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

Abstract

This experimental investigation aims to assess the influence of replacing cement with red mud at different rates (5%, 10%, 15%, and 20%) on M25 grade concrete. Simultaneously, it introduces 20% Class F fly ash as an additional cementitious material and explores various volume fractions of polypropylene fiber (0.5%, 1%, 1.5%, and 2%) to study their impact on the workability of Polypropylene Fiber Reinforced Concrete (PPFRC) and red mud-infused PPFRC. The study also evaluates the compressive, split tensile, and flexural strengths of M25 grade concrete as cement is replaced with red mud (ranging from 5% to 20%) while incorporating 20% fly ash and the optimal polypropylene fiber content. Based on the present experimental study, it was concluded that both red- mud and fly ash can be used as a replacement for cement along with polypropylene fibers that induces good tensile strength and ductility when added at optimum percentage of 1.5%. The findings indicate that a combination of 15% red mud, 20% fly ash, and 1.5% polypropylene fibers yields the best results in terms of strength and sustainability. This approach also contributes to reducing environmental impact and addressing industrial waste disposal challenges.

Keywords: Cement, red mud, fly ash, polypropylene fibre, reinforced concrete.

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I. INTRODUCTION

Concrete is inherently brittle with limited tensile strength and strain capacity, resulting in a vulnerability to cracking. To enhance these properties, fibre reinforced concrete (FRC) has been developed. Fibres 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 fibre reinforced cementitious materials. Various fibre materials in different sizes and shapes have been devised for FRC applications, and among them, polypropylene fibres stand out as a highly successful commercial choice. These fibres often come in forms like smooth monofilaments or triangular profiles, each possessing distinctive qualities that make them well-suited for reinforcing concrete mixes. Polypropylene fibres boast attributes such as low density, chemical inertness, and non-corrosiveness. 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. Red mud, a hazardous waste produced during the alumina production (Al_2O_3) from bauxite ore, contains high levels of residual alkalinity and toxic heavy metals. Consequently, red mud is considered a hazardous by-product 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.

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 noncombustible 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 sulphate, reduction of initial hydration temperature, and hardened concrete strength. Table 1 shows the physical properties of fly ash in the present study.

Ramujee (2013) investigated the strength properties of Polypropylene Fibre Reinforced Concrete, examining compressive and splitting tensile strengths for different fibre percentages (0%, 0.5%, 1%, 1.5%, and 2%). Results favored the samples containing 1.5% Polypropylene fibres. Shwetha et al. (2015) employed fly ash as partial cement replacement along with glass fibres 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 Red mud, 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 fibres, 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 fibres, finding hybridized concrete to perform better. Red mud, 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 purposingred mud in concrete offers environmental benefits and addresses disposal issues. The objective of the present study is to bridge a research gap where-in use of sustainable waste materials such as red mud and fly ash along with polypropylene fibres produces a concrete mix that satisfies the requirements of many construction applications as a viable and sustainable mixture. In this regard an experimental study was conducted to optimize these admixtures in terms of properties such as slump, compressive strength, split tensile strength as well as flexural strength.

II. MATERIAL

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 1 shows the physical properties and chemical composition of ceent used in the present study

2. **Redmud And Fly Ash:** Redmud is an industrial waste produced by aluminium industries and Red mud is collected from “Hindalco Industries Limited, Belgaum, Karnataka”.

   Class F fly ash is a by-product 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 1 shows the physical properties and chemical composition of red mud used in the present study.

