USE OF RECYCLED CONCRETE AGGREGATE IN MAKING CONCRETE - AN OVERVIEW

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Abstract

India is presently generating construction and demolition (C &D) waste to the tune of 23.75 million tones annually and these figures are likely to double fold in the next 7 years. C&D waste and specifically concrete has been seen as a resource in developed countries. Works on recycling have emphasized that if old concrete has to be used in second generation concrete, the product should adhere to the required compressive strength. Literature survey reveals that compressive strength primarily depends upon adhered mortar, water absorption, Los Angeles abrasion, size of aggregates, strength of parent concrete, age of curing and ratio of replacement, interfacial transition zone, moisture state, impurities present and controlled environmental condition. Some of the studies have suggested the mix design procedure for recycled aggregates in concrete, yet a simple and cost effective method of using demolished concrete, taking into account % adhered mortar and thus calculating mix composition needs to be developed. This paper deals with the review of the existing literature work for the use of recycled concrete as aggregates in concrete in respect of mainly the compressive strength and proposes an approach for use of recycled concrete aggregate without compromising the strength.

1. Introduction

Global Construction industry growth is substantial in size. Report by Global Insight [1], predicts an increase in construction spending from 4800 billion US dollars in 2008 to 6200 billion US dollars in 2013. These figures indicate a tremendous growth in the construction sector almost one and a half times in the coming 5 years. The construction industry Worldwide is a conspicuous consumer of raw material of many types and thus large material inventories are required to sustain the growth. The raw materials used in construction are largely naturally occurring and non renewable resources hence using these materials meticulously is the need of the time. Also proportionately related are the issues of cost that is rising since material inventory is becoming scarce and material has to be procured from distant places. Among the various raw materials used in construction, aggregates are important components for all the construction activities and the demand in 2007 has seen an increase by five percent, to over 21 billion tonnes [2], the largest being in developing countries like China, India, etc. Keun- Hyeok Yang[3]has reported construction industry’s global requirement of natural aggregate around 8 - 10 billion tons annually after the year 2010.

Indian construction industry today is amongst the five largest in the world and at the current rate of growth, it is slated to be amongst the top two in the next century [4]. Aggregates supply has also emerged as a problem in some of the metropolis in India. With the shortage as likely seen today the future seems to be in dark for the construction sector. The requirements of natural aggregates are not
only required to fulfill the demand for the upcoming projects, but also are the needs of the extensive repairs or replacements required for the existing infrastructure and dilapidated buildings built few decades back.

Construction and demolition disposal has also emerged as a problem in India. India is presently generating construction and demolition waste to the tune of 23.75 million tons annually as per the Hindu online of March 2007[5], which is comparable to some of the developed nations and these figures are likely to double fold in the next 7 years. The management of construction and demolition waste is a major concern due to increased quantity of demolition rubble, continuing shortage of dumping sites, increase in cost of disposal and transportation and above all the concern about environment degradation. Although a substantial portion of construction materials could be substituted by re-processed construction waste material, these options are not exercised in developing countries due to lack of knowledge and insufficient regulatory frameworks resulting in waste getting piled up causing disposal problems. The increasing problems associated with construction and demolition waste have led to a rethinking in developed countries and many of these countries have started viewing this waste as resource and presently have fulfilled a part of their demand for raw material. Since concrete composes 35% of the waste as per the survey conducted by Municipal Corporation of Delhi [6], India may also have to seriously think of reusing demolished rubble and concrete for production of recycled construction material. Work on recycled concrete has been carried out at few places in India but waste and quality of raw material produced being site specific, tremendous inputs are necessary if recycled material has to be used in construction for producing high grade concrete.

2. Properties of Recycled aggregate concrete
Since the recycled aggregates has the potential to replace natural resources and in the process address the issue of sustainability and environmental degradation many countries outside India have been using the product satisfactorily. However this requires upgrading the waste material to normal standards and reducing it to proper size to attain the desirable properties. Works have shown that aggregates from different sources, exhibit different engineering properties. Aggregates also are the key ingredients in concrete making up 70-80 % of volume in concrete and dictating the strength and density relationship. Hence using recycled concrete as aggregate will require checking the quality of the aggregates, since they are collected from different sources, grades of concrete and age. Works on recycled concrete have emphasized that the basic material properties, such as shape, texture, specific gravity, absorption, moisture content, permeability, strength characteristics, deleterious substance, resistance to freeze–thaw, etc., need to be thoroughly evaluated before it is used to produce concrete[7]. Aggregate’s properties greatly affect the properties of a concrete. It would also be necessary to assess the effect of recycled material on final concrete and work out optimum composition of recycled aggregate to produce concrete of desirable quality[8].

