Urgent need for a new aggregate standard

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With restrictions on indiscriminate dredging of river sand and breaking of mountains there has been a growing need in civil construction industry for identification of alternate eco-friendly aggregates. Some of the feasible and economical solutions that have emerged in recent years are to reuse the industrial process wastes such as slags and recycled aggregates through reprocessing. In India use of alternative aggregates has never been popularized due to non-availability of codes, specifications, standards and guidelines. With ecological concerns and environmental restrictions, availability of natural aggregates is greatly reduced and most of the developed countries have amended their aggregate standards to allow alternative or artificial aggregates such as slags and recycled concrete, in roads and construction. Much of research has been carried out on various alternative aggregates, its testing, specifications and limit of applications. It is the time in India to change/amend the existing standards to include artificial and recycled materials as aggregates along with natural materials. This paper highlights the scope of alternative aggregates, their specifications and required amendments in the standards.

INTRODUCTION

Concrete is one of the most consumed material in volumes and India being a developing country will require concrete in huge proportions. Approximately three-fourths of the volume of concrete is occupied by coarse and fine aggregates. Coarse aggregates are presently sourced from breaking large rocks and mountains which has long term environmental impacts. Fine aggregate or sand is mined from river bed. River sand also is getting depleted and exhausted, and its excessive mining has lead to the ecological imbalance. In India the demand for aggregates is continuously increasing. As per recent estimate India will be consuming 3330 MT of total aggregates (coarse and fine) in 2015 [1] and will require 5075 MT of aggregates by 2020. With restrictions on mining of river sand and stone crushing there has been a growing need in civil engineering fraternity for identification of alternative aggregates. There are numerous works published [2-9] where blast furnace slag, steel slag, copper slag, ferro-nickel slag, electric furnace slag, crushed glass, fly ash aggregate, bricks, roof tiles, pottery, burned ash of garbage and sewage sludge, chopped plastics, mud, etc are utilized as alternative coarse and fine aggregates. However most of them have been limited to laboratories or demonstration projects. Some of the feasible and economical solutions that have emerged in recent years are to reuse the industrial process wastes through recycling or reprocessing. Still, the alternative aggregates were not regularly utilized in civil engineering constructions due to easy availability of natural materials, lack of awareness of its benefits, non-availability of guidelines, limited processing techniques, near availability etc, but most importantly, due to the restriction on usage of non-natural aggregates in the standards. With ecological concerns and environmental restrictions, availability of natural aggregates is reduced and most of the developed countries have amended their aggregate standards and allowed use of alternative or artificial aggregates as partial or complete replacement.

However, for a country like India, with wide ecological variations, it is also important while recommending the alternative materials, to understand the availability, sustainability and performance characteristics under local conditions as compared with those of naturally sourced extracted material. Many of the above listed aggregates vary in composition and properties w.r.t to source and processing. Since the overall performance and durability of the construction needs to be maintained, performance based limits for alternative aggregates must be specified. A number of industry and academically based research projects have been undertaken to ascertain performance limits for recycled, re-used and manufactured aggregates, and published guidelines for their specification [4,7,9]. The level of alternative aggregate substitution which is achievable will depend upon the properties of the aggregate, its availability in the market, the performance criteria of the mix, the whole-of-life sustainability of the product and the economic viability of its inclusion. Additionally, the quality and availability of large quantities of alternative aggregates is still an issue. Among the various alternatives experimented, the materials which are close to meeting the quantity demand of the aggregates are pyrometallurgical slags (specifically, iron and steel, copper and ferro-nickel slags) and re-cycled aggregates. These materials are available in large quantities, have been experimented for a long time, have established durability studies, do not have any environmental and safety issues and are consistent in quality. These materials must be first allowed in the standards. This paper highlights the scope of the promising aggregates to be included in Indian standards.

Table 1. Physical and mechanical properties of air-cooled BF slag and LD slag

Properties	Coarse aggregate specification	BF slag aggregate	LD slag aggregate
Total deleterious material	5	Nil	Nil
Aggregate crushing value			
Normal concrete	45	25 - 39	12 - 25
Wearing surface concrete (roads)	30		
Aggregate impact value			
Normal concrete	45	21 - 42	18 - 24
Wearing surface concrete (roads)	30		
Aggregate abrasion value (Los angeles machine)			
Normal concrete	50	5 - 31	10 - 15
Wearing surface concrete (roads)	30		
Density, kg/lt	1.4 - 1.7*	1.1 - 1.5	1.8 - 2.1
Sp. gravity	2.5 - 2.8*	2.4 - 2.7	3.4 - 3.7
Water absorption, %	1 - 3*	2 - 5	1 - 2
Hardness (Moh's scale)	3 - 4	4 - 6	6 - 7
California bearing ratio (CBR)	> 80	>100	> 200
Polished stone value (PSV)	> 58	50 - 63	53 - 72

