

Effect of the Quality of Recycled Aggregate on Compressive Strength of Recycled Aggregate Concrete

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Abstract: *In the present investigation an attempt was made to study the quality of recycled aggregate (RA) obtained from different strengths of normal concrete and their influence on the properties of recycled aggregate concrete. Four grades of normal concrete mixes viz: M20, M25, M30 and M40 were considered as parent concretes to produce the recycled aggregates. The recycled aggregate derived from M20 parent concrete indicted as RA20. Similarly RA25, RA30 and RA40 were generated from the other parent concretes M25, M30 and M40 respectively. The physical and mechanical properties of each type of RA were investigated. Further, Two grades of recycled aggregate concretes viz. MR20 and MR30 were considered. MR20 was produced with RA20 and RA25 separately. Similarly MR30 was generated with RA30 and RA40 separately. Workability and compressive strength of RAC were studied. The experimental results reveals that the compressive strength of recycled aggregate concrete with recycled aggregate obtained from the same grade of parent concrete is lower than the corresponding grade of normal concrete, whereas, the compressive strength of RAC made with RA obtained from higher grade of parent concrete is quite comparable with the similar grade of parent concrete.*

Keywords: Recycled Aggregate (RA), Recycled Aggregate Concrete (RAC), Compressive Strength, Parent Concrete.

1. Introduction

In the recent times, the extensive increase in the rate of population, urbanization and industrialization made remarkable growth in the infrastructural development, particularly in the field of construction. Hence, there is a lot of demand for new structures, which requires billions of tons of concrete. Further, it plays an important role in countries economy development due to its large volume utilization. Since the coarse aggregate contribute around 60-75% of the total volume of concrete, as it uses approximately 20 billion tons of coarse aggregate in every year [1]. Mehta and Meryman [2] stated that approximately 20 billion metric tons of concrete per annum is utilized in construction in the present scenario. However, the research group of Fredonia has forecasted that the global consumption of aggregate used in construction may exceed 26 billion tons by 2012 [3]. It was anticipated that in the next two to three decades the aggregate demand will be two-fold if the rate of consumption increases with the same pace [4]. On one side the natural resources are significantly affected due to extensive usage of aggregate in the construction sector. Further, this affects the sustainable development of the society. On the other hand, there is a huge amount of debris yields from the construction and demolition waste (C&DW) due to rapid growth in industrialization and modernization of the society. Major amount of these waste concedes from the demolition of old structures as well as the waste leftover concrete of ready mix concrete plants, precast concrete plants and the tested concrete samples from the laboratories. Thus, the C&DW is one of the major contributions of solid waste streams in all over the world. Further, these wastes are just dumping illegally on empty lands or used as back filling material for low lying areas. These have led to a shortage of dumping yards; useful lands becoming landfilling areas, increase in the price of land in recent years and highly increased dumping

cost at landfill areas. Thus, handling of C&DW has become a global concern from the sustainable point of view [1]. The use of recycled coarse aggregate from the construction and demolition waste (C&DW) as an alternative material (aggregates) for making new concrete, acquires the importance to save the natural resources and reduce the need of waste disposal. Indeed, the construction demolition waste deposition has an impact on environment and contributes significantly to the landfill saturation. The maximum possible utilization of the C&DW as an aggregate in concrete is very effective and anticipating technique towards the sustainable development in the construction sector.

2. State of the Art Review

In the recent times many attempts have been made to replace the natural aggregate (NA) partially or fully with the recycled coarse aggregate in concrete [5] - [14]. In general the properties of concrete like compressive strength, tensile strength and modulus of elasticity reduces with increase in the percentage replacement of natural aggregate by recycled coarse aggregate. However, the properties of concrete does not affect significantly if the replacement of NA by RA is limited to 30% [14], [15]. A few of the researchers tried to improve the properties of RAC by using secondary cementitious materials such as fly ash, silica fume, metakaolin, ground granulated blast slag [15], [16]. Further, attempts have been made to improve the quality of recycled coarse aggregate and hence the properties of RAC by various treatment techniques. [17] - [19]. It was found that the properties could be improved significantly due to the improvement in the interfacial transition zones between recycled aggregates and cement mortar. Very few studies are made on the influence of the quality of parent concrete on the properties of recycled aggregate concrete. Padmini et al. [13] examined the influence of parent concrete made with

