**AN EXPERIMENTAL INVESTIGATION ON EFFECT OF PARTIAL REPLACEMENT OF OF CEMENT WITH RED MUD, FLY ASH AND POLYPROPYLENE FIBER**

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**Abastract:** This experimental investigation aims to determine the impact of substituting cement with red mud in M25 grade concrete, with varying replacement percentages of 5%, 10%, 15%, and 20%. Additionally, 20% of Class F fly ash is introduced as a supplementary cementitious material, while optimal volume fractions of polypropylene fiber (0.5%, 1%, 1.5%, and 2%) are incorporated to examine workability characteristics of Polypropylene Fiber Reinforced Concrete (PPFRC) and red mud-infused PPFRC. The study also involves evaluating the compressive, split tensile, and flexural strengths of M25 grade concrete by replacing cement with red mud (across 5% to 20% levels) and 20% fly ash, while integrating the optimal polypropylene fiber content.

***Keywords:*** *Cement,redmud,flyash,Polypropylene fiber reinforced concrete.*

**INTRODUCTION**

**1.1 GENERAL**

Ramujee (2013) investigated the strength properties of Polypropylene Fiber Reinforced Concrete, examining compressive and splitting tensile strengths for different fiber percentages (0%, 0.5%, 1%, 1.5%, and 2%). Results favored the samples containing 1.5% Polypropylene fibers. Shwetha et al. (2015) employed fly ash as partial cement replacement along with glass fibers to enhance various structural properties of concrete. Vinit et al. (2015) explored work ability and compressive strength in concrete with different PPC replacements, while Mahadeva et al. (2017) utilized Rice Husk Ash for soil stabilization. Notably, concrete production significantly contributes to carbon dioxide emissions; hence, industrial by-products like Redmud, Fly Ash, and GGBS are used to mitigate environmental impact. Sabarish et al. (2017) proposed fly ash substitution for cement, while Murumi and Gupta (2019) established limits for fly ash utilization based on concrete strength and water-reducing potential. Mahadeva et al. (2020) examined flexural strength with natural and synthetic fibers, and Rajiv et al. (2020) determined mechanical properties of Self-Compacting Concrete with GGBFS and Copper slag substitutions. Rudraswamy et al. (2020) evaluated shrinkage in concrete reinforced with various fibers, finding hybridized concrete to perform better. Redmud, an alkaline waste from alumina refineries, accelerates hydration, improves durability, and reduces micro cracks in concrete. With a global annual production exceeding 300 million tonnes, re purposing red mud in concrete offers environmental benefits and addresses disposal issues.

**1.2 REDMUD**

Red mud, a hazardous waste produced during the bayer process of alumina production (Al2O3) from bauxite ore, contains high levels of residual alkalinity and toxic heavy metals. Consequently, red mud is considered a hazardous byproduct of the alumina industry. The quantity of red mud generated in alumina processing plants varies based on bauxite ore quality. Typically, these plants dispose of liquid red mud into reservoirs, posing significant risks of environmental contamination. A pozzolan refers to siliceous and aluminous material with limited inherent cementitious value, but when finely divided and exposed to moisture, it chemically reacts with calcium hydroxide at normal temperatures to form compounds with cement-like properties. Given the nearly identical chemical composition of cement and red mud, substituting cement with red mud can enhance the properties of hardened concrete.

**Table 1.1: Chemical composition of cement and redmud**

|  |  |  |
| --- | --- | --- |
| **Chemical composition** | **Cement** | **Red mud** |
| Cao | 63.6 | 35.3 |
| SiO2 | 19.49 | 18 |
| Al2O3 | 4.54 | 6.31 |
| Fe2O3 | 3.38 | 12.38 |
| Na2O | 0.13 | 2.71 |
| Mgo | 2.36 | 1.13 |
| K2O | 0.58 | 0.45 |

