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Recycled Aggregates used in New Concrete

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ABSTRACT

Concrete is the world's second most consumed material after water, and its widespread use is the basis for urban development. It is estimated that 25 billion tones of concrete are manufactured each year. Twice as much concrete is used in construction around the world when compared to the total of all other building materials combined. In India 27% of the total waste generated is construction and demolition waste (C&DW), and of this concrete represents 25%, i.e. 7% of the total waste. Many countries have recycling schemes for C&DW to avoid dumping to landfill, as suitable landfill sites are becoming scarce particularly in heavily populated countries. In landfill levy was introduced in 2008, and this will inevitably increase in the future as landfill sites become scarcer. Charges or levies on landfill dumping often make recycling concrete aggregate a preferred option. Because waste minimisation and reducing the burden on landfills is a global issue, extensive research has been carried out worldwide on the use of recycled aggregate in concrete. This includes substantial research reports by WRAP4, NRMCA5 and RILEM6. Globally the concrete construction industry has taken a responsible attitude to ensuring its natural resources are not overexploited. In some cases the preservation of dwindling natural aggregate sources is a significant issue driving the use of recycled aggregates. Reduction in the impact of aggregate cartage on cost and environmental issues is also a factor where material processed from the demolition phase of a project, using a portable aggregate processing plant, can be reused in concrete for the construction phase of the project. This is a better option than transporting natural aggregates from quarries which through urbanisation are located at an ever increasing distance from city areas. In some cases in Auckland for instance, quarried aggregate is transported over 100 km from source to construction project.

INTRODUCTION

The key to local materials recovery and the recycling industry sector is to achieve a balance between economic pressures and ecologically sound practices. This balance is critical not only to ensure a sustainable future for the industry, but also to secure essential quality improvements and development of markets for value-added products, which are required to make recycled materials more attractive and economical. Several market constraints and technical challenges exist when developing markets for secondary products. Notable among these barriers is consumer uncertainty about the quality and consistency of products. In addition, there can be a lack of practical performance and engineering data on recycled materials. Such data is necessary to assist with the development of appropriate design codes to guide product specification and performance information on recycled materials. This Best Practice Guide and its references are intended to provide such information particularly for the New Zealand market. The need to develop and adopt performance requirements specifically for secondary and recycled products will not only promote secondary and recycled materials specification, but will also ensure that externally verified quality certification and compliance systems covering both materials and recycling plants are adopted.

This will inevitably create further market opportunities for using recycled materials as aggregate in concrete, which constitutes a step forward in providing contractors and clients with confidence when specifying recycled products. Nevertheless primary materials will continue to meet the bulk of the demand for construction materials. The India cement and concrete industry sources its cement feedstock, water and aggregates locally and it is in its interest to use these resources efficiently and in a manner which can be sustained in the long term. Significant steps have been made by the industry as a whole in recent years in the efficiency of the cement manufacturing operation itself, with use of waste material to fuel the cement kilns – used car tyres, sewage sludge, used oil and wood waste; and in the use of supplementary industrial waste materials such as fly-ash and blast furnace slag as partial substitution for cement. The use of recycled materials has become accepted throughout the ready mixed concrete industry in response to increasing environmental focus, including product stewardship, and the increasing cost of disposing of waste material.

The reuse of hardened concrete as aggregate is a proven technology - it can be crushed and reused as a partial replacement for natural aggregate in new concrete construction. The hardened concrete can be sourced either from the demolition of concrete structures at the end of their life recycled concrete aggregate, or from leftover fresh concrete which is purposefully left to harden leftover concrete aggregate. Alternatively fresh concrete which is leftover or surplus to site requirements can be recovered by separating out the wet fines fraction and the coarse aggregate for reuse in concrete manufacture recovered concrete aggregate. Additionally, waste materials from other industries such as crushed glass can be used as secondary aggregates in concrete. All these processes avoid dumping to landfill whilst conserving natural aggregate resources, and are a better environmental option.

Recycling or recovering concrete materials has two main advantages - it conserves the use of natural aggregate and the associated environmental costs of exploitation and transportation, and it preserves the use of landfill for materials which cannot be recycled. Whilst crushed concrete can be used as a sub-base material for pavements and civil engineering projects, this Best Practice Guide outlines its use as a higher grade resource - as aggregate in new concrete. However, recycled concrete aggregate that is significantly contaminated may not be economical to decontaminate for use as concrete aggregate, whereas it may be suitable 'as is' for use as sub-base material.