Table 1: Properties of cement, Red Mud and Fly Ash Used in the Present Study

<table>
<tr><th colspan="4">Physical Properties of Cement Used</th></tr>
<tr><th>Properties of Cement</th><th colspan="2">Test Results</th><th>Standard Values</th></tr>
<tr><td>Specific gravity</td><td colspan="2">3.15</td><td>2.9-3.16</td></tr>
<tr><td>Fineness</td><td colspan="2">10%</td><td>-</td></tr>
<tr><td>Normal consistency</td><td colspan="2">32 %</td><td>24%-32%</td></tr>
<tr><td>Initial setting time</td><td colspan="2">35 min</td><td>Not less than 30 min</td></tr>
<tr><th colspan="4">Chemical Composition of Cement and Red mud</th></tr>
<tr><th>Chemical composition</th><th colspan="2">Cement (%)</th><th>Red mud (%)</th></tr>
<tr><td>Cao</td><td colspan="2">63.6</td><td>35.3</td></tr>
<tr><td>SiO2</td><td colspan="2">19.49</td><td>18</td></tr>
<tr><td>Al2O3</td><td colspan="2">4.54</td><td>6.31</td></tr>
<tr><td>Fe2O3</td><td colspan="2">3.38</td><td>12.38</td></tr>
<tr><td>Na2O</td><td colspan="2">0.13</td><td>2.71</td></tr>
<tr><td>Mgo</td><td colspan="2">2.36</td><td>1.13</td></tr>
<tr><td>K2O</td><td colspan="2">0.58</td><td>0.45</td></tr>
<tr><th colspan="4">Physical Properties of Red mud and Fly ash Used</th></tr>
<tr><th>Properties Red mud</th><th>Test Result</th><th>Properties of Fly Ash</th><th>Test Result s</th></tr>
<tr><td>Specific Gravity</td><td>2.98</td><td>Specific gravity</td><td>2.52</td></tr>
<tr><td>Fineness(sq.cm/gm)</td><td>2600</td><td>Fineness</td><td>30%</td></tr>
<tr><td>PH</td><td>11.8</td><td>Normal consistency(%)</td><td>24%</td></tr>
<tr><td>-</td><td>-</td><td>Initial setting time(minutes)</td><td>30</td></tr>
</table>

3. **Fine Aggregate And Coarse Aggregate:** Locally available M-sand belonging to zone II of IS 383-1970 crushed aggregates (size<20mm) confirming to IS 383-1970 was used for the present study. Table 2 shows the various physical properties of both M-sand and Crushed aggregates.

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Table 2: Properties of Fine Aggregates

Properties	Fine aggregates		Coarse aggregates	
	Test Results	**Standard Values**	**Test Results**	**Standard Values**
Specific gravity	2.65	2.4-2.9	2.63	2.6-2.8
Absorption of water(%)	1.0	-	0.4	0.1- 2.0
Sieve analysis	Confirms to Zone II	-	-	-
Impact test(%)	-	-	18.64	Not more than 30

4. **Polypropylene Fiber:** Polypropylene fibre, often referred to as polypropylene or PP, constitutes a synthetic fibre 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 fibre. Boasting thermoplastic qualities, resilience, lightweight characteristics, and resistance to mildew and numerous chemicals, polypropylene fibre stands out as a durable choice for diverse applications. Table 3 shows the properties of polypropylene used in the present study

Table 3: Properties of Polypropylene Fibres

Properties	**Test Results**
Density (kg/m^3)	900
Length (mm)	12
Diameter (Micron)	34
Tensile Strength (MPa)	1750
Specific Gravity (Kg/m3)	2.68

5. **Concrete Mix Proportion:** The mix design for the proposed study were done as per guidelines of IS 10262 (2009) and accordingly the proportion of materials and ratios incorporated are as below:
Cement = 329 Kg/ m^3
Water = 148 Lt/ m^3
Fine aggregate = 845 Kg/ m^3
Coarse aggregate = 1106.4 Kg/m^3
Chemical admixture = 6.58 Kg/m^3
w/c ratio = 0.45
Mix Ratio = 1: 2.57: 3.36

III. RESULTS AND DISCUSSIONS

1. Slump Test Results

- **Slump Test for Polypropylene Fiber Reinforced Concrete (PPFRC):** A slump test was performed for polypropylene fibre reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibres at different percentages from 0.5% to 2.0% in 0.5% intervals. Slump test results of PPFRC are tabulated in Fig. 1. It can be seen that as percentage of polypropylene fibres increases, the slump value decreases. This is due to the fact that distribution of fibres into concrete matrix induces better cohesive mix causing a reduction in slump of concrete mix. Based on the test results a slump value of 84 mm obtained with PPF percentage of 1.5% is considered as optimum for the concrete mix used in the present study.