Table 2. Properties of BF and LD slag sand

Properties	Fine aggregates specification	BF slag sand	LD slag sand
Total deleterious material	5%	Nil	Nil
Density, g/cc	1.4 - 1.7 *	1.1 - 1.5	1.8 - 2.1
Sp. gravity	2.5 - 2.8 *	2.4 - 2.7	3.4 - 3.7
Water absorption, %	1 - 3 *	2 - 5	1 - 2
Soundness			
Sodium sulphate	10	1.7	0.8
Magnesiun sulphate	15	2.08	0.92
Alkali reactivity	Nil*	Nil	Nil

* River sand

SUSTAINABLE ALTERNATIVE AGGREGATES

Many aggregates have been utilized in civil construction, but quantities are relatively small compared to the demand. The economic viability of the aggregates industry, and indeed the environmental sustainability of the industry depend on the right selection of alternative aggregates. Few environmental friendly and sustainable aggregates proposed to be included in the standard are discussed below.

Iron making and steel making slags

Iron and steel slags are an industrial by-product that is manufactured under extensive quality control and can be used as aggregates in civil construction. These contain no organic impurities, clay, shells, or similar materials and have uniform chemical composition. Slags can be used as both coarse and fine aggregates in mortar and concrete. Slag aggregates are comparable to natural aggregates in terms of strength and other property requirements and are extensively utilized in developed countries [10 -12] .

Allowing the molten slag to cool slowly in air or by water in an open pit produces the air-cooled slag in the form of large boulders. The air-cooled BF/LD slag is crushed screened and can be used as coarse aggregate for roads and bases, asphalt paving, railway ballast, landfills and concrete aggregate. Air cooled BF/LD slag exhibits similar mechanical properties as that of a natural aggregate such as good abrasion resistance, good soundness characteristics, high bearing strength etc. Physical and mechanical properties for BF/LD slag aggregates [4] are given in Table 1.

Water granulation (close system) and air granulation (open system) technologies is used by steel makers to granulate slags. The slag disintegrates and forms into granules having good stability, size, and shape control with high glassy content. The comparison of properties between granulated BF slag and granulated LD slag is shown in Table 2. These properties for the aggregates produced at M/s JSW were determined and checked in the laboratory being set up at the factory premises as well. Granulated slags can be used as 100% replacement of natural sand in concrete mix design if slag density is greater than 1400 kg/m^3 and as 50-75 % replacement for lesser densities. Low density granulated slags can be used in combination with river sand, manufactured sand and even crusher dust in concrete mix designs for all strengths. However, Low density granulated slags can be used as 100% replacement of natural sand in plastering applications.

In addition to density, some apprehensions were raised on presence of reactive form of minerals which can cause alkali aggregate reaction, volumetric instability in the presence of water and leaching behavior of heavy metals from slags. There has been numerous test reports published on the slags being innocuous and not showing any alkali aggregate reaction and any leaching behavior. But steel slags shows expansion when it comes in contact with water due to free lime and MgO and therefore all steel slags must be aged before using in construction activities and must be tested for expansion. The use of slag as aggregate reduces the need for virgin material, energy and polluting emissions generated during the mining, processing and transportation of that material. Ferrous slag has been already included in ASTM, JIS, EN standards.

Most of the papers confirm the usage of slags as replacement of aggregates up to 75 % and few up to 100%. This difference is due to the variation in the quality of slag and processing being used from different sources. Various tests conducted at a reputed steel company have confirmed that processed slags can be used as 100% replacement of natural aggregates in concrete mix design. Some of the steel test results in concrete using processed BF and steel slag as fine aggregates is shown in Table 3.

Here it is important to mention that optimization of slag processing parameters and adoption of innovative techniques for processing the slag to maintain the shape and structural consistency for use as aggregate in civil construction is quite important.

