Production of Manufactured Sand & Constraints Faced

Moussa Baalbaki – Head Products and Solutions Portfolio

Agenda

- Key challenges to cope with increasing society's need for construction materials
- Manufactured sand (M-Sand) – Definition!
- Manufacturing driving forces influencing M-Sand quality
  - Adjustments for INSEE Blu™
  - Adjustments for INSEE Shape™
  - Adjustments for 150 µm content
- Cost of production of M-Sand
- Conclusions

The real matter – in theory

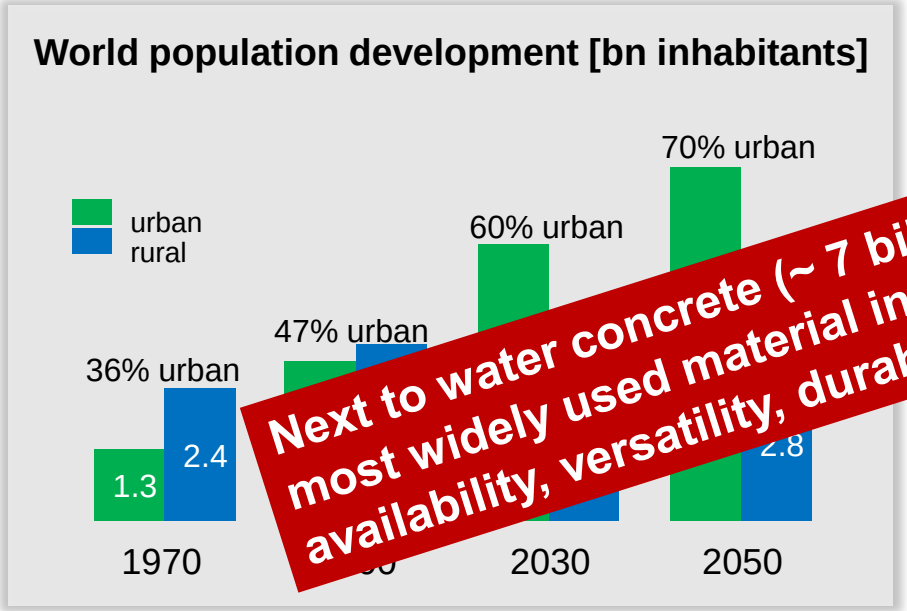
Global population growth over the last 2,000 years, with the doubling times marked

FIGURE 1.3 *Global population growth over the last 2,000 years, with the doubling times marked.*

Source: Michael F. Ashby, Materials and the Environment

The real matter – in practice for society

World population grow & Ongoing trend towards urbanization, particularly in emerging countries



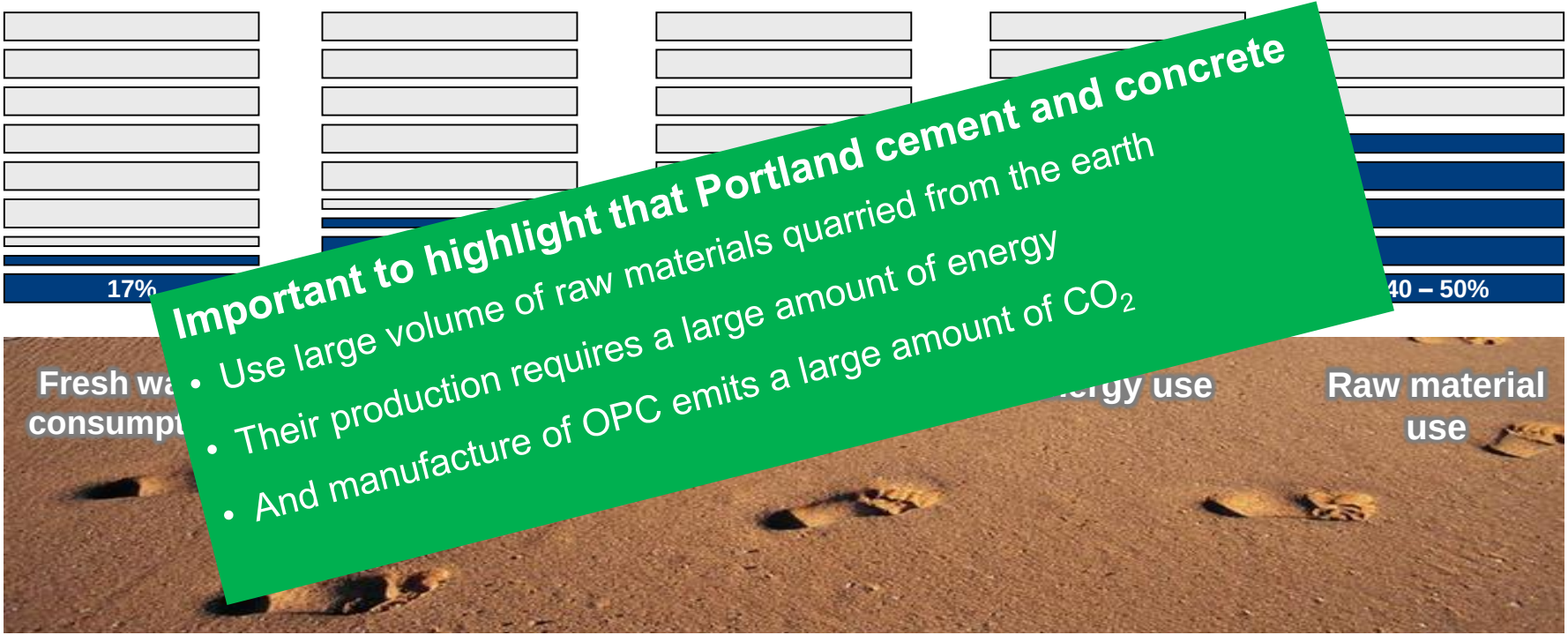
Next to water concrete (~ 7 billion m^3) is by far the most widely used material in the world (economic, availability, versatility, durability and adaptability)

Both trends will significantly increase society's need for construction materials

Source: United Nations, World Urbanization Prospects: The 2007 Revision (www.un.org)

Buildings have an important ecological footprint…

Unfortunately we use these natural resources at a rate that cannot be sustained indefinitely



Important to highlight that Portland cement and concrete

- Use large volume of raw materials quarried from the earth
- Their production requires a large amount of energy
- And manufacture of OPC emits a large amount of CO_2

Source: World Green Building Council, The ecological footprint

Sand in fact has become a scarce resource

Increasing public attention…

SPIEGEL ONLINE INTERNATIONAL

The Sand Thieves: World's Beaches Become Victims of Construction Boom

By Laura Höflinger

Sand is becoming so scarce that stealing it has become an attractive business model. With residential towers rising ever higher and development continuing apace in Asia and Africa, demand for the finite resource is insatiable.

Sandmining is destroying Asia's rivers

Uncontrolled and mostly illegal extraction of sand and rocks from riverbeds for construction is killing rivers across South Asia and China, and must be tightly controlled

DIE WELT

DIE WELT Digital 2 Monate für nur 0,99 €!

In Asien tobt ein Sandkrieg

Singapur und Malaysia streiten um eine künstliche Insel. Rohstoff weltweit immer begehrter Von Adrian Lobe

werden, um die Strände zu erhal… …rer Kreislauf. In Indonesien sind ganze 2… …nwunden. In Marokko stammt die Hälfte des San… …illionen Kubikmeter, aus illegalen Sand-Minen. Sand… …r haben einen Strandabschnitt bei Essaouira in ein Ber… …ber Tage transformiert. Wo eigentlich Urlauber in der Sonne am Strand liegen, stehen nun Lastwägen, die mit Sand beladen werden. Das Geschäft blüht, auch weil die Nachfrage nach Sand stetig steigt.