different maximum sizes of coarse aggregate (10, 20 and 40 mm) of different strength as recycled coarse aggregate on strength of RAC. It was concluded that the RAC needs lower w/c ratio than the parent concrete from which the recycled coarse aggregate derived, to achieve a particular compressive strength and the difference in strength between RAC and parent concrete increased with higher strength. This means the presence of adhered mortar does not have significant effect on lower strength of RAC. In addition, the authors concluded that for a given target means strength, with an increase in maximum size of RA the strength achieved was increased.

In light of the above scenario, the present paper explores the properties of recycled aggregate obtained from different strengths of parent concrete and their influence on the strength properties of recycled aggregate concrete.

3. Experimental Details

Portland Pozzolana Cement (PPC) conforming to the requirements of BIS (IS: 8112-1989) is used in the present study. The compressive strength of cement at 3, 7 and 28 days are 16, 22 and 33 MPa respectively. The locally available natural sand and 20 mm maximum size natural coarse aggregate available from the local quarries conforming to the grading requirements of IS: 383 (1970) were used.

3.1 Recycled coarse aggregate

The recycled coarse aggregates are obtained by crushing the laboratory tested specimens of different strengths of parent concretes. Four types of recycled aggregates viz: RA20, RA25, RA30, and RA40 are prepared from M20, M25, M30 and M40 parent concretes respectively. The physical and mechanical properties of these recycled coarse aggregate are studied and are presented in Table 1. In the Table RA20 indicates the recycled coarse aggregate obtained from M20 normal (parent) concrete. Similarly RA25, RA30, and RA40 represent the recycled coarse aggregate obtained from M25, M30 and M40 normal concretes respectively.

3.2 Details of Normal Concrete Mixes

Normal concrete mixes of grades M20, M25, M30 and M40 are designed as per the guidelines of BIS (IS: 20262 - 2009) using fully natural aggregates. The details of the mixes are listed in Table 2. Two grades of recycled aggregate concrete mixes MR20 and MR30 whose target compressive strengths are kept equal to the corresponding parent concretes M20 and M30 respectively are designed. MR20 is prepared with RA20 and RA25 separately and these are designated as MR20RA20 and MR20RA25 respectively. Similarly, MR30 is prepared with RA30 and RA40 separately and are designated as MR30RA30 and MR30RA40 respectively. The details of the recycled aggregate concrete mixes are presented in Table 2.

Table 1: Physical and mechanical Properties of RA and NA

Properties	NA	RA20	RA25	RA30	RA40	FA
Bulk density (kg/m ³)	1556	1381	1375	1370	1364	1565
Specific gravity	2.6	2.41	2.41	2.39	2.29	2.62
Water absorption (%)	0.9	3.0	3.3	3.62	4.85	--
Impact value (%)	12.24	15.5	16.34	17.35	19.14	--
Elongation index (%)	33.95	24.02	25.16	25.61	31.43	--
Flakiness index (%)	24.81	18.67	19.60	21.88	22.30	--

Table 2: Details of normal concrete mixes (quantities are per cubic meter of concrete)

Mix	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	w/c
M20	387.5	568.726	1175.8	0.48
M25	420	530	1155	0.46
M30	450	514	1119	0.43
M40	492.5	594.97	1069.4	0.38
MR20RA20	387.5	568.7	1047.82	0.48
MR20RA25	387.5	568.7	1100.80	0.48
MR30RA30	450	514	1093.05	0.43
MR30RA40	450	514	1070.65	0.43

4. Results and Discussion

4.1 Physical and Mechanical properties of Recycled Coarse Aggregate

Using the guidelines given in BIS (IS 2386 (Part I, III and IV)), the physical and mechanical properties of fine, natural and recycled coarse aggregates are determined and are listed in vide Table 1. The properties examined are gradation, bulk density, specific gravity, water absorption, elongation and flakiness indices and impact value. Figs. 1 – 5 presents the gradation of natural coarse aggregate and recycled coarse aggregate obtained from different strengths of normal concrete. The limits specified by BIS (IS: 383-1970) for natural coarse aggregate are also presented.

