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Experimental Research on The Strength Properties of Concrete with Recycled Aggregate, Pond Ash, and Rubber Powder Replaced in Part for Concrete Materials in Standard Grades

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Abstract

Concrete, a fundamental material in modern construction, poses environmental concerns due to its significant carbon footprint. To mitigate this impact, researchers explore alternative materials like fly ash, GGBS, alcofine, and rubber powder as cement replacements. This study examines the durability and strength of concrete that contains recycled aggregate, pond ash, and waste rubber powder. Waste rubber, abundant from industrial and automotive sources, poses disposal challenges. Pond ash, a byproduct of power plants, and recycled aggregate from demolished structures offer environmentally friendly alternatives. The study examines these materials' effects on concrete, aiming for lightweight yet robust compositions. Experimentation involves varying proportions of waste rubber, pond ash, and recycled aggregate in concrete grades M30 and M40. Parameters like compressive strength, splitting tensile strength, permeability, and flexural strength are assessed after 28 days of curing. Results indicate that a mix containing 5% waste rubber, 20% pond ash, and 20% recycled aggregate yields optimal compressive strength and improved water penetration. However, despite promising results, structural applications of these concrete blends are hindered by lower compressive strength compared to conventional concrete. Further research is needed to enhance the structural viability of compositions containing waste rubber, pond ash, and recycled aggregate. In conclusion, this study sheds light on the potential of incorporating waste rubber, pond ash, and recycled aggregate in concrete to reduce environmental impact while maintaining performance. Optimizing material proportions and addressing strength limitations will be crucial for broader adoption in structural applications.

Keywords: Waste rubber powder, pond ash, recycled aggregate, cement, partially replaced, M30 and M40 grades, Compressive strength, Splitting tensile strength, Permeability, and flexural strength test.

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INTRODUCTION

General

The most common building material is concrete. The term "concrete" comes from the Latin word "concretus," which meaning "grow together." [13] The components of concrete include cement, water, and fine and coarse particles. Concrete mixes with high workability, high durability, and high ultimate strength are referred to as "high-performance concrete" (HPC) [13]. The components, ratios, and manufacturing techniques of HPC concrete are specifically selected to meet unique performance and uniformity requirements that are not always achievable with standard materials such as cement, aggregates, water, and chemical admixtures, as well as standard mixing, placing, and curing procedures. These performance criteria include things like high strength, high early strength, high workability, low permeability, high durability for hard service circumstances, and so on. The architectural and engineering materials have to compete with other materials to fulfil the ever-rising demands of economy, quality, productivity, and environment [13]. Examples of these materials are plastic, steel, and wood. Concrete needs to be resistant to weathering, chemical erosion, and other degradation processes in order to be deemed durable. Durable concrete will not lose its original form quality or functionality when exposed to the elements [13].

MATERIALS USED AND THEIR PROPERTIES

Cement

The minimum specified strength of 53 MPa (N/mm2) for a 28-day period is required for OPC 53 Grade cement, as per the Bureau of Indian Standards (BIS) specification IS:12269-1987 [13]. 53 grade OPC's optimal particle size distribution and outstanding crystalline structure give constructions great strength and longevity. When concrete is needed for certain high-strength applications, such building skyscrapers, bridges, flyovers, chimneys, runways, concrete roadways, and other heavy load-bearing structures [13], this high-strength cement offers many benefits. According to Bureau of Indian Standards (BIS) specification IS:12269-1987, OPC 53 Grade cement must have a minimum specified strength of 53 MPa (N/mm2) for a 28-day period. 53 grade OPC's optimal particle size distribution and outstanding crystalline structure give constructions great strength and longevity. When concrete is needed for certain high-strength applications, such building skyscrapers, bridges, flyovers, chimneys, runways, concrete roadways, and other heavy load-bearing structures, this high-strength cement offers many benefits. The test results for the cement used in this study are summarized in Table 1. These results include the standard consistency, setting times, specific gravity, and compressive strength of the cement.

Table 1. Test results of cement.

