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REVIEW PAPER

EVALUATION OF DIFFERENT ASPECTS OF RECYCLED AGGREGATE AND RECYCLED AGGREGATE CONCRETE

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Abstract: Concrete is one of the most popular and widely used construction materials in the world. Concrete provides suitable features for construction such as durability, fire resistance, satisfactory compressive strength, availability and is economic as well compared to other construction materials. Now a day, depletion of natural resources and disposal of construction & demolition (C & D) waste related problems claim environmental threat. Recycled aggregate sourced from those construction and demolition waste can be a promising solution to replace natural aggregate in concrete production. This paper identifies some of the important features and properties of recycled aggregate (RA) and recycled aggregate concrete (RAC) from an engineering point of view. Some unsolved issues like limiting the values for characterization of recycled aggregate, stress-strain relations, lack of development of code provisions are also addressed in this paper. Moreover, brief features of a numerical study in RAC are described. Lastly, several positive and negative aspects of the economics of RAC is emphasized. In a nutshell, this research paper pointed out the numerous essence of using RAC in concrete engineering.

Keywords: *Concrete, aggregate, strength, recycling*

1.0 Introduction

Environment preservation and reduction in the rate of rapidly diminishing natural resources are the key requirement for sustainable development. Recycling of waste material are modern days environmental priorities and considerable efforts is devoted to this area. Recycled aggregate mostly generated from construction and demolition (C & D) waste for the production of new concrete has received huge interest from construction industry. Various recycling methods for construction and demolition waste have been explored and well developed in the last two decades.

Global consumption demand of natural aggregate ranges from 8 to 12 billion ton after 2010 (Tsung *et al*. 2006) and on the other hand production of construction and demolition waste exceeds 1 billion every year (Katz 2003). Cost of dumping construction and demolition debris increased substantially over the recent years. C & D waste was initially used as landfill and for low-value purpose due to limitation of recycling facilities and economic effectiveness. However, the scenario has changed over time and now extensive research & development work has been conducted on applicability of recycled concrete in many countries. (Imam *et al*. 2015) reported that use of recycled aggregate for manufacturing low strength concrete shows better results. In recent times recycled aggregates are found to be applied in intermediate application like ground bearing floor slabs, road base, paving blocks, embankment fills etc. rather than structural application. (Etxeberria *et al*. 2007) shows some prospect of using recycled aggregate as a structural material and his results depicts that replacement rate less than 25 % has no significant effect on the shear capacity of reinforced concrete beams. The same authors have reported that tensile strength of RAC is better than the normal aggregate concrete. Behavior of recycled aggregate concrete has been influenced by properties of RA such as source, grade of recycling, water absorption, shape and size, contaminants and chemical composition. The use of this recycled products are encouraged by developing international standardization, such as BS-8500-2 (2002) and RILEM (1994). Reuse of C & D waste has environmental benefits but still some unresolved and inconclusive issues prevent large scale application of recycled aggregate as structural concrete.

Physical and mechanical properties of plain concrete made with recycled coarse aggregate possess great importance for effective application of recycled aggregate. A number of issues are studied in the field of recycled aggregate and recycled aggregate concrete. Mostly includes: (1) strength, (2) durability, (3) crushing behavior, (4) amount of contaminants. Moreover, a well-documented discussion highlighting engineering aspects of recycled concrete with some practical outlines is necessary for future research advancement. This paper concludes by identifying and discussing some important parameter and factors to explore the potential or the limitation of using recycled aggregate as a replacement of natural aggregate.