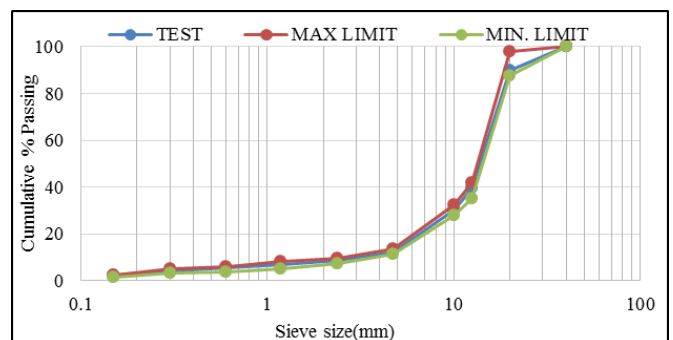


Figure 1: Particle size distribution of natural coarse aggregate along with Min and Max.limits specified by BIS (IS: 383-1970)

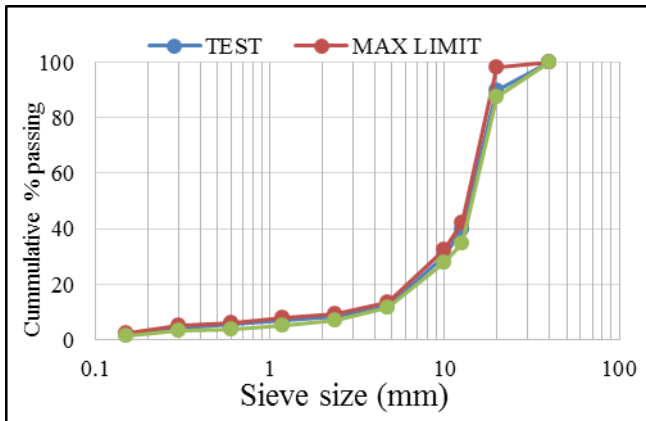


Figure 2: Particle size distribution of RA20 along with Min and Max. limits specified by BIS (IS: 383-1970)

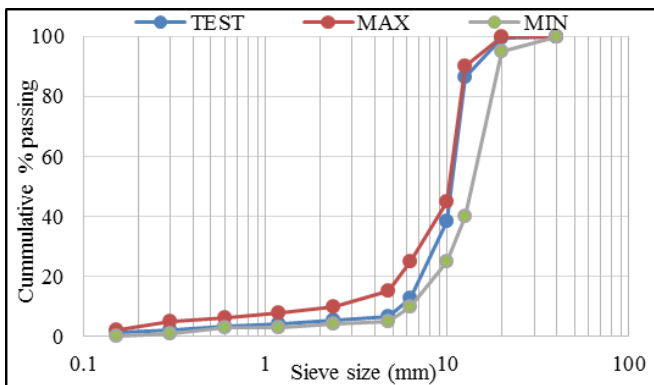


Figure 3: Particle size distribution of RA25 along with Min and Max. limits specified by BIS (IS: 383-1970)

