ASSESSMENT OF RECYCLED AGGREGATE CONCRETE

Parekh D. N. and Dr. Modhera C. D.

Address for Correspondence
1Research Scholar; Applied Mechanics Department; Sardar Vallbhbhai National Institute of Technology; Surat; Gujarat (India);
2Professor and Dean (P & D); Applied Mechanics Department; Sardar Vallbhbhai National Institute of Technology; Surat; Gujarat (India)
Email: divyaparekh@yahoo.com; cdm@amd.svnit.ac.in

ABSTRACT
Use of recycled aggregate in concrete can be useful for environmental protection and economical terms. Recycled aggregates are the materials for the future. The application of recycled aggregate has been started in many construction projects in many European, American and Asian countries. Many countries are giving many infrastructural laws relaxation for increase the use of recycled aggregate. Paper reports the basic properties of recycled fine aggregate and recycled coarse aggregate. It also compares these properties with natural aggregates. Basic changes in all aggregate properties were determined and their effects on concreting work were discussed at length. Similarly the properties of recycled aggregate concrete were also determined and explained here. Basic concrete properties like compressive strength, flexural strength, workability etc are explained here for different combinations of recycled aggregate with natural aggregate. Codal guidelines of recycled aggregates concrete in various countries were stated here with their effects, on concreting work. In general, present status of recycled aggregate in India with their future need and its successful utilization were discussed here in detail.

KEY WORDS: Recycled aggregate, secondary aggregates, sustainability, appropriate use, concrete.

INTRODUCTION
Recent research by the Fredonia group has established that the global demand for construction aggregates may exceed 26 billion tones by 2011[1]. Leading this demand, are the single user: China (25%), EU (12%) and the USA (10%). However, because of industrialization and significant infrastructure and construction development, there are expected to be significant increase in use of aggregates in India (which is already one of the major national markets at 3%) beyond 2011. In India, about 14.5 MT of solid wastes are generated annually from construction industries, which include wasted sand, gravel, bitumen, bricks, and masonry, concrete. However, some quantity of such waste is being recycled and utilized in building materials and share of recycled materials varies from 25% in old buildings to as high as 75% in new buildings [2,3].

Hence the subject of concrete recycling is regarded as very important in the general attempt for sustainable development in our times. In a parallel manner, it is directly connected with (a) increase of demolition structures past out of performance time, (b) demand for new structures and (c) results—of destruction by natural phenomena (earthquakes, tsunami etc.). [4] Construction & Demolition (C&D) wastes are normally composed of concrete rubble, bricks and tiles, sand and dust, timber, plastics, cardboard and paper, and metals. Concrete rubble usually constitutes the largest proportion of C&D waste. It has been shown that crushed concrete rubble, after separation from other C&D waste and sieved, can be used as a substitute for natural coarse aggregates in concrete or as a sub-base or a base layer in pavements [5-8]. This type of recycled material is called recycled aggregate. [9]
CONCRETE AND THE ROLE OF THE AGGREGATE

Regarding concrete, which is the construction material of our era, the protection of the environment concerns three basic axes.¹⁻⁴

- Use of high amounts of raw materials (aggregates for the production of cement and concrete) which result in the decrease of available natural resources which is continuously sub-graded.
- Consumption of high amounts of energy for the production, transport, use of raw materials and final ones, as cement and concrete.
- Creation of big volumes of old concrete from old construction works (demolition wastes).

The cementing medium has two main functions.

1. To fill voids between aggregate particles providing lubrication of the fresh (plastic) concrete and water tightness and durable structure in the hardened concrete
2. To give strength to hardened concrete

The aggregate in concrete has three main functions.

1. To provide a relatively cheap filler for the cementing material.
2. To provide a mass of particles which are suitable for resisting the action of applied loads, abrasion the percolation of moisture and the action of the weather.
3. To reduce the volume changes resulting from the setting and hardening process and from moisture changes in the cement paste.

Aggregate comprise 70 to 80% of the volume of concrete and exert a significant influence on concrete properties. Generally, they are granular material derived from natural rock or natural sands and gravels. However, one of the fact that has made concrete, the world’s most widely used construction material is its ability to absorb a wide range of quality of materials, including recycled and industrial by products, as a component of the aggregate (and cement).

