HORIBA Scientific

Application Note

Particle Size and Shape Analysis of Sand using Digital Image Analysis

AN173

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. Used in many industries ranging from construction to abrasives, sand grading and performance is closely related to particle size and shape. Traditional sieve measurements are being replaced with automated digital image analysis. Successful incorporation of digital image analysis often includes data correlation to sieve results, followed by realizing the advantages offered by this technique.

Introduction

Sand is loose rock material of a grain size between 63 µm and 2 mm. Material coarser than 2 mm is called gravel; however, everything written here about sand can also be said for gravel. Sand can be composed of different materials, but quartz is the major component. Other minerals are feldspar, carbonates, mica and, additionally, garnet, apatite, magnetite and many more. For some industrial applications, the sand has to be as pure as possible.

ISO 14688 grades sands as fine, medium and coarse with ranges 0.063 mm to 0.2 mm to 0.63 mm to 2.0 mm. In the USA, sand is commonly divided into five sub-categories based on size: very fine sand (1/16 - 1/8 mm diameter), fine sand (1/8 mm - 1/4 mm), medium sand (1/4 mm - 1/2 mm), coarse sand (1/2 mm - 1 mm), and very coarse sand (1 mm - 2 mm). These sizes are based on the Φ sediment size scale, where size in Φ = -log base 2 of size in mm. On this scale, for sand the value of Φ varies from -1 to +4, with the divisions between sub-categories at whole numbers.

Building material

Most construction materials are mixtures of cement, aggregates and other additives such as fly ash, perlite or fumed silica. Sand and gravel are used as aggregate, e. g. in concrete, mortar and plaster. Concrete has a maximum grain size larger than 4 mm. If the largest grains are smaller than 4 mm the material is called mortar. The particle size of the aggregates affects mechanical behavior and stability of the material as well as the outer appearance. For 1 m^3 of “normal” concrete, 545 kg of aggregates 0-2 mm, 725 kg aggregates 2-8 mm and 545 kg aggregates 8-16 mm are needed (according to EN206 and DIN1045).

If these ratios are not fulfilled or if the size distribution changes within the individual aggregate fractions, the compaction and stability of the concrete will also change.

A special type of concrete is so-called self compacting concrete. This aggregate size is generally smaller than that of regular concrete. Certain additives (polycarboxylates) make the freshly mixed concrete highly flowable and compaction is achieved by gravity alone. Compaction behavior of the concrete is linked to particle size and shape. The more spherical the particles are shaped, the higher the flowability of the fresh concrete. This effect is more pronounced the finer the sand aggregate is and the less fine additives, like e. g. fly ash, are added (Fig. 1).

