An Experimental Study on Strength Analysis of Fully Recycled Mortar Cubes

Mr. Amal Anand[1*], Ms. Lekshmi Priya R[2]

[1]P.G Student, Department of Civil Engineering, Sree Narayana Institute of Technology, Adoor

[2]Assistant Professor, Department of Civil Engineering, Sree Narayana Institute of Technology, Adoor

*Corresponding author's e-mail: amalanandadoor@gmail.com
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ABSTRACT

Concrete has non-renewable raw materials that are in high demand globally as a result of the construction industry's explosive growth. In order to stop the depletion of natural resources, a substitute for these basic materials is needed. Concrete can be made with recycled aggregates (RA) and recycled powder (RP), which are materials made from construction and demolition (C&D) waste. However, more research and development are needed before this method can beput into practice. The purpose of this study is to evaluate the compressive strength of mortar cubes made with recycled powder and aggregates. Additionally, polypropylene fibers are added to this blend as an additive to test how well it performs.

Keywords: Recycled aggregates, Recycled powder, C&D wastes

1 Introduction

The world is running at a fast pace in the past few decades and the growth rate of the world mostly depends on the construction industry [1], [2]. The construction industry relies on materials, manpower, technology, etc. and the major construction material used worldwide is concrete. In the current situation, concrete has a major role in the sustainable development of the construction sector due to a variety of reasons such as the production of concrete causing problems increasing the consumption of resources and the production of cement, which is an ineluctable raw material of concrete, causes several environmental impacts like airborne pollution in the form of dust and gases. A large quantity of greenhouse gases was emitted into the atmosphere during the production of cement.

The increasing requirements of aggregates require an expansion of a quarry that makes a threat to valuable natural areas, or a preserved species. Moreover, the disposal of C&D wastes is still not possible in an effective manner [3]. Such a significant volume of waste concrete depletes vast amounts of land resources and, particularly in large cities, creates environmental and social dilemmas. In late years, various regions of the world have experienced a decline in the quality of their natural aggregates [1], [2], [4]. Thus, long-distance transportation of materials from their available resources to construction areas is required, drastically increasing construction costs and aggravating environmental pollution.

Contending all these problems researchers advocated the technology for recycled aggregate concrete in response to the C&D waste disposal and shortfall of raw materials, since recycling an immense quantity of waste concrete is considered to be the most convincing proposal to clear up the complications associated with concrete waste and resource depletion [2].

Prior to using recycled aggregates in place of natural aggregates in concrete, the current study considers recycled fine aggregate (RFA) and recycled powder (RP) as integral substitutes for natural fine aggregate and cement in a mortar mix. RFA is used to completely replace natural fine aggregate and varying percentages of RP are used to partially replace cement, thereby reducing the use of conventional resources and reusing C&D waste. Compressive strength is one of the most important features in considering both mortar and concrete mixes. This study examined the fully recycled mortar cubes (FRMC) compressive

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strength, which comprises varying amounts of recycled powder (RP) and recycled fine aggregate (RFA) [1]. Additionally, an analysis of the compressive strength of FRMC containing various volume fractions of polypropylene fibers was conducted [5].

Abbreviations

C&D waste- Construction and demolition waste
FRMC- Fully recycled mortar cubes
NFA- Natural fine aggregate
NMC- Normal mortar cubes
PP- Polypropylene fibers
RA- Recycled aggregate
RFA- Recycled fine aggregate
RP- Recycled powder

2 Experimental Programs

2.1 Material study

2.1.1 Cement

The cement used is ordinary Portland cement 53 grade shown in Figure 1. It is used as a binder in both normal mortar cubes and recycled mortar cubes. In fully recycled mortar cubes cement is partially replaced with recycled powder. The physical properties of cement are tested as per Indian Standards and are given in Table 1.