In selecting aggregate for use in concrete certain constituents should be avoided. For example, reactive silica leads to deterioration of concrete if moisture and alkali are present; weak friable aggregate should not be used if hardness is desired concrete property; and a highly porous aggregate is potentially unsuitable with respect to aggressive permeation – based deterioration processes (e.g. chloride ingress and carbonation). Some of these properties are directly dependent upon the parent rock whilst others are not. For example, those dependent on parent rock are chemical and mineralogical descriptions, petrographic description, specific gravity, strength, hardness, and color, whilst, surface texture, size and shape are independent of parent rock.

The simplest and most common method for characterization of aggregate is on the basis of the specific gravity, i.e. (i) normal weight (ii) light weight and (iii) heavy weight. Further characterization may be achieved using the following: grading, shape, inclusion, bulk density, water absorption, chemical composition and drying shrinkage.

NECESSITY FOR THE RE-USE OF RCA

Due to issues relating to sustainability and limited natural resources, it is clear that the use of recycled and secondary aggregates (RSA), for example crushed concrete and asphalt and industrial byproducts such as fly ash and blast furnace slag, will grow. However, currently, it is only in the USA, Japan, parts of Western.
regulations have been sufficiently put in place that the use of RSA exceeds 10% of the total aggregate usage. Consequently, worldwide the use of RSA stands at approximately 750 million tones. (<3% of total aggregates use). Sustainability is generally recognized as a foundation for resource and energy-saving technology developments in many fields including that of construction.

The term ‘sustainable construction materials’ has increasingly been adopted throughout the concrete industry; but usually incorrectly as a synonym for recycled materials. Since recycled materials do not necessarily mean greater sustainability, since they in turn require energy to produce, it is perhaps better to not use this term and instead consider the appropriate use of materials for both performance and function.[10]

The main reasons for the increase of this volume of demolition concrete waste are:

- Many old buildings and other structures have over-come their limit of use and need to be demolished;
- Structures even adequate to use are under demolition because there are new requirements and necessities;
- Creation of building wastes which result from natural destructive phenomena (earthquakes, storms etc).

In spite of that concrete demolition waste has been proved to be an excellent source of aggregates for new concrete production. 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 and even high-strength concrete is nowadays a possible goal for this environmentally sound practice[11–13]. However, the fine fraction of these recycled aggregates has not been the subject of thorough similar studies since it is believed that their greater water absorption can jeopardize the final results. The results of several studies presented in the past have caused the existing codes concerning recycled aggregates for concrete production to strongly limit the use of these products[14–16].

**CURRENT KNOWLEDGE BASE ON THE USE OF RECYCLED AGGREGATES IN CONCRETE**

Regarding that the quality data of old concrete is often unknown (w/c ratio, kind and amount of admixtures, aggregates origin and gradation, etc.), as well as the differentiation of its properties during its performance time, the knowledge and tests of RCA should refer to four categories:

(a) Historical data of RCA referring to the composition of old concrete, masonry etc. petrography characteristics, data of old structures.

(b) Physical characteristics, especially in water absorption, specific gravity, amount of chlorides and sulphates, amount of contained foreign ingredients, possibility of creation of alkali–silica reaction.

(c) Mechanical characteristics, testing resistance to abrasion/degradation by the use of L.A. machine, percentage of soft granules.

(d) Environmental characteristics, especially in cases where RCA seem to create “leachates”.

There were a number of seminal works on use of recycled aggregate in concrete prior to 1996, it was from 1996 until 2002 that the main knowledge base on use of recycled concrete aggregate (RCA) was formed since at that time these materials reflected the highest and most consistent quality of all recycled aggregates available.

Mobile crushers whilst often more economical in that they avoid transporting C&D waste...
away from site, are rarely sophisticated enough to remove all impurities. Therefore, recycled aggregates produced from mobile crushers are usually used as fill or capping layers, and used at, or close to the location that they were crushed. In contrast, recycled aggregates from central recycling facilities undergo a number of processes to ensure higher quality. This may include: magnets, picking stations, (although these are becoming rare), trash screen, screens, log washers, water pumps and sludge tanks. Furthermore, central recycling facilities take great care to control the type of C&D waste that is allowed to be stockpiled. Impact crushers are beneficial as they give RA a more rounded shape which aids engineering performances.

