Experimental Investigation of Mechanical and Durability Properties of Recycled Aggregate Concrete Added With Marble Powder, Copper Slag, and Polypropylene Fibre

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Abstract

As a byproduct of the marble industry, marble waste is a very important resource that requires proper environmental disposal. Directly releasing these waste elements into the environment might result in issues with the environment, such as a rise in soil alkalinity, effects on plants, animals, and human beings. Marble powder can be used as an additive in concrete to boost strength and other mechanical qualities and this way, we can avoid environmental degradation. As a byproduct of the metal industry purifying process for Copper, Copper slag is produced. In order to utilize less natural sand, an effort is undertaken to recycle this waste material into concrete coupled with the copper slag (CS). When compared to control concrete, concrete with a 20% copper slag with replacement of fine aggregate showed a significant increase in compressive strength. The results reveal that after replacing 20% of the Copper slag (as replacement of sand) and 10% of marble dust powder (as partial substitute to cement), compressive strength improved. Flexural strength and split tensile strength also increased after replacement. In engineering applications, polypropylene fiber (PPF) is frequently added to concrete to enhance its mechanical properties. Polypropylene Fabrics (PPFF) which are widely utilized in the textile industry are manufactured in enormous quantities every year. This fibered concrete is primarily used for studies on Sulphur resistance, durability, and corrosion resistance. There is a new opportunity to produce eco-friendly concrete blocks using RCAs taking into account their mechanical features and environmental advantages. RCA-content concrete blocks exhibit improved water resistance and are more cost-effective. All of these elements are applied in research in the present investigation using M30 grade concrete. With a constant PPF content (0.5% by volume of concrete) & constant RCA (40% of CA), marble powder is partially replaced by cement in different percentage by weight of cement (5%,10%,15%), and copper slag is partially replaced by FA in various percentage by weight of cement (20%, 40%, and 60%).

Keywords : Compressive strength, Copper slag (CS), Durability test (curing with salt and acids), Flexural strength, Marble powder (MP), Polypropylene Fibre (PPF), Rebound hammer test (RHT), Recycle Concrete aggregate (RCA), Split tensile strength, Tensile strength, Scanning Electron Microscopy (SEM), Ultra sonic Pulse Velocity (UPV)

NOMENCLATURE

NA Natural Aggregate.

PP Polypropylene.

MP Marble Powder.

CS Copper Slag.

RCA Recycle Concrete Aggregate.

RAC Recycle Aggregate Concrete.

GGBFS Ground Granulated Blast-Furnace Slag.

BF-PF Basalt fibre-Polypropylene Fibre.

PPFRC Polypropylene Fibred Recycled Concrete.

GBFS Granulated Blast Furnace Slag.

SF Silica Fume.

AR Analytical Reagent.

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I. INTRODUCTION

A. General

Concrete is presently the second most utilised material in the world and is most frequently employed in the construction industry. Due of its accessibility, versatility, and durability, concrete is frequently employed. Due to the rapid expansion of superstructures such high-rise buildings, where area cannot be wasted by growing component size, dams, bridges, marine foundations, etc., high-strength concrete is widely utilised in these constructions. This ultimately results in increased cement output, and increased cement manufacturing is responsible for the environment's release of Carbon Dioxide, which causes the Ozone layer to thin. For civil and environmental engineers, the increased demand for cement and superplasticizer presents difficulties. The study of environmentally friendly, economically practical, and socially beneficial cement substitutes for concrete has grown during the past ten years. Alternatives include recycling, reusing, and rebuilding methods to identify the potential benefits of industrial and agricultural waste. Utilising these wastes as supplemental and replacement elements might result in significant energy savings, a decrease in the amount of Portland Cement (PC) needed, and a decrease in Carbon Dioxide (CO_2) emissions. Therefore, for sustainable growth that is also good for the environment, experts are looking for innovative and eco-friendly alternatives to traditional resources. Many waste stone and industrial by-products have the potential to partially replace cement in productive and advantageous ways. So that marble powder, copper slag, PPF, and recycled concrete aggregate will all be employed in this project, along with a variety of destructive and non-destructive testing, durability research, and SEM analysis.

B. Marble Powder

In India, marble is very useful, and is often utilised as a building material. Natural stone processing facilities now produce a significant quantity of marble dust, which has a negative impact on both the environment and people. Due of its typical form, marble production results in about 30% waste for various uses. The unutilized wastes create a lot of dust, fine marble dust particles that are suspended in the air and cause air pollution, clog drains, reduce soil productivity, and impede aquifer movement, all of which are negatively impacted by the discarded wastes. These waste materials were used in concrete in earlier research projects in place of cement and fine aggregates. Because of its tiny size, marble powder may be used in place of cement and sand in concrete with good results. Additional applications for marble powder include glass, paper, plastic, and dying industries. Sludge is not entirely consumed by these companies. However, it causes contamination of the air and water. Concrete technological advancements can reduce the need for energy and other natural resources, as well as the number of pollutants that are released into the environment. The bulk of researches have substituted cement with marble powder waste, and they have hypothesised that after 10, 15% of cement replacement with marble dust, the cement matrix loses its ability to bond. Upto 15% partial replacement with cement, it offers adhesive nature as well as helps to increase various mechanical properties. Concrete can also employ the marble waste in place of fine aggregate due to the fact that fine aggregate is used in greater quantities than cement, the primary motivation for substituting fine aggregate with marble waste is to increase its consumption. This study describes the importance of using marble dust in concrete as a partial replacement for cement to determine the physical and mechanical properties of freshly poured and cured concrete. Table I shows the chemical composition (percentage) of marble powder.

C. Copper Slag

High deposits of waste materials that cannot be further processed provide issues for mining operations and recycling facilities at the same time. Copper mining operations or copper recycling facilities create (secondary) copper slag (CS), the production of which is

TABLE I.
CHEMICAL COMPOSITION (PERCENTAGE) OF MARBLE POWDER

CHEMICALS	AMOUNT (PERCENTAGE)
SiO_2	0.94
Fe_2O_3	0.46
$CaCO_3$	97.35
Others	1.25

TABLE II.
CHEMICAL COMPOSITION (PERCENTAGE) OF COPPER SLAG

CHEMICALS	AMOUNT (PERCENTAGE)
Cu	0.42–4.6
Fe	29–40
SiO_2	30–40
CaO	11
Al_2O_3	10

increasing by around 50 million tonnes annually. Due to the presence of dangerous substances including Arsenic, Cadmium, Chromium, Lead, and Zinc. Copper Slag is still considered a hazardous waste. Therefore, stabilisation or solidification is the best treatment option for these hazardous wastes. The environmental deterioration and building expense issues will both be solved by the use of Copper Slag. Various steps of purification of Copper ore result in the production of Copper slag. Copper slag is frequently used as a building ingredient and is abrasive in the production of concrete and paving products. The majority of studies indicate that Copper slag may replace fine aggregates upto 40% and upto 60% (by volume of sand) of Portland cement and can lower stress by upto 15% due to hydrated lime's decreasing capillary porosity. Copper slag is a high quality, plentiful type of secondary material. Table II shows the chemical composition (percentage) of Copper slag.

D. Recycle Concrete Aggregate

Recycled Concrete Aggregates (RCA), which might either entirely or partially replace natural aggregates in concrete mixtures have attracted more attention in recent years. Large new areas must be set aside for the disposal of these worthless construction material wastes as a result of the restoration of significant inventory of historic buildings, which generates enormous volumes of waste materials from the old structures that are demolished. Instead, the building of brand new, contemporary structures necessitates the considerable use of natural aggregates from already existing quarries as well as the creation of new ones to supply the enormous amounts of natural materials necessary. The bigger specific gravity, better water absorption, and improved angularity of the recycled coarse aggregates made from leftover concrete boosts their strength and load-bearing capability. For instance, BS 8500-2 (BSI, 2006) [30] specifies that recycled aggregate has a maximum masonry/fines content of 5%, a maximum lightweight material/asphalt content of 0.5%, and a maximum other foreign materials content of 1%. In rare circumstances, it is possible to completely (100%) or significantly replace NA with RCA. The use of fine RCA below 2 mm is unusual due to the highwater required for fine material smaller than 150 µm, which weakens the strength and significantly increases concrete shrinkage. The high fine RCA cohesiveness and high water absorption make controlling the concrete's quality very challenging. As a result, a number of standards and specifications (DAfStb, 2004; BSI 2006) [31] forbid the use of fine RCA in RAC for structural purposes.

E. Polypropylene Fibre

Concrete and steel reinforcing bars are used to create reinforced concrete. Brittleness, a low tensile strength, and a substantially higher compressive strength are all characteristics of concrete. The rebars excel for their ability to absorb energy and their function in regulating fracture breadth, in addition to providing the necessary tensile strength and ductility. For the reinforcement and concrete to transmit loads and enable composite activity, an interfacial connection is necessary. By enhancing the pore size distribution of concrete by adding PPF, a three-dimensional random distribution network structure may be produced, effectively limiting the emergence and spread of microcracks. Therefore, the PPF can prevent harmful ions like water from infiltrating concrete. Concrete can have PPF added to it to make it more durable. Fibres made of Polypropylene could be helpful for distributing impact loads and enhancing frost resistance. It is lightweight, very durable, and corrosion-resistant.

II. LITERATURE SURVEY

In [3], the physical, mechanical, durability, and thermal properties of concrete containing basalt fibre (BF), marble dust (MD), and ground granulated blast furnace slag (GGBFS) were investigated. Foamed concrete samples were tested for porosity, water absorption, and sorpitivity. The maximum compressive strength was achieved with 30% GGBFS and 1% BF. In [15] dry marble slurry was replaced with 20 and 30% of fine aggregate in the ratios of 25%, 75%, and 14.28%:85.72%, respectively. In [27], MP was used to replace upto 30% of the fine aggregate. In [24] the researchers investigated the mechanical and durability performance of concrete when cement was substituted with waste marble powder. The aim [2] was to investigate the possibility of replacing sand and cement amalgam in part with waste marble powder.

In [8], the work involved the experimental investigation of the binding behaviour of copper slag concrete and corroded steel bar. Chloride ion diffusion coefficient of high temperature damaged Copper slag concrete increased as the replacement ratio of Copper slag and heating temperature increased. The experimental results of [20], which looked at how Copper slag affects hardened concrete's abrasion and slake resistance demonstrated that utilising Copper slag in place of natural sand significantly enhanced both of these properties. In addition to the copper slag (CS), Patil and Patil [21] researched using less natural sand in concrete. In order to examine the material's strength and endurance, Copper Slag (CS) was employed in [18] as a partial or total replacement for natural fine aggregates (FNA) concrete (20%, 40%, 60%, 80%, and 100% of the volume of natural fine aggregates). It is suggested to use upto 40% of natural fine Copper slag particles in concrete to produce concrete with high strength and durability attributes. In [6] slag was used in place of cement to create a variety of fiber-reinforced concrete types, and the concrete's resistance to chloride penetration was assessed.

The question of whether it was appropriate to utilise varying ratios of type was addressed in [28]. A fine RCA (FRCA) and coarse RCA (CRCA) while producing structural concrete that had been exposed to an XC1-XC4 environment was addressed in this study. In [19] the researchers looked at the suitability of using recycled concrete aggregate in place of natural aggregates and calcined termite mound as a partial replacement for cement. It was shown that when combined with CTM for structural load bearing parts, 60% RCA, 40% NA, and 5% CTM were the optimum combinations. In order to determine the local bond-slip behaviour, in [16] the researchers compared the bond behaviour of concrete with RCA to concrete with natural aggregates. In [17] the properties of concrete made from excavated soil (ES) and Recycled Concrete Aggregates (RCAs) were examined. However, throughout wetting-drying cycles, the compressive strength of ES-based concrete blocks increased by 20% to 80%, especially for those with a greater ES content. Mortar, natural aggregate plus interfacial transition zone, and recycled concrete aggregate plus interfacial transition zone were the three components that made up the composite that was considered as concrete in the technique [29].