2.0 Properties of Recycled Aggregate

2.1 Contaminants

Recycled aggregate processed from construction and demolition waste include ceramic particles, small amount of gypsum and asphalt particles (Agrela *et al*. 2011). The amount of impurities depends on the source of waste material as well as the process involved in recycling plant, and according to RILEM (1992) it can range from 0% to 35% for asphalt particles, from 0% to 5% for gypsum. Presence of these impurities generally lead to worse physical properties in the recycled concrete, such as water absorption and carbonation. Presence of asphlat reduces the concrete compressive strength significantly. For example, 30% asphlat in aggregate reduces the strength by approximately 30% reported by Hansen (1992). Soluble sulphate content is directly related to gypsum content. (Agrela *et al*. 2011) limits the gypsum content to 1.5 %, so the soluble sulphate content does not goes beyond the tolerable limit. Khalaf and DeVenny (2004) describes presence of chlorides and other salt in recycled aggreagte may leads to corrosion of steel rebar in case of reinforced concrete even though it has little detrimental effect on plain concrete. Impurities like old cement paste clinging to the recycled aggregate plays significant role in determining the concrete properties in terms of permeability and strength. Orchard (1973) contends that while using recycled aggregates, the dust content must be taken into account, as it causes reduction in workability. Aggregate characterization and limiting the properties for use of recycled aggregate in the manufacture of concrete is necessary.

2.2 Size of Aggregate

Recycled aggregate generated from construction and demolition waste involved two stages of recycling process, removal of impurities and crushing. The size distribution of RA has significant effect on properties of concrete. (Rahman *et al*. 2009) founds in his experimental study that recycled aggregate of size 10mm and 14mm gives better strength than 20mm. Emphasize should be given on cost effective recycling process to achieve proper graded recycled aggregate.

2.3 Specific Gravity and Absorption Capacity

Kumar & Dhinakaran (2012) found that the specific gravity of recycled aggregate was lower than the natural aggregate and the absorption capacity was found relatively higher than the natural aggregate. Specific garvity reduces with the increase in the age of source material of recycled aggregate. The higher absorption mainly depends on the source of the aggregate and the amount of old cement mortar adhering to it.

2.4 Crushing and Impact Values

Crushing and impact values are generally associated with the strength of aggregate. Kumar and Dhinakaran (2012) reports crushing values of recycled aggregates ranges from 19.86%-31.44% , higher than the natural aggregate rising with the increase in age of source material. The same author also reports impact values of recycled aggregates ranges from 9.66%-18.45%, higher than the natural aggregate and also rises with the increase in age of souce material. The author also confirms that both the crushing and impact values are well within the range of Bureau of Indian Standrads (BIS) limits.

3.0 Properties of Plain Concrete Made with Recycled Aggregate

3.1 Workability

Slump test is widely accepted as a measure of workability of concrete. The water absorption capacity of recycled aggregate ranges from 3-12% reported by Jose (2002) and Katz (2003), is much higher than the natural aggregates. This high absorption attributes to difficulties in controlling the workability and other properties of fresh concrete. It is added by many authors to soak the aggregate before use in the mix to attain a given consistency (Mas *et al*. 2012, Agrela *et al*. 2011, Correira 2006 and Chen *et al*. 2003). The use of recycled aggregate in saturated surface dried (SSD) condition, may result in bleeding during casting due to presence of high water content inside the aggregate (Poon *et al*. 2004). High degree of bleeding results in lower concrete strength. Poon *et al*. (2007) depicts that replacement of cement by 25% fly ash increase the slump of concrete mix and reduce the bleeding, with minimal negative effects on concrete strength. Figure 1 and Figure 2 shows the changes of slump of concrete mixes excluding and including fly ash respectively. It can be seen that slump value increases as amount of recycled aggregate increase. This may happen due to the initial free water content in the concrete mixture.

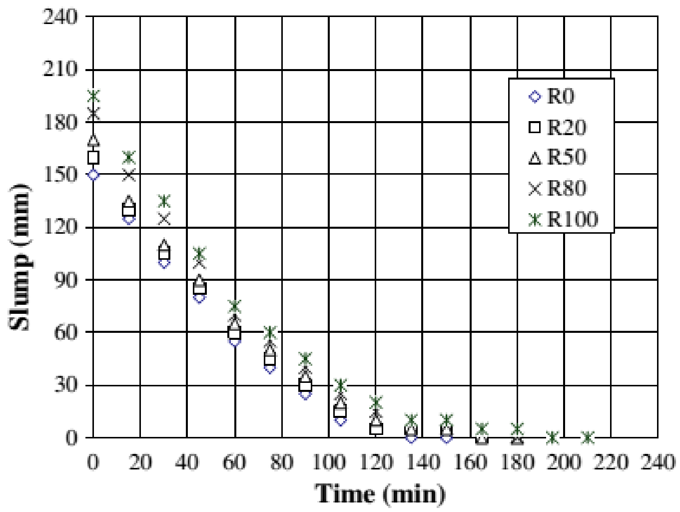

Figure 1: Changes of slump of concrete mixes without fly ash with varying replacement rate of recycled aggregate, Poon *et al*. (2007)