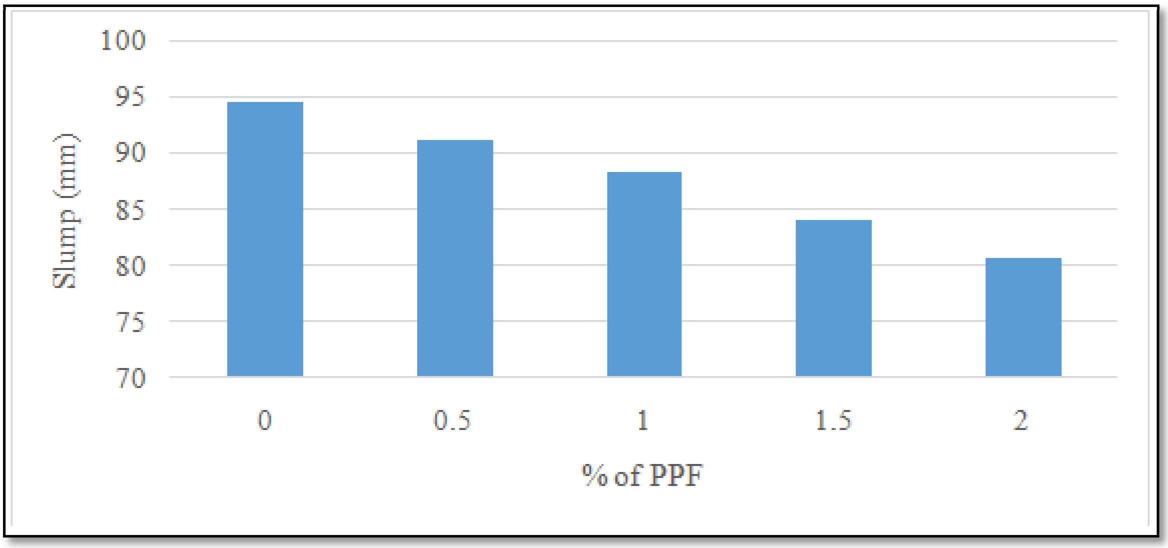

Figure 1: Variation of Slump for PPFRC

- **Slump Test Results for Redmud PPFRC:** Variation of Slump for red mud mixed polypropylene fibre reinforced concrete was also conducted to assess the pozzolanic action of addition of red mud into concrete matrix. The concrete mix is prepared by replacing cement with red mud at different percentages from 5% to 20% in 5% intervals and 20% fly ash is used as a replacement for cement. Optimum percentage of polypropylene fibre 1.5% is also added. Variation of Slump for the PPFRC along with red mud is as shown in Fig.2. The trend in results clearly indicate that the addition of red mud along with replacement of cement with 20% fly ash reduces slump due to the induction of pozzolonic cementation of addition of sustainable admixtures used in the present study. The trend in results confirms the trend obtained by several investigators earlier.

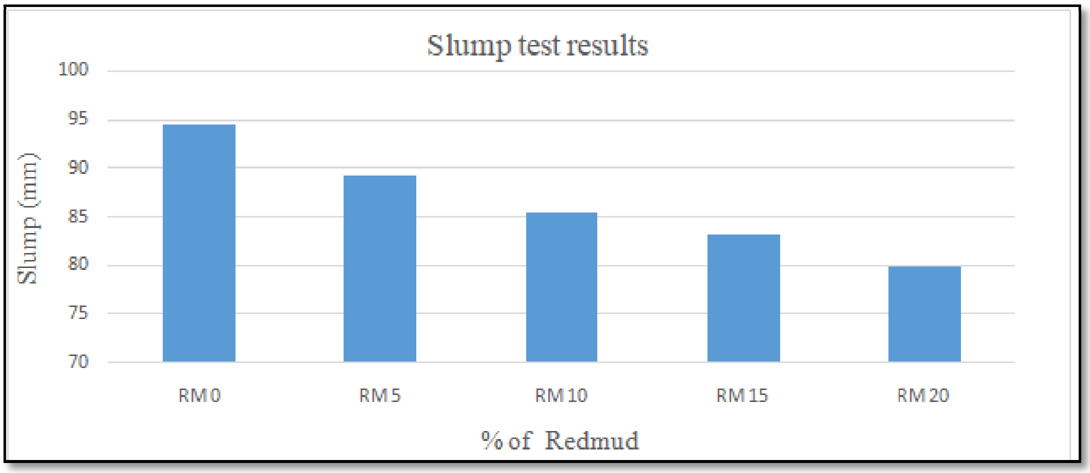

Figure 2: Variation of Slump for Red mud PPFRC

2. Compressive Strength Test Results

- **Compressive Strength Test for PPFRC:** Compressive strength test was conducted for polypropylene fibre reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibres 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. Variation of compressive strength of PPFRC is as shown in Fig 3. The compressive strength for polypropylene fibre reinforced concrete increased up to 1.5% polypropylene fibre addition, beyond which addition of 2% polypropylene fibre caused reduction in compressive strength. This is due to the fact that, addition of higher percentage of fibres causes a reduction in workability of concrete as evidenced also by slump variation leading to reduction in cohesiveness of concrete matrix. The trend in results also confirms the trend observed by earlier studies. Based on the variation of compressive strength, it was concluded that a percentage of 1.5% PPFRC can be considered as optimum.