Basalt-Polypropylene Hybrid Fibre Reinforced Concrete's (BPHFRC) chloride diffusion capabilities in a salt spray environment were examined in [25]. The 0.2% hybrid BF-PF addition raised the Chloride level in the concrete. In [23] the researchers employed waste PPFF as the research object. Results showed that waste PPFF may replace PPF in concrete in some cases and had a wide variety of potential applications in green concrete. In [26], the findings demonstrated that RCA acquired from PPFRC recycling had a big impact on the creation of fresh concrete. This was done by the recovered fibres reintroduced into the new concrete, as well as through the fibres imbedded in the recycled aggregates leading to greater residual tensile strength. In [1], the researchers concentrated on two materials, namely, Ultra-High Performance Geopolymer Concrete (UHPGPC), which is made of micro silica, and granulated blast furnace slag (GBFS), which is built of steel and polypropylene fibres [10]. The results demonstrate that the addition of PF enhanced the mechanical properties of samples containing SF. Thus, mechanical durability and strength improve. In [22] the researchers used plain concrete as the reference material and examined the damage permeability of polypropylene fibre-reinforced concrete The results suggest that concrete's ability to withstand damage would be more affected by curvature and roughness than by fibre content. Although, there was a peak impact, adding fibres will improve the correction coefficient compared to the PC specimens.

A. Research Significance

The main purpose of this investigation is to solve the environmental issue caused by disposing of the MP and CS on the open ground rather than recycling them because of their cementous qualities. Combination of MP, CS, PPF, RCA to investigate the properties of concrete and the durability properties has not been tried till date as per the research papers available in open literature. So, to determine the effect of MP, CS and PPF in various properties of concrete. Here, the workability test (slump test), compressive strength, split tensile strength, tensile strength, and flexural strength test will be conducted. Various non-destructive tests that is, UPV test and rebound hammer test will be conducted to compare various mechanical and physical properties of conventional concrete with these control mixes [9] and to determine the optimum percentage of MP, CS and RCA with constant percentage of PPF. Durability property by water absorption test will be conducted by carrying out curing with acid (Magnesium Sulphate, Hydrochloric Acid) to perform Scanning Electron Microscope (SEM) test for observing the microstructure of the control mixes. Sustainability is a major need to protect the limited resources along with strength and longevity. So, concrete should be a self-sufficient material to fulfil all these requirements, which can be worked out by using all of the materials mentioned here.

III. EXPERIMENTAL INVESTIGATION

A. Materials

1) Cement: According to BIS specification IS 12269-1987 [32], OPC53 Grade OPC provides remarkable strength and longevity to buildings because of its superb crystallised structure and optimum particle size distribution. OPC 53 which is manufactured by RAMCO, was used in this investigation, which was procured from SB Sahoo & Co. Pvt. Ltd., Rasulgarh, Bhubaneswar, Odisha. Various properties of cement that were tested in the concrete lab. Table III shows the properties of cement.

2) Fine Aggregate and Coarse Aggregate: Typically, naturally occurring sand is created by mineral particles that have been finely split. Fine material was retained on a 75 micron sieve after passing through a 4.75 mm IS sieve. For this experiment, we used locally accessible natural river sand. The coarse aggregate makes around 60–65% of the total volume of the concrete. Construction typically employed natural coarse material that was kept on a 4.75 mm sieve after passing through a 20 mm IS sieve. The principal building material's accessibility contributed to concrete's increased durability and crushing power. The study's natural stone aggregate came from a local quarry. The coarse aggregate utilised has a nominal maximum size of 20 mm. For the selected coarse aggregate and fine aggregate, physical characteristics such as specific gravity, water absorption, moisture content, and fineness modulus were discovered.

Table IV shows the properties of coarse aggregate and fine aggregate.

TABLE III.
PROPERTIES OF CEMENT

S. NO.	PROPERTY	VALUE
1.	Specific gravity	3.15
2.	Consistency	32%
3.	Initial setting time	65 min
4.	Final setting time	260 min

TABLE IV.
VARIOUS PROPERTIES OF COARSE AGGREGATE AND FINE AGGREGATE

PROPERTIES	VALUE FOR FINE AGGREGATE	VALUE FOR COARSE AGGREGATE
Specific gravity	2.6	2.9
Water absorption	1%	0.5%
Moisture content	Nil	Nill
Fineness modulus	3.625	–
Grading zone	Zone ll	–

3) Super Plasticizer: Super plasticizer is a chemical additive that helps to strengthen concrete by lowering the water content. For the current study, We have used Hind Plast Super™160, which is a third generation Polycarboxylic Ether based Superplasticizer that reduces range of water used and suitable for concreting in all climatic condition. It conforms to IS 9103, 1999 (REAFFIRMED 2004) [14] and ASTM C 494, Type F, and IS 2645, 2003 [33]. Table V shows the properties of super plasticizer.

TABLE V.
PROPERTIES OF SUPER PLASTICIZER

S. NO.	PROPERTY	VALUE
1.	Aspect	Light orange liquid
2.	Specific gravity	From 1.02 to 1.08 at 27o C temperature
3.	Chloride content	0 (maximum)
4.	pH	Greater than or equal to 6

4) Marble Powder, Copper slag, and Recycled Concrete Aggregate: Calcium Silicate Hydrate (CSH) and Calcium Hydroxide (CH) are produced during the hydration of cement particles [7]. Concrete gains strength from CSH while CH serves as a filler. Iron and Silicon are present in marble powder. Therefore, some marble powder may be utilised in place of cement, which can serve as a superior filler for concrete. The used marble powder was collected from Marbles shop, Cuttack, Odisha. The waste material named Copper slag, which is created during the extraction of Copper metal in refinery facilities is inexpensive and can be used as a fine aggregate in the manufacturing of concrete to reduce disposal problems and enhance the environment. The Copper slag used in this study was collected from Paradeep, Odisha via India Mart. In order to lower the overall cost of cement, we can utilize recycled concrete aggregate, which is a waste of concrete building pieces that are either repaired or pulled down or are from prior castings. This is similar to how concrete has a higher percentage of coarse aggregate. The major reason recycled concrete aggregates are utilised is that they provide a less expensive alternative to crushing natural raw materials and help lower carbon emissions. For this study, a combination of 60% 20 mm and 40% 10 mm sizes were taken. Table VI shows the properties of various admixtures.

5) Polypropylene Fiber: It is used in case of reinforcement to make the concrete light weight. It is characterized by high tensile strength, good flexibility, and bending stability. It has excellent tolerance to Ultraviolet rays, weather resistance, resistance to water, humidity, acid and alkali, and is anti-rust. It is non-corrosive in nature. The PP fiber used for this study is 12 mm in size and were ordered from Amazon India. It is characterized by high tensile strength, good flexibility, and bending stability.

TABLE VI.
PROPERTIES OF VARIOUS ADMIXTURES

S. NO.	PROPERTY	VALUES FOR VARIOUS ADMIXTURE		
		MP	CS	RCA
1.	Fineness	80%	–	–
2.	Consistency	32%	–	–
3.	Specific gravity	2.73	2.9	2.6
4.	Colour	White	Black	Gray
5.	Water absorption	–	0.13%	0.5%

Source : Specification for concrete admixture, IS 9103, 1999 [14]

TABLE VII.
PROPERTIES OF PP FIBER

S. NO.	PROPERTY	VALUE
1.	Colour	White
2.	Brand	Buildingshop.in
3.	Specific gravity	0.9g/cm^3

6) Acid (Hydrochloric Acid) and Salt (Magnesium Sulphate Heptahydrate): Acid and salt were used for curing, which helped to determine the durability property of various control mixes. For this investigation, Magnesium Sulphate Heptahydrate ($MgSO_4,7H_2O$) and Hydrochloric Acid (HCl) were used.

Hydrochloric acid (HCl) of 35.4% AR of specific gravity 1.18 was used for this study. For this study, HCl acid was adopted from Loba Chemie Pvt. Ltd.

Magnesium Sulphate Heptahydrate ($MgSO_4,7H_2O$) also known as Epsom salt with specification, Assay (EDTA Titration) = min 99%, pH (5% aq. Solution) = 5–8, Magnesium Sulphate Heptahydrate, extra pure AR, 99% of SRL brand was used.

Both the chemicals were bought from Mohapatra Scientific Supply Syndicate, Nayapalli, Bhubaneswar.

Table VIII shows the properties of various salts and acids used**.**

B. Mix Proportion

Free water-cement ratio = 0.4

Ratio = 1:1.644:3.26

TABLE VIII.
PROPERTIES OF SALT AND ACID USED

S. NO.	PROPERTY	SALT	ACID
1.	Colour	White	Transparent like water
2.	Appearance	Crystalline	Liquid form
3.	Nature	Salt	Acid

C. Methodology

18 tiny cubes and a total of 72 cubes, cylinders, beams, and cubes were utilised for casting. Prior to casting, all of the concrete's components—cement, fine aggregate, coarse aggregate, water, and plasticizers were accurately weighed. The next step involves pouring and mixing dry cement, fine aggregate, and other partial replacement components. Then, all different kinds of coarse material and fibres were added. Equal parts of water and plasticizer were partitioned. The ingredients were thoroughly combined to create a mixture with an appropriate consistency. In this investigation, variations of varying percentages of MP, CS, and RCA with constant PPF were used to build the concrete mix. Cement was used to replace MP by 5%, 10%, and 15% of the weight of the total cementous material fine aggregate by 20%, 40%, and 60% of the volume of fine aggregate, and coarse aggregate by 10%, 20%, and 40% of the weight of the total coarse aggregate. The amount of fibre used was kept constant at 0.5% of the total concrete volume. The IS codes used for this study are IS 456 [11], IS 10262 [13], SP 23, IS 516 [12], and IS 10086-1982 [34].

TABLE IX.

MIX PROPORTIONS FOR M30 AS PER IS 10262

S. NO.	MATERIALS	AMOUNT (Kg/m^3)
1.	Cement	396
2.	Fine Aggregate	651
3.	Coarse Aggregate	1,291
4.	Water	166
5.	Chemical Admixture	1.98

Source : *Concrete mix portion,* IS 10262, 2009 [13]

TABLE X.

THE RATIO OF PROPORTION FOR VARIOUS MIXES

TRIALS	MP% (BY % WEIGHT OF CEMENT)	CS% (BY % VOLUME OF FA)	RCA% (BY % WEIGHT OF CA)
M5C0R0	5	0	0
M10C0R0	10	0	0
MP15C0R0	15	0	0
M0C20R0	0	20	0
M0C40R0	0	40	0
M0C60R0	0	60	0
M0C0R10	0	0	10
MOC0R20	0	0	20
MOC0R40	0	0	40

TABLE XI.

SPECIFICATIONS OF SPECIMEN DIMENSIONS, SIZE, AGE OF TESTING, AND STANDARDS FOLLOWED

S. NO.	PROPERTY	STANDARD USED	DIMENSION	REMARKS	AGE AND CONDITION OF TESTING
1.	WORKABILITY TEST	IS 1199 [4]	Slump cone of top diameter of 100mm, a bottom diameter of 200mm,and a height of 300mm	The difference between the height of the cone slump and the height of the collapsed concrete which offered workability.	7 and 28 days after water curing in open atmosphere under moderate environmental conditions with normal temperature range. 3 samples for each testing date and proportion were cast.
2.	COMPRESSIVE STRENGTH	IS 516 [12]	Concrete cubes of 150 * 150 *150 mm	Continuous application of load at a rate of approximately 4.2N/mm^2	
3.	SPLIT TENSILE STRENGTH	IS 516 [12]	Cylindrical specimens 150 mm diameter * 300 mm height	Continuous application of load at a rate of approximately 4.2N/mm^2	
4.	FLEXURAL STRENGTH	IS 516 [12]	Concrete prisms of 100 * 100 * 500 mm	Two-point loading specimens placed 13.3 cm apart. Fixed rate of load 180 kg/min	

5.	**WATER ABSORPTION TEST**	BS 6349 [5]	Concrete cubes of 100 * 100 * 100 mm	Oven dried for 7 and 28 days to measure weight. Amount of water concrete can absorb is shown.
6.	**ULTRASONIC PULSE VELOCITY TEST**	IS 13311, 1992 [9]	Concrete cubes of 150 * 150 * 150 mm	It measures how quickly an electrical pulse travels through concrete from a transmitting transducer to a receiving transducer
7.	**REBOUND HAMMER TEST**	IS 516 (part1) [12]	Concrete cubes of 150 * 150 * 150 mm	28 days compressive strength is observed
8.	**DURABILITY TEST**	BS 6349 [5] and IS 456, 2000 [11]	Concrete cubes of 100 * 100 * 100 mm	Water absorption of concrete specimen

IV. TEST ON CONCRETE

According to Indian requirements, there are various types of destructive and non-destructive tests that were conducted for this study to observe the mechanical and physical properties of concrete specimen.

