

# Dynamic Compressive Strength of Recycled Aggregate Concrete

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**Abstract**— Over the years the construction waste has enormously increased, this may be attributed to different factors such as (i) demolition (ii) accidents (iii) impact loads (iv) earthquakes. These activities have caused an increasing burden on already exhausted waste management system globally. As a result, the concrete waste produced in a large quantity has become a major issue to manage due to limited landfill sites. Therefore, the recycling of waste concrete can prove to be beneficial and necessary for the environmental preservation and effective utilization of natural resources. Number of studies have been conducted to study the static mechanical properties of recycled aggregate concrete; however, limited test data has been published which focused on the dynamic properties of the concrete prepared with recycled coarse aggregates. Therefore, in this investigation aim was to study the behavior of recycled aggregates concrete under increasing dynamic compressive loading. For this purpose, cylindrical specimens having a diameter of 100 mm and height of 200 mm were used. These specimens have been prepared with constant concrete mix ratio, having varying percentages of RA such as 0%, 30%, and 50% 70 % and 100%. The dynamic compressive behaviour was studied by using drop hammer system. The height drop hammer system consist of a frame having a maximum height of 15ft. Firstly, three samples (1, 1R, 2R) from each percentage replacement (0%, 30%, 50%, 70% and 100%) were tested on six different velocities of 2.44m/s, 3.45m/s, 4.23m/s, 4.89m/s, 5.46m/s and 7.45m/s with varying strain rates of 12.04/s, 17.00/s, 20.83/s, 24.08/s, 26.89/s and 36.73/s respectively. Weight of the drop hammer was 10 kg. Based on the detailed experimental investigation, it was found that the behaviour of the recycled aggregate concrete under dynamic loading differ significantly from the static loading.

**Keywords**— Recycled Aggregate Concrete, Dynamic Increase Factor, Strain Rates, Drop Weight, Impact Tests

## I. INTRODUCTION

As countries are moving towards infrastructure development, numerous structures are demolished each year. Construction and demolition waste generated annually in European Union (EU) is more than 450 million tons. Most of which is being managed by dumping on the landfilling sites, consequently creating environmental problem by deposition of heaps of demolished waste. Most of the demolition waste consists of concrete. The world is moving towards reducing this waste to reduce the environmental impacts of construction

sector. For this purpose, the concrete waste is recycled and reutilized along with ensuring the strength of structures. The old buildings are now being demolished and the waste is being utilized by crushing it into smaller pieces as recycled aggregates, land fillers and road bases.

Recycling of concrete is a sustainable solution for the environmental problems. It decreases the concrete waste that is required to be landfilled, saving energy, efforts, space and environmental impacts. The requirement of fresh aggregate reduces, consequently reducing the extraction of virgin aggregates resulting in conservation of natural resources.

Use of recycled aggregates concrete (RAC) in structures implies that the determination of mechanical properties of RAC is crucial. Several studies have been conducted on the static mechanical properties of concrete[1-7]. On the contrary, the dynamic properties are rarely discussed. The project, therefore, focus on the determination of dynamic compressive strength of RAC under impact loading. The dynamic impact loads imitate sudden loads which are applied to the structures in different forms. By determining static as well as dynamic properties of RAC, the aggregates can be utilized effectively in the structures achieving ultimate strength.

An experimental study was conducted by Li *et al.* [8] to investigate the dynamic compressive strength of recycled aggregate concrete specimens under increasing loading rates of  $10^{-5}$  to  $10^{-1}$  s<sup>-1</sup> using Split Hopkinson Pressure Bar (SHPB) apparatus. Concrete cylinders were cast with five different percentages of 0%, 30%, 50%, 70% and 100% recycled aggregates and a constant water to cement ratio of 0.45. The specimens were cured for 28 days at 20-degree temperature and were also air dried for 365 days after 28 days moist curing. It was observed that irrespective of natural and RAC, the concrete compressive strength increases with the increase in strain rates. However, the result was found to be more profound for cylinders cast with natural aggregates. It was also observed that the effect of the use of recycled aggregates was negligible at the strain rate of 0.1 s<sup>-1</sup> as similar concrete compressive strength was observed when compared with natural aggregate concrete (NAC). Similarly, except for the cylinders cast with 100% recycled aggregates, the concrete compressive strength was found to be similar at the static loading for all specimens.