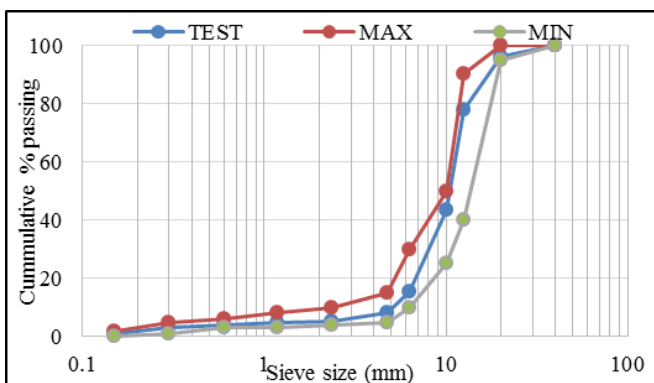


Figure 4: Particle size distribution of RA30 along with Min and Max. limits specified by BIS (IS: 383-1970)

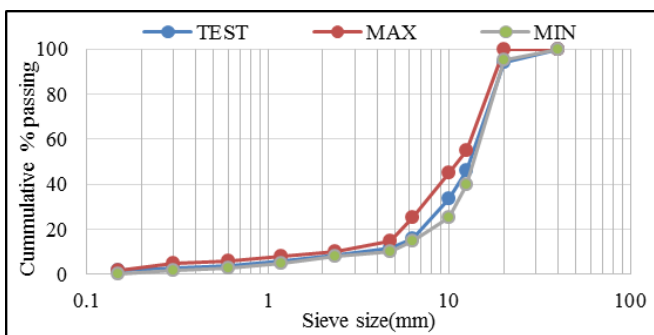


Figure 5: Particle size distribution of RA40 along with Min and Max. limits specified by BIS (IS: 383-1970)

Figs. 1 – 5 reveals that the gradation of both natural and recycled coarse aggregates are almost the similar trend and they are well within the limits specified by BIS (IS:383-1970) for natural aggregate. Further, these Figs. shows that the recycled coarse aggregates are relatively finer than the natural coarse aggregate. This is mainly due to the adherence of old mortar in RA, which produces the finer particles during the crushing process of aggregate.

The physical and mechanical properties of natural and recycled coarse aggregates are presented in vide Table 1. It reveals that the bulk density, specific gravity of all RA is lower than those of the natural aggregate and the water absorption is higher than that of the natural aggregate. This attributes the adherence of the old cement mortar to aggregate in RA which is light and porous in nature. Further, it reveals that the density and specific gravity of RA40 which is obtained from higher strength of original (normal) concrete (M40) are slightly lower than those (RA20) of obtained from lower strength parent concrete (M20) i.e. the specific gravity and density of RA are slightly decreased with the increase in the strength of original concrete. The water absorption of RA40 obtained from the higher strength of original concrete (M40) is higher than that of RA20 obtained from the lower strength of normal concrete (M20). This could be possible due to the presence of relatively higher quantity of cement mortar in RA in higher strength of original concrete compared to RA in lower strength of original concrete. The flakiness and elongation indices of all RA are relatively better than those of the natural coarse aggregate. This may be due to the appropriate care and method of crushing adopted i.e. jaw crushing in the production of RA. The impact value of all RA is higher than that of natural aggregate. Further, there is a slight increase in the impact value of RA with the increase in the strength of original concrete. Since, the aggregate obtained from higher strength of original concrete has relatively higher quantity of adhered mortar compared to the aggregate obtained from lower strength of original concrete, which produce more percentage of powder formation during the impact.

4.2 Compressive Strength

The compressive strength of both normal concrete and recycled aggregate concrete are studied at 3, 7 and 28 days of curing. The development of compressive strength of different grades of normal concrete w.r.t. different curing periods is presented in Fig. 6. It is observed that for all the grades, the compressive strength attained at 3 and 7 days curing period is ranging from 47-51% and 65-70% respectively those of 28 days compressive strength. In general the strength of normal concrete at 7 days curing period is approximately 60 – 70% of that of 28 days compressive strength.