S no.	Test parameters	Observed values	Methods of tests adopted	Requirement as per standard specifications of IS 269:2015
1.	Standard consistency (%)	28	IS 4031PART 4	-----
2.	Initial setting time (min)	110min	IS 4031PART 5	Not less than 30 min
3.	Final setting time (min)	410min	IS 4031PART 5	Not more than 600 min
4.	Specific gravity of cement	3.16	IS 4031PART 1	3.1-3.16
5.	Compressive strength of cement	52.5n/mm2	IS 4031PART 6	-----

Fine Aggregate

High-quality Aggregate Crushed stone sand or natural sand should make up fine aggregate. It needs to be strong, resilient, and devoid of organic materials. Harmful contaminants such alkalis salts and a significant proportion of clay ball should not be present in fine aggregate. coal deteriorated the amount of silt in vegetation shouldn't be more than 4% [11]. According to IS 383 in general, a fine aggregate with a coarser size (Zone 1 or Zone 2) is chosen for high strength [12].

Table 2. Fineness modulus of fine aggregate.

Sieve Size	Weight retained(g)	%(Retained)	%Cumulative retained	%Cumulative passing
10	0	0	0	0
4.75	58.5	2.93	2.93	97.07
2.18	309.5	15.47	18.4	81.6
1.18	237.5	11.88	30.28	69.72
0.006	888	44.4	74.68	25.32
0.003	390.5	19.52	94.2	5.8
0.0015	97	4.85	99.05	0.95
Pan	19	0.95	100	

Coarse Aggregate

Coarse Mixture It made use of crushed gravel from nearby crusher mills that came in various sizes, including 20 mm Figure 1- and 12.5-mm Figure 2. In compliance with IS: 2386-1963, the aggregates' physical specifications, including specific gravity and water absorption, were tested [11][12]. The fineness modulus of the fine aggregate used in this study is presented in Table 2. This table outlines the distribution of particle sizes in the aggregate, as measured by sieve analysis. The physical properties of the coarse aggregate are detailed in Table 3.

Figure 1. 20 mm coarse aggregate.

Figure 2. 12.5mm coarse aggregate.

Table 3. Coarse Aggregate Physical Properties.

S.no	Physical properties	Results
1.	Specific Gravity	2.83
2.	Water Absorption	0.2%
3.	Fineness Modulus	7.71

Rubber Powder

Waste rubber powder (WRP) particles were obtained by incinerating waste rubber tires at 850 ◦C for 72 h. The particle size of WRP particles varies between 0.090 mm and 0.450 mm, in Fig. 3 and its specific gravity is 0.92. The chemical components of the WRP are presented in Table 4 [1][2][4][6][9].

Figure 3. Waste rubber powder.

Table 4. Chemical properties of the used waste rubber powder (WRP).

Chemical components	Value (%)
Rubber hydrocarbon	47.5
Acetone extract	13.4

Inorganic sulfur	0.8
Ash content	4.9
Carbon black	28.7
SiO_2	0.6
TiO_2	0.2
ZnO	1.8
CaO	0.5
Fe_2O_3 + Al_2O_3	0.3
Fiber content	0.5

Figure 4. Recycled aggregate.

Figure 5. Pond ash

Pond Ash

Features of Pond Ash Coal combustion residuals (CCR) are determined by the kind of coal, the fineness of the coal particles, the percentage of ash in the coal, the combustion method employed, the air/fuel ratio, the number of burners utilized, and the type of burner. The ratio of black carbon to total particle mass and coal combustion efficiency are likely connected to the non-sphericity of ash particles [3], [4]. We can see the Figure 5 how pond ash looks.

Recycled Aggregate

Processing of used material and using processed material in the new product is called recycling. Technology advancements in the building sector are driving the industry toward sustainability. To employ recycled aggregate in a reinforced concrete structure, shows in Fig 4. properties like compression, crushing resistance, the ratio of water absorption, and modulus of elasticity of concrete are to be known to understand mechanical behavior and reliability [4], [6], [7], [8]

Specific Gravity and Fineness Modulus

The concrete blocks were crushed in machine crusher and received aggregates of size 12.5mm and 20mm. Tests are similar to normal coarse aggregate (NCA), and results are presented in table 5 [10], [11], [12].