Copper slags

Copper slag is a glassy material, produced during matte smelting and copper conversion. It has been estimated that for every ton of copper production about 2.2-3 tons of slag is generated. Primary constituents in this slag are iron oxide and silica. The specific gravity of the slag is in the range of 3.5 to 3.9 depending on the source (as per our findings it is 3.9) and the bulk density of granulated copper slag varies between 1.70 to 1.90 g/cc which is almost similar to the bulk density of conventional fine aggregate. Its particle sizes are of the order of sand and have a potential for use as fine aggregate in concrete. The physical and mechanical properties of granulated copper slag shows that it can be used to make products like coarse and fine aggregates, cement, fill, ballast, roofing granules, glass, tiles etc. Key aggregate properties of copper slag are shown in Table 4. Addition of slag in concrete increases the density thereby the self weight of the concrete. Several studies have been carried out using copper slag as fine aggregate and found to have variable effects on the resulting concrete properties, depending on the sand replacement level and water to cement ratio.

Table 3. Compressive strength of concrete samples prepared using slags as fine aggregates

Sl. no.	Percentage replacement of natural aggregate	Compressive strength, (N/mm^2)	
		7 days	28 days
	Granulated BF slag as fine aggregate		
1	50	39	52
2	100	42.9	53.3
	Granulated steel slag as fine aggregate		
1	50	40.2	53.4
2	100	42.8	55.2

Table 4. Properties of copper slag

Properties	Copper slag
Total deleterious material	Nil
Density, g/cc	1.7 - 1.9
Sp. gravity	3.2 – 3.6
Water absorption, %	0.14
Chloride content, ppm	<15
Free moisture, %	<1
Angularity number	49
Fineness modulus of	3.47
Alkali reactivity	Nil

However most mixes with copper slag gave concrete with adequate properties, with the optimal sand replacements in the region of 30-60% [13-15]. Majority of the results of compression & split-tensile test indicated that the strength of concrete increases with respect to the percentage of slag added by weight of fine aggregate up to 40% of additions. A recent investigation [16] on the feasibility of using copper slag, as a partial replacement of sand in the preparation of pavement quality concrete (PQC) and dry lean concrete (DLC) mixes and concluded that a blend of stone dust with copper slag content up to 40% could be used as fine aggregate for PQC as well as DLC. The most recommended maximum percentage replacement of sand by copper slag is 40%. Due to low water absorption, coarser (in nature than sand) and glassy surface of copper slag the workability of concrete increases with increase of copper slag content in the concrete mixture. It is also claimed that concrete having copper slag is more dense, compact, free from pores and more impermeable than normal concrete. Use of copper slag in bituminous mixes also showed good interlocking and improved volumetric and mechanical properties. Acid resistance test showed that the concrete containing copper slag has a low resistance to H_2SO_4 and HCl solution. The leachant studies revealed that the addition of slag does not pave way for leaching of harmful elements like copper (Cu) and iron (Fe) present in slag in concrete and does not pose any environmental problems. The use of copper slag within the specified limits should be permitted as an eco-friendly replacement for river sand. Copper slag has been included in JIS standard in 1997.

Recycled aggregates

A huge amount of solid concrete waste is generated annually from construction and demolition activities. This has led to the promotion of reusing of recycled concrete aggregate (RCA) or recycled aggregate (RA) as a major measure to reduce waste and to mitigate the harmful effects of construction activities on the environment. RCA is one of the major construction wastes capable of being recycled and reused. Due to the ease of availability near to the construction site, especially in the cities, RCA can be an economical alternative aggregate. These aggregates are extracted by a relatively simple process involving breaking, removing, and crushing existing concrete into a material with a specified size and quality. The RCA in general are angular in shape and have a rough surface texture and hence provides a better interlock with aggregates and adhesion to cement paste. However, as extracted by crushing the hardened concrete, their properties are not same as those of the natural (virgin) aggregates. The properties of RCA are shown in Table 5.

Relatively inferior properties of the RCA are primarily due to presence of adhered mortar. It is mainly the quantity of adhered mortar which influences to a large extent the engineering, mechanical and durability properties of the aggregate. These limitations have to be taken into consideration when RCA is used in any concrete so that the associated problems can be minimized at the design stage itself. There are many studies that prove that concrete made with this type of coarse aggregates can have mechanical properties similar to those of conventional concretes. Several guidelines have been published for the use of RCA for use as replacement of natural aggregates without compromising on the final quality of the construction. The workability of RCA concrete can be improved by pre-wetting the aggregate, use of aggregates coated with poly vinyl alcohol, reduction in water cement ratio of concrete, using supplementary cementitious materials like fly ash, silica fume, GGBFS, adopting two stage mixing or three stage mixing, increasing the powder content of mix and use of super plasticizer. It has been found that workability of concrete with natural and recycled aggregate is almost the same if water saturated surface dry recycled aggregate is used. Also, if dried recycled aggregate is used and additional water quantity is added during mixing, the same workability can be achieved after a prescribed time. Several independent studies [17-19] have reported that the properties of concrete do not change substantially when RCA is used in the range of 20 - 30% as a replacement of natural aggregates. RCA has been successfully used in large proportion in roads, concrete kerb and gutter, pavement section, and as base and shoulder material. The application of RCA has been started in a large number of construction projects of many European, American, Russian and Asian countries. Many countries are giving infrastructural laws relaxation for increasing the use of recycled aggregate. RCA has been included in ASTM, JIS, Australian, Korean and British standards with critical specifications. With proper understanding of behavior of recycled aggregate and adoption of necessary precautions, recycled aggregate can find a considerable usage in construction reducing the dependence on natural aggregates.