A. On Fresh Concrete

The test that was performed as part of the inquiry to determine the workability property of concrete is stated here:

- Workability by slump cone method

B. On Hardened Concrete

When marble powder, copper slag, recycled concrete aggregate, and polypropylene fibre were added to concrete specimens in varying amounts, various tests were carried out to assess the mechanical and physical attributes of the specimens. The various properties that were tested to observe the quality of concrete are:

- Compressive strength test on cube
- Split tensile strength test on cylinder
- Flexural or modulus of rupture test on prismatic beam
- Water absorption test
- Ultra-Sonic Pulse Velocity test (UPV)
- Rebound hammer test
- Durability analysis

V. RESULTS AND DISCUSSION

For the current experiment, several specimens with different replacement materials (Marble powder, Copper slag, Recycled Concrete Aggregate, and PPF) were used. To determine the quality of concrete specimen, fresh and hardened concrete properties, various tests were conducted.

A. Workability

The values of all the concrete mix design were done by slump cone method. The values were measured in mm. The slump value for the nominal mix is least among all the mixes. Table XII shows the slump value for various mix.

TABLE XII.
SLUMP VALUE FOR VARIOUS MIX

S. NO.	MIX	SLUMP VALUE (IN mm)
1.	Nominal	90
2.	M5C0R0	100
3.	M10C0R0	120
4.	MP15C0R0	130
5.	M0C20R0	90
6.	M0C40R0	120
7.	M0C60R0	140
8.	M0C0R10	110
9.	MOC0R20	100
10.	MOC0R40	95

Fig.1 shows that the slump value increases as the percentage of marble dust in the partial replacement of cement increases. Fig. 2 shows increasing the amount of copper slag in the concrete mix also raises the slump value. Fig. 3 shows slump value is decreasing as the percentage of recycled concrete aggregate increases.

B. Compressive Strength of Concrete

Fig. 4 shows that in contrast to the other two proportions of mix as well as nominal mix, the compressive strength of concrete mix with a 10% replacement of marble powder by cement offered the largest value after 7 days

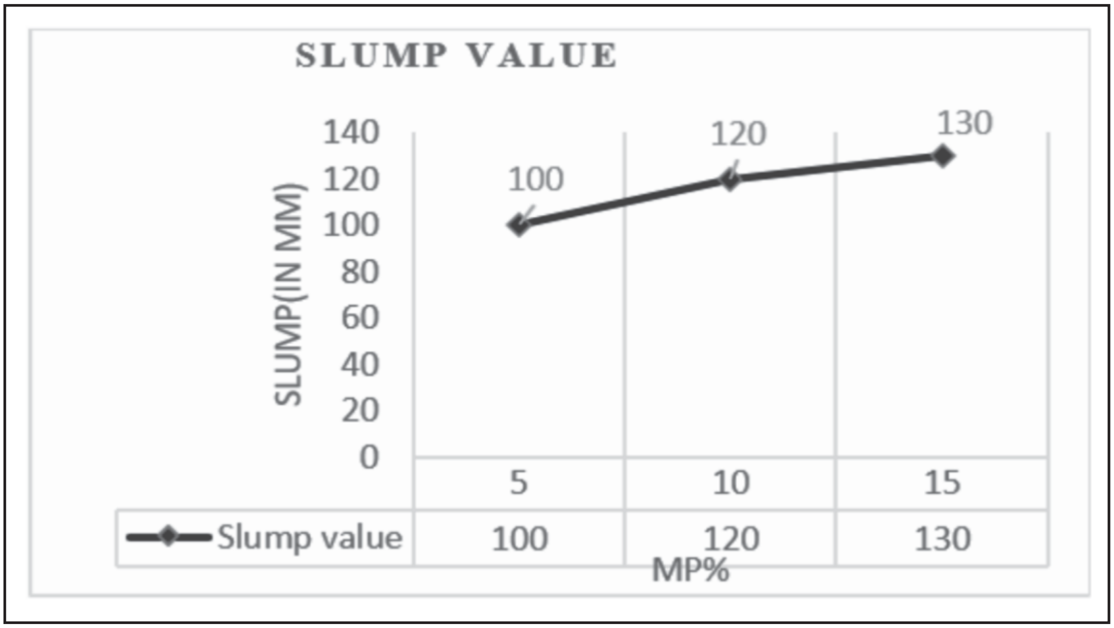


Fig. 1. Slump value for various proportions of marble powder

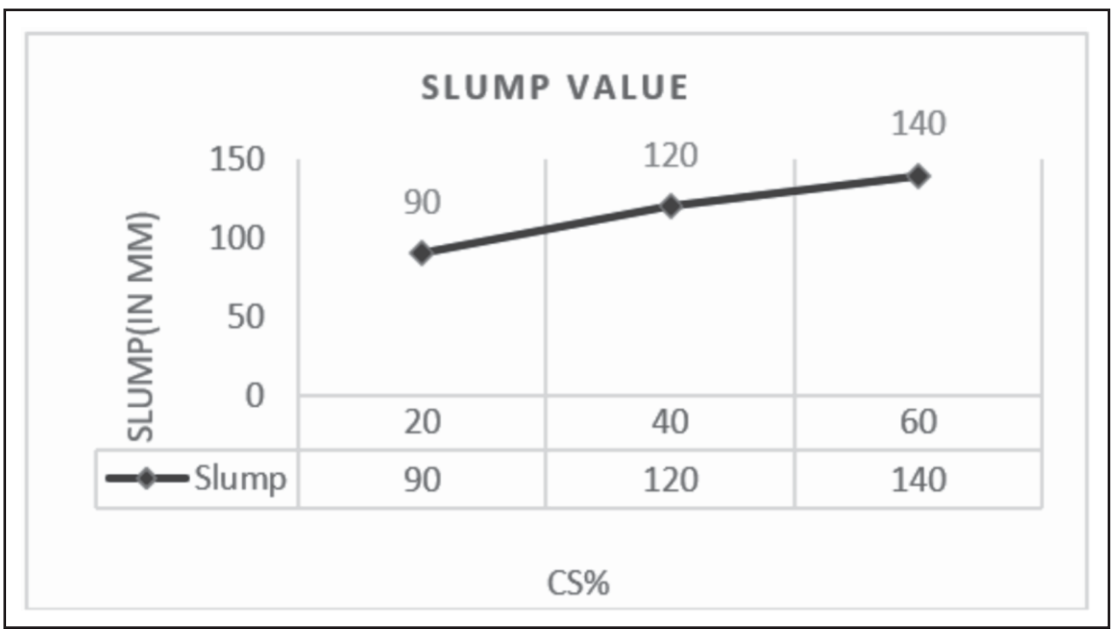


Fig. 2. Slump value for various propertion of Copper Slag

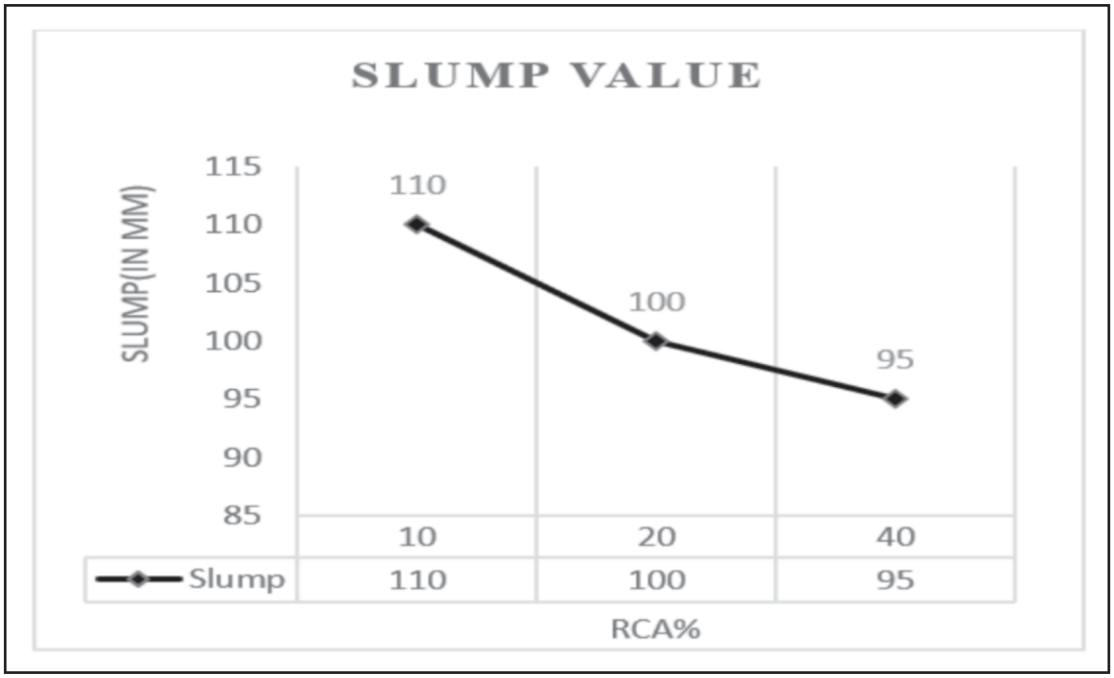


Fig. 3. Slump value for various proportions of Recycled Conrete Aggregate

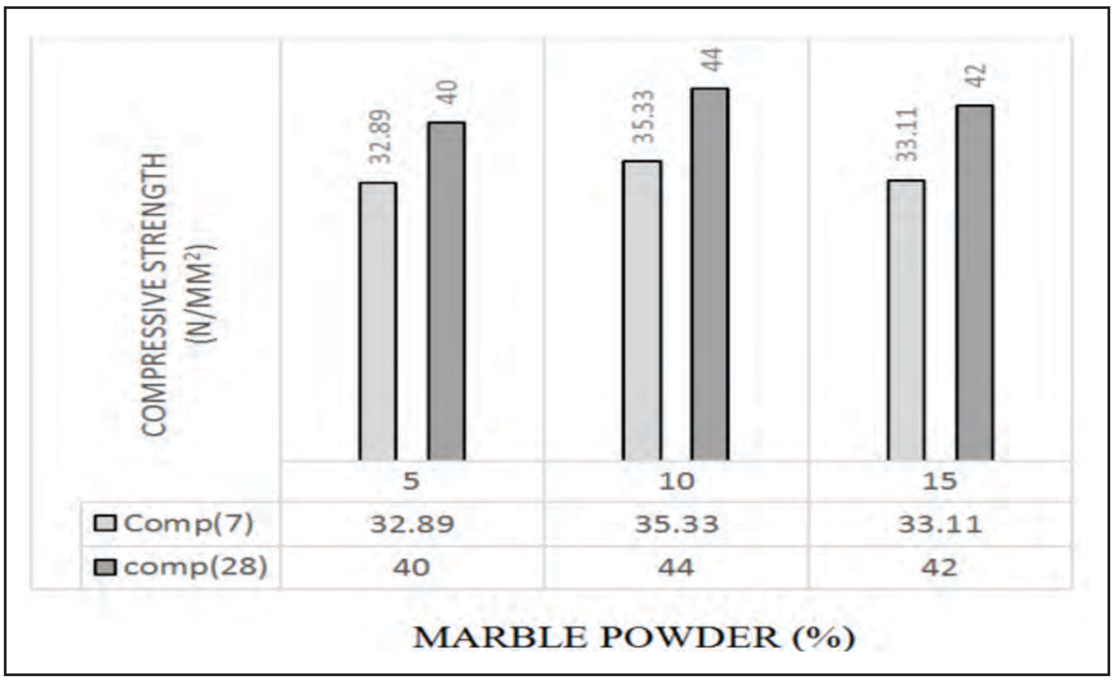


Fig. 4. Compressive strength for various proportions of marble powder

and 28 days of curing and testing respectively. Fig. 5 shows that in contrast to the other two proportions of mix as well as nominal mix, the compressive strength of concrete mix with a 20% replacement of Cupper Slag by Fine aggregate offered the largest value after 7 days and 28 days of curing and testing, respectively. Fig. 6 shows that in contrast to the other two proportions of mix as well as nominal mix, the compressive strength of concrete mix with a 10% replacement of RCA by coarse aggregate offered the largest value after 7 days and 28 days of curing and testing respectively.