OBJECTIVE

This Best Practice Guide outlines the processes involved in the use of recycled materials as aggregate in concrete and the effects of these materials on the fresh and hardened properties of concrete made from them. It is based on experience gained from the use of recycled materials in concrete construction projects and research projects both overseas. It is intended to act as a resource on the practical performance and engineering properties of recycled materials as aggregate in concrete supplied.

This Best Practice Guide is intended to raise the awareness of the need for concrete recycling in India and to present the technical guidelines to specifies, contractors, aggregate suppliers, and concrete manufacturers on the use of recycled aggregate in concrete, and on the recovery of concrete aggregate and fines from leftover fresh concrete. By providing a general overview of recycled concrete in construction, it will also be of interest to regulatory bodies providing relevant information for determining the suitability of recycled material for use in building and civil engineering projects.

LITERATURE REVIEW

Recycling concrete is not an end in itself. A full Life Cycle Assessment of the concrete structure, including the recycling phase at the end of its life, is required to assess the overall sustainable credentials of the structure. It is useful to place concrete in the context of the environmental impact of other construction materials. As regards the concrete manufacturing phase, much effort has gone into reducing the environmental footprint of cement manufacture. Cement manufacture is the target area for carbon emissions reduction efforts as it is this stage of production where the most greenhouse gas impact occurs. Transportation and delivery at all stages of concrete production is the second greatest source of impact. Any savings in transport by using recycled aggregate as compared to using natural aggregate reduce both the cost and the environmental burden. Also recycling concrete into aggregate tends to produce environmental benefit by preserving natural aggregate, a finite resource. Nevertheless the environmental impact of concrete manufacture is a small part of the Life Cycle Assessment, which is dominated by the operational phase of a product (e.g. a structure).

The importance of recycling waste concrete gained impetus with the publication of overseas research which found that a significant quantity of the CO2 released during the calcinations process in cement manufacture has the potential to be chemically reabsorbed by concrete during its lifecycle. The amount of reabsorption depends on, amongst other things, the surface area of the concrete exposed to the atmosphere. By processing hardened concrete into aggregate-sized particles, its surface area is greatly increased, which increases its capacity to reabsorb CO2. The research found that recycled concrete aggregate with a water/cement of between 0.49 and 0.67 if allowed to recarbonate in a sufficient time frame, could reabsorb 70-83% of the original calcinations CO_2 emissions. Higher strength concretes (and concrete containing SCM's) will take a longer time to carbonate. Currently (2011) this is a voluntary scheme, however the environmental lobby is gaining in momentum and significant credibility is being placed on buildings with a 5 or 6 Star Rating. Government buildings are showing the way in that all new. To date, the use of recycled aggregate in concrete is usually driven by concrete building solutions for green credits through a stipulated level of recycled aggregate substitution and/or a level of cement reduction by using an SCM such as fly ash or blast furnace slag.

The use of crushed aggregate from either demolition concrete or from hardened leftover concrete can be regarded as an alternative coarse aggregate, typically blended with natural coarse aggregate for use in new concrete. The use of 100% recycled coarse aggregate in concrete, unless carefully managed and controlled, is likely to have a negative influence on most concrete properties compressive strength, modulus of elasticity, shrinkage and creep, particularly for higher strength concrete. Also the use of fine recycled aggregate below 2 mm is uncommon in recycled aggregate concrete because of the high water demand of the fine material smaller than 150 μm, which lowers the strength and increases the concrete shrinkage significantly.

Many overseas guidelines or specifications limit the percentage replacement of natural aggregate by recycled aggregate. In general leftover concrete aggregate can be used at higher replacement rates than demolition concrete aggregate. With leftover concrete aggregate, information will generally be known about the parent concrete – strength range and aggregate source etc. whereas for demolition concrete very little information may be known about the parent concrete, and the resulting aggregate may be contaminated with chlorides or sulphates and contain small quantities of brick, masonry or timber which may adversely affect the recycled aggregate concrete. Often the sources of material from which a recycled aggregate came (and there could be more than one source), are unknown and the variability and strength of the recycled aggregate concrete could be adversely affected in comparison with a recycled aggregate concrete where the recycled aggregate came from one source with a known history of use and known strength. It is therefore necessary to distinguish between the properties of recycled aggregate concrete made using demolition concrete aggregate and that using leftover concrete aggregate. Nevertheless, recycled aggregate concrete can be manufactured using recycled aggregate at 100% coarse aggregate replacement where the parent concrete, the processing of the recycled aggregate and the manufacture of the recycled aggregate concrete are all closely controlled. However as target strengths increase, the recycled aggregate can limit the strength, requiring a reduction in recycled aggregate replacement.