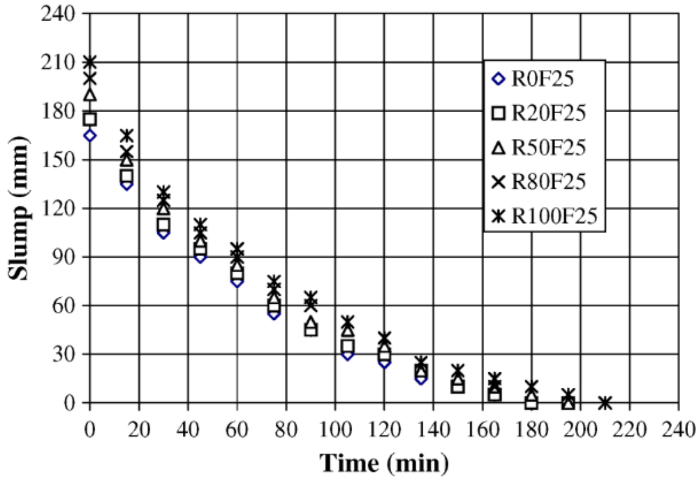

Figure 2: Changes of slump of concrete mixes with 25% fly ash with varying replacement rate of recycled aggregate, Poon *et al*. (2007)

3.2 Porosity, Air Content and Density

The porosity of recycled aggregate is higher than normal aggregate which eventually points to increase in the air content of the recycled aggregate concrete. Katz (2003) states air content of recycled aggregate concrete from 4% to 5.5 % for 100% replacement by recycled aggregate. This increased air content also leads to lower density of recycled aggregate concrete. Density declines approximately linearly with rising rate of replacement and the decrease is of the order of 7.7% (Lage *et al*. 2012) for concrete containing 100% recycled aggregate.

3.3 Compressive Strength

Concrete with recycled aggregate has less compressive strength compared to concrete made with natural aggregate. But the extent of reduction in strength depends on the source of recycled aggregate, degree of replacement, water cement ratio and moisture state of the recycled aggregate as well. For 100% replacement the estimated loss found 23%, with values ranging from 20%-31% (Lage *et al*. 2012). Debieb and Kenai (2008) reports that reduction in compressive strength were 30%, 40%, 50% where 100% of the coarse or fine aggregates or both were replaced, and recommends replacement rates for coarse and fine aggregate not over 25% and 50%, respectively. But some heterogeneous results, both increase and decrease in compressive strengths are also reported (Evangelista *et al*. 2004). Katz (2003) reported that the strength of recycled concrete is comparable to control concrete for replacement ratio 0.75, at a high w/c ratio (0.6-0.75). Rao (2005) states for w/c ratio higher than 0.55 the recycled concrete strength found to be comparable with reference concrete even at 100% replacement. No significant change has been observed for replacement rate under 15% depicted by Cachim (2009). The determination of optimum degree of replacement should be established.

3.4 Stress-Strain Relations

The relation between compressive stresses against longitudinal strain is used to estimate the modulus of deformation and failure strain in concrete made from recycled aggregate. (Lage *et al*. 2012) reported that slope of stress-strain curve declined with higher replacement ratio. Subsequently, failure strain of the concrete made with recycled aggregate was also increased. 30-40% decline in modulus of deformation is stated for concrete containing 100% recycled aggregate. Failure strain increase reported with a value of 2.1% for concrete with only natural aggregate, 2.3% and 2.5% for concrete with 50% and 100% recycled aggregate respectively. Figure 3 shows the experimental results reported by (Lage *et al*. 2012).

(Chen *et al*. 2003) reported that the decrease in the modulus of deformation was around 30%, which was independent of aggregate type. More experimental data is needed to draw a conclusive result for application of recycled aggregate concrete where the modulus of deformation and failure strain are critical parameters.