An investigation was carried out by Chen, *et al.* [9] to study the behavior of concrete specimens subjected to dynamic loading using SHPB apparatus. A total of 110 cylinders were cast having diameter of 72mm and height of 37mm using three different materials i.e. concrete, mortar and cement paste and constant water cement ratio of 0.45. It was observed that irrespective of the percentages of RAC used, the initial elastic modulus till the stress of 10 MPa was found to be similar under increasing strain rates. However, as the strain rates increase the response differ significantly for each type of the specimen and the affect is found to be more profound as the percentages of the RCA increases. When comparing the softening branch under increasing strain rates, the response differ significantly, however the failure strain was observed to be the same for all types of specimens irrespective of the percentages of RAC used.

An experimental study was conducted by Lu *et al.* [10] to investigate the dynamic behavior of RAC using both, SHPB and drop hammer apparatus. In order to carry out dynamic tests, cylinders of 100 mm height 50 mm diameter of 50 were cast using five different percentages (0%, 25%, 50%, 75% and 100%) of recycled coarse aggregates and having constant water cement ratio of 0.477. The specimens were tested using Split Hopkinson Pressure Bar with varying strain rates of 10-100 s<sup>-1</sup> after 28 days curing. It was also observed that for the case of specimens prepared with recycled aggregates irrespective of its percentage used, the increase in concrete compressive strength was lower under increasing strain rates when compared with natural aggregate concrete. Thus, based on above, it can be concurred that, RAC was less strain rate sensitive.

An experimental study was carried out by Guo *et al.* [11] to investigate the dynamic compressive strength of recycled aggregate concrete specimens. For this purpose, cylinders having diameter of 68 mm and height of 34 mm were tested using SHPB apparatus with impact velocities ranging between 4.76 m/s to 11.32 m/s corresponding to strain rates range of 15.9 s<sup>-1</sup> to 63.4 s<sup>-1</sup>. The cylindrical specimens were casted using four different percentages of 0%, 30%, 70% and 100% recycled coarse aggregates with a common water cement ratio of 0.40 and were cured for 28 days. It was observed that irrespective of the percentage of the recycled coarse aggregates used in preparing the specimens a parabolic relationship can be formed between the increasing DIF and the strain rates.

## II. EXPERIMENTAL PROGRAMME

### A. Specimens Details

To study the dynamic compressive behavior of RAC, specimens were cast using both natural aggregates (NA) and recycled aggregates (RA), having a constant water to cement ratio of 0.45. Specimens were cast having natural coarse aggregates replacement of 0%, 30%, 50%, 70% and 100%

with recycled coarse aggregates whose details are given in Table 1.

Table 1: Quantities of materials used in preparation of the mix.

Specimens Table	Cement (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	NA (kg/m <sup>3</sup> )	RA (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )
RAC00	454	568	1183	0	195
RAC30	454	536	783	335	195
RAC50	454	517	539	539	195
RAC70	454	500	313	729	195
RAC100	454	475	0	991	195

### B. Impact Test Setup

The dynamic compressive behavior of RAC specimens was investigated using drop hammer equipment. The drop hammer equipment consists of the frame having maximum drop height of 15 ft as shown in Fig. 1. Test rig was developed indigenously to perform the dynamic tests.

### C. Impact Velocities Investigated

Three specimens (1, 1R, 2R) of each percentage (0%, 30%, 50%, 70% and 100%) were tested on six different velocities of 2.44m/s, 3.45m/s, 4.23m/s, 4.89m/s, 5.46m/s and 7.45m/s having varying strain rates of 12.04/s, 17.00/s, 20.83/s, 24.08/s, 26.89/s and 36.73/s respectively. The mass of the impactor used in these drop weight impact tests was 10 kg.

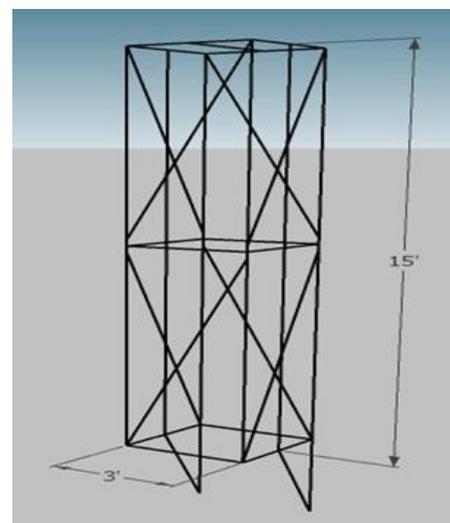


Fig. 1. Schematic representation of impact test rig

## III. RESULTS AND DISCUSSIONS

### A. Force Time Histories

The force time history relationship was formed using image motion processing technique using open source software Tracker [12]. The technique has been used confidentially in investigating the dynamic response of different structural elements under impact loading [13].