Table 5. Recycled concrete aggregate properties

Properties	Recycled concrete aggregates
Shape and texture	Angular with rough surface
Water absorption, %	3.7 – 8.7
Specific gravity	2.1 – 2.4
L. A. abrasion, %	20 – 45
Sodium sulfate soundness, %	18 – 59
Magnesium sulfate soundness, %	1 – 9
Chloride content, kg/m3	0.6 – 7.1

Table 6. Indian standards for aggregates

Application	Specifications	Sources of materials allowed
Concrete (Structural and Roads)	IS 383 (1997): Specification for coarse and fine aggregate from natural sources for concrete	Crushed or uncrushed, derived from natural sources, such as river terraces and riverbed, glacial deposits, rocks, boulders and gravels,.
Masonry mortar	IS 2116 (1980): Specification for sand for masonry mortars	Naturally occurring sands, crushed stone sands and crushed gravel sands
Plaster	IS 1542 (1992): Specifications of sand for plaster	A fine aggregate which is either natural sand crushed stone sand or crushed gravel sand.

Lack of specifications / standards discourages a practicing engineer to adopt these new material for construction. All these materials in its produced form may not be suitable for direct usage and must be manufactured or processed for meeting the requirement of aggregates. Hence all such materials can be categorized under the term "manufactured aggregates" for introduction into the standards. Carrying out research and generating sufficient experimental data is the only way forward which leads to development of specifications or guidelines.

AMENDMENT IN STANDARD

IS 383 [20], IS 2116 [21] and IS 1542 [22] are the primary standards for aggregates to be used in concrete, mortar and plaster respectively. These standards laid down by the Bureau of Indian Standards; stipulate that concrete/mortar/plaster can be made only with "natural material" as shown in Table 6. These standards are also widely referred in other standards applicable for different applications like roads (MORTH specifications), concrete (IS 456 and IS 10262) and masonry mortar (IS 2250) etc.

Use of slags is remotely allowed in only two Indian standards IS 456 [23] (as second preference aggregate in addition to fly ash and crushed over-burnt bricks and tiles, without specifications) and IS 9142 [24] (as light aggregate for masonry work) but with little clarity and is rarely followed. No other alternative aggregate is allowed in any of the standards. Thus the primary standards used in India do not include other aggregates derived from artificial or recycled materials and hence does not permit the users to use alternative aggregates. Whereas, most of the global standards specifies the properties of aggregates and filler aggregates obtained by processing natural, manufactured or recycled materials and mixtures of these aggregates making it an important construction material.

IS 383 was originally drafted from British standards, which has now been modified in 2004 under EU to include artificial and recycled materials as aggregates. This has also been done in most of the developed countries. The applicable standards in different countries for various applications are presented in Table 7. It is therefore recommended to include

Table 7. Global specifications for aggregates

Country	Standard	Description
European Union (EU)	EN-12620 / EN 13139	Natural, manufactured & recycled materials for concrete/mortar [25]
	EN 13242	Aggregate for civil and road construction [26]
USA	ASTM C-33/C33M-13	Natural, manufactured or a combination, recycled aggregate [27]
	ASTM D – 5106	Steel Aggregates for Bituminous Paving mixtures [28]
	ASTM D –2940	Graded Aggregates for highways and Airports [29]
Australia	AS2758.1 -1998 Part-1	Aggregates and rock for engineering purposes [30]
	HB 155 (2002)	Standards Australia. Use of recycled concrete and masonry materials [31]
Korea	KS F 2573. (1999)	Recycled Aggregates for Concrete", Korean Industrial Standards [32]
Hong Kong	WTBC (2002)	Specifications facilitating the use of recycled aggregates [33]
Japan	JIS A 5015	Iron and steel slag for road construction [34]
	JSTM H 8001	Crushed Steelmaking Slag for Civil Engineering Works [35]
	JIS A 5011-1	Slag aggregate for concrete - Part 1: Blast furnace slag aggregate [36]
	JIS A 5011-3	Copper slag aggregate [37]
	JIS A 5021/5022/5023	Recycled aggregate for concrete [38]

manufactured aggregates into IS 383 defining as aggregates of mineral origin resulting from an industrial process involving thermal or other modification and recycled aggregates. The permissible replacement ratio of these alternatives aggregate must also vary according to the performance required for concrete (plain concrete and reinforced concrete).