Table 5. Physical Properties of Recycled Coarse Aggregate

Tests	**Values**
Specific gravity	2.23
Fines modulus	8.05
Water absorption	4.38%

METHODOLGY

Steps In Methodology

The following steps are the procedure for experimental work

- Collection of raw materials.
- Basic tests conducted on collected materials as per IS codal provisions [12], [10].
- preparing the mix design for concrete with a grade of M30 and M40.
- Concrete mixes are to be prepared by varying the Rubber powder proportion of 0%, 5%, 10%, 15% and 20% (by weight of cement) replacement of cement. Pond ash content as 0%, 20%(by weight of fine aggregate) replacement of fine aggregate and recycled aggregate content as 0%, 20% (by weight of coarse aggregate) replacement of coarse aggregate
- casting specimens of cubes (150mm*150mm*150mm), cylinders (150mm*300mm) and prisms (100mm*100mm*500mm) Number of cubes 96 no’s, cylinders 48 no’s and prisms 48 no’s.
- Conducting the tests of compressive strength test, split tensile test, permeability test and flexural strength test.
- Curing of specimens for 28 days.
- Testing of concrete specimens.

RESULTS AND CONCLUSIONS

Mix Design Procedure

General

The process of determining the ratios of cement, fine aggregate, and coarse aggregate in a concrete mix is known as mix design. Concrete's required characteristic strength is indicated by the grade designation. According to IS: 456-2000 [12] and IS: 10262-2009 [13], the mix design is completed.

EXPERIMENTALWORK

Compressive Strength of Concrete

Numerous variables, including the cement-water ratio, the strength of the cement, the caliber of the raw materials used to make the concrete, quality control procedures used in the concrete manufacturing process [10], [12], etc., affect the compressive strength of the concrete. A compressive strength test is performed on a cylinder or a cube. Concrete cubes or cylinders are suggested by several standard codes as the test's standard specimen. The ASTM C39/C39M Standard Test Method for Cylindrical Concrete Specimens' Compressive Strength is provided by the American Society for Testing Materials [13].

Procedure of Compressive Strength Test on Concrete Cubes

The process for testing concrete cubes' compressive strength For the majority of the works, two types of specimens are utilized for the cube test: cubes measuring 15 cm by 15 cm by 15 cm or 10 cm by 10 cm by 10 cm, depending on the size of the aggregate. These are called cubical molds. In order to prevent voids [12]. this concrete is carefully tempered after being put into the mold. After a day, these molds are removed, and the test specimens are cured by immersion in water. The top surface of these specimens need to be smooth and level. Apply cement paste uniformly across the specimen area to achieve this. These specimens undergo evaluation utilizing compression testing apparatus following Table 6 a 28-day curing period. The load should be applied gradually at a rate of 140 kg/cm2 per minute until the specimens fail. The load at failure is divided by the area of the specimen to get the compressive strength of the concrete [13].

Table 6. Number of Specimens Casted.

Percentage replacement of cement with rubber powder	Percentage replacement of fine aggregate with pond ash	Percentage replacement of coarse aggregate with recycled aggregate	CUBES 150 mmside		CYLINDER150mm*300mm		PRISMS100 mm*100mm*500mm	
			M30	*M40*	*M30*	*M40*	*M30*	*M40*
0%	0%	0%	6	6	3	3	3	3
0%	20%	0%	6	6	3	3	3	3

0%	0%	20%	6	6	3	3	3	3
0%	20%	20%	6	6	3	3	3	3
5%	20%	20%	6	6	3	3	3	3
10%	20%	20%	6	6	3	3	3	3
15%	20%	20%	6	6	3	3	3	3
20%	20%	20%	6	6	3	3	3	3
Total			48	48	24	24	24	24
Total Number of Specimens			144					

TEST RESULTS AND DISCUSSIONS

Compressive Strength Results

The compressive strength test is the one on concrete that is most frequently conducted since the desirable distinctive features of the material are quantitatively connected with its compressive strength [10], [12]. The compressive strength was determined using a 300-ton capacity Compression Testing Machine (CTM). Concrete cube specimens of 150 mm by 150 mm by 150 mm were used to assess the compressive strength of the material [12]. Between the loading surfaces of a CTM, a specimen was placed, and the load was applied until the specimen broke [10], [12]. Three test specimens were cast for each %, and the compressive strength was determined under each set of test conditions [13]. The average outcome was taken into account. Table 7 displays the average compressive strength values of three specimens for each category after 28 days of curing [12], [13].

