A review of the quality of crushed rock aggregate based on NBRO test results

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ABSTRACT: Crushed rock aggregate is commonly used as coarse aggregate in concrete and asphalt production. Fine aggregate could also be produced from crushed rock and it is one of the suitable materials identified for use on alternative to river sand. This material usually has a high content of fines associated with clay size particles considered to be harmful in a concrete. However, if properly controlled, the fines in crushed rock aggregate could be used to advantage in improving the strength of concrete produced or in reducing the cement content.
NBRO test results show poor grading of coarse aggregate due to inefficient process control and the lack of application of standards. The need to implement standards is discussed.

1 INTRODUCTION

Crushed rock can be used to manufacture coarse aggregate as well as fine aggregate. In Sri Lanka almost the entire requirement of coarse aggregate has been produced from crushed rock and a need for an alternative did not arise. Although the rock quarrying and crushing industry has been in existence for many decades, the development that has taken place in this industry is very little compared to other local industries. As a result, the standards of production are inadequate to meet the requirements of the fast expanding construction industry in Sri Lanka.

Production and use of crushed rock sand as fine aggregate, although new to Sri Lanka, is quite common in many parts of the world. There are reports that this material has been used as an alternative to river sand in the Victoria Project. However, it came into focus rather recently when extraction of river sand became a problem.

In order to find suitable alternatives to river sand extensive research (and field studies) were carried out at that time (around 1999 to 2001), by many institutions including NBRO (National Building Research Organisation). Sand produced by rock crushing was identified as one of them; other alternatives identified were as follows:

i. Off-shore sand, the extraction of which requires a costly operation of dredging sand from deep sea and a large extent of land near the shore for stock piling the sand,
ii. Dune sand, which if extracted could cause other environmental problems,
iii. Land based pit sand from selected locations: This process also involves a costly washing operation and it is difficult to find a suitable source for mining which will produce a satisfactory yield.

High fines content invariably present in crushed rock aggregate was considered to be unsuitable for use in concrete because of the high water demand and the presence of clay size particles. Another disadvantage was the particle shape. Yet, crushed rock material, after removal of fines (by washing or other means) was successfully used as fine aggregate in concrete. (It should however be noted that quarry dust should not be used directly in concrete).

2 RESEARCH AND DEVELOPMENT

Recent research results in developed countries reveal that fines in aggregate could be used to advantage in concrete production to achieve the required strength with reduced cement content. Research has also shown that if fines could be used

to reduce voids in concrete, it will result in an increase in strength and reduction of permeability [1,2]. The conventional water to cement (w/c) ratio has therefore been replaced by 'water to cement plus fines (w/c+f) ratio' in the estimation of strength. According to research

- Properties of concrete could be improved by incorporating fines either in aggregate or in cement (the latter would be more suitable) and
- The content of clay size particles in the fines should be controlled

In fact, cement incorporating finely crushed lime stone is being manufactured even in Sri Lanka. Standards in most countries are now being revised in the light of new research findings and it is reflected in the new British and European standards on aggregates.

3 STANDARD SPECIFICATIONS

The Sri Lanka Standard Specification (SLS1397) for aggregate [3] was issued recently. It covers only fine aggregate for use in concrete and mortars. Most of the requirements specified in it have been derived from two British Standards- BS EN 12620 specifies the properties of aggregates (coarse and fine aggregate) for use in concrete [4] and BS EN 13139 specifies the properties of aggregates for mortar [5]. (Both standards are adoptions of the corresponding European standards). Since these standards are of recent origin, it has been the practice in the industry to examine the quality of aggregate (where necessary) in terms of the British Standard BS 882[6] (which preceded BS EN 12620 and BS EN 13139).

These standards (SLS 1397, BS EN 12620 and BS EN 13139) are applicable to aggregate obtained by processing natural, manufactured or recycled material and mixtures of these aggregates for use in concrete. There are many common features between the Sri Lanka Standard and the two current British Standards mentioned above. Important requirements specified in SLS 1397 and in BS EN 12620 (as applicable to crushed rock aggregate) are given below.

3.1 SLS 1397 Specifications

3.1.2 Grading:

Aggregate is designated in terms of lower (d) and upper (D) sieve sizes and expressed as d/D. This designation accepts the presence of some particles which are retained on the upper sieve (oversize) and some which pass the lower sieve (undersize). For fine aggregate, the undersize (d) can be equal to zero (but not necessarily so).