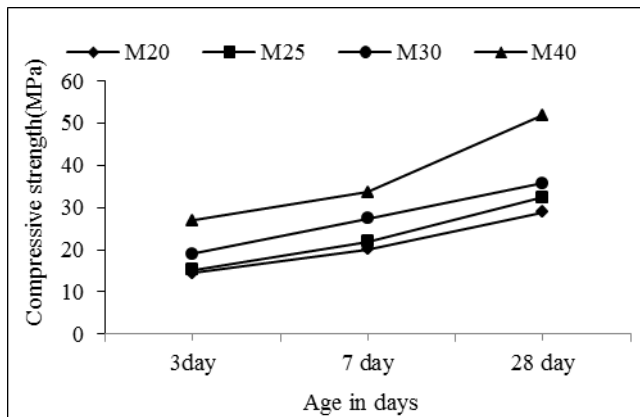


Figure 6: Development of compressive strength of normal concrete of different grades with curing periods

The compressive strength variation in recycled aggregate concrete with different curing periods is presented in Fig. 7.

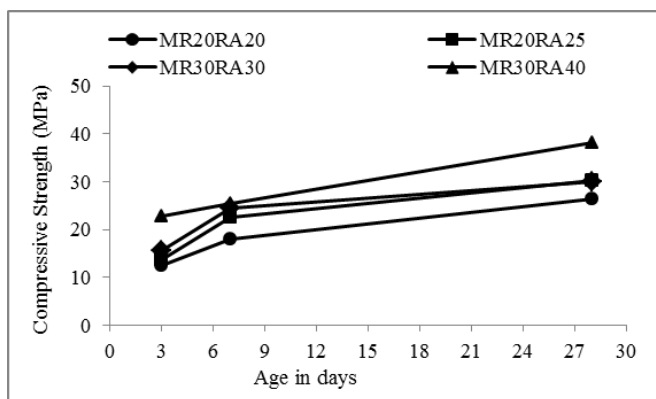


Figure 7: Variation of compressive strengths of all recycled aggregate concretes with curing period

It is observed that the development of compressive strength at different curing periods in recycled aggregate concrete made from different RA are almost similar. The Fig shows that irrespective of the type of RA the development of compressive strength at 3 and 7 days curing periods in all recycled aggregate concrete ranges from 45-59% and 66-80% respectively to those of 28 days compressive strength. These developments of strength are in tune with the strength developments in normal concrete (Fig.6) at different curing periods.

The variation of compressive strength in normal concrete (M20) and recycled aggregate concrete MR20 made with RA20 and RA25 are presented in Fig. 8. It is observed that at 3 days, 7 days and 28 days curing periods, the compressive strength of MR20RA20 is lower by 13.8%, 10.8%, and 9.1% respectively than those of corresponding normal concrete M20. Whereas in MR20RA25, the reduction in compressive strength noticed only for 3days curing period and the percentage reduction in compressive strength is 5.34%. A change in trend has been observed for 7 day and 28 day curing period and it has been slightly improved than its parent concrete compressive strength. It is increased by 12.2%, and 4.6% respectively at 7 and 28 days curing periods than those of normal concrete M20. The compressive strength development in normal concrete (M30) and recycled aggregate concrete MR30 prepared with RA30 and RA40 are presented in Fig. 9. The development of compressive strength

in recycled aggregate concrete prepared with different strengths of parent concrete aggregate i.e. RA30 and RA40 are almost similar trend as it is in normal concrete (M30) with respect to different testing periods.

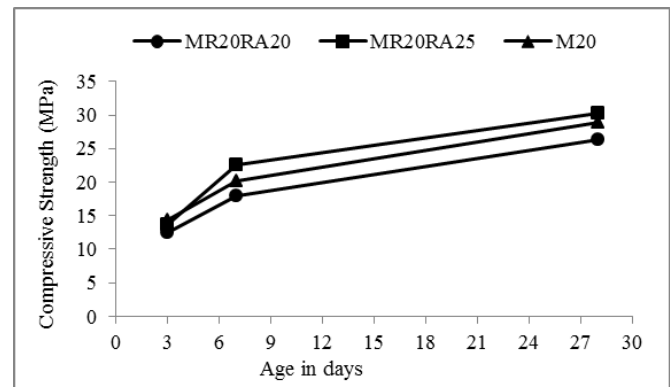


Figure 8: Compressive strength variation in normal concrete (M20) and RAC (MR20) made with RA20 and RA25