Figure 1: *Ordinary Portland cement*

Table 1: *Physical properties of cement*

Fineness	Specific Gravity	Consistency	Initial setting time	Final setting time
5%	3.16	33.6%	45 minutes	600 minutes

2.1.2 Recycled powder

Particles in the recycled fines smaller than 4.75 mm in size were ground into the recycled powder (RP), which was then sieved through sieves with a minimum mesh size of 0.15 mm in Figure 2. The un-hydrated cement component of RP caused it to have a high hydration reactivity and the high fineness of RP is an aid for it. The physical properties of RP are tested as per Indian Standards and are given in Table 2.

Figure 2: *Recycled powder*

Table 2: *Physical properties of cement*

Specific Gravity	Consistency	Initial setting time	Final setting time
2.27	42%	60 minutes	900 minutes

2.1.3 Natural fine aggregate

The natural fine aggregate (NFA) used to prepare the mortar mix in this study was M-sand. Manufactured sand (M-Sand) crushed from natural stone, provided by a local factoryhas a size is less than 4.75mm Figure 3. Table 3 lists the physical characteristics of fine aggregate that have been examined in accordance with Indian Standards.

Figure 3: *Natural fine aggregate (M-sand)*

Table 3*: Physical properties of fine aggregate*

Specific Gravity	Particle size distribution	Water absorption
2.56	Zone 2	16.67 %

2.1.4 Recycled fine aggregates

Concrete was crushed into size to create the recycled fineaggregate (RFA) employed in this study shown in Figure 4. The concrete used for this purpose was C&D waste obtained from local areas. The C&D waste is crushed and sieved through specified IS sieves. The same batch of products is used to prepare recycled aggregates and recycled powder to assure the stability of recycled aggregate quality. The basic performance

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of RFA as per Indian Standards are shown in Table 4.

Figure 4: *Recycled fine aggregate*

Table 4: *Physical properties of recycled fine aggregate*

Specific Gravity	Particle size distribution	Water absorption
2.57	Zone 2	21.43 %

Due to mortar residue attached to the aggregates' surface, the water absorption in recycled aggregates is greater than in natural aggregate. Figure 5 shows the aggregates' particle size distribution for this investigation.

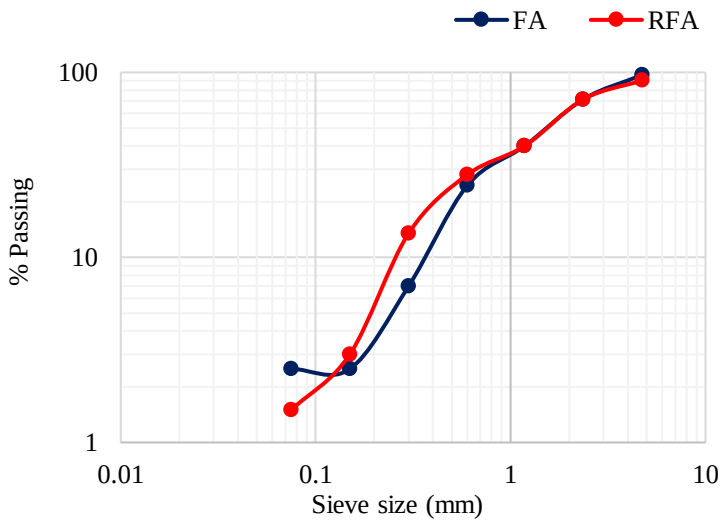

Figure 5: *Particle size distribution of aggregates*

2.1.5 Water

Ordinary tap water available in the research lab

2.1.6 Polypropylene fibers

Polypropylene fibers used were microfibers with a standard length of 12 mm in Figure 6. The specific gravity of the fiber was given as 0.91 g/cc with 19% elongation. It is added to recycled mortar cubes to analyze their performance.

Figure 6: *Polypropylene fibers*

2.2 Mix proportions

Mortar is the combination of cement and fine aggregate mixed with water. A common mix ratio of the mortar used is 1:3, 1:4, and 1:6, cement to fine aggregate ratio. For crucialstructures, a 1:3 ratio is used. The ratio of 1:3 is used to prepare the cement mortar blend as per IS specifications.