In Asia a sand war is raging

SAND WARS

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Soon there will be no more sand on the sea

Gibt es bald keinen Sand am Meer mehr?

Kinder bauen mit ihm Burgen, die Bauindustrie macht daraus Beton: Die Rede ist vom Rohstoff Sand. Weil er so begehrt ist, könnten die Ferien am Strand mit Sand am Meer bald der Vergangenheit angehören. Was gibt es für Alternativen?

Von Sabina Galbiati

INSEE CEMENT

… and a billion $ business!

- The annual consumption is around 7 billion tons
- Most sand is used for construction
  - Concrete (~800 kg/m^3), annual consumption ~ 5 - 6 billion tons
  - Land reclamation
- In some areas of the world no sand suitable for construction is remaining (e.g. Singapore, Dubai)

One family house

200 t

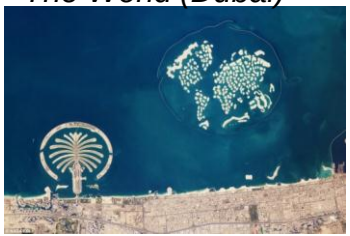
Highway (1 km)

30’000 t

Burj Khalifa (Dubai)

257’000 t

The World (Dubai)



300’000‘000 t

Imported from Australia!

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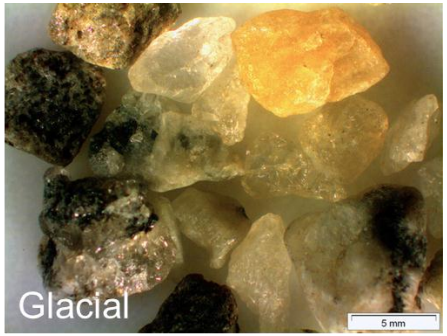
Fine aggregates are referred to by many names

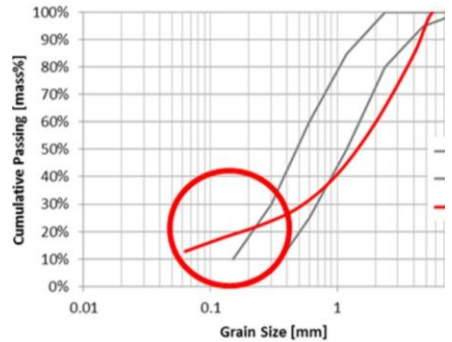
- Natural sand is used to identify the material traditionally recovered from geologically recent deposits of sand-sized materials
  - Typically these deposits are from Quaternary deposits in streams, rivers, estuaries, lakes, lagoons or dunes
  - …therefore many different properties!



Pictures by K.Ramseyer (Uni Bern) and B.Hofmann (Natural History Museum, Bern)

Fine aggregates are referred to by many names

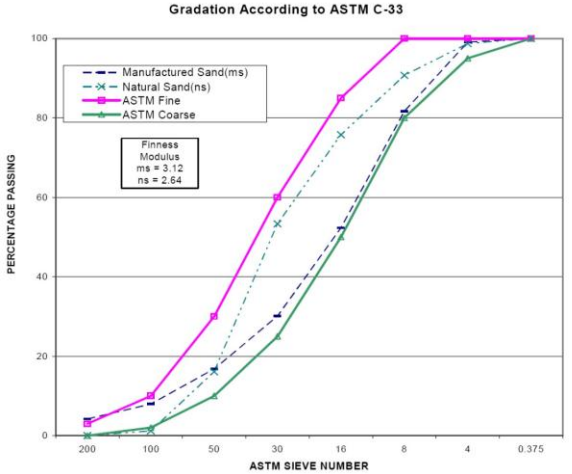
- Crusher fines / quarry dust are not a purpose made product and are produced from a crushing and screening process (usually 20–40% of total product mix) →opportunity to replace natural sand if beneficiated!
  - Granular material passing the 9 mm sieve, almost entirely passing the 4.75 mm
  - Do not meet the gradation, cleanliness (clay and organic content), or particle shape requirement for use in RMX or concrete products (inconsistency due to various rock types and different crusher types / control)



Fine aggregates are referred to by many names

- Manufactured sand (M-Sand) is a purpose made crushed fine aggregate produced from a suitable source material
  - Production involves crushing, screening and possibly washing to meet specifications and/or end product performance requirements. (For example: RMX performance)
  - It is not simply a fine gradation material "by-product" of the processing plant

- The challenge in producing quality manufactured sand for RMX is to economically achieve:
  - Elimination of contaminants and excess fines less than 62µm
  - Adequate cubical or rounded particle shape to enhance mix flowability and reduce water demand
  - continual distribution of different grain sizes across the product's gradation curve



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Manufactured sand processing alignment with INSEE M-Sand decision tree approach for quality assessment

1 INSEE Blu™

High value

- Negative impact on workability
- Select admixtures carefully

Low value

2 INSEE Shape™

Difficult shape

- Improve shape [Flakiness and roughness of grains]
- Blend with other sand

Good shape

3 Fineness Modulus (FM)

Lower FM

4 Fines <150 µm

Too much fines

- Blend with other sand
- Fines correction

Good range of fines

Higher FM

4 Fines <150 µm

Not enough fines

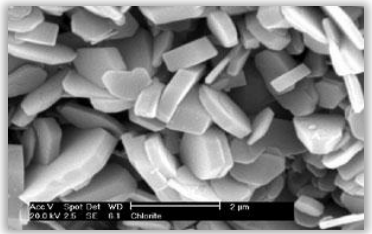
- Fines correction
- Blend with other sand

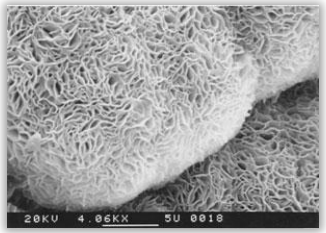
Good range of fines

INNSEE Flow ™ - Target flow expected

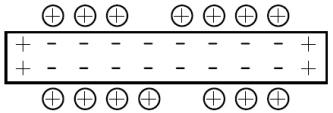
INSEE Blu™: rapid methylene blue test
Estimation of clay content

- Clays have a very high specific surface
  - e.g. montmorillonite: 50–800 m^2/g (→10 g equals to soccer field surface!)
  - Wetting all this surface increases the water demand

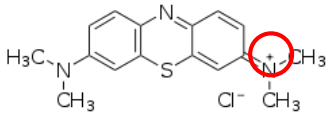




- The surfaces of clays are charged
  - ↳ absorption of polar molecules like PCE superplasticizers or methyleneblue



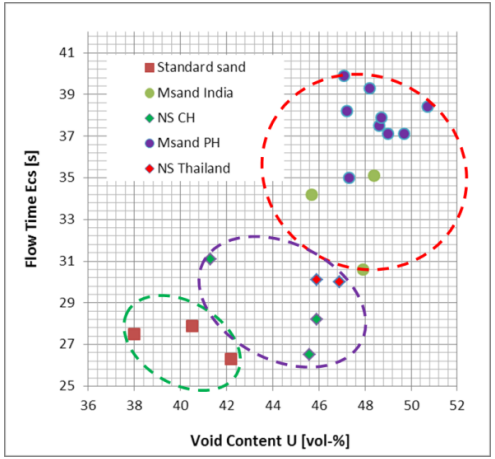
Clay particle charge distribution



Methylene blue molecule

INSEE Shape™
Sand particle shape characterization

- EN 933-6:2001 (adapted)
  - Flow coefficient of aggregate
  - Equipment for sand (63 µm – 2 or 4 mm)
- Principle
  - **1 kg** of sand (**250 µm – 4 mm**) flows trough a funnel with an **opening Ø 16 mm**.
  - The sand is combined from 4 screen fractions in order to maintain a constant gradation
  - **EN** or **ASTM** screen fractions can be used
  - **Flow time Ecs** is longer with more irregular (flat) and rough particles
  - **Void content U** depends on particle roughness, shape and gradation
  - Subsequent density correction of flow time