Fig.1

Processing Hardened Concrete In to Concrete Aggregate

India production of natural aggregate per capita is relatively low. In 2008 the UK and US the figures were approximately 5 tonnes and 8 tonnes23 respectively. This is likely to reflect in the high India roading kilometres per capita. In Europe and North America, it is evident that where the demand for aggregates is high, and supplies of natural aggregates are scarce, the level of recycling activity is greatest. In New Zealand, this is becoming the case in Auckland where natural aggregate reserves are inaccessible because of land use constraint issues. In Auckland as the cost of quarrying and transporting aggregates (which are sourced some distance from urban areas) is high, the use of recycled aggregates can be economically viable. In other areas such as, where river run gravel is sourced closer to the urban area, the cost of producing natural aggregates is low compared to the cost of recycled aggregate processing.

Worldwide there is a significant shortfall in the amount of demolition and waste concrete available, and the amount which could potentially be used as recycled aggregate in new concrete. WRAP4 reports that it is economic to use recycled aggregates along with natural aggregates, however this is currently limited to 25% replacement of coarse aggregate owing to the shortfall in recycled and secondary aggregate supply. There is scope for better utilisation of secondary aggregate sources in the future to increase this to 30%.

Processing of hardened concrete refers both to crushing demolition concrete and to crushing leftover concrete. However, recycled concrete aggregate is different from leftover concrete aggregate, as demolition concrete tends to have a higher level of contamination (chlorides, oils etc.). Moreover leftover concrete will generally be crushed at an earlier age so leftover concrete aggregate will have less adhered mortar than recycled concrete aggregate. The presence of adhered mortar on the surface of crushed concrete aggregate generally degrades the quality of the recycled aggregate and consequently the fresh and hardened properties of concrete made from it. Recycled fine aggregate is rarely used in recycled aggregate concrete because of the increase in water demand and effect on compressive strength and shrinkage. Control of the amount of material passing the 150 μm sieve is an issue. Also it is difficult to accurately determine the absorption, saturated surface dry (SSD) condition and free water content of such fine material. Depending on the age of crushing, recycled fine aggregate retains some cementitious capacity, which can be desirable in low strength concrete applications such as trench fill.

Production of Concrete Aggregate from Demolition Material

Recycled aggregates to be produced from aged concrete that has been demolished and removed from foundations, pavements, bridges or buildings, is crushed and processed into various size fractions. Reinforcing steel and other embedded items, if any, must be removed and care must be taken to prevent contamination by dirt or other waste building materials such as plaster or gypsum. It is prudent to store old concrete separately to other demolition materials to help avoid contamination. Records of the history of the demolition concrete strength, mix designs etc. would seldom be available, but if available these will be useful in determining the potential of the recycled aggregate concrete.

Processing

There are few dedicated facilities for recycling infrastructure construction materials in New Zealand. However, recycled concrete aggregates can be produced in plants similar to those used to crush and screen conventional natural aggregates. Large protruding pieces of reinforcing steel are first removed using hydraulic shears and torches. Then most recyclers use a jaw crusher for primary crushing because it can handle large pieces of concrete and residual reinforcement. Jaw crushers also fracture a smaller proportion of the parent concrete aggregate. The residual reinforcement is removed by large electro-magnets. Impact crushers are preferred for secondary crushing as they produce a higher percentage of aggregate without adhered mortar. In general the shape of recycled aggregate is rounder and less flaky than natural aggregate.

Most recycling plants have both primary and secondary crushers. The primary crusher usually reduces material down to 60-80 mm which is fed into a secondary crusher. The material from the secondary crushing then passes through two screens that separate the aggregate into sizes greater than 19 mm, between 19 mm and 7 mm, with the material finer than 7 mm being removed (and used as road metal). The plus 19 mm material is fed back into the secondary crusher.

Aggregate reclaimed from demolition concrete with fully hydrated cement could contain a significant amount of adhered mortar. Prolonged processing will reduce the amount of adhered mortar. Moreover, there will be relatively more adhered mortar on the 13 mm aggregate than on the 19 mm aggregate. Wet processing improves the quality of the aggregate, with less dust or organic matter and improved separation and classification; however such plants are more costly, have a significant water demand and therefore are few in number. However in the Netherlands the introduction of wet processing plants has played an integral part of the increase in use of recycled concrete aggregate.