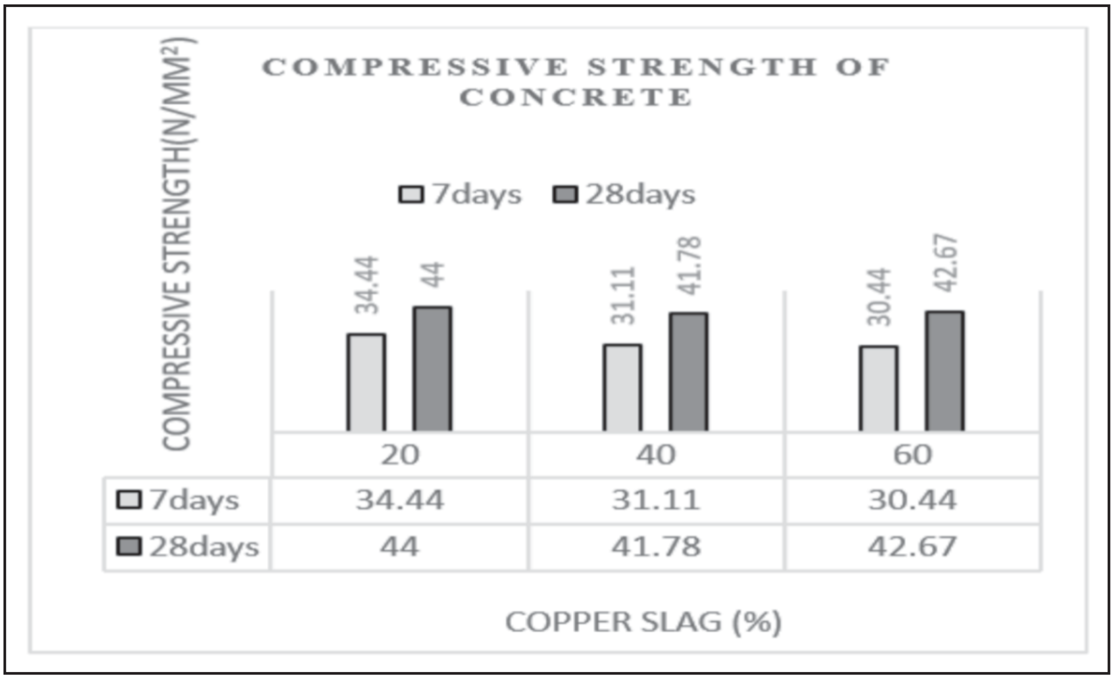


Fig. 5. Compressive strength for various proportion of Copper Slag

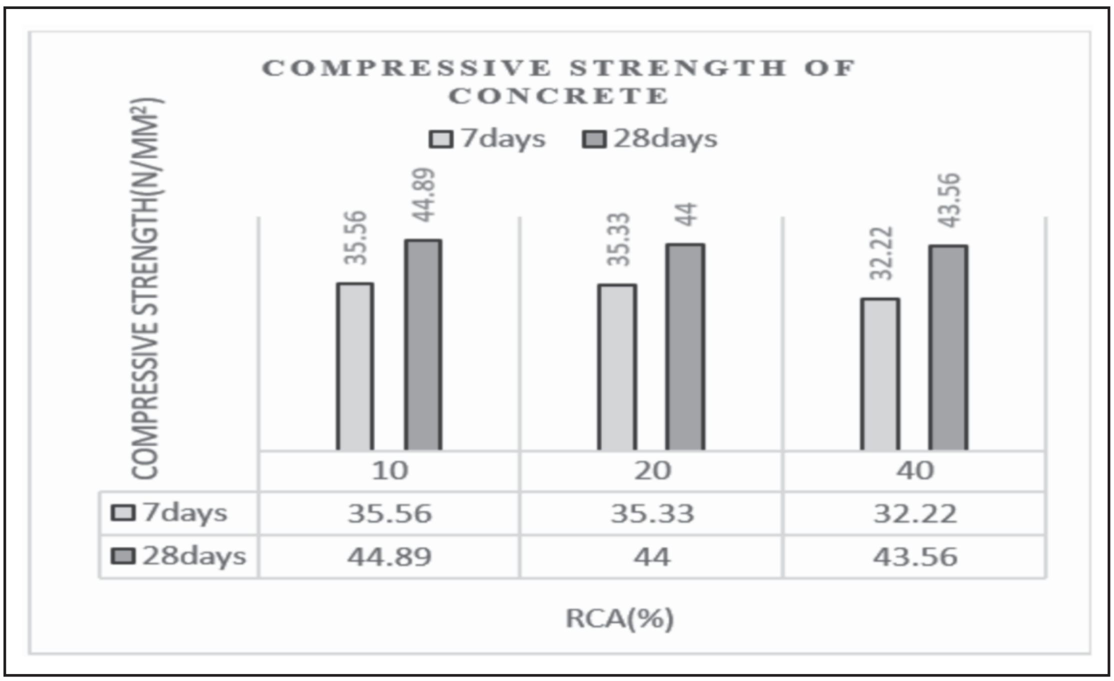


Fig. 6. Compressive strength for various propertion of Recycled Concrete Aggregate

C. Split Tensile Strength

Fig. 7 demonstrates that after 7 days and 28 days of curing and testing respectively, the Split tensile strength of concrete mix with a 10% substitution of Marble Powder with cement supplied the biggest value in comparison to the other two proportions of mix as well as nominal mix. Fig. 8 demonstrates that after 7 days and 28 days of curing and testing respectively, the Split tensile strength of concrete mix with a 20% substitution of Copper Slag with Fine aggregate supplied the biggest value as compared to the other two proportions of mix as well as nominal mix.

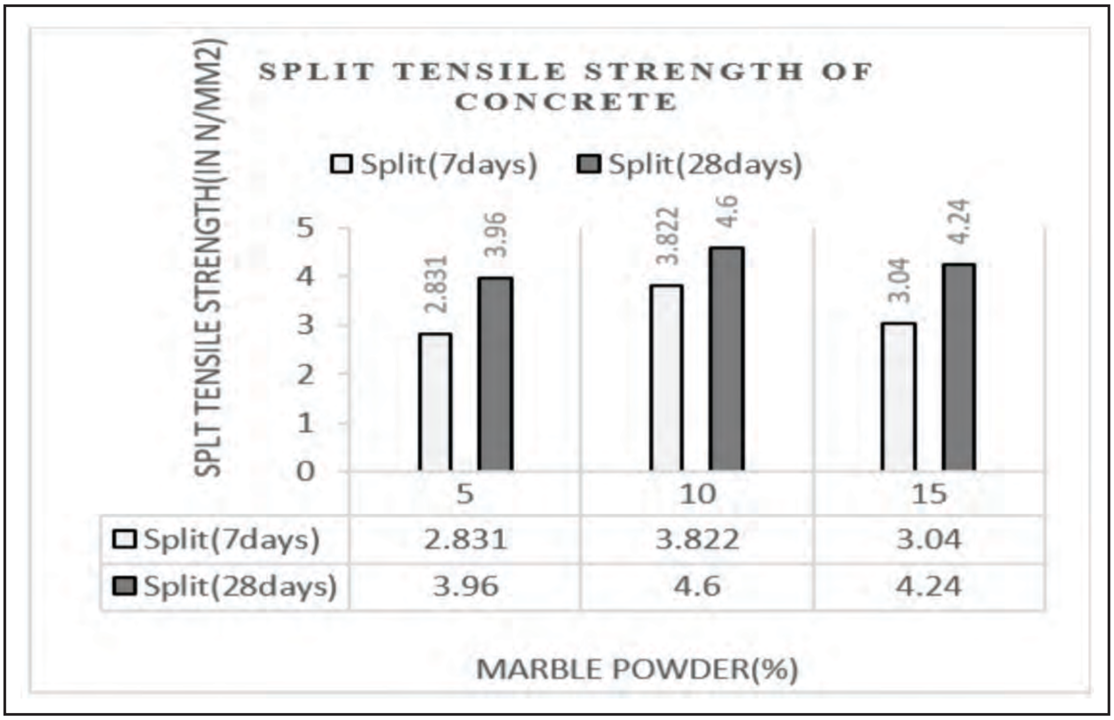


Fig. 7. Split tensile strength for various propertions of marble powder

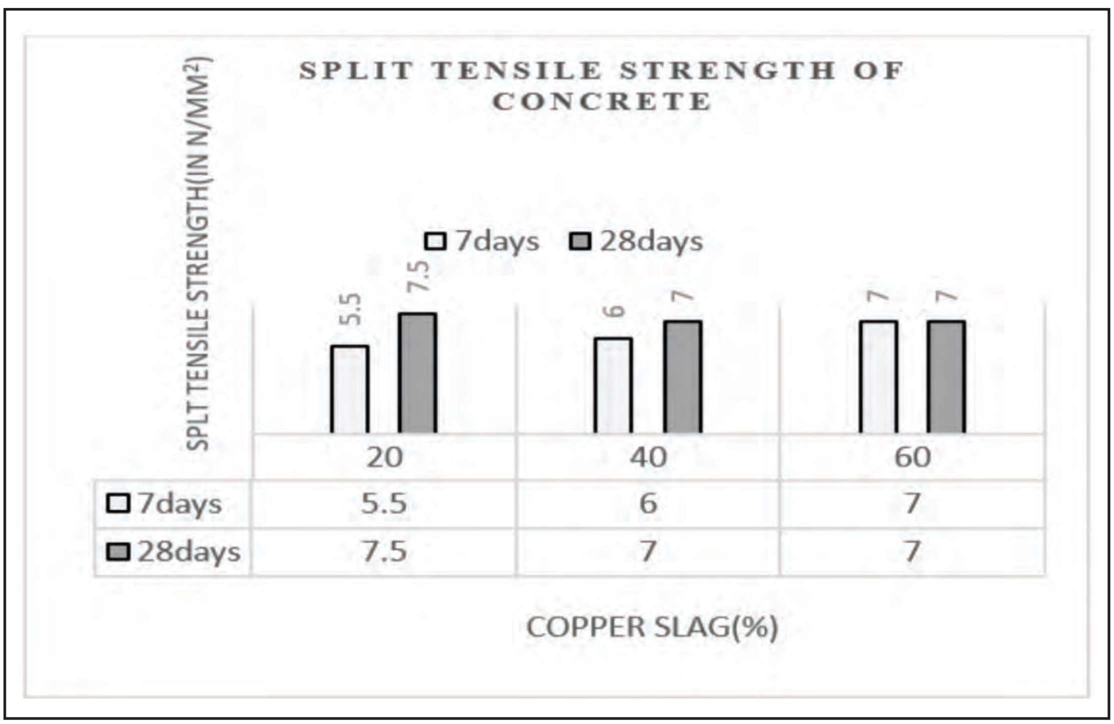


Fig. 8. Split tensile strength for various propertions of Copper slag

Fig. 9 demonstrates that after 7 days and 28 days of curing and testing respectively, the Split tensile strength of concrete mix with a 10% substitution of Recycle Concrete Aggregate with Coarse aggregate supplied the biggest value as compared to the other two proportions of mix as well as nominal mix.