Void Content **U**
- based on density
- **EN 1097-3** (adapted)
- Loose bulk density

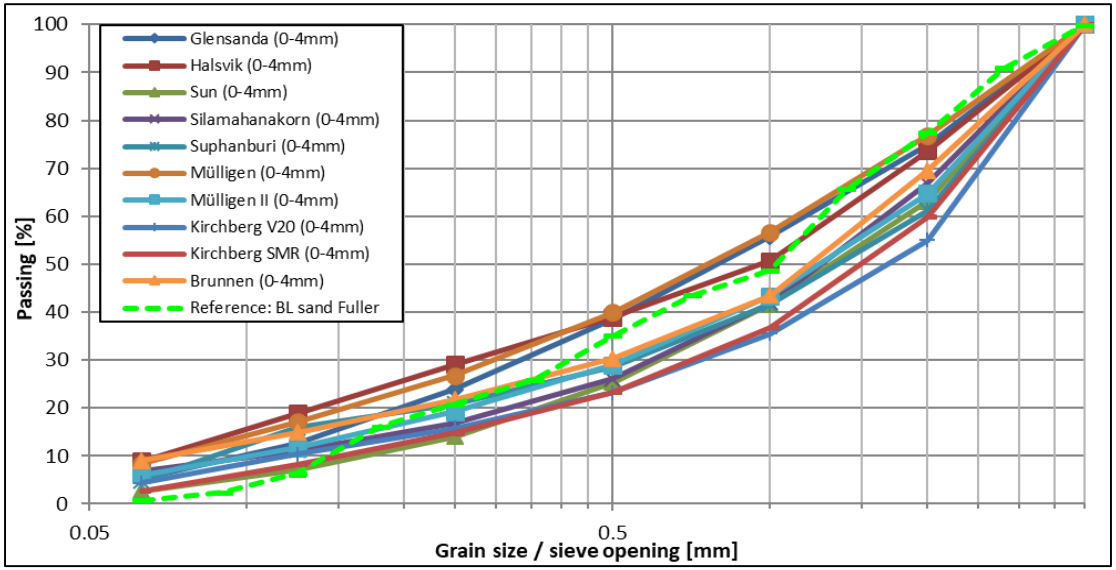
Equipment

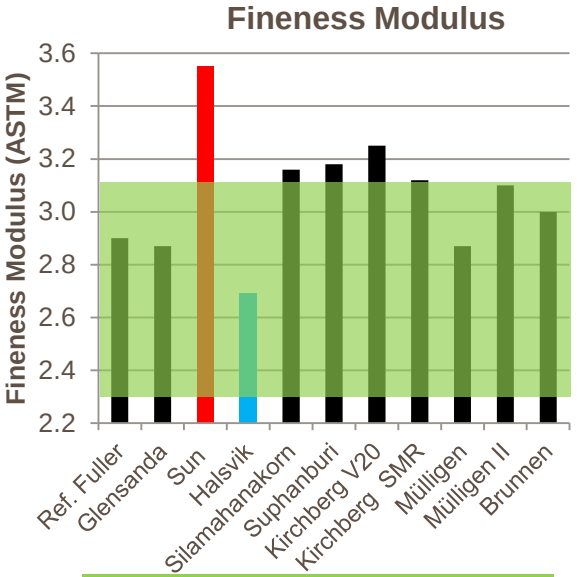
Start of sand flow

Flow time **Ecs**

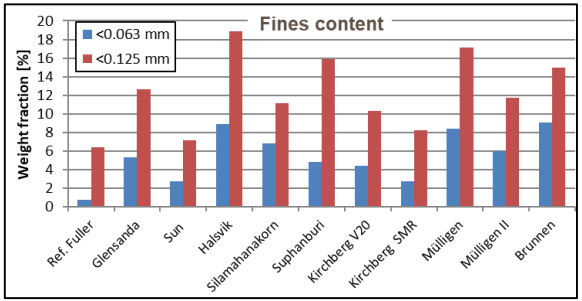
Gradation and fineness

Findings - Investigation on 10 different M-Sand





ASTM C33: FM 2.3 – 3.1



Fines have to be considered up to 0.125 mm (or 0.150 mm for ASTM)!

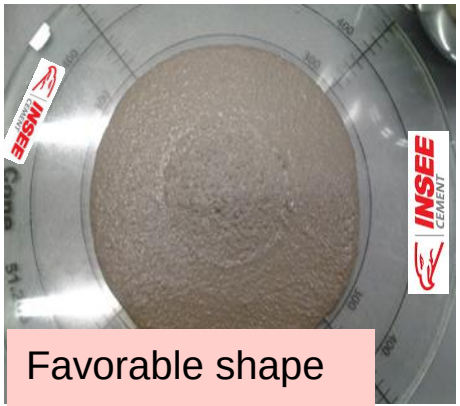
INSEE Flow™

Findings - Investigation on 10 different M-Sand

- Grains Shape favorable to difficult
- Fines content inconsistent
- High to very high clay contamination
- Most INSEE Flow™ values below target flow → up to 50% superplasticizers dosage increase

Lack of fines

High clay content

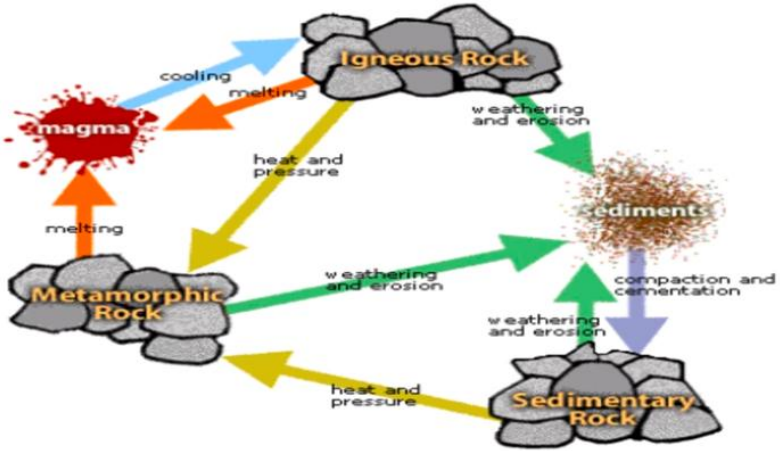


Favorable shape

- Challenges for high performance concrete
  - ↳ More complex mix designs required (higher cement content, admixtures etc.)
  - ↳ Issues with product consistency (quality control is key!)

Appropriate rocks for M-Sand

- Quality Manufactured Sand can be produced from many different rock types – igneous, metamorphic, and sedimentary
- Rock that has proven performance as RMX coarse aggregate and/or meets the RMX coarse aggregate specifications
- More abrasive rocks (generally higher in silica and metallic oxide content) are more expensive to process
- Fines produced from recycled aggregates generally are not suitable for manufactured sand



Twelve recommended tests to determine suitability of Raw Material for M-Sand

Aggregates Raw Material, Coarse and Fine Products		Type of test	ASTM Specification	European Union Specification
MST1	Specific Gravity (solid density - fine)	Classification - fine aggregate	ASTM-128-07a	
MST2	Absorption %	Classification coarse/fine	ASTM C-127/128	EN-1097-6
MST3	Abrasion	Los Angeles/Micro Deval	ASTM C-131	EN-1097-1
MST4	Soundness	Sodium or Magnesium Sulfate	ASTM C-88	EN-1367-2
MST5	Sand Equivalent (fine material)	Assessment of fines	ASTM D-2419	EN-933-8
MST6	Methylene blue test (fine material)	Assessment of fines		EN-933-9
MST7	Durability Index	Weathering/Degradation	ASTM D-3744	EN-1367-1:1999
MST8	Impact Work Index	F.C. Bond Method		
MST9	Chemical Reactivity - Silica	Alkali Silica reactivity	ASTM C1293, C1567, C1260, C227	CEN Report CR1901
MST10	Chemical Reactivity - Carbonate rocks	Carbonate rocks reactivity	ASTM C586-05	
MST11	Petrographic Examination	Chemical analysis	ASTM C-295	EN-1744-1:1998
MST12	Sieve Analysis - Gradation	Classification	ASTM C-136/D-448	EN-933-1