The same ratio is used to prepare a fully recycled mortarcube (FRMC), that is for one part of cement three parts of recycled fines are used to prepare the blend. The cement in the fully recycled mortar cubes (FRMC) is also partially replaced with recycled powder (RP) by varying percentages such as 5%, 10%, 15%, and 20% to obtain FRMC- 5% RP, FRMC- 10% RP, FRMC- 15% RP, FRMC- 20% RP. In addition, the polypropylene fiber added was 0.1 %, 0.15 %, 0.2%, and 0.3% of the volume of the mix.

2.3 Specimen's preparation

For the purposes of this study, the mortar was cast in a controlled setting in a laboratory. The cement and fine aggregates are mixed properly in dry conditions and water isadded according to IS specification, (p/4+3) % of the combined weight of cement and fine aggregate is found to bethe abundance of water necessary to produce a paste with a specified consistency. For each mixture, 9 cubes of 70.6 mmside are cast. In accordance with IS specifications, all specimens were cast promptly after joining and compressed accompanying a standard rod. The cube specimen is shown in Figure 7.

Figure 7: *Mortar cubes*

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2.4 Testing Methods and Equipment

2.4.1 Compressive strength

Cubes of 70.6 x 70.6 x 70.6 mm were used for the cement mortar compressive strength test. As per IS:4031(Part 6), the compressive stress was retained continually and evenly enforced starting from nothing at a rate of 35 N/mm² brief time period. The compressive strength of all combinations was tested at 3 days, 7 days, and 28 days later. All the cubes were healed in the standard cure surrounding 28 days after casting. The compressive strength test of cubes is shown in Figure 8.

Figure 8: *Compressive strength test of mortar cubes*

3 Experimental Results

3.1 Analysis of compressive strength of mortar cubes

There were no glaring cracks in the specimen at the start of the compression test. As the load steadily increased, the first crack emerged at the maximum value. The cracks formed in each specimen corresponding to the maximum loads are depicted in Figure 9.

The maximum compressive strength of all mixtures of mortar cubes was tested for 3 days, 7 days, and 28 days, and the results were summarized in Table 5.

Table 5: *Compressive strength of mortar cubes of different combinations*

Mix	Compressive strength (N/mm^2)		
	3 days	7days	28 days
NMC	13	34	43
FRMC	10	30.2	38.4
FRMC-5% RP	8.86	26.4	36.2
FRMC-10% RP	7.96	24.33	34.4
FRMC-15% RP	6.53	20.08	28.8
FRMC-20% RP	5.07	17.73	25