Fig. 2 to Fig. 7 shows the impact force time history relationship for the case of specimens prepared with 0%, 30%, 50%, 70% and 100% of recycled coarse aggregates and impacted with velocities of 2.44m/s, 3.45m/s, 4.23m/s, 4.89m/s, 5.46m/s and 7.45m/s having varying strain rates of 12.04/s, 17.00/s, 20.83/s, 24.08/s, 26.89/s and 36.73/s respectively.

From Fig. 2 to Fig. 7, in general, it was observed that the specimen prepared with the 100% recycled coarse aggregates exhibited lowest impact force irrespective of the impact velocity used. Furthermore, opposite to the static loading condition in which increase in the recycled coarse aggregates contents result in decrease in the stress resisted, it was found that the behaviour under dynamic loading differs significantly as no direct relationship was formed between the percentage of the recycled coarse aggregates used in preparing specimens and the peak impact force exhibited. It was also observed that for the case of the 100% recycled coarse aggregates the impact duration was found to be least. This may be attributed to the fact that the 100% recycled coarse aggregate specimen exhibited lowest peak load, thus relatively small time was required to cause the failure of the specimen as all the kinetic energy initially stored in the impactor was converted in to potential energy in the specimen causing damage within very small span of the time as can be seen in Fig. 2. it can be seen that the peak impact force exhibited by specimen prepared with 50% recycled coarse aggregate was found to be higher followed by specimens prepared with 0%, 30% and 70% recycled coarse aggregates which exhibited similar peak impact loads (Fig. 2 to Fig. 7). It was also observed generally that with the increase in the impacting velocity, the impact force exhibited also increases for identical specimen.

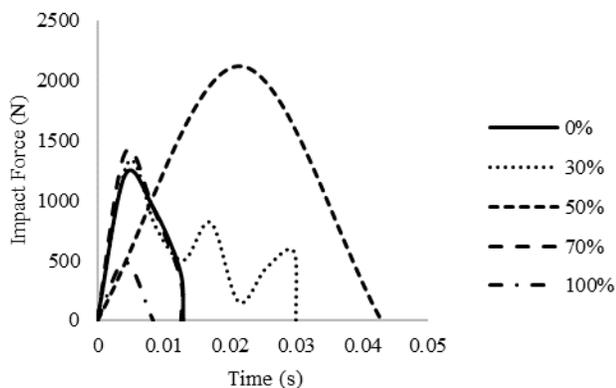


Fig. 2. Impact force time relationship for RAC impacted with a velocity of 2.44m/s

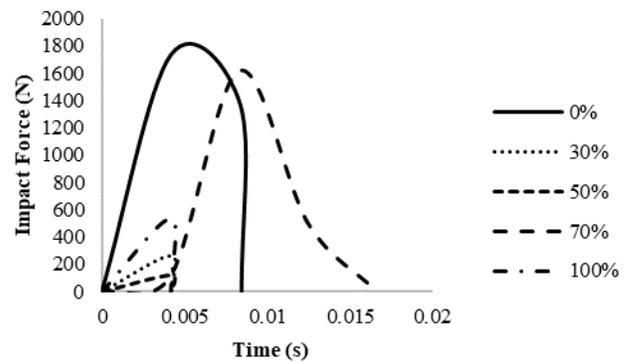


Fig. 3. Impact force time relationship for RAC impacted with a velocity of 3.45m/s

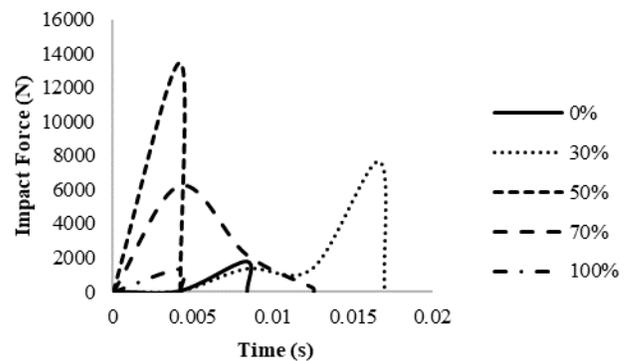


Fig. 4. Impact force time relationship for RAC impacted with a velocity of 4.23m/s

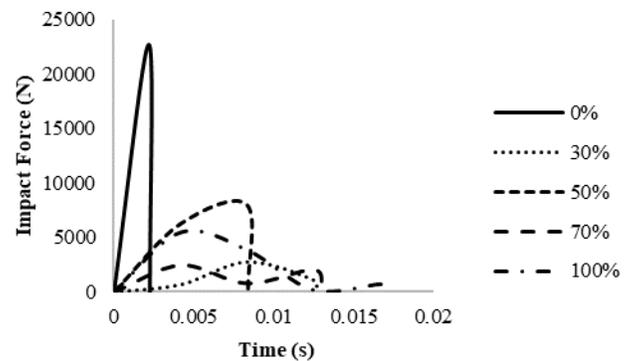


Fig. 5. Impact force time relationship for RAC impacted with a velocity of 4.89m/s