Table 7. Test Results of Cubes for Compressive Strength Test for 28 days

Rubber powder%	**Pond ash%**	**Recycled aggregate%**	**Compressive strength in N/mm^2**	
			M30 Grade	***M40 grade***
0%	0%	0%	38.26	46.53
0%	20%	0%	37.01	42.12
0%	0%	20%	35.25	41.66
0%	20%	20%	32.07	40.84
5%	20%	20%	28.43	38.68
10%	20%	20%	20.06	33.51
15%	20%	20%	15.24	28.79
20%	20%	20%	11.05	21.53

The 28 days compressive strengths of the concrete in the mixes M30 and M40 are observed that the decrease in compressive strength is due to weak bonding between replacing materials and normal concrete materials [10], [12] are in Table 7 and fig 6. The reduction of compressive strength of M30 grade concrete with replacements of cement as 5%,10%,15%,and 20% and fine aggregate as 20% and coarse aggregate as 20% respectively[13] are 4%, 8%, 17%, 26%, 48%, 61.2%, 72.2% .and for M40 concrete is 10%, 11.5% ,12.3% ,17.9%, 28%, 38.2%, 53.8%

Split Tensile Strength Results

It is crucial to understand concrete's tensile strength. Tensile strength was measured using a universal testing machine (UTM) or compression testing machine (CTM) [10], [11]. The split tensile strength of concrete was assessed using cylinder specimens of 150 mm by 300 mm. This test involves sandwiching a specimen between a UTM or CTM's loading surfaces and applying stress until the specimen breaks [10], [11]. For every percentage, three test specimens were cast, and the average value was considered after the tensile strength was measured under each condition. After 28 days of curing [12], [13], Table 8 displays the average values of three specimens for each category

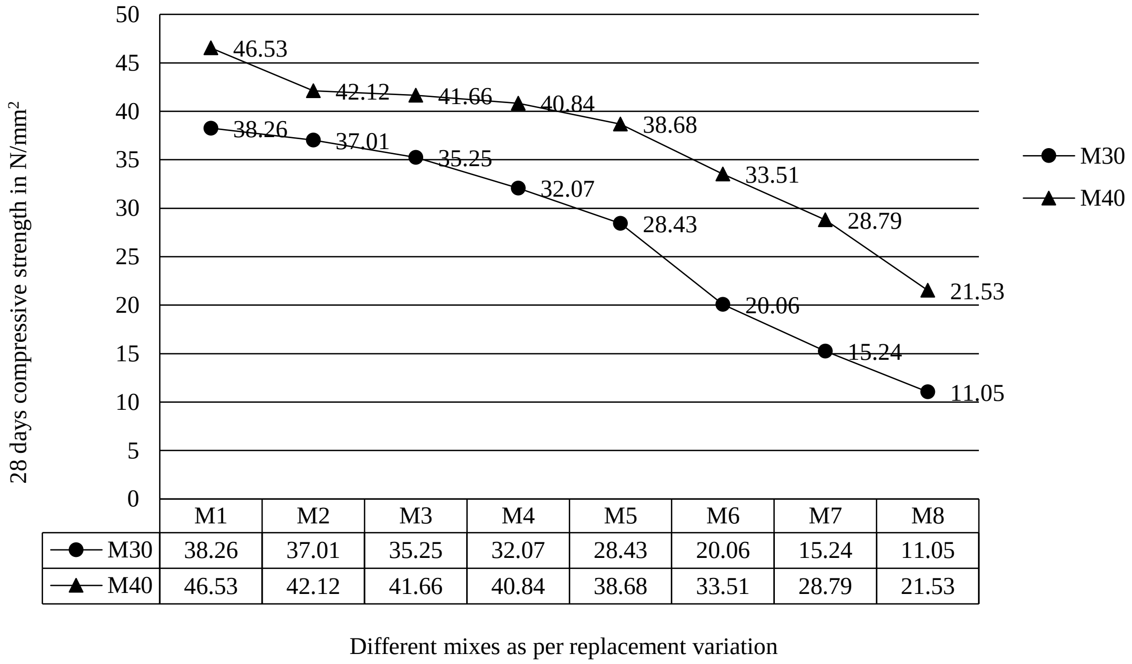

Figure 6. 28 Days compressive strength of M30 and M40 grade.