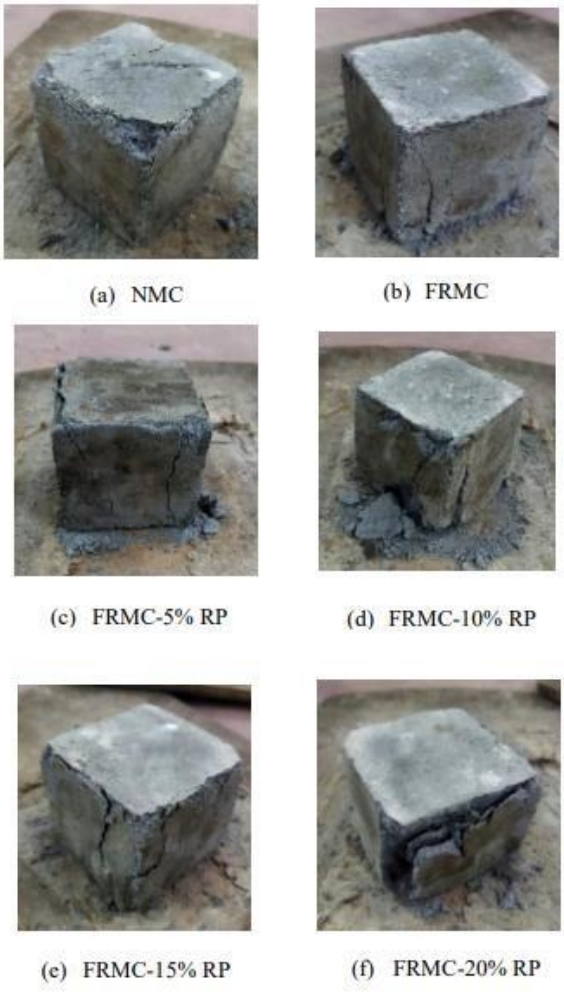

Figure 9: *Failure mode of mortar cubes*

It was evident that the mortar cube's compressive strength abated accompanying the change of the aggregates in the combinations from natural to recycled aggregate. Also, the increase in the amount of recycled powder further reduces thecompressive strength of the cube. The variation in compressive strength of all mortar cubes are shown in Figure 10.

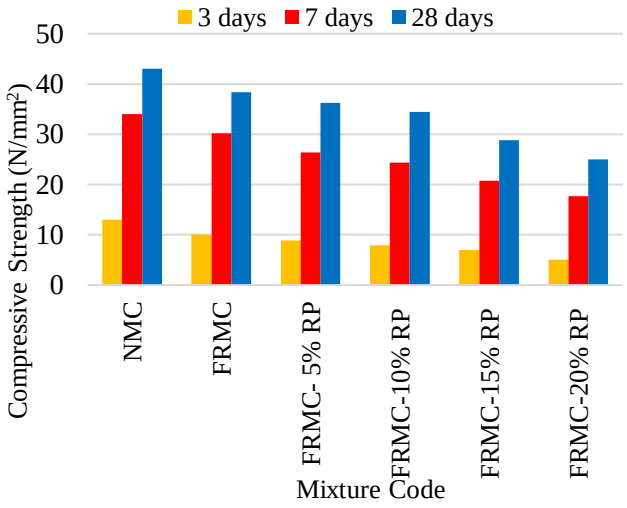

Figure 10: *Compressive strength of all mortar mixes*

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As the amount of recycled powder in the mortar mix increases the compressive strength reduces. The reduction in 28-day compressive strength of FRMC with respect to NMC was almost 11%, while the numbers were 16%, 20%, 34%, and 41% in FRMC- 5% RP, FRMC- 10% RP, FRMC- 15% RP, and FRMC- 20% RP respectively. That is, using recycled powder in a mortar of up to 20% can reduce the compressivestrength of the mix to about half of the normal mortar mix.

3.2 Analysis of compressive strength of mortar cubes with polypropylene fibers

A fully recycled mortar mix with 10% recycled powder was taken for the analysis since it can reduce 10% of cement in the mix and have comparable compressive strength. To improve the compressive strength of this mix polypropylene fibers were added, and to find variations in properties different volume fractions of polypropylene fibers were taken. The workability of the mix reduces with each increment of the percentage of fibers. Therefore, only up to 0.2% is taken for the study. The crack pattern for all the mixtures is shown in Figure 11.

Figure 11: *Failure mode of mortar cubes with polypropylene fibers*

The average compressive strength of all the specimens of mortar cubes in 3 days, 7 days, and 28 days were summarized in Table 6, and the corresponding graph is plotted and shown in Figure 12. By analyzing the data, it is evident that the mortar cube's compressive strength increases with the incorporation of polypropylene fiber.