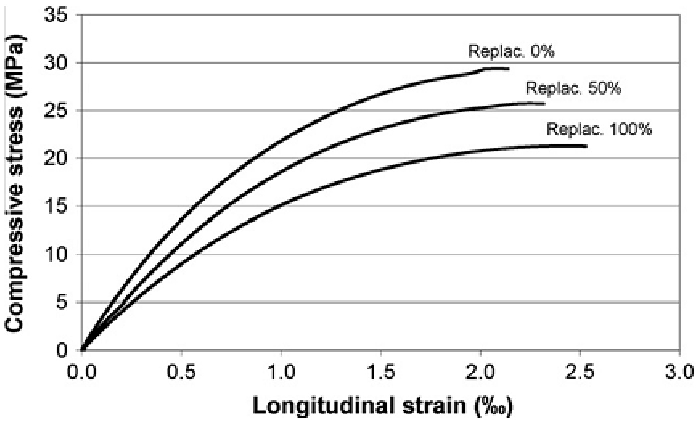

Figure 3: Stress-strain relationship of recycled aggregate concrete with varying replacement rate of recycled aggregate, Lage *et al*. (2012).

3.5 Durability

Depth of water penetration under pressure directly related to durability. (Lage *et al*. 2012) reports lower penetration in concrete with higher replacement rate of recycled aggregate.Carbonation test results stated by (Crentsil *et al*. 2001); Levy and Paulo (2004), shows the carbonation depth of recycled aggregate concrete was 1.3-2.5 times higher than that of the normal aggregate concrete. This could be due to the increased absorption of recycled aggregate resulting from the presence of old mortar adhering to the original aggregate. The high pore content of recycled aggregate concrete attributes to higher frost resistance than normal concrete.

3.6 Non-Destructive Tests

There are a number of non-destructive testing methods have been developed and recommended to apply for structural health monitoring. Rebound hammer test is widely used to relate the rebound number with compressive strength of hardened concrete for different mix proportions and aggregate type. Rebound hammer test results can be a good solution in predicting the strength of recycled aggregate concrete from demolished concrete. Relationship trends between rebound numbers of fresh recycled aggregate concrete and source concrete of recycled aggregate may provide an approximation of recyclability of the concrete to be demolished. No real reference has been found in this regard. This could be an interesting aspect of recycled aggregate concrete.

3.7 Modeling of Mechanical Properties of Recycled Aggregate Concrete

Most of the researchers devoted their effort in experimental investigation of recycled aggregate concrete. However, numerical investigation of RAC is critically important to validate the experimental investigation as well as for practical point of view. Recently, numerical approach for performance analysis of RAC takes attraction to the research community in concrete engineering. Moreover, it is very challenging to develop an analytical and numerical tool for RAC. Describing the complex mixture of recycled aggregate, cement and water is always a critical issue in numerical modeling. Identification or development of proper constitutive model for concrete considering the property of recycled aggregate is the key issue in modeling. An approach keeping all this in mind is almost impossible. Hence, it is recommended to use simpler model rather than a complex model, because the statistical gain for complex models are quite small. (Cabral *et al*. 2010) modeled concrete compressive strength and elastic modulus as a function of water-cement ratio, recycled aggregate type and quantity. Their statistical regression analysis results shows 95 % confidence level for both compressive strength and elastic modulus with high regression coefficient. The same author also proposed correlation between compressive strength and elastic modulus of RAC, which found in similar format with the model proposed by other authors (Nagataki *et al*. 2000 and Ravindrarajah *et al*. 2000).