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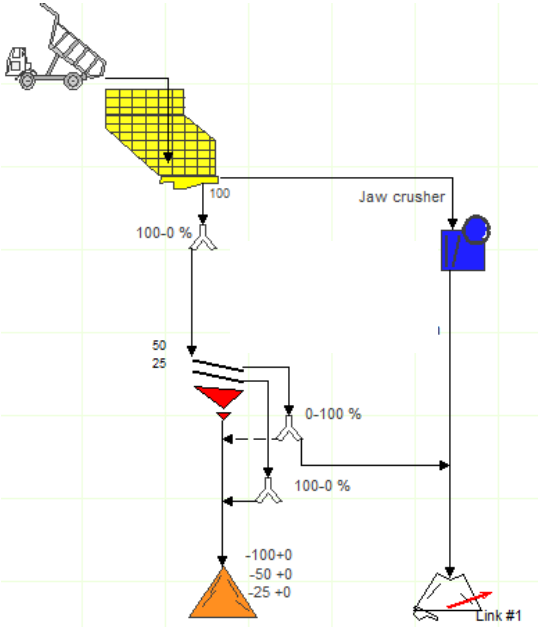
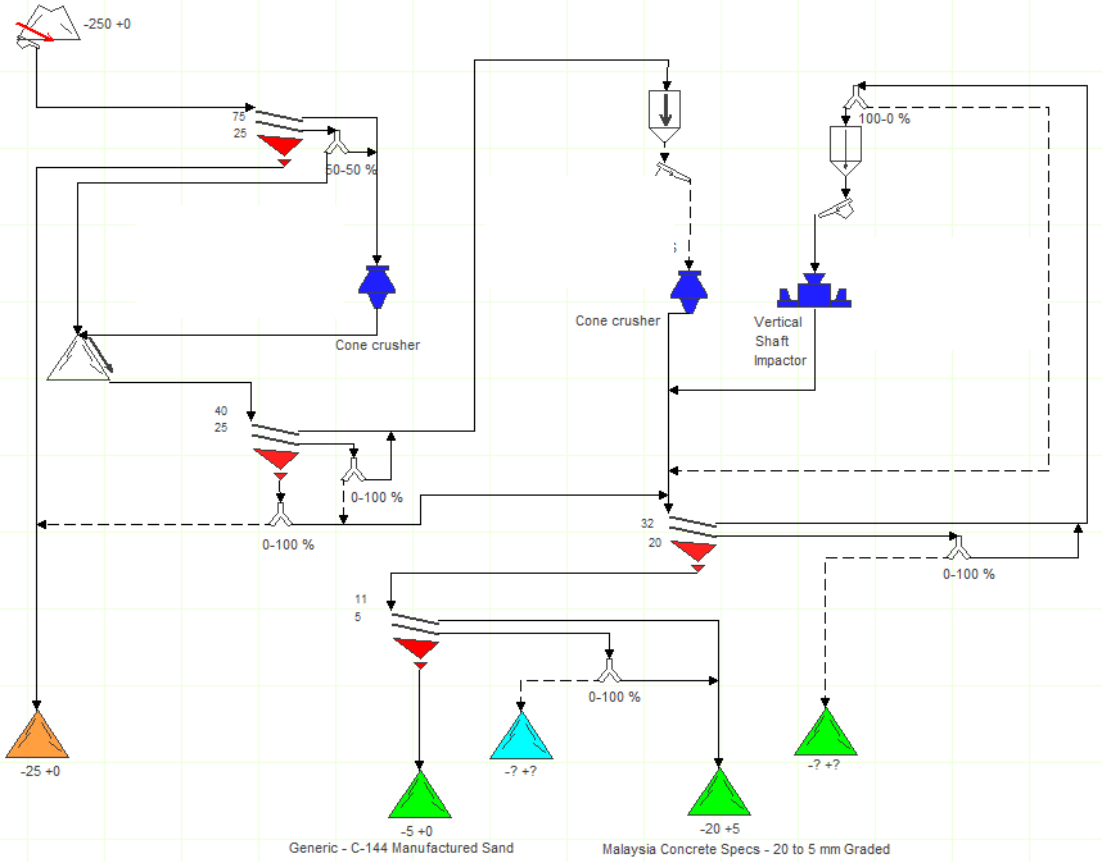
Step by step review to make necessary quality adjustments to the process