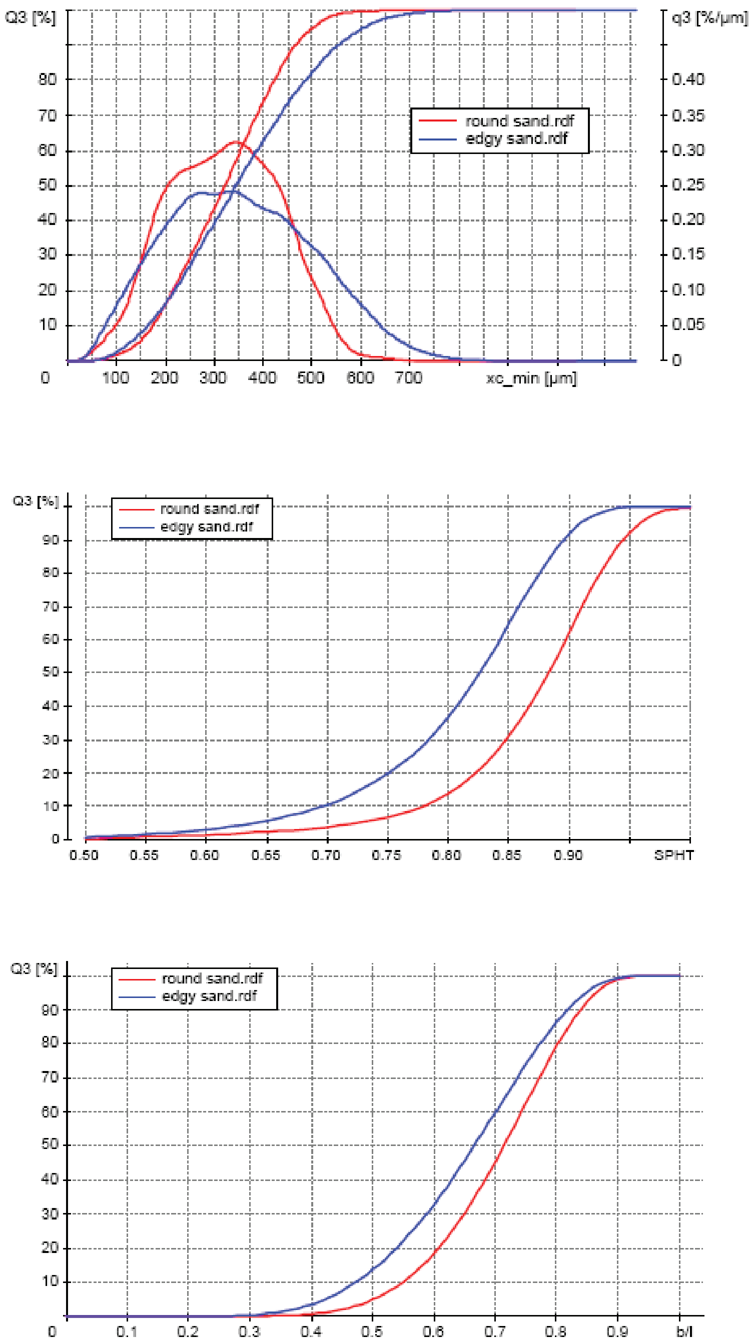

Figure 1: CAMSIZER measurement of one edgy and one rounded sand type. The samples are similar in size, but parameters b/l and SPHT show the different shape. The round sand provides much better flowability if added to concrete as an aggregate.

Filter sand

Sand is used as filter material in well sinking, drinking water abstraction and water treatment. Filter sand is mined out of open pits, then washed, dried and separated into different fractions in large screening plants. Typical fractions of filter sand available on the market (and the tolerances for over and undersized grains) are shown in table 1. The main reasons for the use of filter sand in water treatment or well-building are to guarantee a high pressureless water flow rate and to prevent particles from the surrounding soil (base soil) from washing out.

Generally speaking, if the ratio between the d15 of the filter material and the d85 of the base soil is smaller than 4, no significant amount of material will be washed out and flushed into the filtered water.

$$\frac{d15\ (\text{filter})}{d85\ (\text{base-soil})} < 4 \quad \text{(TERZAGHI's filter rule)}$$

There are other equations describing the relation between grain size and filtration behavior of two adjacent sediment types, but the one above is the most important one.

Since the filter sand is screened at defined mesh sizes, sieve correlation with the CAMSIZER is not easy and a fitting procedure must be established (Fig. 2). Generally speaking, wide distributions have a better sieve correlation than narrow, pre-screened distributions. Because the width of distribution is different for the individual fractions in Table 1, elementary fitting is mandatory.

Grain Size Mm		Allowed Percentage Undersize	Allowed Percentage Oversize
Sand	0.4 – 0.8 0.5 – 1.0 0.6 – 1.18 0.63 – 1.0 0.71 – 1.25	5	5
Sand	0.85 – 1.7 1.0 – 1.6 1.0 – 2.0 1.18 – 2.8 1.6 – 2.5	10	10
Gravel	2.0 – 3.15 2.36 – 4.75 3.15 – 5.6		
Gravel	5.6 – 8.0 6.7 – 13.2 8.0 – 12.5 12.5 – 16.0 13.2 – 26.0	15	15

Table 1: Typical grain sizes of filter sand and gravel

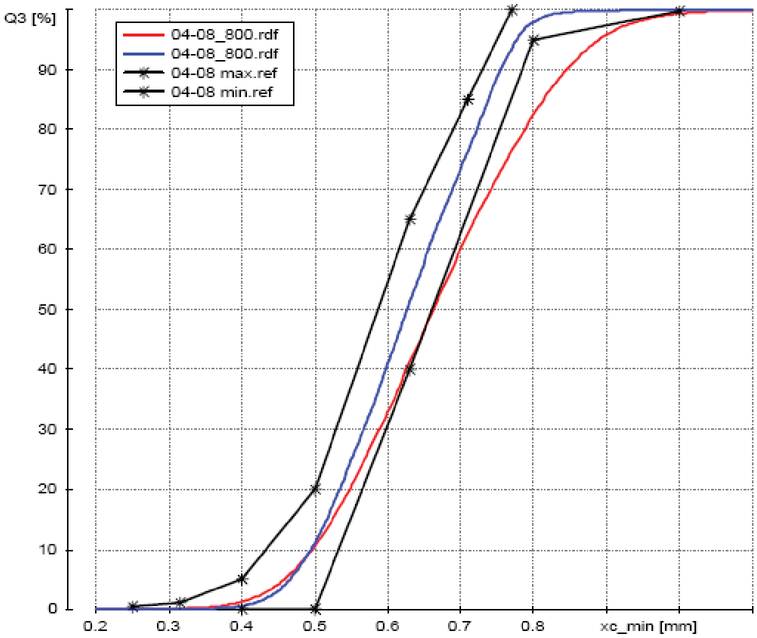

Figure 2: Measurement of filter sand 0.4 – 0.8 mm.
Red: CAMSIZER without fitting,
Blue: CAMSIZER with elementary fitting.
Black Curves: upper and lower product specifications.

