparison of Properties & Performance

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Supplementary Information M-Sand:

- Controllable fines content by mechanical sieving method
- Compensation of high angularity with more fine filler or further grinding/crushing
- Currently limited supply in local market
- Relatively higher material cost
- One of the option for mortar production

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Further Consideration on M-Sand Adoption

- Further define of particular testing standard and requirements in the specification of M-Sand for mortar?
- Acceptance and feedback of M-Sand Mortar?
- Supply for local market?
- Adequate space for storage in batching plants?
- Grace period before thoroughly adoption for all private sector / public works projects?
- Other standard imposed if used for other products?

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Conclusion

- Quality standard and properties of River Sand, CRF and M-Sand have been reviewed.
- The overall performance (measurable and non-measurable) for concrete and mortar with using different fine aggregate has been compared.
- Import quota of River Sand would be further tightened, used as construction material would be in down trending.
- CRF is mainly used for concrete production only.
- M-Sand would be an option for mortar production in future, but the industry might not be ready at this stage.

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THE END