4.0 Economics of Recycling

Tam (2008) reported that concrete waste forms major portion of C & D waste, contributes about 50% of total generated waste. With decreasing landfill areas this huge waste signaling towards environmental risks. Recycling of concrete waste can manage this acute environmental problem. The validation of economic feasibility of using recycled aggregate is a major concern to raise consumer's interest in recycled aggregate products. The economics involved in recycling of C & D waste is very compound as lot of factors involved in it which needs in depth exploration. The recycling of concrete waste consists of various phases namely transportation to the recycling plant, sorting, screening, crushing, grading and transportation to the place of use. All the cost involved must be compared with the cost of natural aggregate production process. Natural Aggregate production involves cost of extraction of aggregate either by mining or dredging and cost of transportation to the place of use. Use of recycled aggregate saves the cost of dumping at the dumping sites. On the contrary the quality of recycled aggregate may not be identical and may not be efficient in concrete as natural aggregate. Both the positive and negative factors must be taken into consideration to calculate the benefit cost ratio of the project and check the economic viability of using recycled products.

5.0 Barriers in Introduction of RAC

Application of recycled aggregate concrete is not yet so popular and widely accepted even though lot of ongoing effort has been made to introduce this as an alternative environment friendly solution for sustainable concrete industry. There are some specific barriers which restricting the use of RAC in large scale. Poor recycling facility, lack of recycling plants in appropriate locations, absence of proper technology to treat construction and demolition waste compatible with demand are the primary level hurdles. Apart from this low cost of waste disposal, lack of awareness and knowledge about recycling of C & D waste are the other obstacles especially in developing countries. Also there is lack of confidence on finished product made from recycled material due to absence of enough research findings and not supported by code specifications unless some technical reports. Proper regulatory framework for waste management and promoting recycled product supported by government with international collaborations will help a great deal in overcoming the barriers to make a notable growth in RAC industry.

6.0 Conclusions

The facts and findings discussed above depicts that the use of recycled aggregate and recycled aggregate concrete represents interesting possibility in future concrete industry. Lack of awareness and absence of recycling in developing countries inhibits the growth of recycled concrete industry. However, engineering properties of RA and RAC needs conclusive evaluation and should be addressed by inclusion in codes. For use of recycled aggregate concrete in structural purpose, the critical parameters for design and construction must be identified and the applicability needs to be examined in greater domain. The optimum dose of application of super plasticizers in case of admixed recycled concrete for durability needs proper attention. Development of relevant code standards for recycled aggregate and recycled aggregate concrete is necessary to provide manufacturers and consumers an assurance of quality. This paper critically discussed important factors of recycled concrete and recycled concrete aggregate. It is felt that more experimental investigations as well as conclusive findings are yet to be done in this field. Besides, numerical investigation of RAC is also an important pathway in concrete engineering. Large scale numerical simulation can be carried out for practical evaluation of recycled concrete. A critical discussion on numerical analysis highlighting the problems was included in this paper. Furthermore, economic feasibility of RAC and its prospect in practical field was also described in subjective manner. Probably, all those could encourage any researcher(s) in this field to work in more rational way.

References

Agrela, A., De Juan, M.S., Ayuso, J., Geraldes, V.L. and Jiménez, J.R. (2011) Limiting properties in the characterisation of mixed recycled aggregates for use in the manufacture of concrete Construction and Building Materials, 25:3950-3955.

BS-8500-2 (2002) Concrete-complementary british standard to BS EN 206-1. Part 2: specification for constituent materials and concrete.

Cabral, A.E.B., Schalch, V., Molin, D.C.C.D. and Ribeiro, J.L.D. (2010) Mechanical properties modeling of recycled aggregate concrete, Construction and Building Materials, 24: 421-430

Cachim, P.B. (2009) Mechanical properties of brick aggregate concrete, Construction and Building Materials, 23(3): 1292-7.

Correira, J.R., De Brito, J. and Pereira, A.S. (2006) Effects on concrete durability of using recycled ceramic aggregates, Materials and structures, 39:169-177.

Chen, H.J., Yen, T. and Chen, K.H. (2003) Use of building rubbles as recycled aggregates, Cement and Concrete Research, 33(1):125-32.

Crentsil, S.K.K., Brown, T. and Taylor, A.H., (2001) Performance of concrete made with commercially produced coarse recycled concrete aggregate, Cement Concrete Research, 31:707-12.

Debieb, F. and Kenai, S. (2008) The use of coarse and fine crushed bricks as aggregate in concrete, Construction and Building Materials, 22(5): 886-93.