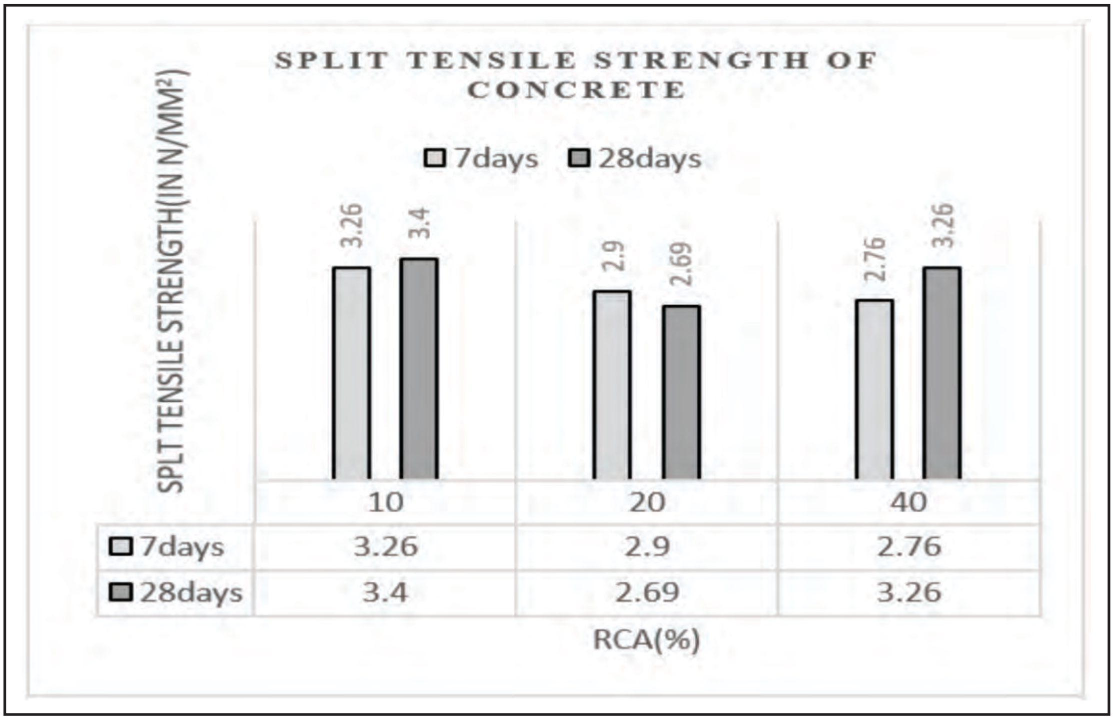


Fig. 9. Split tensile strength for various proportions of Recycled Concrete Aggregate

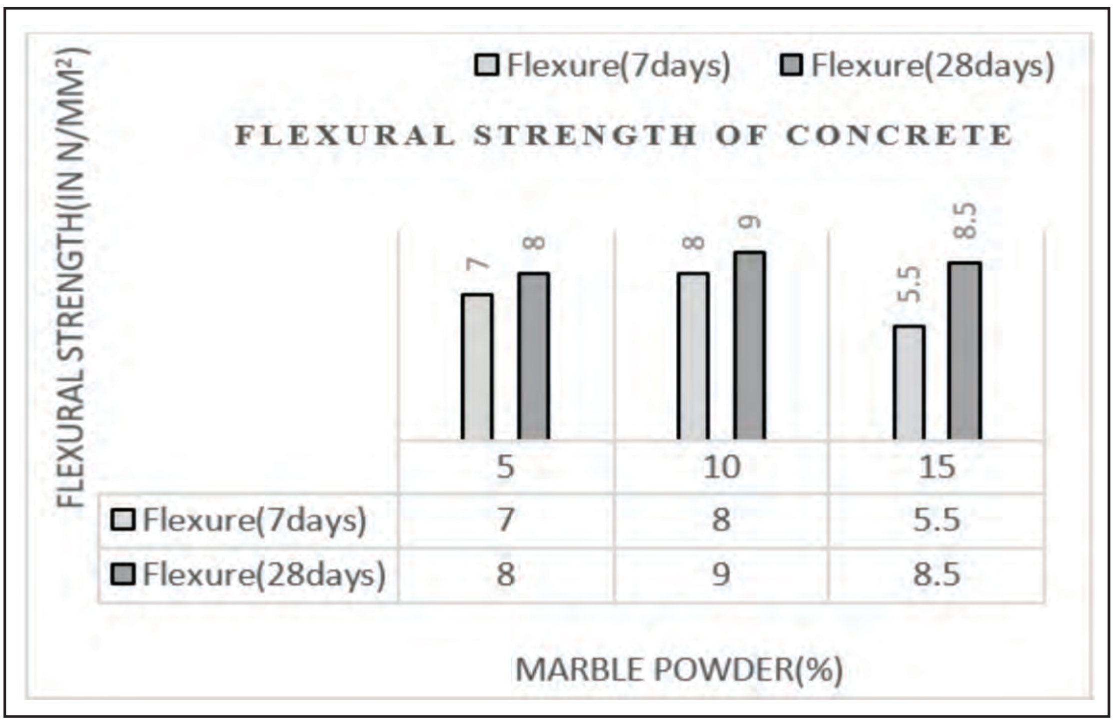


Fig. 10. Flexural strength for various proportions of marble powder

D. Flexural Strength

Fig. 10 shows that the Flexural strength of concrete mix with a 10% substitution of marble powder with cement provided the biggest value as compared to the other two proportions of mix as well as nominal mix after 7 days and 28 days of curing and testing respectively. Very less significant difference is shown in the 7 days and 28 days testing.

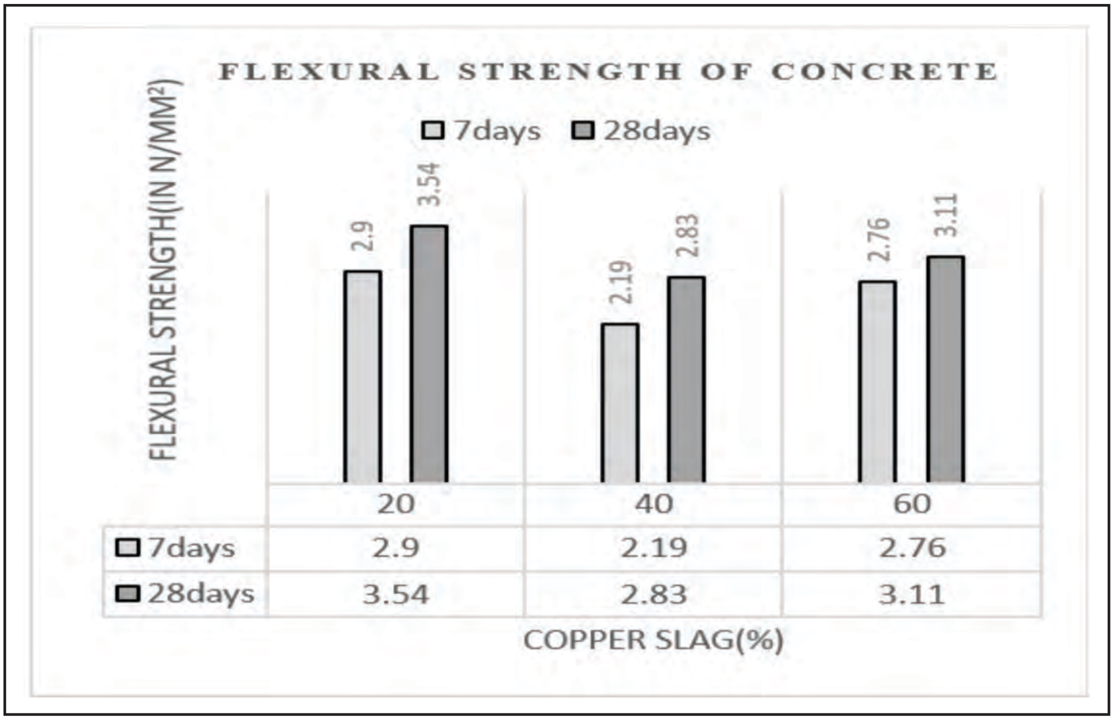


Fig. 11. Flexural strength for various proportions of Copper Slag

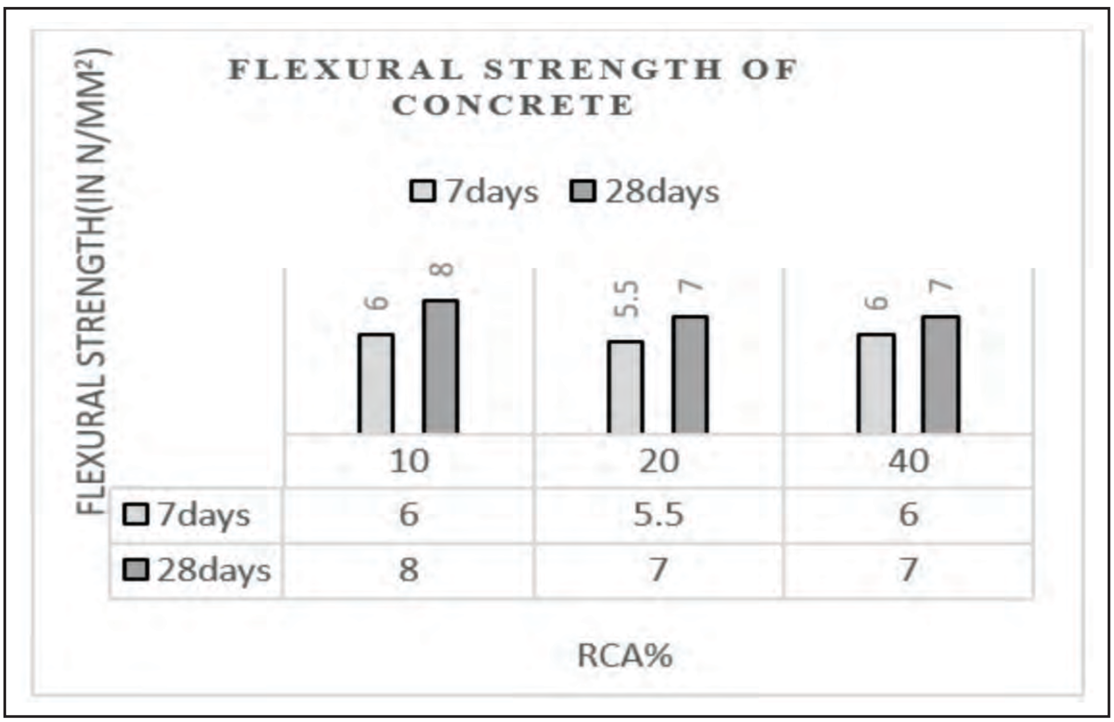
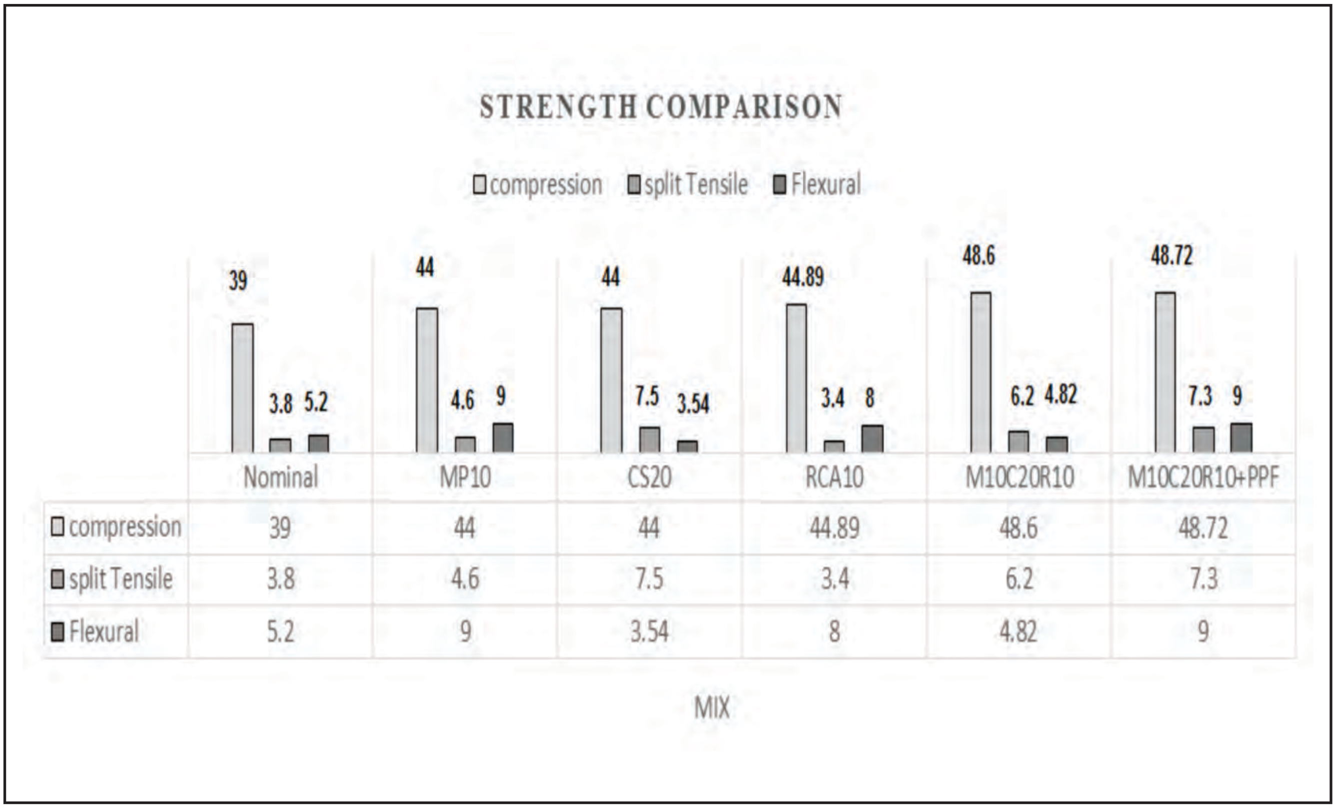