SLS 1397 gives four size designations: 0/1, 0/2, 0/4 and 2/4 out of which only the last two designations are applicable for fine aggregate for concrete. Sizes 0/1, 0/2 and 0/4 are applicable for sand used in mortar. The grading is based on the percentages of aggregate passing test sieves having aperture sizes corresponding to 2D, 1.4D, D for oversize and d, 0.5d for undersize.

This method of grading enables relatively easy process control. The aggregate producer should declare his grading results for any size designation and maintain the grading within specified limits. This will ensure uniformity in grading whenever new stocks of material are purchased. It is a user oriented feature that is very significant for ensuring quality.

3.1.2 Fines (Defined as the particle size fraction of an aggregate which passes the 0.063mm sieve):

Aggregate for applications in mortar are divided into five categories in terms of its fines content. In 'Category 4', a fines content of 30% (maximum) is permitted for use with crushed rock aggregate in mortars. The maximum value of fines content specified under Category 3, which excludes crushed rock aggregate, is 8%. Fines content in aggregate derived from crushed rock, used for concrete should be limited to 16% (with the exceptional limit of 9% for use in heavy duty floor finishes), whereas a maximum limit of 3% is specified for other types of aggregate.

It is clear that a higher limit of fines is permitted for crushed rock aggregate than other types.

3.1.3 Particle density and water absorption:

No limits are specified; but the producer is expected to conduct his own tests and declare the results.

3.1.4 Chemical requirements:

The limits that are specified for the contents of chlorides and sulfur are applicable to any type of aggregate. The standard also specifies that aggregates be tested to determine the effects of,

- Organic matter and other constituents which alter the rate of setting and hardening of mortar, and
- Alkali-silica reactivity.(These requirements are often ignored in assessing the quality of aggregate).

3.2 BS EN 12620 SPECIFICATIONS

The requirements specified in the above British Standard for grading, particle density and water absorption and for chemical requirements are very much similar to those specified in SLS 1397, except that

- A wider range of aggregate sizes are included
- Different types of aggregate (such as blast furnace slag) are provided
- The chloride content of aggregate is to be declared by the producer.

In respect of fines content, the British Standard makes provision for several categories (for different types of aggregate) to be declared by the producer. For fine aggregate, a category having a fines content exceeding 22% is specified. It also specifies a method for assessing the harmfulness of fines in fine aggregate.

It is to be noted that BS EN 12620 covers the properties of coarse aggregate, fine aggregate and filler aggregate whereas SLS 1397 is applicable only to fine aggregate. Some of the important physical requirements specified in the above British Standard for coarse aggregate are,

- Resistance to fragmentation
- Resistance to wear and
- Resistance to polishing and abrasion of aggregate to be used for surface courses

It also specifies durability requirements for freeze/thaw resistance, volume stability (applicable where required) and alkali-silica reactivity.

4 SIGNIFICANT COMMON FEATURES

There are many features common to the Sri Lanka Standard and British Standards beneficial to all stake holders.

4.1 Factory production control

This means that the aggregate production and processing should be carried out in a controlled manner to ensure conformity to the specifications given in the standard. The aggregate producer should follow specified procedures on quality management. Adoption of such a system would promote quality assurance and in order to do so the producer should have,

- The necessary knowhow on quality control and production control
- The resources required to do so, mainly in the form of simple testing equipment and qualified personnel
- Suitable plant and machinery which would enable the application of essential production controls (for example, the control of particle size and shape of aggregate).

4.2 User oriented classification

A system of classification / categorization based on the properties of the aggregate is specified in the standards. The producer should declare the appropriate category in accordance with the classification system on the basis of his test results.

This system would enable the purchaser to order a product according to his requirements and the producer to enhance his ability to meet customer requirements. It also provides flexibility in production and minimizes waste.

4.3 Promote product certification

Product certification or third party certification of quality (such as SLS marking) is not a mandatory requirement of the standard. However, when aggregate producers comply with factory production control requirements specified, they will be qualified to seek SLS product certification on their own.