Etxeberria, M., Vázquez, E., Mari, A. and Bara M. (2007) Influence of amount of recycled aggregates and production process on properties of recycled aggregate concrete, Cement and Concrete Research, 37 (5): 735-742.

Evangelista, L. and De Brito, J. (2004) State-of-the-art on the use of fine recycled materials in concrete production, Conference on the use of recycled materials in building and structures, Barcelona, Spain.

Hansen, T.C. (1992) Recycling of demolished concrete and masonry, RILEM Rep. 6, E&FN Spon, London.

Imam, M.O., Salauddin, M., Ali, S.B. and Ullah, M.S. (2015) An investigation on strength of recycling of demolished concrete by using recycled aggregate as coarse aggregate, International Journal of Civil and Environmental Engineering, 37(1): 1354-1359.

Jose, M.V.G. (2002) Porosity of recycled concrete with substitution of recycled concrete aggregate: an experimental study, Cement and Concrete Research, 32:1301-11.

Kumar, P.S. and Dhinakaran, G. (2012) Effect of admixed recycled aggregate concrete on properties of fresh and hardened concrete. Journal of Materials in Civil Engineering, ASCE, 24(4):494-498.

Khalaf, F.M. and DeVenny, A.S. (2004) Recycling of Demolished Masonry Rubble as coarse aggregate in concrete: Review, Journal of Materials in Civil Engineering, ASCE, 16 (4): 331-339.

Katz, A. (2003) Properties of concrete made with recycled aggregate from partially hydrated old concrete, Cement and Concrete Research, 33(5):703-711.

Lage, I.M., Abella, F.M., Herrero, C.V. and Ordóñez, J.L.P. (2012) Properties of plain concrete made with recycled coarse aggregate, Construction and Building Materials, 37:171-176.

Levy, S.M. and Paulo, H. (2004) Durability of recycled aggregates concrete: a safe way to sustainable development. Cement and Concrete Research, 34(11):175-80.

Mas, B., Cladera, A., Olmo, T.D. and Pitarch, F. (2012) Influence of the amount of mixed recycled aggregates on the properties of concrete for non-structural use, Construction and Building Materials, 27(1):612-22.

Nagataki, S., Iida, K., Saeki, T. And Hisada, M. (2000) Properties of recycled aggregate and recycled aggregate concrete, In: Proceedings international workshop on recycled aggregate. Niigata, 53-68.

Orchard, D.F. (1973) Concrete technology: Properties of Material, 3rd Ed, Applied Science, London.

Poon, C.S., Kou, S.C. and Lam, L. (2007) Influence of recycled aggregate on slump and bleeding of fresh concrete, Materials and Structures, 40:981-988.

Poon, C.S., Shui, Z.H., Lam, L., Fok, H. and Kou, S.C. (2004) Influence of moisture states of natural and recycled aggregates on the properties of fresh and hardened concrete, Cement and Concrete Research, 34(1):31-36.

Rahman, I.A., Hamdam, H. and Zaidi, A.M.A., (2009) Assessment of recycled aggregate concrete, Modern Applied Science, 3(10):47-54.

Rao, A. (2005) Experimental Investigation on use of recycled aggregates in mortar and concrete, Thesis submitted to the Department of Civil Engineering, IIT Kanpur.

Ravindrarajah, SR., Stewart, M. and Greco, D. (2000) Variability of recycled concrete aggregate and its effect on concrete properties: a case study in Australia. In: Proceedings international workshop on recycled aggregate. Niigata, 09-25.

RILEM (international union of testing and research laboratories for materials and structures) (1994) specifications for concrete with recycled aggregates, Materials and Structures, (27): 557-9

RILEM (1992) Recycled aggregates and recycled aggregate concrete, Recycling of demolished concrete and masonry, In: Hasen TC, editor. RILEM report 6, 1st ed. E&FN Spon, 2-6 Boundary Row, London SE 1 8HN.

Tam, V.W.Y. (2008) Economic comparison of concrete recycling: A case study approach, Resources, conservation and recycling, (52), 821-828.

Tsung, Y.T., Yuen, Y. and Chen, L.H. (2006) Properties of HPC with recycled aggregates, Cement and Concrete Research, 36(5): 943-950.