**1.3 USE OF FLY ASH IN CONCRETE**

Fly ash is a residual product resulting from the combustion of coal in electric power generation plants. When coal undergoes combustion in the combustion chamber, volatile materials, including carbon, are consumed. However, certain mineral impurities present in materials like shale, clay, and feldspars become fused in the suspension and exit the combustion chamber as exhaust gases. As these gases cool down, the fused substances solidify into spherical glassy particles known as fly ash. Typically, these fly ash particles are minute solid spheres or hollow microspheres. The size of these particles varies but generally resembles that of Type I Portland cement. Electrostatic precipitators or bag filters are utilized to capture fly ash from exhaust gases. Widely employed in construction, fly ash serves as a valuable material and can be used for soil stabilization or as landfill. It constitutes the non-combustible mineral part of coal generated during power plant coal combustion. Since the 1950s, civil engineers have progressively recognized fly ash's utility as a beneficial ingredient in concrete mixes. It enhances various desirable attributes of both fresh and hardened concrete, such as workability, resistance to sulfate, reduction of initial hydration temperature, and hardened concrete strength.

**1.4 POLYPROPYLENE FIBRE REINFORCED CONCRETE**

Concrete is inherently brittle with limited tensile strength and strain capacity, resulting in a vulnerability to cracking. To enhance these properties, fiber reinforced concrete (FRC) has been developed. Fibers are incorporated to augment tensile strength, impact resistance, flexural strength, and toughness. They also modify failure modes by enhancing post-cracking ductility and preventing cracking. Composite tensile strength, which is mainly associated with the stress at which the matrix develops macro-cracks, remains relatively consistent across conventional fiber reinforced cementitious materials. Various fiber materials in different sizes and shapes have been devised for FRC applications, and among them, polypropylene fibers stand out as a highly successful commercial choice. These fibers often come in forms like smooth monofilaments or triangular profiles, each possessing distinctive qualities that make them well-suited for reinforcing concrete mixes. Polypropylene fibers boast attributes such as low density, chemical inertness, and non-corrosiveness.

**1.4.1 APPLICATIONS OF POLYPROPYLENE FIBRE REINFORCED CONCRETE**

Over the recent years, there has been a notable surge in construction projects involving the utilization of concrete infused with polypropylene fibers. These applications encompass a diverse range of structures, including foundation piles, prestressed piles, piers, highways, industrial floors, bridge decks, and flotation units for walkways. Moreover, polypropylene fiber-reinforced concrete (PPFRC) finds effective usage in curbing issues like shrinkage and temperature-induced cracking. The spectrum of PPFRC applications spans across various domains, encompassing building components like slabs, beams, water storage tanks, pool construction, basements, cement tiles, plastering, and foundations, as well as extending to areas such as drainage systems, bridges, industrial flooring, hydraulic structures, highway pavements, blast resistance design, sewage and waste management. Additional applications include the use of PPFRC for plastering to mitigate plastic shrinkage cracking, enhance abrasion resistance, bolster freeze and thaw durability, and manage plastic settlement cracking, among others.

**2. MATERIAL**

**2.1 CEMENT**

In this experimental work. Ordinary Portland Cement (OPC) 53 grade conforming to IS: 8112-1989 was used. The cement used was Birla cement from the local distributors.

**Table 2.1:** Properties of cement

|  |  |  |
| --- | --- | --- |
| **Properties of Cement** | **Test Results** | **Standard Values** |
| Specific gravity | 3.15 | 2.9-3.16 |
| Fineness | 10% | - |
| Normal consistency | 32 % | 24%-32% |
| Initial setting time | 35 min | Not less than 30 min |

**2.2 REDMUD**

Redmud is an industrial waste produced by aluminium industries and Redmud is collected from “Hindalco Industries Limited, Belgaum, Karnataka”.