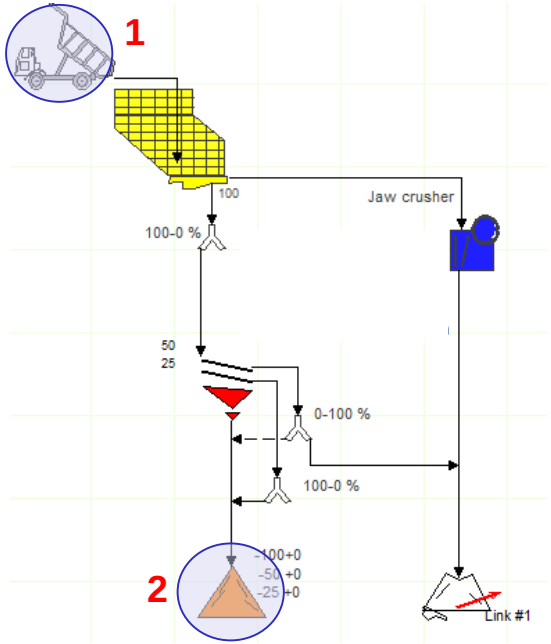


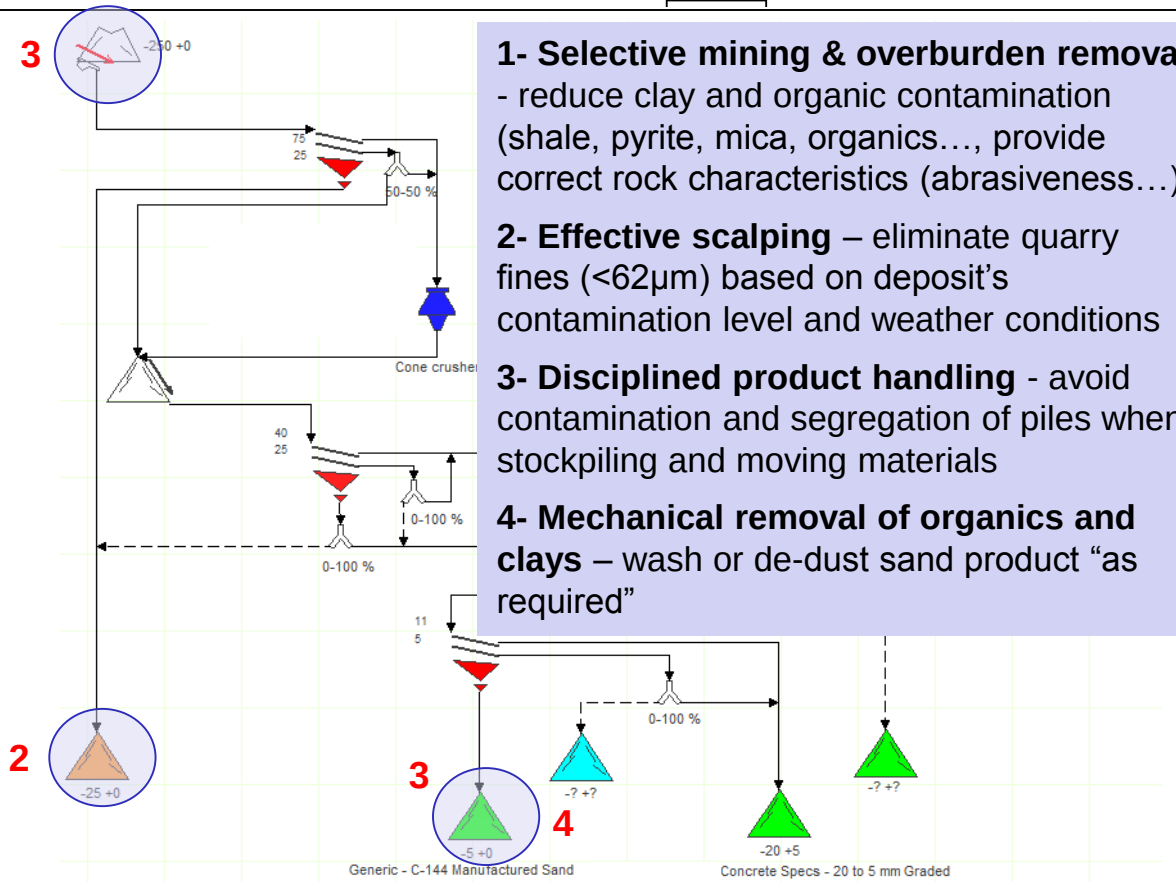


Adjustments to reduce clay/fines content

1 INSEE Blu™ → High value

- Negative impact on workability
- Select admixtures carefully





1- Selective mining & overburden removal - reduce clay and organic contamination (shale, pyrite, mica, organics…, provide correct rock characteristics (abrasiveness…)

2- Effective scalping – eliminate quarry fines (<62µm) based on deposit's contamination level and weather conditions

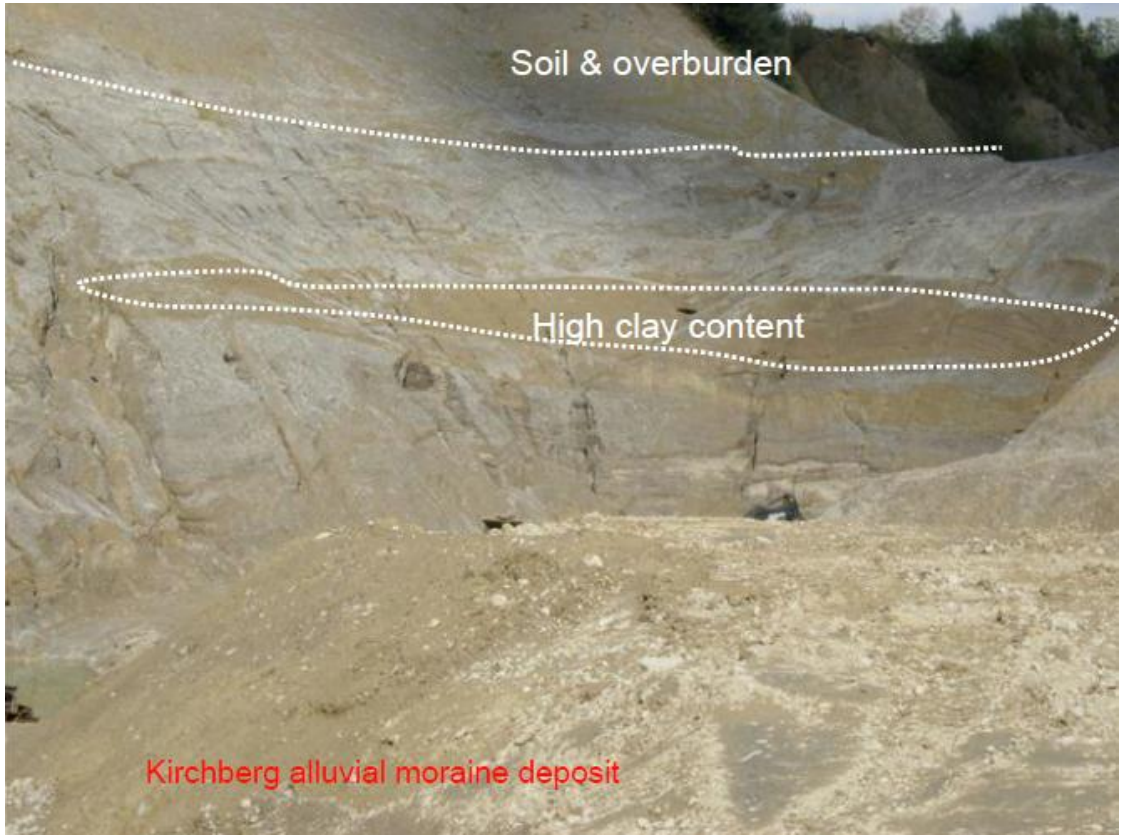
3- Disciplined product handling - avoid contamination and segregation of piles when stockpiling and moving materials

4- Mechanical removal of organics and clays – wash or de-dust sand product "as required"

Covering soil, pockets of clay complicate alluvial deposits can easily contaminate the sand process

1 INSEE Blu™ → High value

- Negative impact on workability
- Select admixtures carefully



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Favorable M-sand shape is required for RMX