Fig. 12. Flexural strength for various propertion of Recycle Concrete Aggregate

Fig. 11 shows that the Flexural strength of concrete mix with a 20% substitution of Copper Slag with FA provided the biggest value in comparison to the other two proportions of mix as well as nominal mix after 7 days and 28 days of curing and testing respectively. In comparison to Marble Powder and RCA mixes, the flexural strength given by Copper slag at various proportions is less.



	Nominal	MP10	CS20	RCA10	M10C20R10	M10C20R10+PPF
compression	39	44	44	44.89	48.6	48.72
split Tensile	3.8	4.6	7.5	3.4	6.2	7.3
Flexural	5.2	9	3.54	8	4.82	9

Fig. 13. Comparison study of strengths for various proportions of mix

TABLE XIII.
COMPARISON OF CHANGE IN STRENGTH FOR VARIOUS PROPORTIONS (IN PERCENTAGE)

MIX	% CHANGE IN COMPRESSIVE STRENGTH	% CHANGE IN SPLIT TENSILE STRENGTH	% CHANGE IN FLEXURAL STRENGTH
M10C0R0	12.82	21.05	73.08
M0C20R0	12.82	97.37	–31.92
M0C0R10	15.10	–10.53	63.16
M10C20R10	24.62	63.16	–7.31
M10C20R10+PPF	24.92	92.11	73.08

E. Various Strength Comparison

Fig. 12 shows that the Flexural strength of concrete mix with a 10% substitution of RCA with CA provided the biggest value as compared to the other two proportions of mix as well as nominal mix after 7 days and 28 days of curing and testing respectively.

According to this graph, the mixture M10C20R10+PPF, which included 10% recycled concrete aggregate, 20% Copper slag, and 0.5% of the mixture's total volume of polypropylene fibre had the maximum compressive strength. 5.6 % change in various strengths. Table XIII shows the comparison of change in strength for various proportions (in percentage).

Fig. 14 shows how the usage of admixtures and fibres has changed different mechanical characteristics or strengths (in percentage value) such as compressive, split tensile, and flexural strength of various mixes of partial replacement by cement, fine aggregate, and coarse aggregate.

F. Rebound Hammer Test

From Fig. 15, we observe that the rebound hammer value

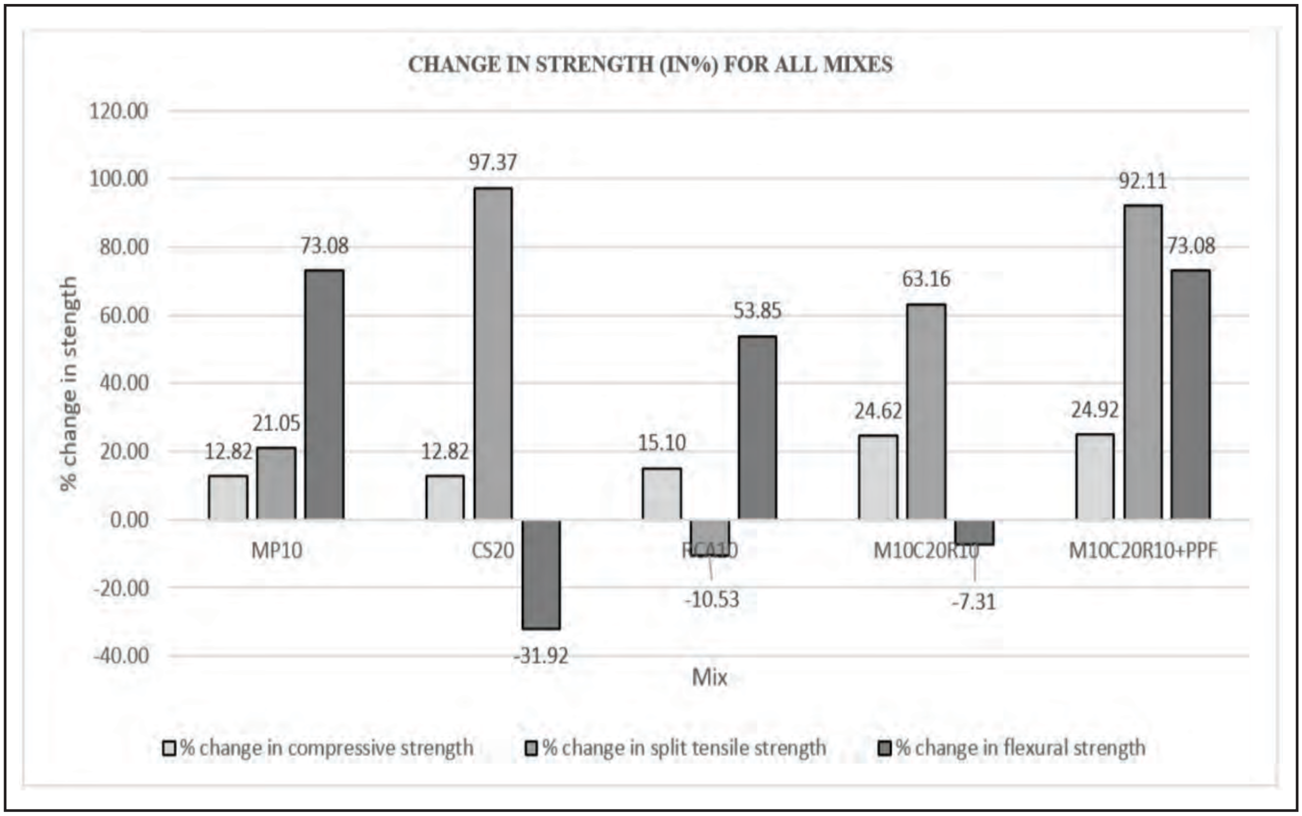
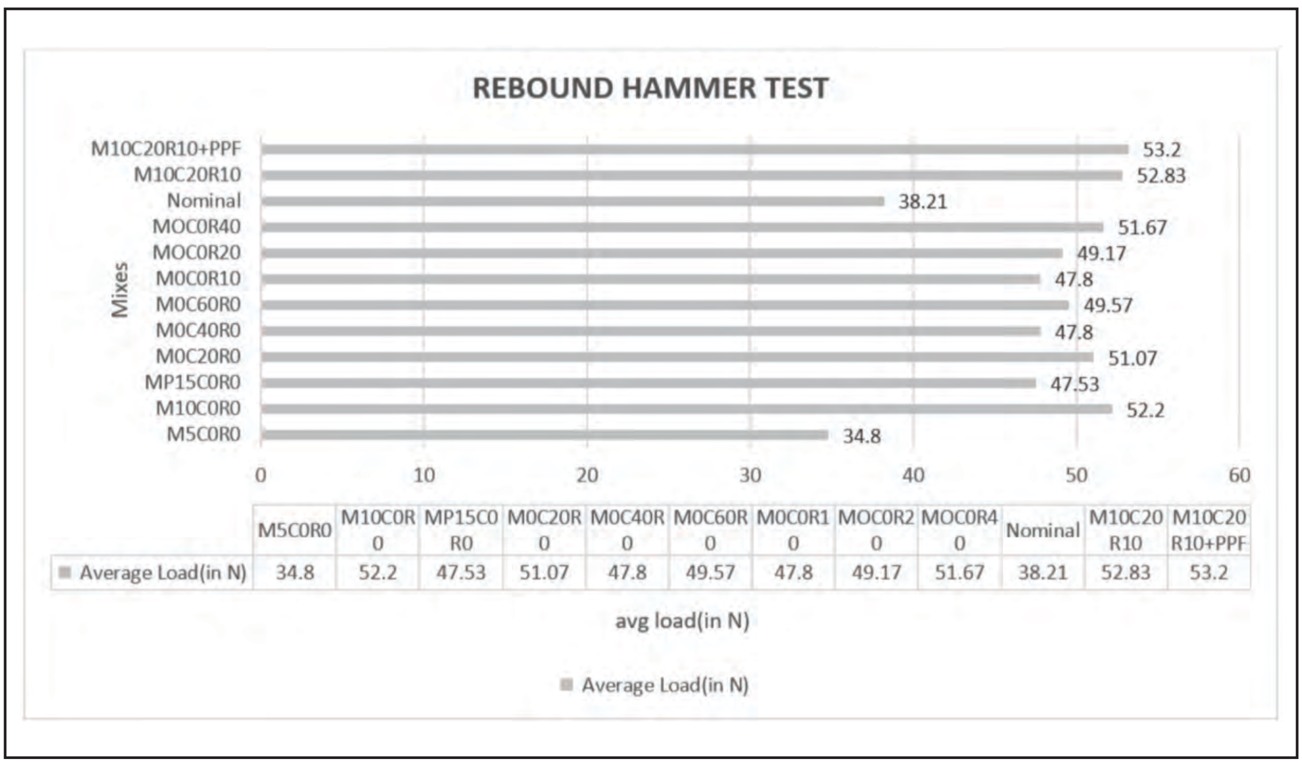


Fig. 14. Comparison study of percentage change in strength for various proportions of mix



	M5C0R0	M10C0R0	MP15C0R0	M0C20R0	M0C40R0	M0C60R0	M0C0R10	MOC0R20	MOC0R40	Nominal	M10C20R10	M10C20R10+PPF
Average Load(in N)	34.8	52.2	47.53	51.07	47.8	49.57	47.8	49.17	51.67	38.21	52.83	53.2