**Table 2.2:** Properties of redmud

|  |  |  |
| --- | --- | --- |
| **SL. No.** | **Properties** | **Test Result** |
| 1 | Specific Gravity | 2.98 |
| 2 | Fineness | 2600 sq.cm/gm |
| 3 | PH | 11.8 |

**2.3 FLY ASH**

Class F fly ash is a byproduct resulting from the combustion of coal in thermal power plants. Specifically, it's generated when burning harder, older anthracite and bituminous coal. This type of fly ash, known as Class F, possesses pozzolanic characteristics and is characterized by its lime content, which is less than 20% (CaO).

**Table 2.3:** Properties of fly ash

|  |  |
| --- | --- |
| **Properties of Fly Ash** | **Test Results** |
| Specific gravity | 2.52 |
| Fineness | 30% |
| Normal consistency | 24% |
| Initial setting time | 30 min |

**2.4 FINE AGGREGATE**

Locally available M sand belonging to zone II of IS 383-1970 was used for the project work.

**Table 3.4:** Properties of fine aggregates

|  |  |  |
| --- | --- | --- |
| **Properties** | **Test Results** | **Standard Values** |
| Specific gravity | 2.65 | 2.4-2.9 |
| Absorption of water  | 1% | **-** |
| Sieve analysis | Zone II | **-** |

**2.5 COARSE AGGREGATE**

Locally available crushed aggregates (size<20mm) confirming to IS 383-1970 are used in this dissertation.

**Table 3.5:** Properties of coarse aggregates

|  |  |  |
| --- | --- | --- |
| **Properties** | **Test Results** | **Standard Values** |
| Specific gravity | 2.63 | 2.6-2.8 |
| Water absorption | 0.4 % | 0.1% - 2.0% |
| Impact test | 18.64 % | Not more than 30% |

**2.6 POLYPROPYLENE FIBER**

Polypropylene fiber, often referred to as polypropylene or PP, constitutes a synthetic fiber derived from 85% propylene, and it serves a multitude of purposes. This versatile material finds application across various industries, with a notable example being its utilization in the production of carpet yarns. Specifically, a significant portion of cost-effective carpets intended for light domestic use are crafted from this fiber. Boasting thermoplastic qualities, resilience, lightweight characteristics, and resistance to mildew and numerous chemicals, polypropylene fiber stands out as a durable choice for diverse applications.

**Table 4.6:** Properties of popypropylene fibers

|  |  |
| --- | --- |
| **Properties** | **Test Results** |
| Density (Kg/m3) | 900 |
| Length (mm) | 12 |
| Diameter (Micron) | 34 |
| Tensile Strength (MPa) | 1750 |
| Specific Gravity (Kg/m3) | 2.68 |

**2.7 Concrete mix proportion:**

Cement = 329 Kg/ m3

Water = 148 Lt/ m3

Fine aggregate = 845 Kg/ m3

Coarse aggregate = 1106.4 Kg/m3

Chemical admixture = 6.58 Kg/m3

w/c ratio = 0.45

**Mix Ratio = 1: 2.57: 3.36**

**3. Results and discussions**

**3.1 SLUMP TEST RESULTS**

**3.1.1 SLUMP TEST FOR POLYPROPYLENE FIBER REINFORCED CONCRETE (PPFRC)**

A slump test was performed for polypropylene fiber reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibers at different percentages from 0.5% to 2.0% in 0.5% intervals. Slump test results of PPFRC are tabulated in table 4.1.

**Table 3.1: Slump test results for PPFRC**

|  |  |  |
| --- | --- | --- |
| **Sl No** | **% OF PPF** | **Slump in (MM)** |
| 1 | 0 | 94.5 |
| 2 | 0.5 | 91.2 |
| 3 | 1 | 88.4 |
| 4 | 1.5 | 84.1 |
| 5 | 2.0 | 80.8 |

**Fig 3.1: Slump test results for PPFRC**

**3.2.2 SLUMP TEST RESULTS FOR REDMUD PPFRC**

Slump test was conducted for redmud polypropylene fiber reinforced concrete. The concrete mix is prepared by replacing cement with redmud at different percentages from 5% to 20% in 5% intervals and flyash is also replaced for cement in 20%. Optimum percentage of polypropylene fiber 1.5% is also added. Slump test results of PPFRC are tabulated in table 4.2.