BS:1047 "Air cooled blast furnace slag for use in construction" was the first standard allowing other than natural materials in construction. Several amendments have taken place thereafter in British and European standards. Japan has been the front runner in adopting alternative aggregates in construction. In 1977 blast furnace slag coarse aggregate for concrete and in 1981 fine aggregate were standardized by JIS. Ferro-nickel slag fine aggregate was established in 1992 and JIS for copper slag fine aggregate was established in 1997 followed by electric furnace slag in 2002. Similarly many aggregate standards have been amended in Australia and USA or special standards have been formulated to utilization of slag and recycled aggregates.

ADDITIONAL REQUIREMENTS FOR MANUFACTURED AGGREGATES

Amended standards should include comprehensive and specific requirements for iron and steel making slag, copper slags and recycled aggregates [39-40] in addition to the property requirements of natural aggregates, due to inherent specific property variations during processing such as the stability of certain basalts, the expansion of certain slags and the constitution of recycled aggregates. Some of the key additional requirements in addition to its composition, to be included and their testing standards are enlisted below.

- Particle density: The Particle density of manufactured materials shall be greater than 2100 kg/m3 as measured in accordance with IS 1963 (part-3) (AS 2758.1)
- Bulk density: The compacted Bulk density shall be greater than 1200 kg/m3 as measured in accordance with IS 1963 (part-3) (AS 2758.1))
- Water absorption: Water absorption shall be less than 5.0% as measured in accordance with IS 1963 (part-3). It is recommended that the aggregates are pre wetted prior to commencement of mixing process(JIS+AS2758.1)
- Iron unsoundness When chemical analysis of the aggregate shows that the ferrous oxide content equals or exceeds 3 percent and the sulfur content equals or exceeds 1.0 percent, the aggregate should be tested for iron unsoundness(AS-2758.1)
- Immersion expansion ratio: The immersion expansion ratio shall be tested as per A5015 shall not be more than 2.0%.
- Alkali Aggregate Reaction: Some aggregates containing particular varieties of silica may be susceptible to attack by alkalis (Na_2O and K_2O) originating from cement and other sources. The aggregate shall comply in accordance with IS 2386.

Also, many standard test methods developed for natural aggregates have to be revised or changed (such as Magnesium/sodium sulphate soundness, aggregate expansion) in order to give relevant results when used with alternative aggregates. On the other hand, most standard test methods can still be referred to without any change, e.g. particle size distribution, water absorption, resistance to fragmentation (LA), impact etc.

All aggregates in the market must meet the requirements of national standards and specifications related to both technical and environmental aspects with regard to its intended use. The lack of clarity in the Indian Standards has been the prime bottleneck for limited use of alternative materials in India. It is therefore necessary to change/amend the existing standards in India to include artificial and recycled materials (especially pyrometallurgical slags and recycled concrete) as aggregates along with natural materials to increase the resource base for aggregates. As slags and other alternative materials generated from different industries with different processing facilities, might possess different properties, additional qualifying tests as suggested above must be carried out to ascertain their long term effect on environment if any. This will help in easier implementation of regulations for effective use of wastes from industries and construction debris, which are available in sufficient quantities to meet the requirements. This will help in controlling illegal and rampant mining of natural resources which causes disastrous impact on environment and economy. The paper suggests that a strong commitment and investment by government bodies as well as private bodies make this necessary for sustainability.

CONCLUSIONS

Pyrometallurgical slags and recycled aggregates are economically viable and environmentally acceptable alternative material for replacing natural aggregates in roads and civil constructions. Effective utilization of these materials has tremendous economic impact, conservation of natural resources and gainful recycling of process byproducts. This can happen only when the standards are amended to include alternative materials with proper specifications. Industry must process and convert by-products into aggregates acceptable by construction industry. Also the construction fraternity must amend the standards and develop guidelines for usage of these environmentally friendly materials in various applications.

Additionally, once the guide lines and the codes of practices are made available, then it becomes the responsibility of the practicing engineers and as well as the professional organizations to utilize and promote the use of such alternative aggregates in the production of concrete keeping in mind the ill effects of aggregate mining and from the point of view of sustainability.

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