Table 8. Test Results of Cylinders for Split Tensile Strength Test for 28 Days

Rubber powder%	**Pond ash%**	**Recycled aggregate%**	**Splitting tensile strength in N/mm²**	
			M30 Grade	***M40 grade***
0%	0%	0%	2.82	3.09
0%	20%	0%	2.74	2.88
0%	0%	20%	2.63	2.80
0%	20%	20%	2.46	2.59
5%	20%	20%	2.31	2.43
10%	20%	20%	1.73	1.92
15%	20%	20%	1.55	1.81
20%	20%	20%	1.09	1.21

The 28 days splitting tensile strength of the mixes M30 and M40 is observed that the decrease in tensile strength is due to weak bonding between replacing materials and conventional concrete are in Table 8 and fig 7 [1], [2], [3]. The reduction in the tensile strength of M30 grade concrete with replacements of cement 5% ,10% ,15% ,and 20%, fine aggregate as 20% and coarse aggregate as 20% respectively are 3%, 7%, 12.8%, 18.1%, 38.7%, 45.1% and 61.4%.and for M40 concrete is 6.8%, 9.4%, 16.2%, 21.4%, 37.1%, 41.5% and 60.9% [4][5][6].

Permeability Test Results

To know the water penetration depth of the concrete permeability test is conducted. The permeability of concrete was investigated using specimens measuring 150 mm by 150 mm by 150 mm [10]. The test involved sandwiching the specimen between the apparatus's supplied plates and applying pressure for 72 hours [10]. For each percentage, three test specimens were cast, and each test condition's water penetration depth was measured. The average value was then considered. Table 9 displays the average values of three specimens for each category after 28 days of curing [10].

The water permeability of concrete after 28 days of curing results is tabulated in Table 9 ang Figure 8. From that as the % of rubber powder increases water penetration depth also increases in the concrete due to the increase in the internal voids. because of this the permeability values in M30 grade increased as proportion of rubber powder increases [10].

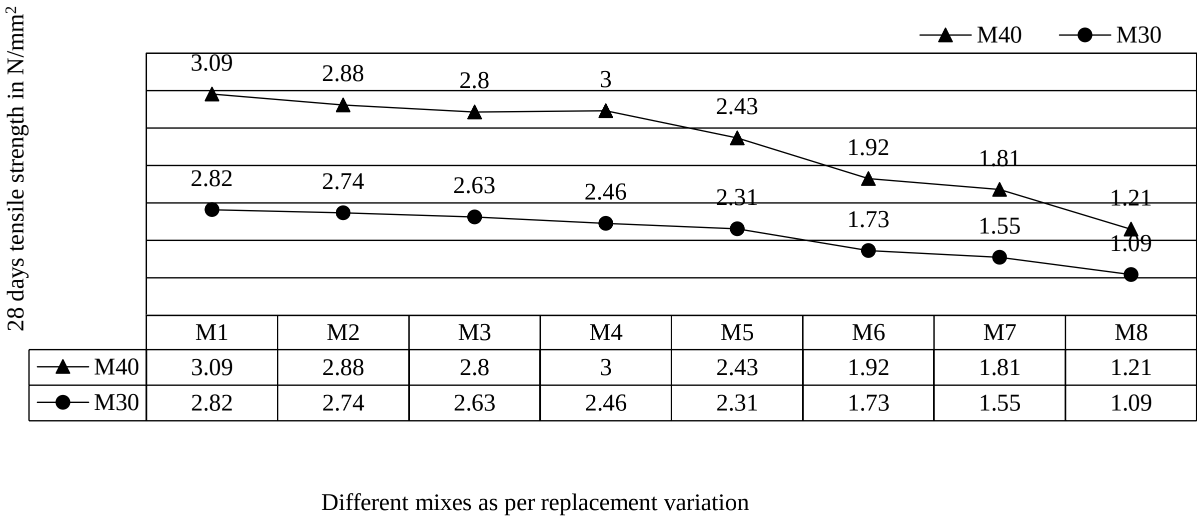

Figure 7. 28 Days split tensile strength of M30 and M40 grades.

Table 9. Test Results of Cubes for Permeability Test for 28 Days.