3. Literature survey
A substantial number of studies have reviewed the properties of RAC. Research work shows marked physical differences between recycled aggregate and natural aggregate in the amount of water absorption and specific gravity. The changes in mechanical properties of recycled concrete aggregate are attributed to the patches of cement mortar present after crushing which increases the water absorption, prolongs the mixing time and affect the strength of the recycled aggregate concrete. Marta Sánchez de Juan et. al, [9] in their studies have concluded that the mortar present on recycled aggregate vary from 40 to 60% depending upon the size of the aggregates and the water absorption lies between 3–10 percent while for natural aggregates the value is less than 5 percent. Work by them also have proved that concrete made with higher water absorptive recycled aggregate will have effect on compressive strength, resistance to freezing and thawing, elasticity, creep, shrinkage and workability. Aggregate in the size of 4 to 8mm is found to have the highest amount of adhered mortar, thus implying that the size of aggregates will have tremendous effect on the water absorption and strength of concrete.

Various relations have been analysed by various researchers. Concretes produced by Frondistou & Yannas [10] with recycled aggregate had 4-14 % lower compressive strength and their moduli of elasticity was also 40 % lower. Hansen & Narud,[11] in their empirical studies however stated that recycled aggregate gave similar test results to natural aggregates. These researchers concluded that in concretes obtained from waste material the percentage of waste mortar stuck on aggregates changed between 30 and 60 %, and these mortars affected the properties of concrete, elasticity, deformations like creep and shrinkage and, water absorption of aggregate. Such composite mixes required 10 % more water in comparison to natural aggregates. They also stated a decreased
workability and loss of slump in a short time [7]. Olorunsogo and Padayachee [12] determined that, depending on the type of the mixture and curing period, an increase in the quantities of recycled aggregate resulted in a decrease in the durability of concrete.

From various research work it can be well summarised that the mortar left behind on recycled aggregate hinders large scale use of economic and environmentally friendly material in the construction industry. Works also emphasize that if proper methods are employed to produce aggregate by recycling concrete waste such that the amount of adhered mortar is significantly less it will give properties that are equivalent to concrete produced by using natural aggregates. In some developed nations methodologies are also investigated to produce recycled aggregate with improved quality but there exists no simple and economical methods taking into account the % adhered mortar left behind and calculating the proportionate mix to achieve the required compressive strength. Hence an attempt would be required to calculate mix proportion by considering the adhered mortar on recycled aggregate, identify the mixing proportions based on % mortar, identify % replacement of recycled in concrete and find the additives if required to achieve concrete of comparable strength.

4. Compressive Strength to be achieved using recycled aggregates

Recycled aggregates to occupy a role in high strength concrete it is necessary that the composition in the first place provides the necessary compressive strength. Various research works carried out on recycled aggregates have pointed the following parameters to be addressed to achieve the required strength.

1. Adhered mortar
2. Water absorption
3. Los Angeles abrasion
4. Size of aggregates
5. Strength of parent concrete
6. Age of curing
7. Interfacial transition zone
8. Ratio of replacement
9. Moisture state in which used
10. Impurities present
11. Controlled environmental condition

4.1 Adhered mortar:
Research has concluded that more than 50% of recycled aggregate have adhered mortar paste. In almost all the cases this paste is identified to be of poorer quality than the new paste. On account of this poor quality, (highly porous mortar) the recycled aggregates are of inferior quality. M.S D .Juan [9] has reported, that percentage of adhered mortar depends on the size of aggregates. The adhered mortar content for aggregate calculated by thermal method in the size range of 4/8mm varies between 33- 55% and for the range 8/16mm is 23-44%. These findings are in line with the literature which suggests that this may vary from 25-65% and will also depend upon the method adopted to evaluate the mortar content. This factor contributes to a large amount of water absorption in recycled aggregates that varies from 4 to 12% as shown in fig 1 which in turn also depends upon the size of aggregates as well as the crushing process and thus affect the compressive strength of concrete.