Soil, silt and clay can be particular problems and care is usually taken to avoid these materials entering the C&D waste stream at source. On site, contractors use a scalping screen ahead of the primary crusher to remove soil and clay balls; whilst washing plants, are able to rely on the soil and clay being removed during washing processes. Furthermore, innovative methods, for example the creation of filter cakes for use in drainage are used to avoid the resulting soil, silt and clay being directed to landfill.

In Japan, there have been attempts to further improve the quality of recycled aggregate via, for example the methods briefly stated below.

1. **HEATING AND RUBBING**: whereby the recycled aggregates are heated to 300°C to remove weaker mortar and cement particles from the aggregate.

2. **ECCENTRIC – SHAFT ROTOR METHOD**: in which the recycled aggregates are passed between two cylinders eccentrically rotating at high speed which separates coarse aggregates from mortar via a grinding effect, and

3. **STRAIGHTFORWARD MECHANICAL GRINDING**: In which aggregates are placed in a rotating drum containing iron balls.

Only a few cases have been reported on the use of recycled aggregates in structural concrete, and the amount of recycled aggregate used has generally been limited to a low level of replacement of the total weight of coarse aggregate.

An example is a viaduct and a marine lock project in the Netherlands in 1988, and an office building in the UK in 1999 \[17\]. In the first case, a total of 11,000 m³ of concrete in which 20% of the coarse aggregates were replaced by recycled aggregates were used in all parts of the structures. Another reported case involved the use of 4000 m³ of ready mixed concrete, which was prepared with recycled aggregates obtained from crushed concrete railway sleepers to replace 40% of the coarse aggregates \[17\].

The limited use of recycled aggregate in structural concrete is due to the inherent deficiency of this type of material. In comparison with natural normal weight aggregates, recycled aggregates are weaker, more porous and have higher values of water absorption. The results of research studies show that when recycled aggregates obtained from crushed concrete are used to replace up to 20% by weight of the coarse natural aggregate in concrete, little effect on the properties of concrete is noticed \[18\].

**MIX PROPORTIONS**

The compressive strength increased with a decrease in a/c ratio and is directly proportional to strength of the blended aggregate. \[19\]
However, when used at a higher level of replacement, the high water absorption ability of recycled aggregate results in a higher total water demand. This renders the control of the free water-to-cement ratio (w/c) and the workability of fresh concrete difficult and, results in a higher shrinkage and creep of the hardened concrete when compared with the concrete prepared with natural aggregates. The extent to which the properties of concrete are affected by the use of recycled aggregate depends on the water absorption, crushing value and soundness of the recycled aggregate.

**STRENGTH AND DEFORMATION CHARACTERISTICS**

It was concluded that concrete strength decreases when recycled concrete was used and the strength reduction could be as low as 40%\(^{[22, 23]}\). However, no decrease in strength was reported for concrete containing up 20% fine or 30% coarse recycled concrete aggregates, but beyond these levels, there was a systematic decrease in strength as the content of recycled aggregates increased\(^{[24]}\). The strength characteristics of concrete was not affected by the quality of recycled aggregate at high water/cement ratio, it was only affected when the water/cement ratio is low\(^{[25, 26]}\). The higher the water/cement ratio, the less reduction in compressive strength\(^{[23–25]}\).

However a conservative value for replacement of aggregate is 20% by mass was later adopted in BS 8500-2\(^{[27]}\). The reason for the loss in strength is usually associated with (i) the weaker interfacial transition zone between aggregate and mortar, due to the aggregate having a coat of weak mortar already attached and (ii) this attached mortar raising the porosity of the concrete.