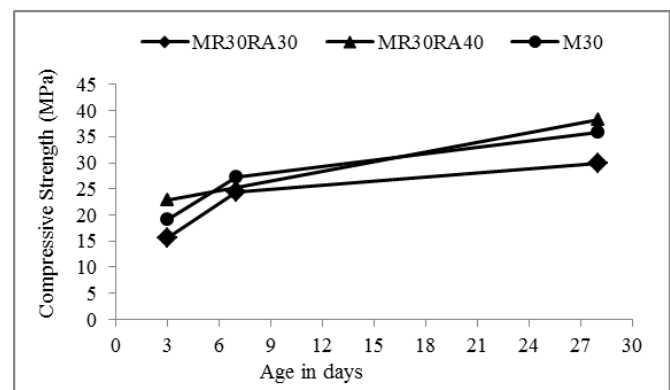


Figure 9: Development of compressive strength of normal concrete (M30) and RAC (MR30) made with RA30 and RA40 with different curing periods

It is observed that at 3, 7 and 28 days testing periods the compressive strength of RAC made with RA obtained from the same grade of normal concrete aggregate i.e. MR30RA30 is lower by 21.85%, 10.84%, and 16.3% respectively than those of the normal concrete M30. Whereas an improvement in compressive strength is found for the same grade of RAC (MR30) when it is made with RA obtained from higher strength of parent concrete i.e. MR30RA40 at 28 days curing period. For MR30RA40, the compressive strength at 28 days curing period is 38.22 MPa which is 6.9% higher than that of the normal concrete (M30). Therefore, from Figs. 8 – 9, the test results of recycled aggregate concrete reveal that the compressive strength of the recycled aggregate concrete made with RA obtained from same grade of parent concrete is always lower than that of the parent concrete at all the curing periods. Whereas, in RAC made with RA produced from relatively higher strength parent concrete, the compressive strength at 28 days testing is slightly higher than that of the normal concrete. That means the RAC made with relatively higher strength of parent concrete aggregate may produce similar strength as the normal concrete of the same grade. The improvement in compressive strength may be due to the higher original strength of cement mortar adhered to aggregate in RA25 and RA40 compared to RA20 and RA30 respectively and hence the old interfacial transition zones in MR20RA25 and MR30RA40 are relatively stronger than

those of the MR20RA20 and MR30RA30 respectively. A similar result is reported in the literature. It was reported in the literature that the compressive strength of high performance concrete made with recycled aggregate obtained from 80 MPa and 100 MPa normal concrete satisfied the designed strength of 65 MPa and it was similar to or even slightly higher than that of the concrete with natural aggregate [20].

5. Closing remarks

The present paper discussed the influence of recycled coarse aggregate obtained from different strengths of parent concrete on compressive strength of recycled aggregate concrete. Based on the test results the following closing remarks can be drawn.

- The bulk density and specific gravity of RA obtained from higher strength parent concrete are relatively lower and water absorption is slightly higher than those obtained from the lower strength of the parent concrete. Possibly this could be due to the adherence of relatively large amount of light porous old cement mortar to the recycled aggregate obtained from higher strength parent concrete compared to the lower strength parent concrete.
- The particle size distribution of recycled coarse aggregate obtained from different strengths of the parent concretes are well within the limits stipulated by BIS for natural aggregate. This could be possible by adopting appropriate care and method of crushing i.e. by jaw crusher.
- The compressive strength of recycled aggregate concrete made with RA obtained from same grade of the parent concrete is always lower than that of parent concrete at all curing periods. However, the RAC made with RA produced from higher strength parent concrete, the compressive strength at 28 days curing is slightly higher than that of the normal concrete. That means the RAC made with higher strength parent concrete aggregate may produce similar strength as the normal concrete of same grade.

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