![Graph showing the relationship between adhered mortar content and absorption](image)

Fig 1: Relationship between mortar and absorption [9]
4.2 Los Angeles abrasion:

Abrasion is linked to the inherent strength of the aggregates. As the % abrasion increases, the compressive strength decreases and this depends on the strength of parent concrete as well as on the size of aggregate. Work by Sami [13] has reported low abrasion in higher parent strength concrete. Since fine aggregates have larger specific surface, the adhered mortar on these aggregates is high thus more is the abrasion. More abrasive aggregates mean lesser parent strength. A. K. Padmini [14] has reported that recycled aggregates can have abrasion upto 48% in case of fine aggregates and this may lead to a loss in strength in the range of 20-35%. Fig 2 indicates the loss of compressive strength as the abrasion percentage increases [9].

Fig 2: Relationship between Los Angeles abrasion and compressive strength [9]

4.3 Size of Aggregates.

Larger size recycled aggregates may replace normal aggregates without reducing compressive strength. Incorporations of fines (10mm) in concrete have more impact on strength and work by A. K. Padmini et.al.[14] has reported strength deterioration by 20-35% even if parent concrete is of high strength. Fig.3 shows the decrease in compressive strength when fines of 10mm size are incorporated in concrete. It is evident from the Fig. 3 and Fig. 4 that as smaller size aggregates are added the compressive strength reduces to a 12.5% and 8% respectively in comparison with 20mm and 40 mm size aggregates for a w/c ratio of 0.4.

Fig 3: Compressive strength as observed with 10mm and 20 mm size aggregates [14]
4.4 Parent concrete Strength:
Work by Sami [13] has stressed that parent high strength concrete only will produce high quality second generation concrete. M.S D.Juan [9] has reported that in order to attain a comparable strength of concrete with recycled aggregates, the minimum strength of parent concrete should be at least 25 MPa. Research has identified parent concrete strength on fresh concrete and works have suggested that higher the parent strength concrete more is the adhered mortar (bond between mortar and aggregate is more) and this may have a detrimental effect on concrete strength. Sami [13] has reported a loss in strength up to 16% with 30MPa concrete and with 50 Mpa to be around 30%. The reduction in compressive strength also takes place with size of aggregates as obtained from known source of concrete. Fig 5 shows the decrease in compressive strength obtained when size of aggregates is altered in making fresh concrete from concrete of known strength[14].

4.5 Interfacial Transition Zone.

The interfacial transition zone formation is related to moisture movement and chemical reaction in the recycled aggregate concrete. Stronger the bond developed at the interfacial zone between the matrix and the coarse aggregate greater is the strength. Works on high performance concrete by
C.S. Poon [15] has proven this fact. A stronger bond between the cement and recycled coarse aggregate may be able to compensate to some degree the negative effect due to the use of weaker aggregate. Work by Sami [13] has concluded that in comparison with normal concrete, recycled aggregate concrete results in 15% reduction in strength. SEM examination has revealed a porous interfacial zone with high porosity in recycled aggregate concrete. The size of pores is found to be larger than 10 µm. The porous interfacial transition zone microstructure is attributed to the higher porosity and absorption capacity of recycled aggregate. This highly porous zone creates the weakest zone in concrete with recycle and thus effectively reduces strength.

4.6 Age and ratio of recycled aggregates to normal aggregates.

The compressive strength of recycled concrete is lower than that of the natural aggregate concrete. The compressive strength decreases with increase in recycled aggregate content for all three different proportions (25, 50 and 100%) of recycled at 28 days strength. As per the experimental work carried out by Limbachiya [16] at 28 days, compared with control concrete the compressive strength of the three types of recycled concrete were reduced by 16.7, 21.7 and 18.8 resp. The reduction however decreased as the curing age increased and for all ratios of recycled to normal aggregates as shown in fig 7. After 5 yrs the reduction was reduced to 10.5, 6.3 and 8.9 resp. Experimental results have proven that in comparison with control concrete, 100% crushed old concrete as recycled had the highest strength gain of more than 60% between 28 days and 5 years.