**Table 3.2: Slump test results for redmud PPFRC**

|  |  |  |
| --- | --- | --- |
| **Sl No** | **Mix Designation** | **Slump in mm** |
| 1 | RM 0 | 94.5 |
| 2 | RM 5 | 89.2 |
| 3 | RM 10 | 85.4 |
| 4 | RM 15 | 83.1 |
| 5 | RM 20 | 79.8 |

**Fig 3.2: Slump test results for redmud PPFRC**

**3.3 COMPRESSIVE STRENGTH TEST RESULTS**

**3.3.1 COMPRESSIVE STRENGTH TEST FOR PPFRC**

Compressive strength test was conducted for polypropylene fiber reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibers at different percentages from 0.5% to 2.0% in 0.5% intervals. The compressive strength tests are conducted on 7, 14 and 28 days of curing and results are compared with conventional concrete. Compressive strength of PPFRC are tabulated in table 4.3.

**Table 3.3: Compressive strength for PPFRC**

|  |  |  |
| --- | --- | --- |
| Sl No | % of PPF | Compressive strength in Mpa |
| 7 days | 14 days | 28 days |
| 1 | 0 | 20.86 | 25.25 | 31.95 |
| 2 | 0.5 | 21.32 | 27.58 | 33.82 |
| 3 |  1 | 23.35 | 28.8 | 34.25 |
| 4 |  1.5 | 25.15 | 30.12 | 36.28 |
| 5 |  2 | 23.89 | 29.02 | 34.22 |

**Fig 3.3: Compressive strength of PPFRC**

**3.3.2 COMPRESSIVE STRENGTH TEST FOR REDMUD PPFRC**

This test conducted for redmud polypropylene fiber reinforced concrete. The concrete mix is prepared by replacing cement with redmud at different percentages from 5% to 20% in 5% intervals and flyash is also replaced for cement in 20%. Optimum percentage of polypropylene fiber 1.5% from table 7.3 is also added. Compressive strength tests were carried out on various curing durations, and the obtained values were juxtaposed with those of conventional concrete. The findings have been organized in Table 4.4 for reference.

**Table 3.4: Compressive strength for redmud PPFRC**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sl No | % of Fly Ash + % of PPF + % of RM | 7 day’s | 14 day’s | 28 day’s |
|  |
| 1 | 0 % | 20.86 | 25.25 | 31.95 |  |
| 2 | 20%+1.5%+5% | 22.25 | 28.2 | 34.98 |  |
| 3 | 20%+1.5%+10% | 23.55 | 29.54 | 36.88 |  |
| 4 | 20%+1.5%+15% | 24.85 | 31.25 | 38.85 |  |
| 5 | 20%+1.5%+20% | 22.7 | 29.36 | 37.54 |  |

**Fig 3.4: Compressive strength of REDMUD PPFRC**

**3.3.3 Discussion,s on compressive strength test results**

* The compressive strength values for polypropylene fiber reinforced concrete are increased upto 1.5% polypropylene fiber addition. For 2% polypropylene fiber addition, compressive strength starts decreasing.
* It is observed that 17.05% increase in compressive strength for 7 days, 17.02% increase in compressive strength for 14 days and 11.93% increase in compressive strength in 28 days for 1.5% of polypropylene fiber addition compared to normal concrete mix.
* The compressive strength results for redmud PPFRC are increased upto 15% replacement of cement by redmud after 15% compressive strength starts decreasing.
* The 15% replacement of redmud gives 16.05% higher compressive strength than the conventional concrete for 7 days, 19.2% and 18.01% higher compressive strength for 14 days and 28 days respectively.
* The maximum compressive strength is achieved for 15% redmud replacement, 20% flyash replacement and 1.5% of polypropylene fiber addition.