Fig. 15. RHT Graph

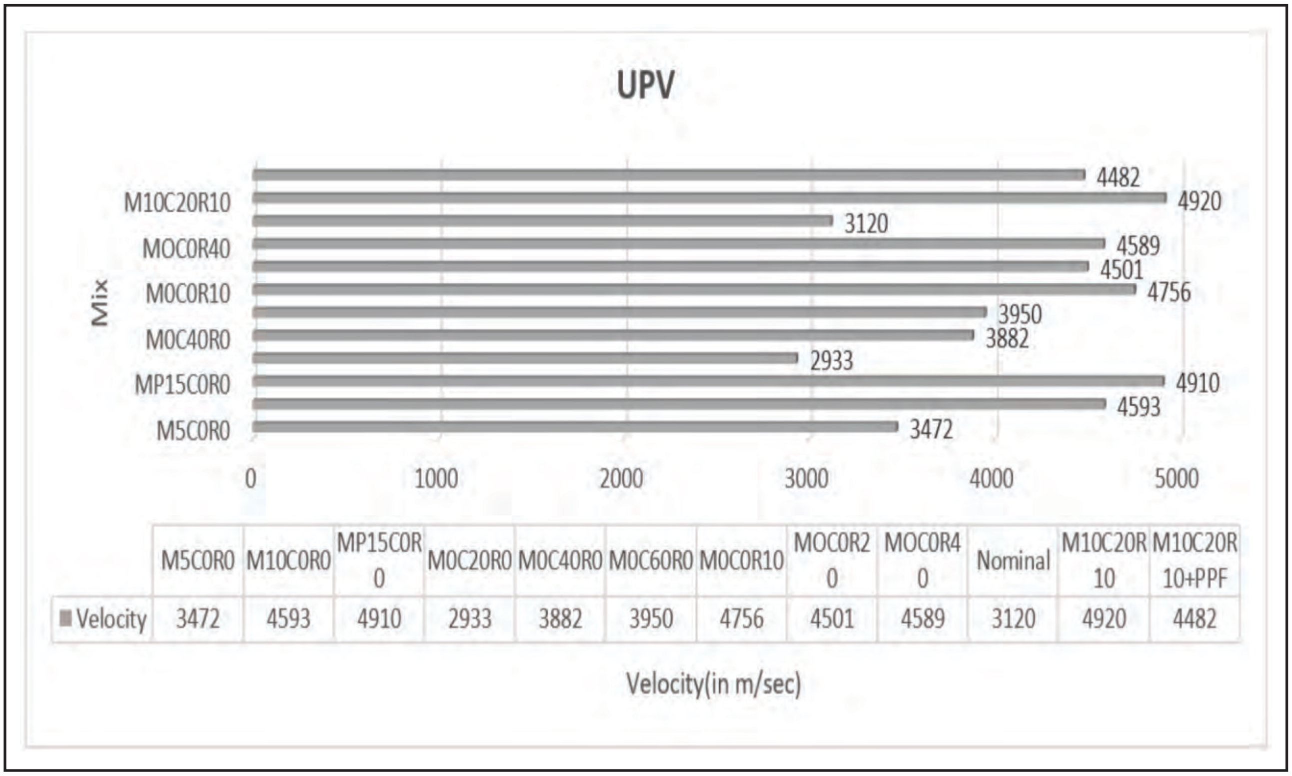


Fig. 16. UPV graph for various mixes

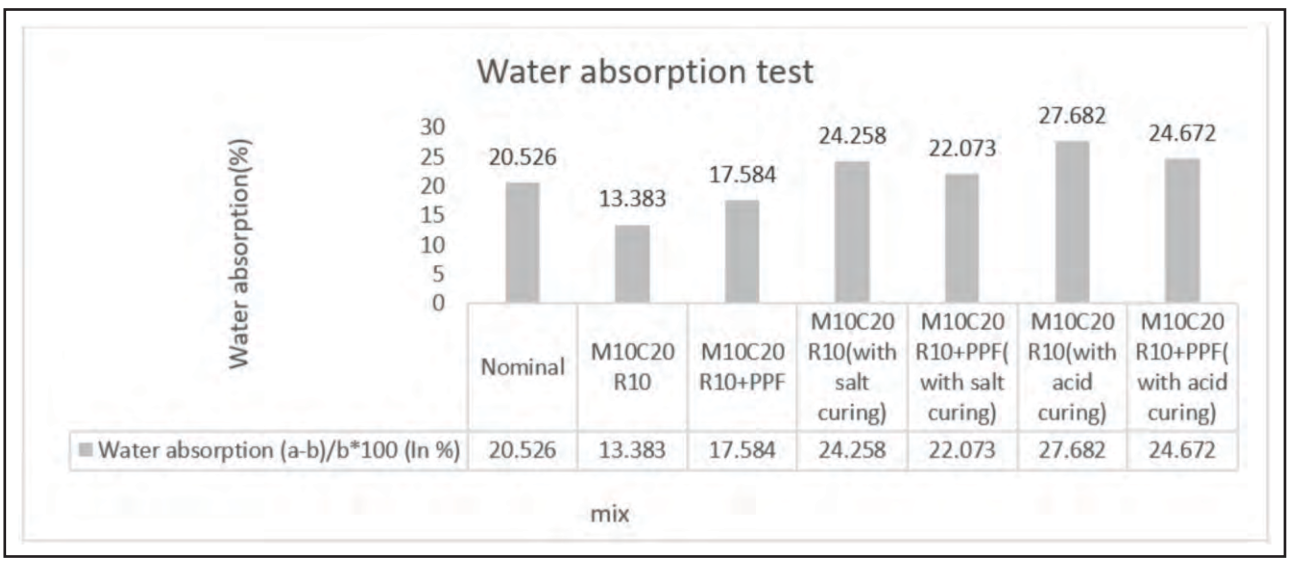


Fig. 17. Water absorption graph

for M10C20R10+PPF gave the maximum value among all mixes.

G. Ultrasonic Pulse Velocity

Fig. 16 shows that the mix M10C20R10 and M10C20R10+PPF were of excellent quality and were better than the nominal mix. The nominal mix is of good quality.

H. Water Absorption Test

Fig. 17 shows that after curing with acid and salt, the mix absorbed more water since there were more holes or voids owing to the harmful chemicals. Hydrochloric Acid curing of M10C20R10 produced the maximum water absorption value.

I. SEM Analysis

Scanning electron microscopy may be very helpful in characterising the microstructure of concrete, cement,