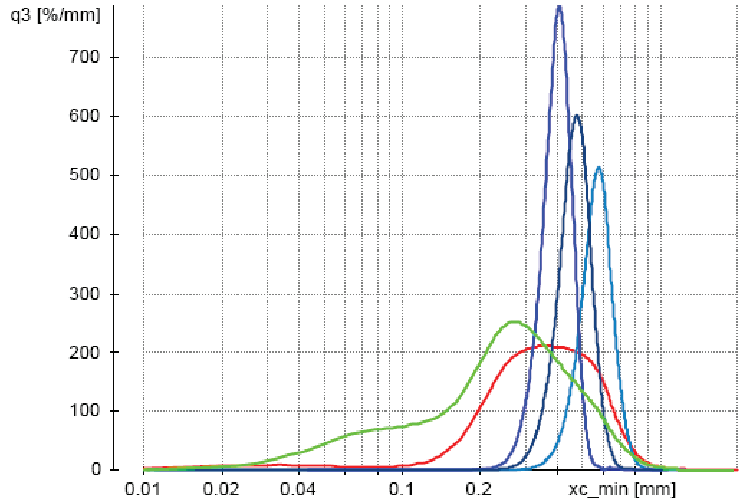

Figure 3: Green: Used sand containing fines and combustion residues. The sand is recycled, cleaned and mixed with new sand (blue) and is then used for new molds (red).

Blasting abrasive

Quartz sand can be used as blasting abrasive as well. Depending on the grain size, it is applied to different materials. Fine sand is used e. g. for glass surfaces, leather or sculpture. Medium grained abrasive is used for rock material, buildings, bridges and cleaning of concrete surfaces. Coarse material is used for large metal parts and laminations as well as for heavy machinery and large cast parts.

Sand molds

Foundries use sand molds for their casting. These molds are made of a mixture of sand and epoxy resin. The resin makes the mold stable, but combusts during the casting process. The porosity of the sand must be high enough to let the gas resulting from the combustion escape. The sand is recycled after casting and used for new molds. However, since the solid combustion residues are finer than the sand grains, they reduce the porosity of the whole mixture preventing the flue gas from properly escape during the next casting process. Therefore, new sand is added to the recycled material, increasing the bulk porosity. In order to make this mixing as efficient as possible, the size distribution of both the new sand and the recycled sand must be determined. The more solid combustion residue there is in the recycled sand, the more new sand has to be added (Fig. 3).

Glass sand

Sand used for glass making must be highly pure quartz (>99% SiO_2) and generally has a grain size of about 0.3 – 0.5 mm. Sand of this quality is very unlikely to be found in nature, so a very expensive and complex processing has to be carried out in order to separate non-quartz components from regular sand.

Glass is made by melting SiO_2 and then rapidly cooling it down, so the amorphous structure of the melt is retained at low temperature. (Slow cooling would lead to the formation of crystals). The melting point of pure SiO_2 is 1723 °C. Alkali oxides, nitrates or sulphates are added in order to reduce the melting point to 1,100 – 1,400 °C. CaO may be added as a stabilizer as well. Apart from the additives, the grain size also affects the melting behavior; it takes oversized particles longer to dissolve in the melt, which leads to longer processing times.

Silicon production

Silicon is a raw material needed for semiconductors, solar calls and electronics. It is extracted from natural quartz in an electric arc furnace. During the production process, SiO_2 is mixed with coal and heated. The SiO_2 transforms into SiO_2 gas at high temperature and reacts with the coal (carbon) to form liquid Si and CO_2.

Large quartz pebbles are used within the furnace because the high porosity allows good circulation of the SiO gas. The liquid Si is extracted from the furnace by tapping (similar to iron or steel production), cooled and crushed into fragments. The initial quartz pebbles might be too large for CAMSIZER applications, however, some customers use the CAMSIZER to monitor the size of the crushed raw silicon.

Conclusions

While the CAMSIZER provides improved accuracy, precision, and resolution over sieves due to the instrument's high resolution, sieve correlation is crucial for industrial applications. Nearly all size-dependant quality standards are based on sieve analysis results. Sand samples show characteristic deviations between CAMSIZER and sieving results because it is composed of edgy, sometimes slightly lenticular particles. This means, correlation is quite good for the fine side of the distribution (CAMSIZER may be a little bit finer if lenticular particles, e. g. mica, are present) and gets worse for the coarse side of the distribution where the CAMSIZER measurement shows bigger particle sizes. Because the width of distribution is not constant for different sand samples, an elementary fitting method has to be established for sand measurements.

Once the sieve correlation is established the user can benefit from the CAMSIZER advantages including:

- High sample throughput
- Reduction of workload
- Repeatability
- High accuracy
- Automated measurement, human errors eliminated
- Particle shape information
- Pictures of the particles

Figure 4: The CAMSIZER