Rubber powder%	**Pond ash%**	**Recycled aggregate%**	**Water penetration depth in mm**	
			M30 Grade	***M40 grade***
0%	0%	0%	19.2	19.7
0%	20%	0%	21.8	22.4
0%	0%	20%	20.5	22
0%	20%	20%	23	23.8
5%	20%	20%	24.6	25.2
10%	20%	20%	26	27.7
15%	20%	20%	27.2	30
20%	20%	20%	32	35

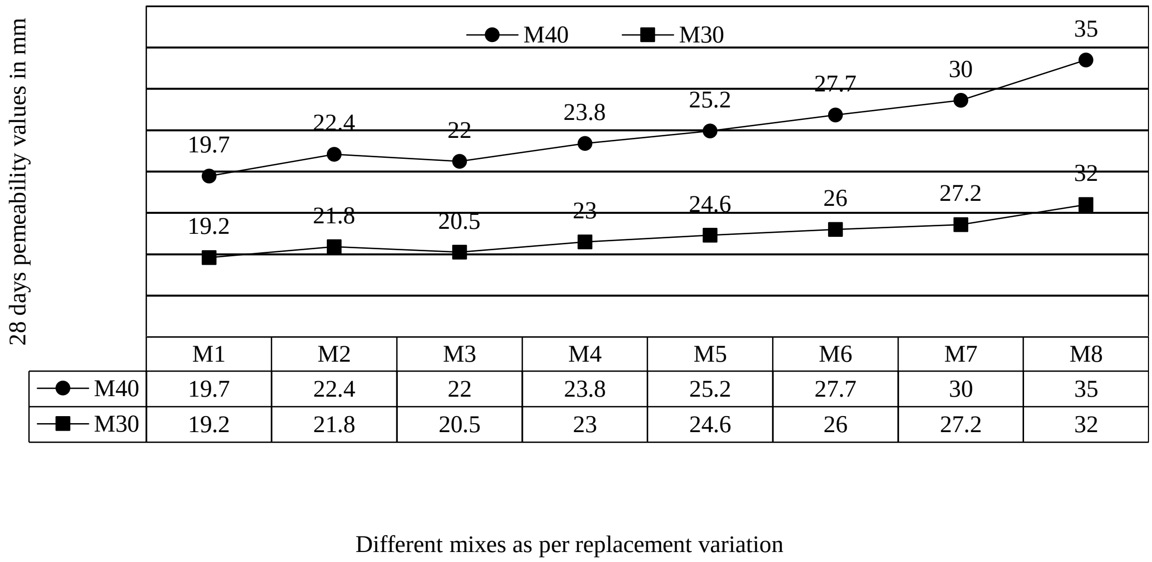

Figure 8. 28 Days permeability results of M30 and M40 grades.

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Flexural Strength Results

To calculate the flexural strength or modulus of rupture for a beam or prism flexural strength test conducted. This test was conducted by using prisms of size (100mm*100mm*500mm) or beam of size (150mm*150mm*700mm). These specimens are cured for 28 days after Moulding, after completion of curing specimens are placed on open air then these specimens are tested on the universal testing machine (UTM) by placing on the two supports with equal distance from end and load gauge will be at the center of the specimen for loading. Then apply the load slowly and gently on the specimen and observe the load value of specimen fails, after measuring the distance between crack line and nearest support then use the suitable formula. For every percentage, three test specimens were cast, and each test condition's flexural strength was measured using these specimens. The average result was taken into account. The average values of 3 specimens for each category at the ages of 28 days curing are in table 10 [10].

Table 10. Test Results of prisms for flexural strength Test for 28 Days.

Rubber powder%	Pond ash%	Recycled aggregate%	Flexural strength in N/mm²	
			M30 Grade	***M40 grade***
0%	0%	0%	3.48	4.27
0%	20%	0%	2.98	3.85
0%	0%	20%	3.12	3.96
0%	20%	20%	2.9	3.58
5%	20%	20%	2.4	3.11
10%	20%	20%	1.96	2.45
15%	20%	20%	1.32	2.05
20%	20%	20%	1.03	1.22

The 28 days flexural strength of the mixes M30 and M40 is observed in Figure 9 that the decrease in flexural strength is due to weak bonding between replacing materials and conventional concrete are in Table 10 [1], [2], [3]. The reduction in the tensile strength of M30 grade concrete with replacements of cement 5% ,10% ,15% ,and 20%, fine aggregate as 20% and coarse aggregate as 20% respectively are 14.4%,10.4%,16.66%,31.1%, 43.7%, 62.11% and 70.5%.and for M40 concrete is 9.9%, 9.4%,17.3%, 16.2%, 27.2%, 52% and 71.5% [4], [5], [6].