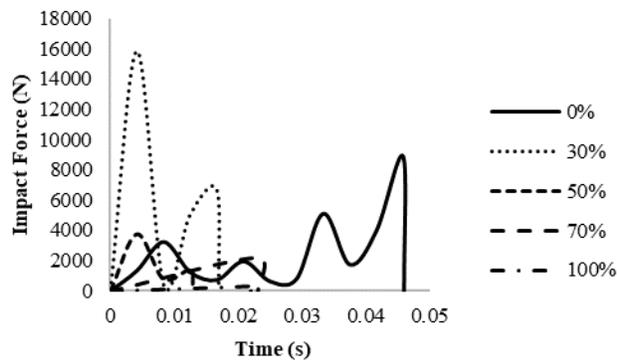


Fig. 6. Impact force time relationship for RAC impacted with a velocity of 5.46m/s

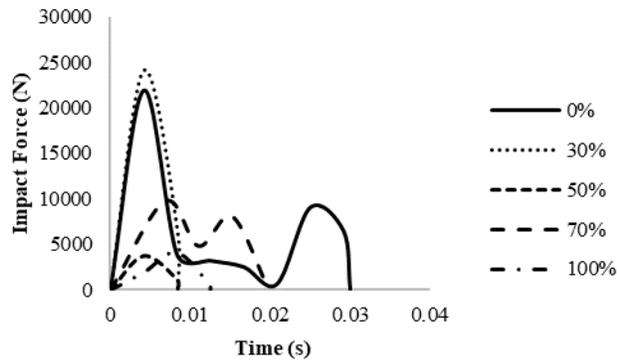


Fig. 7. Impact force time relationship for RAC impacted with a velocity of 7.45m/s

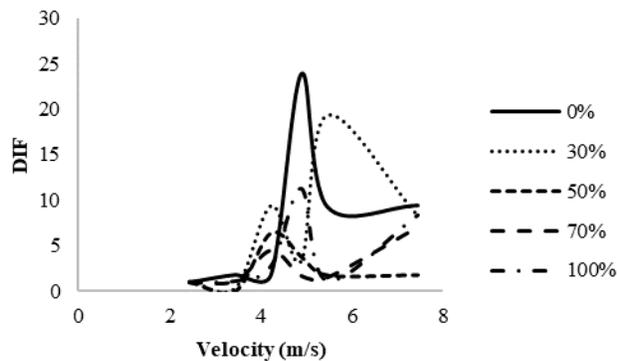


Fig. 8. Variation of dynamic increase factor (DIF) with increasing velocity

### B. Dynamic Increase Factor

Fig. 8 shows the variation of dynamic increase factor (DIF) exhibited by RAC specimens under increasing velocities. The DIF is a ratio between the dynamic force exhibited by the specimen to the quasi-static force. As can be seen from the Fig. 8 that irrespective of the percentage of the recycled aggregate used in preparing the specimen the DIF was found to be essentially 1 for velocity of up to 4 m/s, thus it can be concluded that the behaviour of the both natural aggregate and recycled aggregate concrete specimen is found to be similar to the identical specimen subjected to the static loading. It was

also observed that beyond the velocity of 4 m/s, the DIF increases significantly irrespective of the content of the recycled coarse aggregates. Based on the above discussions it can be concluded that the behaviour of the both natural aggregate and recycled aggregate concrete under increasing velocities significantly differ from that under static loading conditions. Thus, the dynamic affect should be considered while analyzing and the design of the structural elements subjected to dynamic loading conditions in order to ensure safe and smooth operation.