**3.4 SPLIT TENSILE STRENGTH TEST RESULTS**

**3.4.1 SPLIT TENSILE STRENGTH TEST FOR PPFRC**

This test is conducted for polypropylene fiber reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibers at different percentages from 0.5% to 2.0% in 0.5% intervals. The split tensile strength tests are conducted on different curing periods of curing and results are compared with conventional concrete. The Split tensile strength of PPFRC are tabulated in table 3.5.

**Table 3.5: Split tensile strength for PPFRC**

|  |  |  |
| --- | --- | --- |
| Sl No | Mix Designation | Split tensile strength in Mpa |
| 7 days | 14 days | 28 days |
| 1 | PP 0 | 2.28 | 2.82 | 3.22 |
| 2 | PP 0.5 | 2.38 | 2.94 | 3.48 |
| 3 | PP 1 | 2.54 | 3.12 | 3.67 |
| 4 | PP 1.5 | 2.84 | 3.35 | 3.85 |
| 5 | PP 2 | 2.42 | 3.02 | 3.42 |

**Fig. 3.5: Split tensile strength of PPFRC**

**3.4.2 SPLIT TENSILE STRENGTH TEST FOR REDMUD PPFRC**

This test conducted for redmud polypropylene fiber reinforced concrete. The concrete mix is prepared by replacing cement with redmud at different percentages from 5% to 20% in 5% intervals and flyash is also replaced for cement in 20%. Optimum percentage of polypropylene fiber 1.5% from table 7.5 is also added. The split tensile strength test are conducted on 7, 14 and 28 days of curing and compared with conventional concrete. The results are tabulated in table 4.6.

**Table 3.6: Split tensile strength for redmud PPFRC**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sl No | % of Fly Ash+% of PPF+% of RM | 7 days | 14 days | 28 days |
|  |
| 1 | 0% | 2.28 | 2.82 | 3.22 |  |
| 2 | 20%+1.5%+5% | 2.34 | 3.02 | 3.36 |  |
| 3 | 20%+1.5%+10% | 2.52 | 3.28 | 3.54 |  |
| 4 | 20%+1.5%+15% | 2.78 | 3.48 | 3.92 |  |
| 5 | 20%+1.5%+20% | 2.38 | 3.24 | 3.61 |  |

**Fig 3.6: Split tensile strength of redmud PPFRC**

**3.4.3 Discussion on split tensile strength test results**

* The split tensile strength values for polypropylene fiber reinforced concrete are increased upto 1.5% polypropylene fiber addition. For 2% polypropylene fiber addition split tensile strength starts decreasing.
* It is observed that 19.71% increase split tensile strength for 7 days, 15.82% increase in split tensile strength at 14 days and 18.48% increase in split tensile strength in 28 days for 1.5% of polypropylene fiber addition compared to conventional concrete mix.
* The split tensile strength results for redmud PPFRC are increased upto 15% replacement of cement by redmud above 15% split tensile strength starts decreasing.
* The 15% replacement of redmud gives 17.98% higher split tensile strength than the conventional concrete for 7 days, 18.96% higher split tensile strength for 14 days and 17.85% higher split tensile strength for 28 days.
* The maximum split tensile strength is achieved for 15% redmud replacement, 20% flyash replacement and 1.5% of polypropylene fiber addition.

**3.5 FLEXURAL STRENGTH TEST RESULTS**

**3.5.1 FLEXURAL STRENGTH TEST FOR PPFRC**

This test conducted for polypropylene fiber reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibers at different percentages from 0.5% to 2.0% in 0.5% intervals. The flexural strength tests are conducted on 7, 14 and 28 days of curing and results are compared with conventional concrete. The flexural strength of PPFRC are tabulated in table 4.7.