Whilst research has shown that fine RCA could be used in very low quantities it tends to cause difficulties with the stability of the mix and the strength of the resulting concrete\(^{[24]}\). For these reasons BS 8500 – 2 does not permit use of fine RCA in concrete\(^{[27]}\). However, it should be noted that as fine RA contains significantly lower quantities of ‘cement dust’, its use as fine aggregate is of considerably greater potential. In general, the flexural strength and modulus of elasticity of RCA and RA concrete have been reported to be proportional to compressive strength\(^{[28]}\). RCA and RA concrete tend to have higher levels of drying shrinkage than natural aggregate for the same compressive strength. Furthermore, there are very few examples of RA concrete with shrinkage levels that fall outside the upper limit of 0.075% permitted for aggregates in BS EN 12620. In addition, it should be noted that some tests have shown RA concretes to have lower shrinkage than equivalent RCA and NA concretes\(^{[29]}\). There is limited research on the effect of recycled aggregate concrete on creep. However, as creep may be related to the elastic modulus of the aggregate, and in turn the elastic modulus of concrete, in general, results suggests that creep is higher in recycled aggregate concrete than equivalent natural aggregate concrete\(^{[29]}\).

**DURABILITY**

In contrast, many tests for carbonation have shown that the carbonation depth (for concretes of equal compressive strength) after a given length of exposure decreases as the recycled aggregate content of concrete increases, i.e. recycled aggregate concrete has better resistance to carbonation than natural aggregate concrete\(^{[30]}\).

It has been purported that this is due to the fact that recycled aggregate concretes have higher
cement content in order to achieve a given strength. Thus the alkaline reserve acts to protect the concrete surface against carbonation mechanisms. It was noted, however that the best performance overall in terms of carbonation was for concretes with a RA content of between 20 and 50% by mass. Thus there is probably an optimum in terms of balancing the increased alkaline reserve and the increased porosity when using RA in concrete. Tests on air – entrained recycled aggregate concrete used at up to 100% by mass of coarse aggregate have been shown to give good freeze – thaw scaling resistance (56 day scaling , 0.5kg/m²) and to perform similarly to air – entrained natural aggregate concretes. No research has reported any deleterious effect of recycled aggregates on the long – term resistance to sulphate attack of concrete. Abrasion resistance of recycled aggregate concrete has been assessed using an accelerated abrasion method[24]. For concretes designed for equal strength, the results show that there is a tendency for abrasion resistance to reduce as recycled aggregate content increases; up to 1mm difference being recorded between the natural aggregate and 100% recycled aggregate concretes. However, up to 30% by mass of recycled aggregate as coarse aggregate there is only a small difference in abrasion resistance (approximately 0.2 mm), and this is within test repeatability. The abrasion resistance seems to increase with the replacement of fine natural with fine recycled concrete aggregates.

CURRENT STANDARDS FOR RECYCLED AGGREGATES
EUROPEAN (CEN) PRACTICE
EU have expanded since 2002 due to the introduction of the European standard for aggregate for the concrete, BS EN 12620, which defines natural, manufactured and recycled aggregate as
- Natural aggregates, are from mineral sources and subject to nothing more than mechanical processing,
- Manufactured aggregates are of mineral origin resulting from industrial process involving thermal or other modification and
- Recycled aggregate, result from the processing of inorganic material previously used in construction.

However BS EN 12620 provides no guidance on how these different aggregates may be used in 2008, an amendment was made to BS EN 12620 to introduce a number of categories for coarse recycled aggregate based on the proportions of unbound stone (Ru), crushed concrete (Rc), Crushed masonry (Rb), bituminous material (Ra), Glass (Rg), floating material (FL) and other constituents (X). BS 8500 – 2 which defines the constituent materials that may be used in concrete in recycled and manufactured aggregates[27]. However, it classifies recycled aggregates differently to that of BS EN 12620 as RCA and RA.

RCA is obtained from crushing demolished concrete structures, discarded precast elements and unused hardened concrete, and by definition (BS 8500 – 2) it must be predominately composed of concrete (at least 83.5% by mass) with no more than 5% masonry.

JAPANESE (JIS) PRACTICE:
They have recognized that composition of recycled aggregate does not necessarily reflect performance capability. Japanese standards associations are introducing specifications for three standards of recycled aggregate for concrete. JIS A 5021,
established in 2005, is the standard for high-quality recycled aggregate (H) for concrete. JIS A 5023 has also been introduced as a standard for recycled concrete using low-quality recycled aggregate (L), as permitted for use in backfilling, filling and leveling concrete. An additional requirement is that recycled aggregate L be used with blended cements as a measure against alkali–silica reactivity. JIS A 5022 will provide requirements for “normal” recycled aggregates.