2 INSEE Shape™ → Difficult shape →
- Improve shape [Flakiness and roughness of grains]
- Blend with other sand

Natural sand

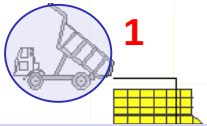
0 -0.150µ

"Typical" crushed fines

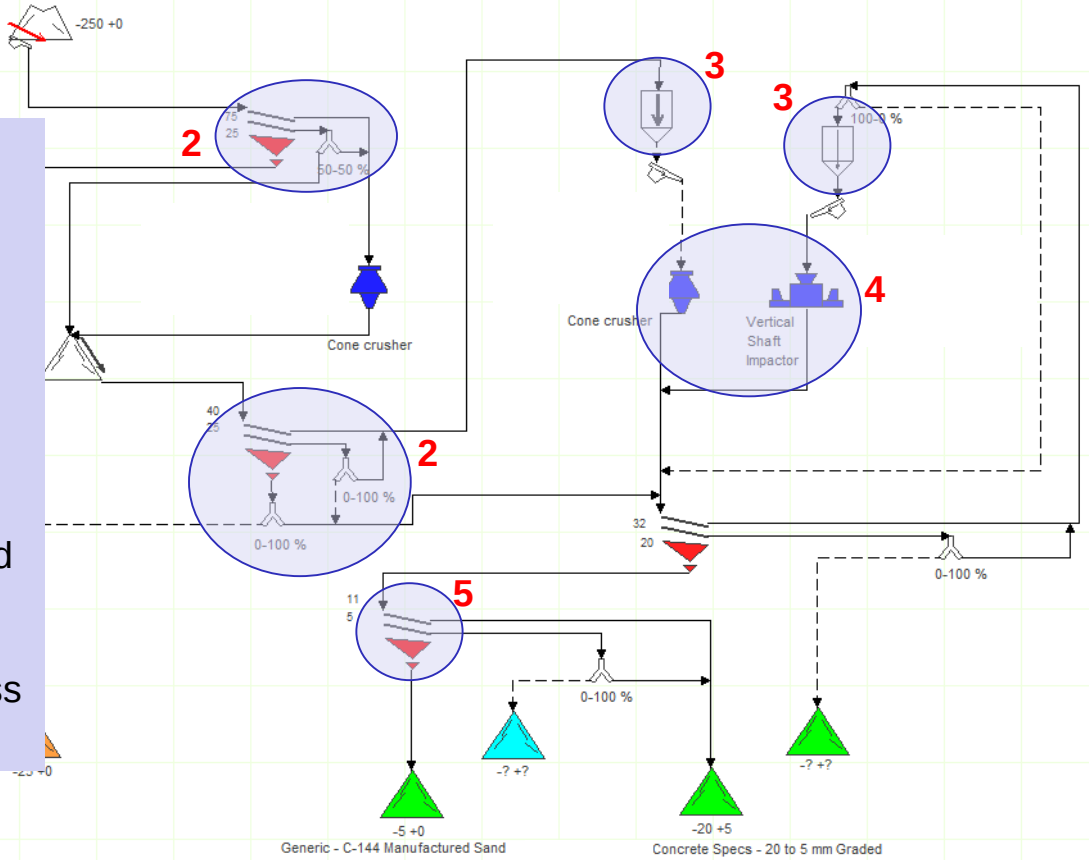
0.300 – 0.600µ

Shaping of crusher fines is generally required for RMX fine aggregate

2 INSEE Shape™ → Difficult shape →
- Improve shape [Flakiness and roughness of grains]
- Blend with other sand



1.Selective mining - reduce flats & elongated in feed and dry condition
2.Correct feed gradation – increase interparticle crushing (fines and coarse materials not segregated)
3.Correct feed level – Surge bin prior to crusher, assure constant choke feed tied to crusher power demand
4.Proper selection of crusher type – based on prior testing of raw material and operating conditions
5.Correct screening media – caution with anti-blinding harp screens – can pass elongated shape



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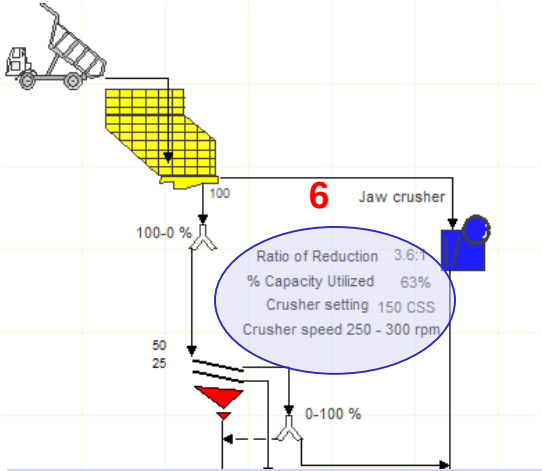

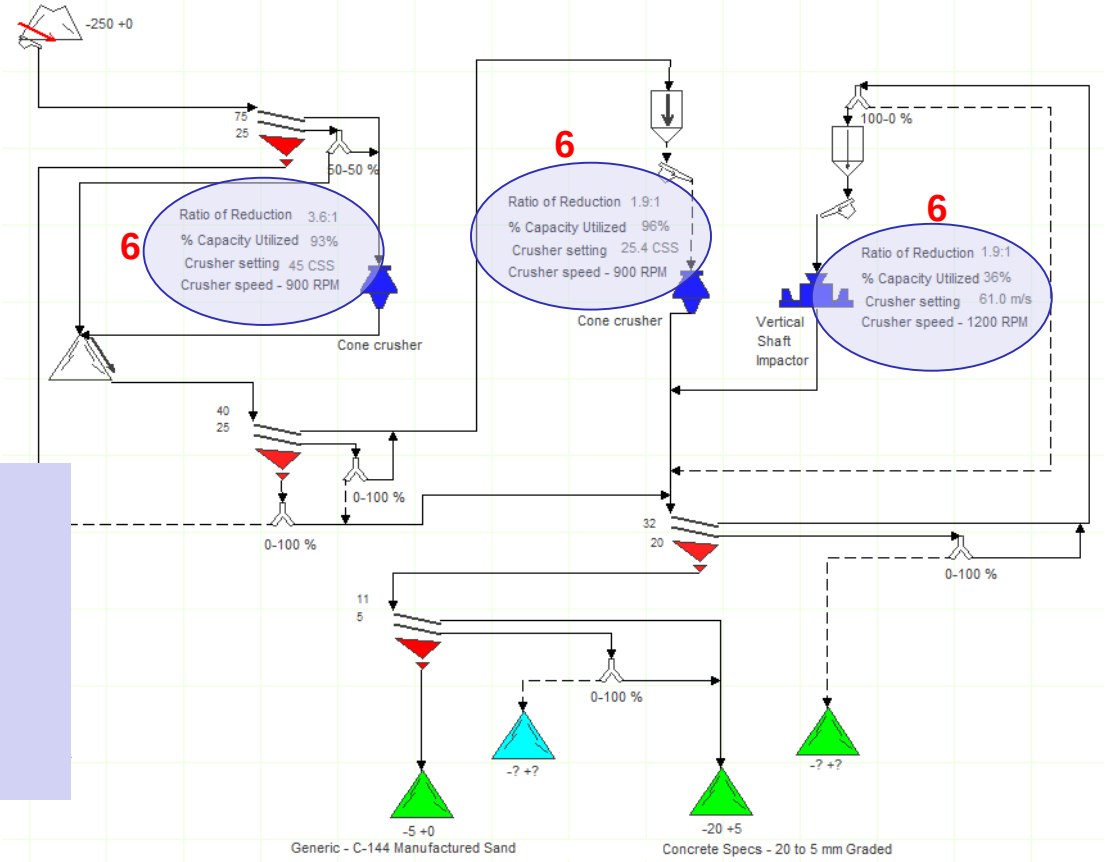

6. Correct crusher operating parameters must be defined through testing and verification in the field:

a. Crusher setting
b. Crusher speed
c. Ratio of reduction
d. % Capacity of crusher utilized

Correct feed gradation – increase interparticle crushing

2 INSEE Shape™ → Difficult shape →
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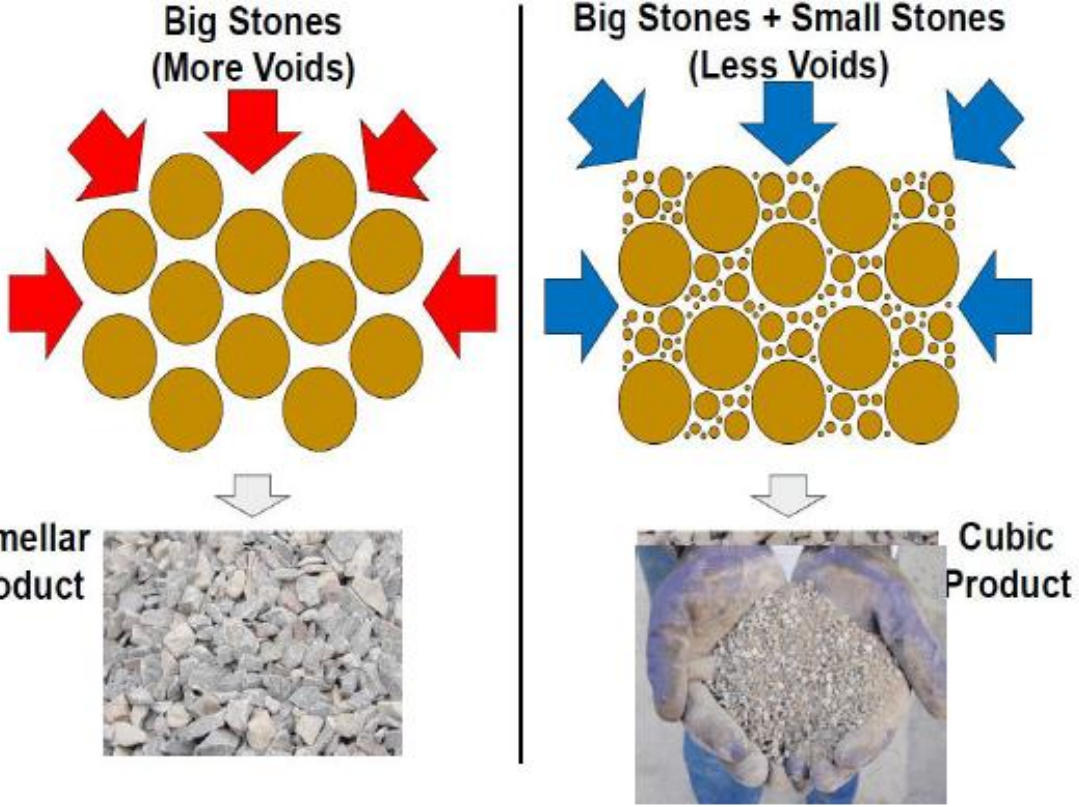