**TABLE 3.7: Flexural strength for PPFRC**

|  |  |  |
| --- | --- | --- |
| Sl No |   | Flexural strength in Mpa |
| % of PPF | 7 days | 14 days | 28 days |
| 1 | PP 0% | 2.72 | 3.24 | 3.82 |
| 2 | PP 0.5% | 2.85 | 3.32 | 3.98 |
| 3 | PP 1% | 3.24 | 3.74 | 4.21 |
| 4 | PP 1.5% | 3.57 | 4.08 | 4.62 |
| 5 | PP 2% | 3.34 | 3.85 | 4.42 |

**Fig 3.7: Flexural strength of PPFRC**

**3.5.2 FLEXURAL STRENGTH TEST FOR REDMUD PPFRC**

The flexural strength test conducted for redmud polypropylene fiber reinforced concrete. The concrete mix is prepared by replacing cement with redmud at different percentages from 5% to 20% in 5% intervals and flyash is also replaced for cement in 20%. Optimum percentage of polypropylene fiber 1.5% from table 7.7 is also added. The flexural strength test are conducted on 7, 14 and 28 days of curing and compared with conventional concrete. The results are tabulated in table 4.8.

**Table 3.8: Flexural strength for redmud PPFRC**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sl No | % of Fly Ash+% of PPF+% of RM | 7 days | 14 days | 28 days |
|  |
| 1 | 0% | 2.72 | 3.24 | 3.82 |  |
| 2 | 20%+1.5%+5% | 2.81 | 3.36 | 3.94 |  |
| 3 | 20%+1.5%+10% | 3.14 | 3.68 | 4.12 |  |
| 4 | 20%+1.5%+15% | 3.45 | 4.02 | 4.54 |  |
| 5 | 20%+1.5%+20% | 3.22 | 3.78 | 4.24 |  |

**Fig 3.8: Flexural strength of redmud PPFRC**

**3.5.3 Discussion on flexural strength test results**

• The inclusion of polypropylene fibers in reinforced concrete results in increased flexural strength up to a 1.5% addition of polypropylene fiber. However, with a 2% addition of polypropylene fiber, flexural strength begins to decline.

• Notably, a 23.8% increase in flexural strength was observed after 7 days, a 20.58% increase after 14 days, and a 17.31% increase after 28 days with the addition of 1.5% polypropylene fiber compared to conventional concrete mix.

• When it comes to red mud-infused PPFRC, the flexural strength rises up to a 15% replacement of cement by red mud; beyond this threshold, flexural strength starts diminishing.

• Specifically, a 15% replacement of red mud leads to 21.15% higher flexural strength than conventional concrete after 7 days, a 19.4% increase after 14 days, and a 15.85% boost after 28 days.

• The most optimal combination yielding maximum flexural strength involves a 15% red mud replacement, 20% fly ash replacement, and a 1.5% addition of polypropylene fiber.

**4. CONCLUSIONS**

In this experimental investigation, redmud and flyash are used in concrete as partial replacement for cement along with polypropylene fibers. Following conclusions can be made from the results obtained.

* Workability of concrete decreases with increase in percentage of redmud.
* Compressive strength results for polypropylene fiber reinforced concrete (PPFRC) has maximum strength at 1.5% of polypropylene fiber addition.
* Split tensile strength and flexural strength for polypropylene fiber reinforced (PPFRC) have maximum strength at 1.5% of polypropylene fiber addition.
* Optimum percentage polypropylene fibers used in concrete is 1.5% of total weight of the concrete.
* Compressive strength results of redmud polypropylene fiber reinforced concrete has maximum strength at 15% of replacement of cement by redmud and 20% of flyash as cementitious material along with 1.5% of polypropylene fibers.
* Split tensile strength and flexural strength of redmud polypropylene fiber reinforced concrete has maximum strength at 15% of replacement of cement by redmud and 20% of flyash as cementitious material along with 1.5% of polypropylene fibers.
* Optimum percentage of redmud replacement in concrete is 15%.
* Total of 35% of cement is replaced by redmud and flyash (20%+15%).
* Redmud and flyash are the industrial waste materials which can be made use in construction field, which can minimize production of cement.
* Use of industrial waste in concrete minimizes the disposal problems of industrial waste, minimizes environmental pollution and it is also economical.

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