INTERNATIONAL EXPERIENCE ON RCA

The research produced general guidance supporting the wider use of recycled aggregates in concrete as well as grouping aggregate particle composition into three classes of recycled aggregate suitable for different applications, as given below.

- **Class A**: recycled aggregates for use in a wide range of concrete including marine environments,
- **Class B**: covering most combinations of natural and recycled aggregate and suitable for most ‘moderate’ exposure conditions, and
- **Class C**: those aggregates suitable for only the ‘mildest’ exposure conditions.

The rapid development in research on the use of RCA for the production of new concrete has also led to the production of concrete of high strength performance. It should be noted, of course, that the use of coarse RCA (up to 30%) is normally recommended but the addition of superplasticizer is often considered necessary for achieving the required workability of new concrete. Three types of RCA are specified by RILEM:

- **Type I** which consists primarily from masonry rubble.
- **Type II** which consists primarily from concrete rubble.
- **Type III** which consists of a blend of recycled aggregates (max. 20%) and natural aggregates (min. 80%).

An alternative way of classifying the composition of recycling aggregates is by density RILEM proposed the use of dense medium separation (ASTM C 123) to exclude too many of the lighter weight materials e.g. not more than 10% with SSD density less than 2.200 kg/m³. BRE Digest 433 takes as its basis the above RILEM specification and specifies the following classes:

- RCA (I), origin: brickwork, brick content (by weight): 0–100%.
- RCA (II), origin: concrete, brick content (by weight): 0–10%.
- RCA (III), origin: concrete and brickwork, brick content (by weight): 0–50%.

ECONOMICS AND BEST PRACTICABLE OPTIONS FOR RCA

The main alternative to using recycled aggregates is, of course, natural aggregate and these are still relatively low cost materials. However, in a purely economic balance, the cost of processing to recycled aggregates in the UK is becoming less than that of disposing of the demolition waste and purchasing new aggregates, due to increases in landfill tax and the newly introduced aggregates levy. If recycled aggregates have to be transported a significant distance from the place of production to the place of use, then both the cost and environmental benefits may become more questionable.

In India, the cost of construction materials is increasing incrementally. As a result, in India, the informal sector and secondary industries recycle 15–20% of solid wastes in various building components.
THE WAY FORWARD

The challenge for the future is,

- For researchers, to become much more pragmatic and realistic in their approach.
- Government bodies, to invest more liberally in research where the perceived deliverables are attainable and workable.
- Concrete and aggregates producers, to engage actively in research and thereby help to achieve the desired results.
- End users, to actively seek opportunities to put research into practice.

CONCLUDING REMARKS

This paper has shown that:

- There is significant potential for growth of recycled and secondary aggregates as an appropriate and “green” solution to the anticipated increased world – wide construction activity and with it the demand for RSA.
- Major research world – wide has shown that RA can be used in concrete – and that there are few (if any) applications issues related to its use. However, further work is needed to gradually develop the much wanted knowledge base and the necessary tools for the industry to be able to use these resources routinely and with confidence.
- Significant steps are being taken to improve the quality of RA and new standards are easing its use in higher value applications. Nonetheless, this is very much limited to few countries and the message has to travel worldwide to make a meaningful difference to the sustainable use of RSA in concrete.
- Practice has yet to catch up with the knowledge, and/or it could be argued that the knowledge needs to be sufficiently sound and capable of being packaged in a manner that is easily workable. This will help to share information on real use and allow confidence to be gained.

REFERENCES:

1. Fredonia; World Construction Aggregates to 2011 – Demand and Sales Forecasts; Market Share, Market Size, Market leaders, Industry Report, 2007, pp 321
14. Task Force of the Standing Committee of Concrete, Draft of Spanish regulations for the use of recycled aggregate in the production of structural concrete. Use of recycled materials in buildings and


19. Poon Chi Sun, Lam Chi Sing; The effect of aggregate-to-cement ratio and types of aggregates on the properties of pre-cast concrete blocks Cem Conc Comp 30 (2008) 283–289


27. Specification for constituent materials and concrete, BS 8500 2:2002, Concrete – Complementary British Standard to BS EN 206 – 1, British Standard Institute