### C. Failure Pattern

Fig. 9 shows the failure pattern exhibited by specimens prepared with different percentages of the recycled coarse aggregates under increasing velocities. It was observed that for the case of 0% RAC specimen at velocities of 2.44m/s, 3.45 m/s and 4.23 m/s cracks appear with minor crushing at top. As the velocity increases to 4.89 m/s and 5.45 m/s specimens are crushed from top. When the velocity reaches to 7.45 m/s crushing of cylinders occur from top till centre. With the replacement of 30% RAC at velocities of 2.44 m/s, 3.45 m/s, 4.23 m/s, 4.89 m/s, 5.45 m/s and 7.45 m/s specimens are majorly crushed from top to centre. With the replacement of 50% RAC at velocities of 2.44 m/s only cracks appear on cylinder. As the velocities increase to 3.45 m/s, 4.23 m/s, 4.89 m/s, 5.45 m/s and 7.45 m/s specimens were crushed from top till centre. With the replacement of 70% RAC with velocity of 2.44 m/s only minor cracks appeared on cylinders. As the velocity increases to 3.45 m/s, 4.23 m/s, 4.89 m/s, 5.45 m/s and 7.45 m/s major crushing occurs on cylinders from top till centre. With the replacement of 100% RAC at velocities of 2.44 m/s, 3.45 m/s, 4.23 m/s, 4.89 m/s, 5.45 m/s and 7.45 m/s major crushing occurs on cylinders from top till centre.

## IV. CONCLUSIONS

The investigation was conducted to investigate the dynamic compressive behaviour of RAC. Cylindrical specimens having different percentages of RAC with constant water cement ratio were tested using drop weight impact testing rig. The influence on the concrete specimens was studied using a mass of 10 kg with varying velocities.

It was found, on the basis of the conducted study, that the increase in the replacement percentage of RAC leads to weakening in compressive strength of concrete specimen under increasing velocities. However, this was not the case with DIF which enhanced with the increasing percentage of RAC. Varying percentages of RAC and different velocities leads to different failure modes. Minor cracks were observed on the specimens with low percentage of RAC tested at lower strain rates.

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Fig. 9. Failure modes exhibited by specimens under increasing velocities

REFERENCES

- [1] Wang, X., Yang, X., Ren, J., Han, N., and Xing, F., A novel treatment method for recycled aggregate and the mechanical properties of recycled aggregate concrete, *Journal of Materials Research and Technology* 10 (2021) 1389-1401 DOI: <https://doi.org/10.1016/j.jmrt.2020.12.095>.
- [2] Khan, A.-u.-R., Khan, M.S., Fareed, S., and Xiao, J., Structural Behaviour and Strength Prediction of Recycled Aggregate Concrete Beams, *Arabian Journal for Science and Engineering* 5, 45 (2020) 3611-3622 DOI: 10.1007/s13369-019-04195-w.
- [3] Bai, G., Zhu, C., Liu, C., and Liu, B., An evaluation of the recycled aggregate characteristics and the recycled aggregate concrete mechanical properties, *Construction and Building Materials* 240 (2020) 117978 DOI: <https://doi.org/10.1016/j.conbuildmat.2019.117978>.
- [4] Khan, A.-u.-R., Aziz, T., Fareed, S., and Xiao, J., Behaviour and Residual Strength Prediction of Recycled Aggregates Concrete Exposed to

- Elevated Temperatures, *Arabian Journal for Science and Engineering* 10, 45 (2020) 8241-8253 DOI: 10.1007/s13369-020-04682-5.
- [5] Deng, Z., Liu, B., Ye, B., and Xiang, P., Mechanical behavior and constitutive relationship of the three types of recycled coarse aggregate concrete based on standard classification, *Journal of Material Cycles and Waste Management* 1, 22 (2020) 30-45 DOI: 10.1007/s10163-019-00922-5.
- [6] Khan A. R, F.S.a.K., M. S, Use of Recycled Concrete Aggregates in Structural Concrete, 2019: Fifth International Conference on Sustainable Construction Materials and Technologies.
- [7] Ghanchibhai, S.F., Rasoolbhai, I.U., and Pandya, T.H., A review paper on use of recycled concrete aggregate in concrete, (2019).
- [8] Li, L., Xiao, J. and Poon, C.S., 2016. Dynamic compressive behavior of recycled aggregate concrete. *Materials and Structures*, 49(11), pp.4451-4462.
- [9] Chen, X., Wu, S. and Zhou, J., 2013. Experimental and modeling study of dynamic mechanical properties of cement paste, mortar and concrete. *Construction and Building Materials*, 47, pp.419-430.
- [10] Lu, Y., Chen, X., Teng, X. and Zhang, S., 2013. Impact behavior of recycled aggregate concrete based on split Hopkinson pressure bar tests. *Advances in Materials Science and Engineering*, pp.1-8.
- [11] Guo, J., Chen, Q., Chen, W. and Cai, J., 2019. Tests and numerical studies on strain-rate effect on compressive strength of recycled aggregate concrete. *Journal of Materials in Civil Engineering*, 31(11), p.04019281.
- [12] Brown, D., Tracker video analysis and modeling tool, Open source, physics 4 (2009).
- [13] Fareed, S., Subsea pipes under high-mass low-velocity impacts, 2017, Heriot-Watt University.

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