Table 6: *Compressive strength of mortar cubes with polypropylene fibers*

Mix	Compressive strength (N/mm^2)		
	3 days	7days	28 days
FRMC-10% RP	7.96	24.33	34.4
FRMC-10%RP- 0.1% PP	8.4	24.4	36.33
FRMC-10% RP- 0.15% PP	9.87	26.6	38.33
FRMC-10%RP- 0.2% PP	12.26	27.86	43.06
FRMC-10%RP- 0.3% PP	9.5	26	37.33

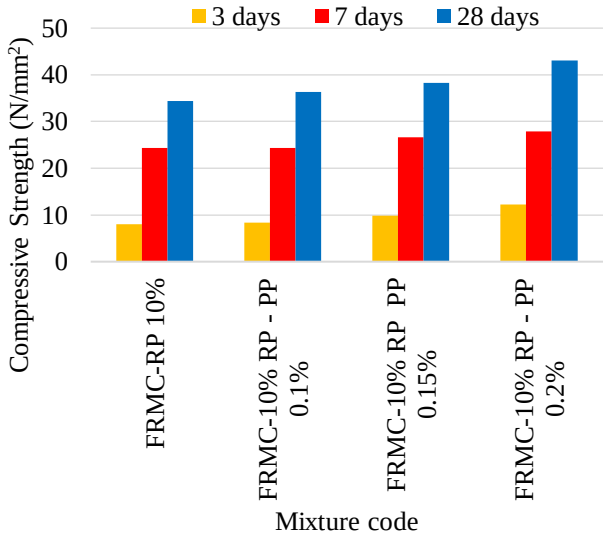

Figure 12: *Compressive strength of all mortar mixes with polypropylene fibers*

From the figure, it can be found that for the recycled mortar mix incorporated with recycled powder and with polypropylene fiber, the increment of the polypropylene fiber content can improve the compressive strength of the mortar cubes initially. By incorporating 0.2% of polypropylene fiber into the mix the strength increased to a value comparable with a normal mortar cube. From the figure, it is evident that it became increasingly clear that adding polypropylene fiber improved the compressive strength of cubes. The addition of polypropylene fibers in 0.3% of the volume fraction of the mix results in a decline in the mix's compressive strength also the mix becomes too stiff. Hence 0.2% of polypropylene fibers can be taken as optimum for fully recycled mortar cubes.

4 Discussion

The compressive strength of both regular and recycled mortar cubes was tested using standardized techniques in accordance with Indian norms. The outcomes demonstrated that variations in aggregate combinations and recycled powder contents had an impact on the compressive strength of cubes. The reinstatement of cement partly accompanying RP curtails the mix's compressive strength. But the objective concerning this study search out lower the use of aggregates and cement in the mix by incorporating recycled fines made from C&D waste.

The water absorption of aggregates made from C&D waste is found to be higher than natural aggregates and the addition of polypropylene fibers reduces the workability of the blend. Thus, there is a limit to the addition of fibers to increase their properties. It is evident from the figure that, with the hike in volume fraction of polypropylene fiber to 0.2 %, the compressive strength of FRMC- 10% RP is increased and obtained a value comparable with NMC. Further addition of fibers culminates in the decrease of compressive strength of the mix.

The use of FRMC-10% RP with 0.2% polypropylene fiber can reduce the use of about 10 kg of cement per bag and completely eliminate the use of fine aggregate. Also, it eliminates the construction and demolition wastes disposed of on land, which makes it cost-effective and environment- friendly if applied industrially.

5 Conclusions

In this work, an experiment was used to gauge the compressive strength of mortar cubes made entirely of recycled aggregate. The aftermath of recycled powder and recycled aggregate contents on the strength of mortar cubes were the main topics of discussion. These inferences were made in light of the testing results:

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1. With the usage of recycled aggregate and an increase in the amount of recycled powder, the compressive strength of mortar cubes on day 28 diminishes.
2. With the inclusion of polypropylene fiber into the recycled mortar cubes the strength is enhanced, but the increased amount of fiber has an adverse effect on the workability of the mix.
3. By using recycled aggregates and recycled powder in mortar mix helps in sustainable development by reducing C&D waste disposal and natural resource depletion.

6 Publisher's Note

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