Tests on Recycled Aggregate

Demolished material of reinforced cement concrete (RCC) & PCC is used for recycling in foundation. The life of RCC demolish material is 25 yrs. Such mated crushing, sieving & separation process are done by manual crushing method. On demolish material, aggregate tests are conducted which are mentioned in Indian Standard code for natural aggregate & check feasibility

Properties of Recycled Concrete Aggregate:

Particle Size Distribution:-

Sieve analysis is carried out as per IS 2386 for crushed recycled concrete aggregate and natural aggregates. It is found that recycled coarse aggregate are reduced to various sizes during the process of crushing and sieving, which gives the best particle size distribution. The amounts of fine particles less than 4.75mm after recycling of demolished waste were in the order of 5-20% depending upon the original grade of demolished concrete. The best quality natural aggregate can be obtained by primary, secondary & tertiary crushing, whereas the same can be obtained after primary & secondary crushing incase of recycled aggregate. The single crushing process is also effective in the case of recycled aggregate. The particle shape analysis of recycled aggregate indicates similar particle shape of natural aggregate obtained from crushed rock. The recycled aggregate generally meets all the standard requirements of aggregate used in concrete.

Table 1:-

SR.NO.	PARTICULARS	VALUES	
		Natural Aggregate	Recycled Coarse Aggregate
1	Specific Gravity	2.4-3.0	2.35-2.58
2	Water Absorption	0.29%-0.3%	0.3%-0.32%
3	Bulk Density	1678.2 KN/m^3	1469.8KN/m^3
4	Crushing Values:	18.4%	36.3%
5	Impact Values:	17.65%	35.2%

Specific Gravity:**-** The specific gravity in saturated surface dry condition of recycled concrete aggregate was found from 2.36 to 2.59 which are less but satisfying the results. If specific gravity is less than 2.4, it may cause segregation, honeycombing & also yield of concrete may get reduced.

Water Absorption:**-** The RCA from demolished concrete consist of crushed stone aggregate with old mortar adhering to it, the water absorption ranges from 1.6% to 7.0%, which is relatively higher than that of the natural aggregates. Thus the water absorption results are satisfactory.

Bulk Density: The bulk density of recycled aggregate is lower than that of natural aggregate, thus results are not satisfactory; due to less Bulk Density the mix proportion gets affected.

Crushing and Impact Values: The recycled aggregate is relatively weaker than the natural aggregate against different mechanical actions. As per IS 2386 part (IV), the crushing and impact values for concrete wearing surfaces should not exceed 30% & for other than wearing surfaces 45% respectively. The crushing & impact values of recycled aggregate satisfy the BIS specifications limit. From crushing & impact test it is found that use of recycled aggregate is possible for application other than wearing surfaces.

Compressive test on cubes: The average compressive strengths of cubes cast are determined as per IS 516 using RCA and natural aggregate at the age 3, 7, & 28days and reported in Table2. As expected, the compressive strength of RAC is slightly lower than the conventional concrete made from similar mix proportions. The reduction in strength of RAC as compare to NAC is in order of 8-14% and 10-16%for M-30 & M-40 concretes respectively. The amount of reduction in strength depends on parameters such as grade of demolished concrete, replacement ratio, w/c ratio, processing of recycled aggregate etc. As per test results the strength of recycled aggregate cube is more than target strength, so RCA can be used for construction purpose.

Flexural Strength: The average flexural strength of recycled aggregate are determined at the age 7, & 28 days varies from 3.30 N/mm2**-** 5.637 N/mm2 respectively. The reduction in flexural strength of recycled aggregate as compared to NAC is 3 **-**16% respectively, so it is satisfactory.

CONCLUSION

The following conclusions are drawn from the experimental study.

1. Recycled aggregate concrete may be an alternative to the conventional concrete.
2. Water required producing the same workability increases with the increase in the percentage of demolished waste.
3. Up to 30% replacement of coarse aggregate with recycled aggregate concrete was comparable to conventional concrete.
4. Up to 30% of coarse aggregate replaced by demolished waste gave strength closer to the strength of plain concrete cubes and strength retention is in the range of 86.84-94.74% as compared to conventional concrete.

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