Crushers type

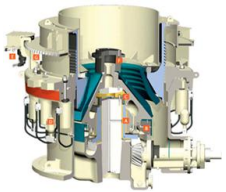
2 INSEE Shape™ → Difficult shape →
- Improve shape [Flakiness and roughness of grains]
- Blend with other sand

Crushing type for **ABRASIVE** Feed Material

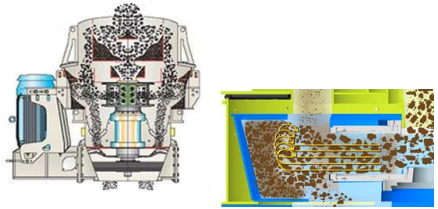
- **High Speed Cone Crusher** with fine liner manganese selection

OR

- **Rock-on-Rock** Vertical Shaft Impactor **(VSI)** (note a VSI will have a lower ratio of reduction thereby will produce larger recirculating loads)
- Feeder velocity is often tied into the power draw of the crusher to maximize production and avoid crusher overload
- Do not forget CRUSHER PROTECTION with magnet or metal detector !



High Speed Cone Crusher



VSI Rock on Rock

Crushing type for **NON-ABRASIVE** Feed Material

- **Horizontal Shaft Impactor (HIS)** noting that feed should fall across full width of interior rotor breaker bars

OR

- **Rock-on-Metal Anvils** Vertical Shaft Impactor **(VSI)**
- These type of impact crushers have a higher ratio of reduction thereby will produce a smaller recirculating loads than cone crusher circuits or VSI rock-on-rock circuits.
- Feeder velocity is often tied into the power draw of the crusher to maximize production and avoid crusher overload
- Do not forget CRUSHER PROTECTION with magnet or metal detector !

HSI

VSI Rock on Metal Anvils

Cubicity according to crusher type and crushing Stage – bear in mind fines are produced at each crusher stage in the circuit

	Crushing Stage		
Crusher Type	Primary stage	Secondary stage	Tertiary stage
Jaw crusher	Poor	Poor	Poor
Primary gyratory	Poor	NA	NA
Horizontal shaft impactor	Fair	Fair / Good	Fair / Good
Vertical shaft impactor	NA	Good	Good
High speed cone crusher	NA	Fair	Good when operated correctly
New design high pressure roll crusher	NA	NA	Good when operated correctly

*slide adapted from Metso training materials

Screening circuit options

2 INSEE Shape™ → Difficult shape →
- Improve shape [Flakiness and roughness of grains]
- Blend with other sand

- Screening fine materials requires more open area per ton of material processed than for coarse aggregate
- Fine materials have a tendency to blind the screen media – special screen media is commonly used to prevent blinding

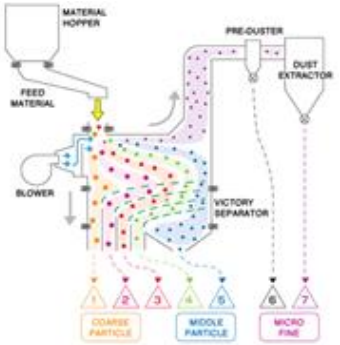
Wire z-slot mats

Flex polyurethane mats

- Fine screening requires higher frequency (RPM) and reduced eccentric throw
- Three shaft horizontal screens permit adjustment of speed, eccentric throw and throw direction to increase efficiency
- Buell air gravitational inertial separation

High frequency screen

Horizontal 3 shaft vibrating screen



Buell Air screen

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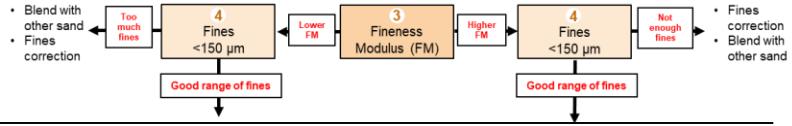
- Conclusions

Sand gradation correction and removal of deleterious materials



Sand screw

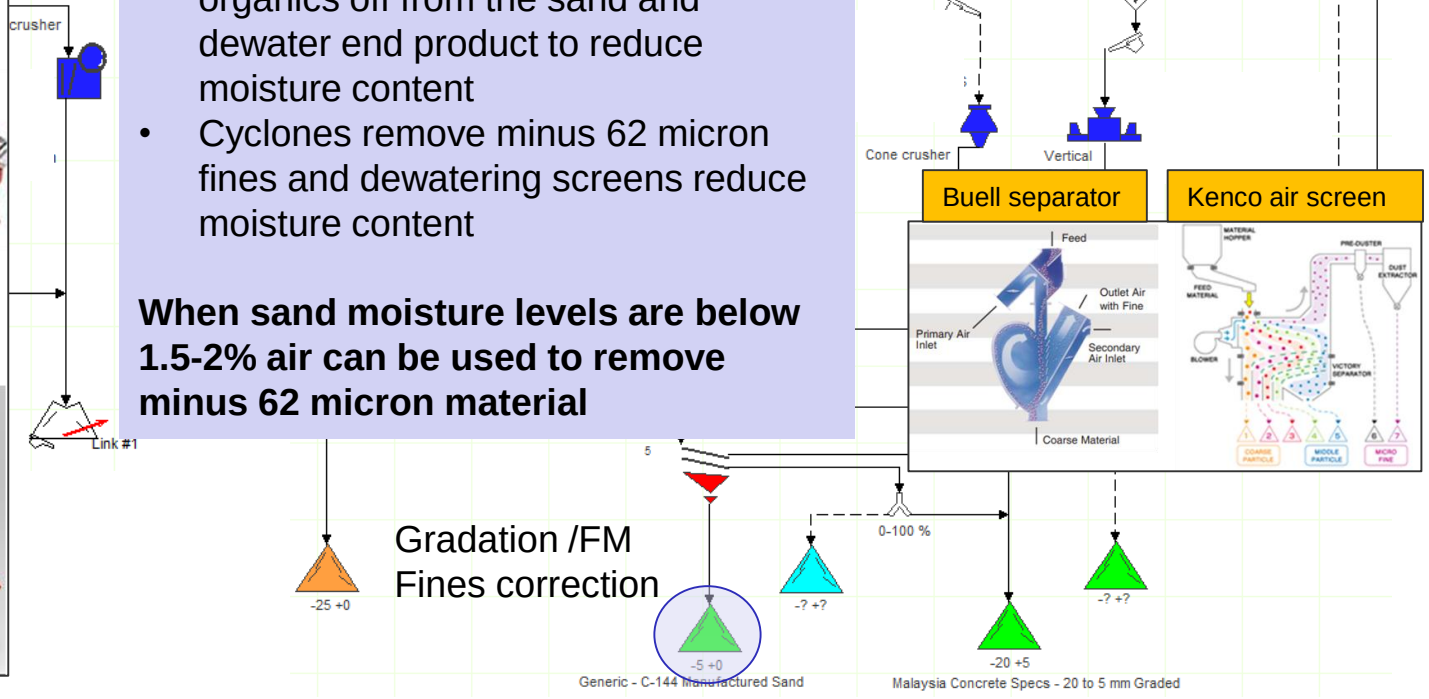
Sand wheel

Cyclone with dewatering screen

Deleterious clay material and organics are most often <u>removed by water</u>

- Sand screws and wheels float organics off from the sand and dewater end product to reduce moisture content
- Cyclones remove minus 62 micron fines and dewatering screens reduce moisture content