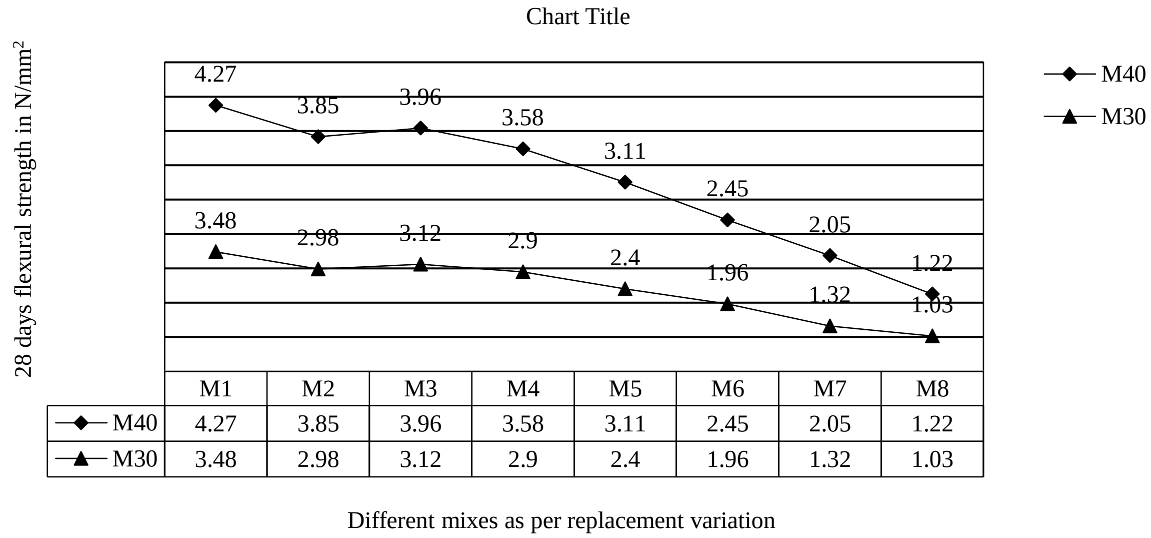

Figure 9. 28 Days flexural strength of M30 and M40 grades.

CONCLUSION

- The strength properties of concrete are not much effected with 20% replacement of fine aggregate with pond ash and 20% replacement of coarse aggregate with recycled aggregate.

- Here, the strength (compression, split tensile, flexural strength) values of concrete decreased by the replacement of rubber powder increased.
- When it comes to durability (permeability) study the water penetration into the specimens increased by the replacement of rubber powder increased.
- The mass density of specimens was decreased because increment of proportion of rubber powder and pond ash due to less specific gravity and density of these materials.
- When, rubber powder percentage in concrete increased the specimen crack length is decreased in flexural strength test it cause severe failure in in flexural load.
- Generally, rubber powder is a flexural material but here, when it mixes with concrete materials it does not affect the failure of specimens and it decreases the strength when proportion increased.
- In this experiment the proportion of pond ash and recycled aggregate in the concrete does not have much impact on strength and durability properties of concrete. Because here we taken proportion is optimum to conventional and the replacement of rubber powder up to 5% also not much affected but when it comes to 10%,15% and 20% it makes a big difference in strength and durability.
- Finally, concluded that the higher percentage replacement of rubber powder is cause effect to the concrete specimen in standard grades (M30 and M40).

Scope of Study

In this investigation the target strengths are partially decreased but 5% to 10% replacement of rubber powder the reduction is high so, up to 5% replacement with other partial replacements of fine aggregate and coarse aggregate is not much effected. It is used the future projects with these materials.

Limitations

The study is limited to the specific proportions of waste rubber powder, pond ash, and recycled aggregate tested.

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Conflict Of Interest

The authors declare no conflict of interest regarding the publication of this paper

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