4.4 Improve vendor – vendee relationship

The producer is expected to have a system of controlled production (auto controls), carry out in-house tests and declare the results of same to the purchaser. Thus the producer takes the responsibility for the quality of his products. It relieves the burden on the purchaser / user to carry out tests on aggregate before use.

5 PRODUCT QUALITY

The quality of aggregate (or that of any product) will depend primarily on the materials and machinery used and the management of resources.

5.1 Raw material

In Sri Lanka aggregate is usually produced from granite, or granite-gniesses. Aggregates produced from these materials have high strength, good resistance to abrasion and fragmentation and good surface characteristics with low absorption. Therefore it is important to make optimum use of these characteristics in aggregate production.

Other types of rock intrusions are usually encountered in mining and this gives rise to

appreciable variation in the properties of aggregate produced. Hence it is necessary to be aware of such variations and control the raw material quality.

5.2 Plant and machinery

Jaw crushers and cone crushers are mostly used in aggregate production in Sri Lanka. Most of the producers find it difficult to meet the requirements on particle shape and size of aggregate. However, production of rock crushing machinery and equipment overseas has undergone much transformation and development. Improved machines capable of controlling the aggregate shape and size factors are now available and such machinery should be utilized to provide quality assurance in aggregate production.

5.3 Production practices

Rock fines or quarry dust has been regarded as a by-product in the metal crushing industry. In view of scarcities of sand, this material has gained a high market value. Crushed rock sand has been correctly identified as an alternative to river sand. But unprocessed rock fines or quarry dust should not be regarded or marketed as crushed rock sand. Such a practice should be highly deprecated. Crushed rock sand or fine aggregate form crushed rock should be produced, in the same manner as other quarry products using appropriate machinery and production techniques.

5.4 Management

Good product quality cannot be assured even with the best of material and machinery unless there is proper management of resources. In Sri Lanka, aggregate production is carried out as a small or medium scale industry and quality management would be a new concept. Nevertheless it is an essential tool in assuring product quality.

5.5 Present situation

Aggregate production is carried out in many parts of the country. If a proper assessment of the quality aggregate is to be made, it would be required to carry out an island wide survey at rather high cost. However, a review of results of tests carried out at the NBRO will shed some light on the quality of aggregate produced in Sri Lanka.

Samples of aggregate and sand received from the clients of NBRO were tested at the Building Materials Laboratory to examine conformance to the relevant standards. A summary of the results of such tests carried out during the years 2011 and 2012 are given in the Annex.

6 INFERENCES

The following inferences may be made from the above study:

i. The high failure rate in respect of grading requirements for coarse aggregates arise from poor process control or inefficiency of the machinery used.
ii. The raw material quality (as indicated from AIV test results) is generally satisfactory for most applications including road works.
iii. Although only three samples were tested , fines content in crushed rock sand was within the specified limits even in present-day production. Improvements (such as on particle shape) could be effected with better equipment and process control.
iv. River sand is still being used to a large extent than other alternatives, perhaps due to the reason that such material is not being produced at the required scale.

A similar study on aggregate previously carried out (from samples tested at NBRO during the years 2008 and 2009) [7] showed that the rate of failure of coarse aggregate was even higher.

The results of the above studies clearly show the need for process control in aggregate production. The reasons for this unsatisfactory situation may be attributed to,

- Lack of commitment to quality by aggregate producers
- The inadequate knowledge on the subject by aggregate producers, most of whom are small scale entrepreneurs
- Poor management of resources
- High demand for the material in view of scarcities especially fine aggregate
- The aggregate producer not taking the responsibility for the quality of material supplied
- Very slow development of the industry in terms of modern techniques of production.

The ultimate outcome of the lack of process control or quality assurance will be detrimental to the overall economy because

- The construction companies will have to bear the additional burden of testing and assessing the quality of sand and aggregate prior to use
- Material purchased at a high price may be rejected if they do not conform to the specified quality levels

- Quality requirements which are vital from the points of view of safety, health and environment tend to be ignored.

7 RECOMMENDATIONS

Most of the cement based products used in construction work would contain a large proportion of aggregate. Hence the quality of aggregate is equally important or even more important in comparison to other materials. A significant improvement has been observed over the years in many other products such as cement, steel, roofing materials, tiles etc. and these materials are now being manufactured with certification of compliance to standards. However, a parallel improvement has not been observed in aggregate production. The quality of aggregate should actually be a matter of prime concern, especially in view scarcities.