When sand moisture levels are below 1.5-2% air can be used to remove minus 62 micron material



Gradation /FM
Fines correction

Silt / dust wastes can be costly to dispose
Suitable end uses should be determined early

- 28 typical uses of waste by-product of manufactured sand processing plants

Construction
Blended into Crusher run, base, sub-base
Soil stabilization
Fill/backfill
Underground cable protection
Reinforced earth walls

Asphalt Concrete/Roofing
Asphalt filler
Slurry seal/micro surfacing
Roofing shingle backing

Agriculture
Livestock feed additive, poultry grit
Livestock stall linings/bedding
Horse track surfaces
Agglime
Pesticide/fertilizer bulking agents
Trace elements remineralization

Concrete Products
Concrete additive
Mortar sand additive
Flowable fill
Masonry cement mineral filler
Lightweight aggregates

Industrial
Ceramics, earthenware, stoneware
Paint filler /paper filler
Portland cement additive
Mineral and rock wool

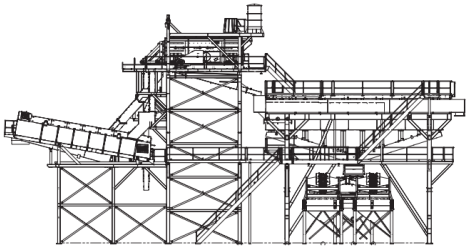
Environmental
Acid neutralization
Flue gas desulphurization
Landfill daily cover
Hazardous waste solidifiers
Pond liners, impermeable layer separators

Agenda

- Key challenges to cope with increasing society's need for construction materials
- Manufactured sand (M-Sand) – Definition!
- Manufacturing driving forces influencing M-Sand quality
  - Adjustments for INSEE Blu™
  - Adjustments for INSEE Shape™
  - Adjustments for 150 µm content
- Cost of production of M-Sand
- Conclusions

Costs associated with Manufactured Sand Processing

- **Investment costs**
  - sand processing plant can range from a low of $5,000/tph to $15,000/tph of sand production capacity
  - depending on how abrasive and contaminated is the raw material.



Plant designs can be stationary, modular skid, or portable

- **Operating costs**
  - Maintenance costs – generally higher as fines combined with moisture require shorter service intervals more servicing
  - Wear materials consumption – Wear costs can be from a low of $0.02 to $0.30/ton
  - Power consumption – Fine crushing consumes more power per ton than coarse crushing. Crushing and screening costs can be from $0.15 – $0.25/ton

Sand plants can be maintenance intensive.

- Environmental costs $$$
  - Dust abatement
  - Reject material handling and disposal
  - Water consumption and recycling

Silt / dust wastes can be costly to dispose. Suitable end uses should be determined early.

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- Key challenges to cope with increasing society's need for construction materials
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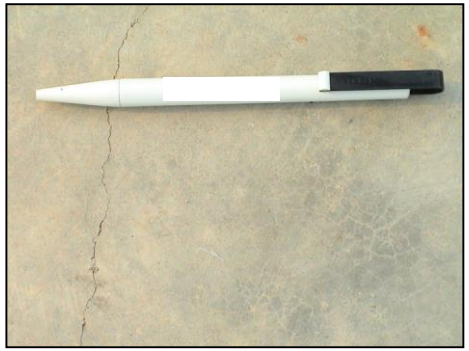
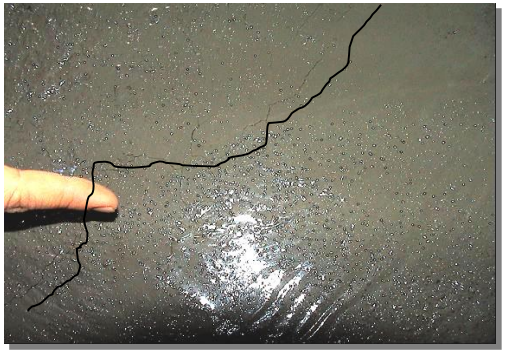
Conclusions

- Quarry
  - Optimized mine planning to avoid detrimental components like clays
  - Assurance of consistent feed to plant
- Processing
  - Optimization of crushers to improve grain shape
  - Right balance of fines with regard to the sand gradation
- Procurement
  - Selection of right sand available on market
  - Cost / performance estimations
- Concrete technology (RMX)
  - Impact of sand quality on concrete performance
  - Admixture interactions
  - Cost of “non-quality”
  - Successful producers of manufactured sand work closely with their clients to provide good mix designs for RMX strength, workability, set times, and finishing characteristics

What really matter?

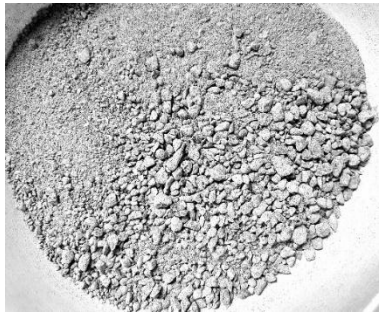




Sri Lanka

Different Crusher Plants Configurations & Aggregate Shapes

Sample 1



Jaw ➡ Cone ➡VSI

Sample 2

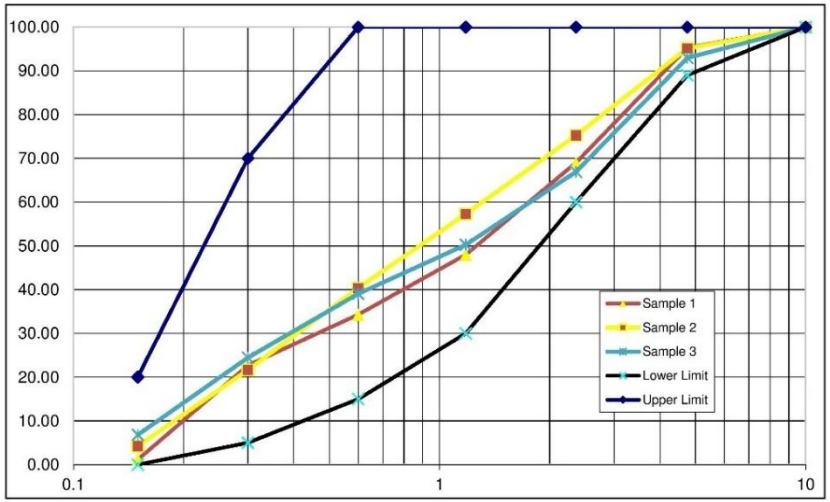
Jaw ➡ Cone ➡VSI

Sample 3

Jaw ➡ Cone ➡ Cone

Fineness Modulus & 150µm Passing

Sieve Size (mm)	% Passing		
	Sample 1	Sample 2	Sample 3
10	100.0	100.00	100.00
4.75	95.3	95.14	92.94
2.36	69.0	75.22	66.94
1.18	48.0	57.29	50.24
0.6	34.3	40.35	39.06
0.3	22.7	21.67	24.47
0.15	1.2	4.23	6.82
Pan			



	Sample 1	Sample 2	Sample 3
Fineness Modulus:	3.3	3.1	3.2

Workability of Mix Designs with Similar Fine Aggregate Percentage

Jaw ➡ Cone ➡ VSI

Sample 1

Jaw ➡ Cone ➡ VSI

Sample 2

Jaw ➡ Cone ➡ Cone

Sample 3


INSEE
CEMENT