4.7 Moisture state in which used

Work by C.S. Poon [15] on recycled aggregate as a replacement of the normal aggregate had identified a positive effect on the mixes in the oven dried state (OD) and stated an increase in strength as % recycled increased, but a negative effect in the saturated surface dried (SSD) state, while the air dried (AD) mixes remained unchanged as shown in table 1., which is generally contradictory to the concrete prepared with normal aggregates. Since strength of concrete depends on the strength of the cement matrix, the aggregates and the interfacial bond between the cement matrix and the aggregates, this increase in strength is related to the interfacial bond strength developed. Recycled in the SSD since undergoes bleeding creating a relatively high local w/c in the vicinity of the particles that weaken the bond between RA and cement matrix. On the contrary in the OD state recycled aggregates and cement particles accumulate around RA particles and stronger bond gets formed between cement matrix and aggregate particles at the early age.
Table 1: Compressive strength of concrete at varying age with varying moisture state[15]

<table>
<thead>
<tr>
<th>Mix</th>
<th>Compressive strength (MPa)</th>
<th>3 days</th>
<th>7 days</th>
<th>28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD1</td>
<td>25.0</td>
<td>34.9</td>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>OD1</td>
<td>18.2</td>
<td>27.9</td>
<td>40.2</td>
<td></td>
</tr>
<tr>
<td>SSD1</td>
<td>25.2</td>
<td>33.1</td>
<td>46.0</td>
<td></td>
</tr>
<tr>
<td>AD2</td>
<td>23.3</td>
<td>34.8</td>
<td>44.9</td>
<td></td>
</tr>
<tr>
<td>OD2</td>
<td>19.4</td>
<td>29.2</td>
<td>43.2</td>
<td></td>
</tr>
<tr>
<td>SSD2</td>
<td>20.4</td>
<td>30.3</td>
<td>43.0</td>
<td></td>
</tr>
<tr>
<td>AD3</td>
<td>22.9</td>
<td>32.2</td>
<td>44.7</td>
<td></td>
</tr>
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<td>39.7</td>
<td></td>
</tr>
<tr>
<td>SSD3</td>
<td>17.7</td>
<td>27.0</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>AD4</td>
<td>24.4</td>
<td>33.9</td>
<td>46.8</td>
<td></td>
</tr>
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<td>OD4</td>
<td>21.7</td>
<td>32.1</td>
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</tr>
<tr>
<td>SSD4</td>
<td>17.5</td>
<td>28.5</td>
<td>39.1</td>
<td></td>
</tr>
</tbody>
</table>

4.8. Impurities and controlled environment

Urban recycling requires more concern for contaminants such as plaster, soil, wood, gypsum, asphalt, plastic, vinyl, or rubber. While contaminants are usually not a concern for recycled aggregates used as a base course, strict control must be used for recycled aggregates in structural concrete to ensure that there are no contaminants than are allowed for virgin coarse aggregate. Environmental Council of Concrete Organizations (ECCO 1999) lists the following allowable limits for various contaminants:

- Asphalt: 1% by volume
- Gypsum: 0.5% by weight of SO$_3$
- Organic substances: 0.15% by weight
- Glass: Nil (because of the potential to induce alkali-silica reactions)
- Chloride sources and soil should be kept to low concentrations. The allowable limits of chloride as per European standards are 0.06% and soil or clay lumps to be limited to 0.6%.

5. Conclusions

Though there has been extensive research carried out on recycling yet construction industry does not have a simple and cost effective method to use the recycled aggregates in second generation concrete. Works on recycled aggregate concrete have considered water absorption and other parameters in finding the mix proportions and strength but this is not sufficient since the percentage and quality of the adhered mortar is essential in calculating the final strength of concrete without adding the cost towards processing. Though all the above parameters as discussed are essential in evaluating and obtaining strength but still a methodology taking into consideration the quality and the % of adhered mortar would be essential if recycled aggregates have to be taken in preparation of high strength concrete.

Mix design methodology depends upon water absorption as well as density of aggregates. Since these properties depend upon the adhered mortar content hence it would be primarily necessary to calculate the % adhered mortar. Research work has concluded that a 25-30% recycled may not have significant effect on concrete properties, but if these aggregates contain more than 65% of adhered mortar its impact on concrete properties have not been evaluated. Hence it would be necessary to understand what % of adhered mortar could be tolerated on recycled aggregates in making concrete and also calculate the % replacement based on % adhered mortar. The work thus would simplify the work for contractors who would be interested in using demolished concrete and give a simple procedure of using recycled by considering % adhered mortar and evaluating the mix proportions for attaining a comparable strength for high grade applications.
References