The term 'customer satisfaction' is synonymous with quality. Customer-oriented features of the recently published standards were discussed in the preceding paragraphs and the implementation of these standards would be instrumental in providing the much needed quality assurance in aggregate production.

Such a step would bring in the following benefits to the industry:

- Sub- standard material being marketed will be controlled
- Production of alternative forms of fine aggregate/sand (other than river sand) would be encouraged.
- Engineers and construction companies could rely on the quality of aggregate and use alternative materials, such as crushed rock aggregate, with confidence.
- A system of quality certification could be introduced for the benefit of all stakeholders.

Proper implementation of standards cannot be done overnight or by way of regulations. Considering the rather primitive nature of aggregate production in Sri Lanka, standards should be implemented with careful thought and planning. Aggregate producers and new investors should realize the benefits of standardization and quality management and the authorities must step-in to ensure that such benefits are accrued by all stake holders. In order to accelerate this effort the government should consider,

- Giving tax concessions and other financial benefits to aggregate producers who could meet the requirements that would be stipulated regarding the quality and standards of production
- Providing know-how on modern techniques of production and process control and
- Providing training on management of materials, quality and environment to aggregate producers.

8 CONCLUSION

The Sri Lankan construction industry is at cross roads. Massive development projects tacking place in the country are facing obstacles in the form of restrictions on river sand mining, lack of alternative materials and escalating prices on one hand and poor quality aggregates on the other hand. These issues, unless urgently addressed will vitally affect the sustenance of the construction industry which is the main artery in the heart of development. We should leave no stone unturned in the efforts to achieve the ambition of being the wonder nation in Asia. Issues regarding the scarcity and the quality of sand and aggregate should be no exception.

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ANNEXE

NBRO Test Results

A summary of test results of coarse aggregate and fine aggregate produced by the Building Materials Research and Testing Division of NBRO from samples submitted by its clients is given in the following tables.

- Period of coverage : January 2011 to November 2012
- Analysis: Results of tests examined for compliance with BS 882: 1992 and tested in accordance with the methods stated therein.

Table 1: Description of the samples tested

Coarse Aggregate		Fine Aggregate	
Type	Number of samples	Type	Number of samples
20 to 5mm (graded)	40	river sand	26
20mm single sized	02	crushed rock	03
Other	07	Other	39
Total	49	Total	68

Table 2: Summary of the test results of fine aggregate

Test	Number of Samples tested	Compliance (No. of samples)				Non compliance	Remarks/ Compliance Requirements
Grading	68	Category				07	
		C	M	F			
		06	48	07			
Fines Content*	67	FI_3	FI_{10}	FI_{16}	FI_{20}	0	Maximum 16 for crushed rock aggregate Maximum 3 for other types
		60	07	0	0		
Organic Impurities	24	21				03	Organic impurities unlikely to occur in crushed rock

*Based on fraction passing 0.075mm size

Table 3: Summary of test results of coarse aggregate

Test	Number of Samples tested	Compliance (No. of samples)				Non compliance	Remarks/ Compliance Requirements
Grading 20 – 5 mm graded	40	16				24	
Grading Other size categories	09	04				05	
Flakiness	19	≤15	≤20	≤35	≤50	0	Maximum 35 for concrete grades 20 and above
		04	07	07	01		
AIV (Resistance for fragmentation)	48	≤25	≤30	≤40		0	Maximum 25 for heavy duty concrete floor finishes Maximum 30 for pavement wearing surfaces Maximum 45 for others
		15	28	05			

Observations

1. All fine aggregate samples (including the three samples of crushed rock sand) have complied with the requirements specified for the fines content (Maximum 16%). A high percentage of river sand samples had a fines content of 3% or less (f_3) indicating compliance with the relevant requirements specified.
2. A high percentage of coarse aggregate samples (approximately 60%) have failed in respect of grading.
3. All except one sample of coarse aggregate comply with the requirements or flakiness specified for use in concrete (grades 20 and above).
4. AIV test results indicate that 95% of crushed rock aggregate is suitable for use in road pavements (This indicates that the raw material quality is such as to produce aggregate with surface characteristics and high resistance to fragmentation.)