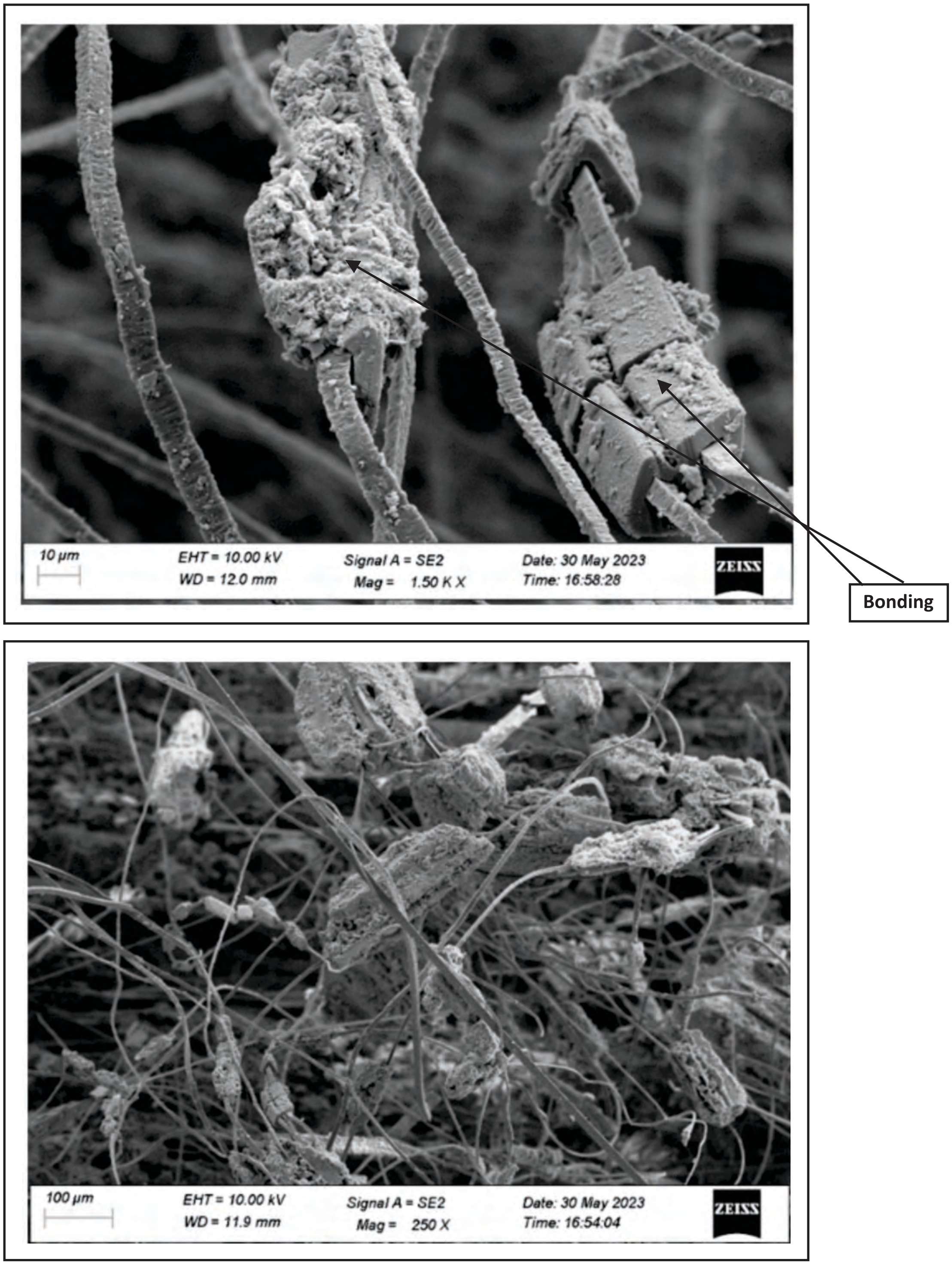


Fig. 18 (a). Micro Structure Study

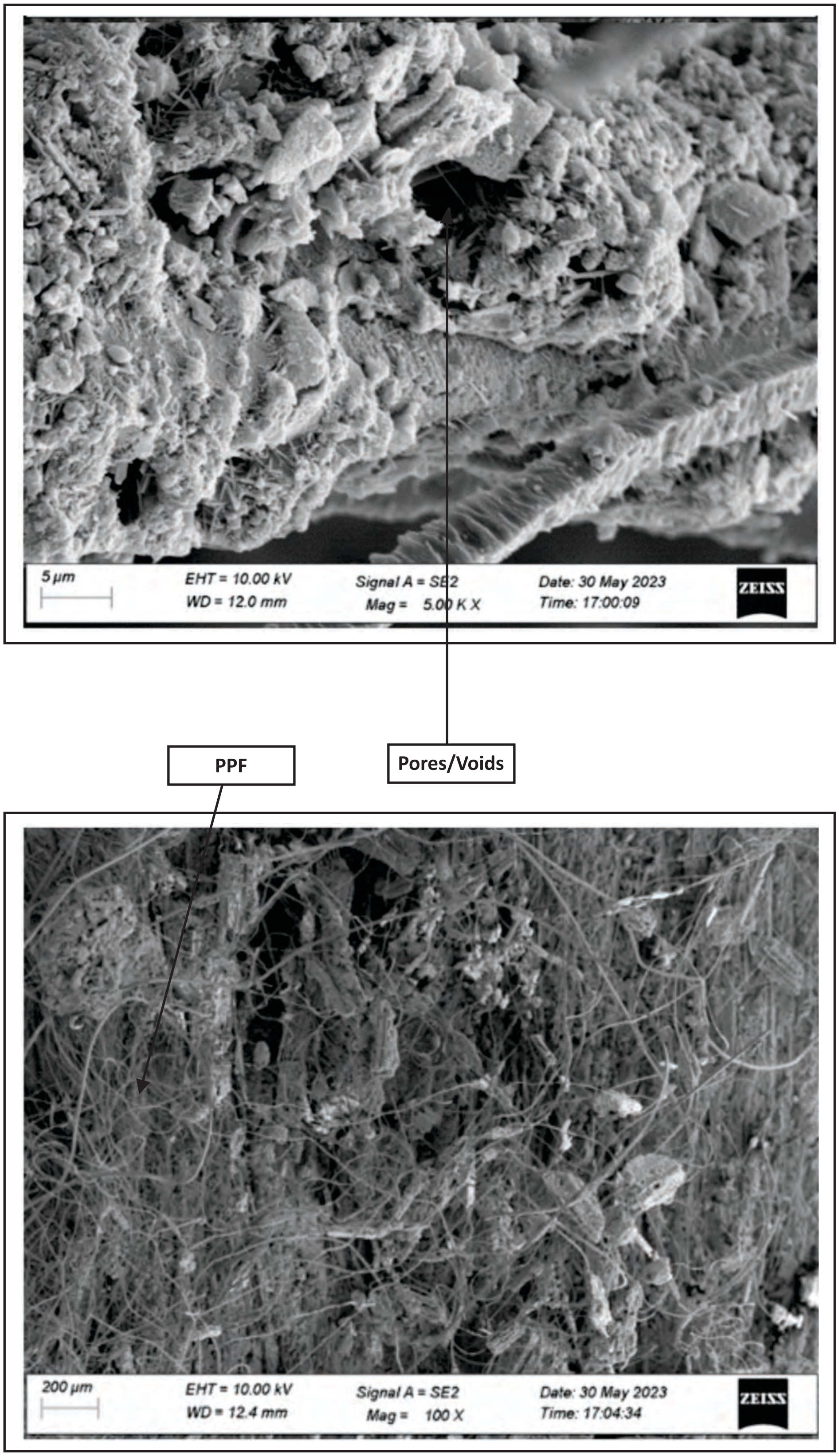


Fig. 18 (b). Micro Structure Study

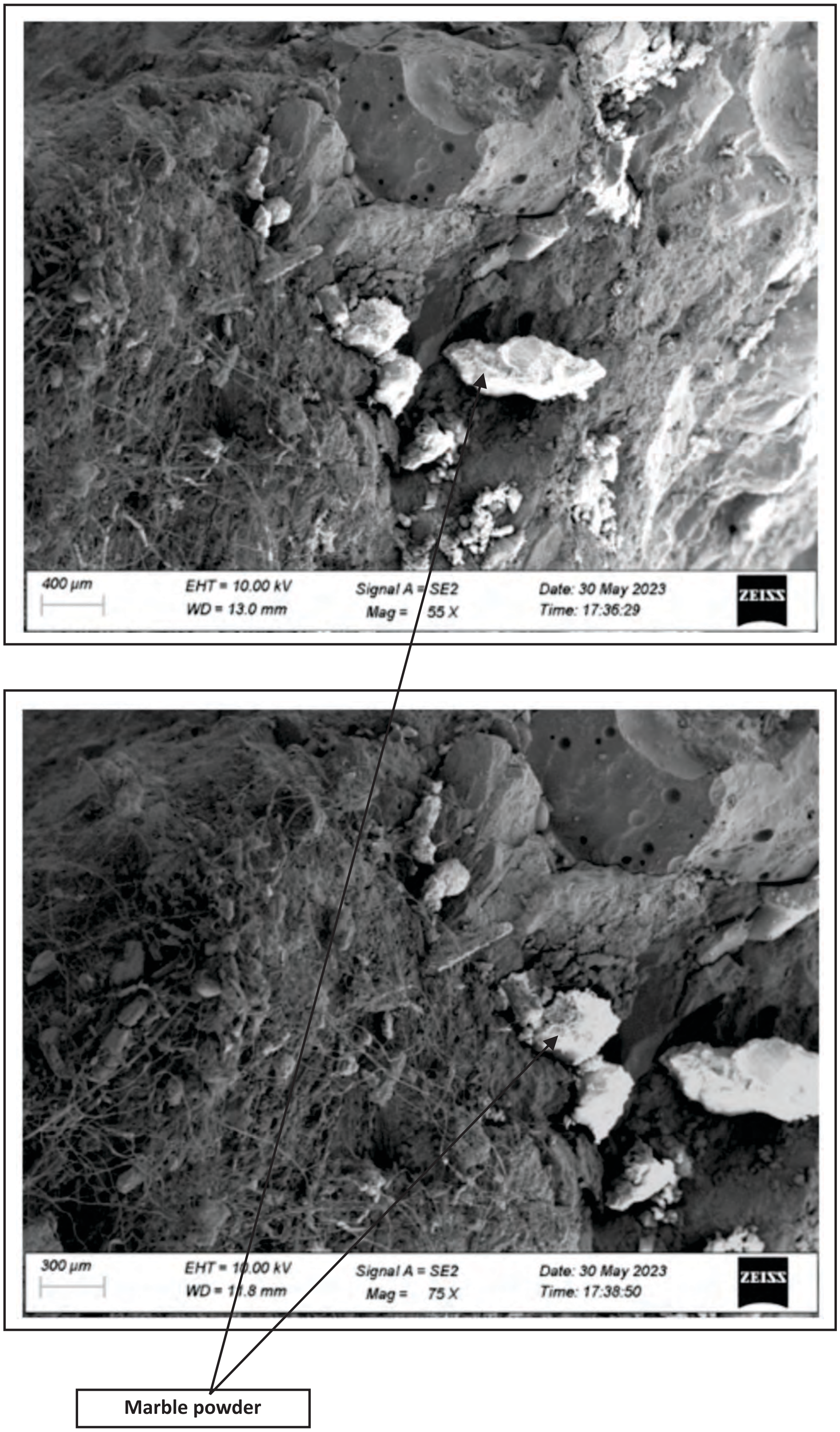
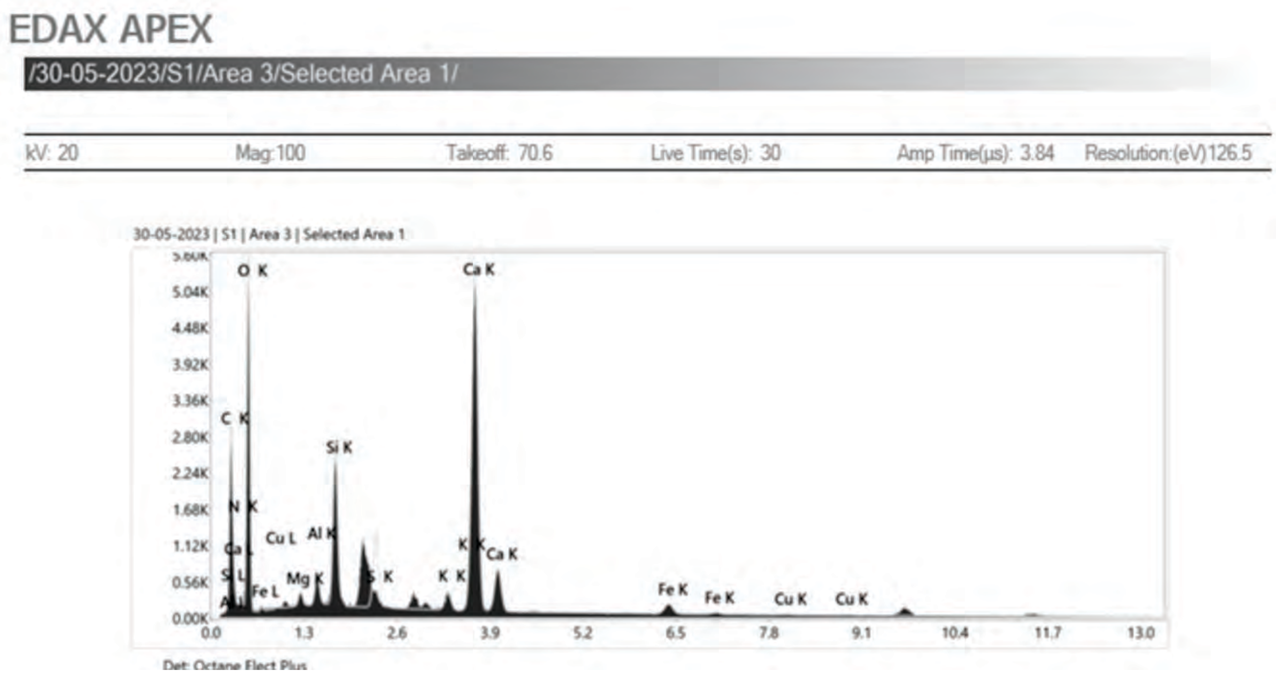


Fig. 18 (c). Micro Structure Study



Element	Weight %	Atomic %	Net Int.	Error %	R	A	F
C K	31.6	43.8	359.1	11.2	0.9100	0.1080	1.0000
N K	0.4	0.5	3.8	88.3	0.9157	0.0414	1.0000
O K	42.5	44.3	978.5	10.7	0.9203	0.0854	1.0000
Mg K	0.4	0.3	50.8	13.4	0.9354	0.4055	1.0055
Al K	0.7	0.4	119.8	9.7	0.9387	0.5459	1.0093
Si K	3.2	1.9	632.5	5.5	0.9419	0.6622	1.0122
S K	2.0	1.0	350.6	5.7	0.9476	0.8074	1.0274
K K	0.7	0.3	99.6	11.1	0.9554	0.9206	1.0957
Ca K	17.1	7.1	1873.5	2.3	0.9578	0.9389	1.0157
Fe K	1.3	0.4	73.1	11.6	0.9711	0.9711	1.0621
Cu K	0.2	0.0	5.5	62.6	0.9773	0.9850	1.1121

Fig. 19. Various chemical components present in the mix

and aggregate as well as identifying the causes of concrete deterioration. The components of hardened cement paste may be more easily identified, thanks to scanning electron microscope imaging, which has superior contrast and spatial resolution than optical methods. Additionally, it provides supplementary imaging and element analysis capabilities. These data may be utilised to provide quantitative information on concrete's composition, its fractures and pores, and the connection between its fibres and matrix.

The SEM test has been conducted at KIIT University, Patia, Bhubaneswar.

VI. CONCLUSION

Based on the test results and statistical analysis, the following tasks in the thesis were entailed, which helped to find out the exact result that we got from various tests. To choose the optimum option from the partial replacement of marble powder by cement, partial replacement of Copper Slag with fine aggregate and partial replacement of Recycled Concrete Aggregate with natural Coarse Aggregate. After that according to the optimum values for all replacements, two kinds of casting were conducted, that is, with and without use of polypropylene fibre. According to the standards, workability, compressive strength, split tensile strength, and flexural strength were tested to identify the mix of materials that optimises various desired concrete properties. Additional lab testing confirmed that the optimal components combination produced gave a positive result.

The conclusions that were observed from these results are:

➩ The workability of mix concrete was seen to be increased when the percentage of marble powder as well as copper slag increased in the concrete while the workability of mix concrete decreased when we partially replaced recycle concrete aggregate with natural coarse aggregated due to its irregular shape, rough texture, and higher water absorption capacity as it adhered to old cement mortar. The mix M0C60R0 gave the higher workability among all concrete mixes.

➩ By using 10% of marble powder, 20% of copper slag, and 10% of RCA individually the compressive strength was increased. The concrete mix of M10C20R10 with addition of Polypropylene fibre gave the highest compressive strength(about 25% more than nominal mix) among all the concrete mixes and not so significant difference was shown in the M10C20R10 and M10C20R10+PPF mix. Due to the presence of marble powder, it helped to form the bond between materials leading to an increase in the compressive strength.

➩ By using Polypropylene Fibre in the optimum mix, highest split tensile strength value was observed. About more than 90% strength was increased due to the fibre effect. It was due the interfacial connection between the concrete matrix and the fibre.

➩ Flexural strength also showed a positive result by using polypropylene fibre in the optimum mix. By using PPF, the flexural strength was increased by about 73% than the nominal mix.

➩ Due to copper slag's high bonding effect, all the voids were filled, high desification of concrete mix was done. So the ultrasonic pulse velocity showed an excellent result in the optimum mix (without using PPF). It helped to lengthen the route of the wave which travelled from one end to another end of the concrete cube.

➩ Using the PPF, when the concrete samples were cured in salt and acid, showed good durability quality in comparison to concrete mix without PPF. It was due to the resistivity capacity of PPF to adverse condition.

➩ Through the SEM technique, the micro structure of the hardened concrete was observed. Various pores and bonding zones were able to be examined. Various components present in the mix were also investigated through EDAX APEX of SEM machine.

AUTHORS' CONTRIBUTION

Aparajita Sahoo carried out all the experimental investigations under the supervision of Prof. Pravat Kumar Parhi who helped her by providing the idea about the research topic and helped in review of literature and correction of the manuscript.

CONFLICT OF INTEREST

The authors certify that they have no affiliation with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter, or materials discussed in this manuscript.

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