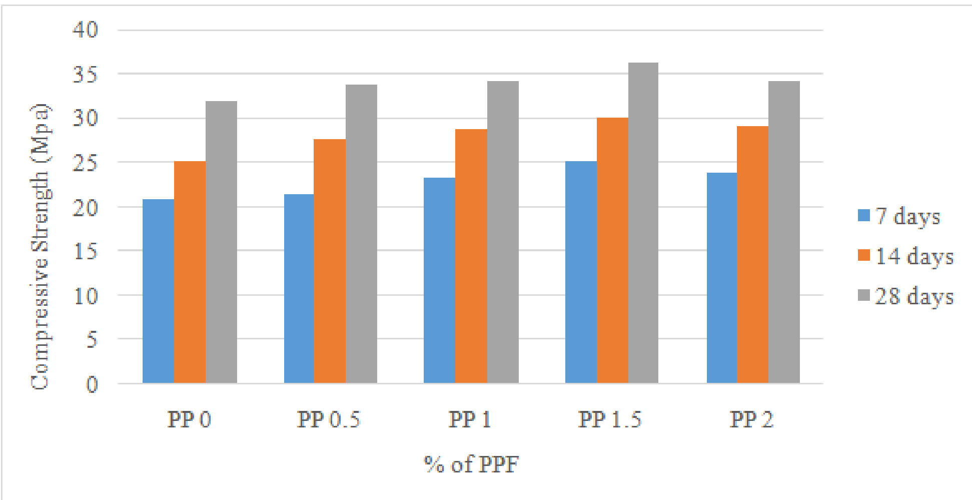

Figure 3: Variation of Compressive Strength of PPFRC

- **Compressive Strength Test for Redmud PPFRC:** Variation of compressive strength for red mud polypropylene fibre reinforced concrete was also verified. The concrete mix is prepared by replacing cement with red mud at different percentages from 5% to 20% in 5% intervals and fly ash is also replaced for cement in 20%. Optimum percentage of polypropylene fibre 1.5% is also added. Compressive strength tests were carried out on various curing durations, and the obtained values were juxtaposed with those of conventional concrete. Fig 4 shows variation of compressive strength obtained for the concrete matrix. It can be seen that the compressive strength for red mud PPFRC are increased up to 15% replacement of cement by red mud and beyond 15%, the compressive strength decreases. The 15% replacement of red mud 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. Based on the present study, it can be concluded that the maximum compressive strength was achieved with 15% red mud replacement, 20% fly ash replacement and 1.5% of polypropylene fibre addition.

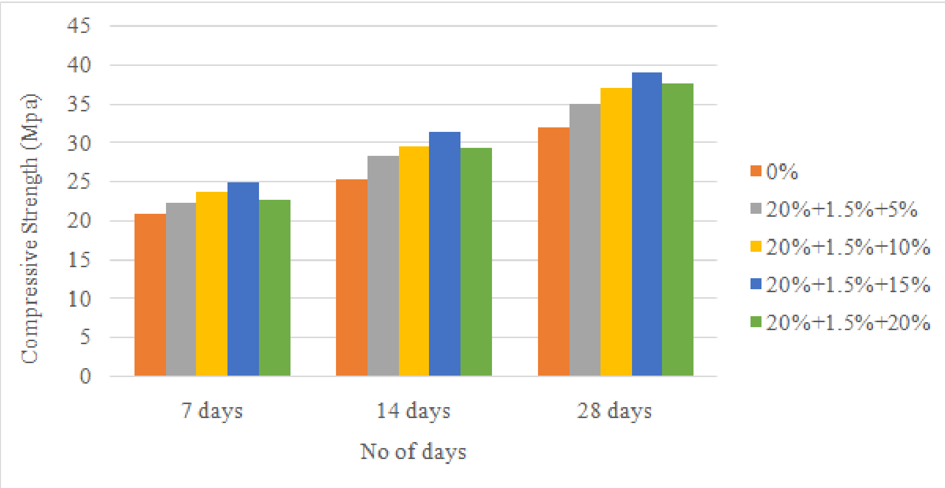

Figure 4: Compressive strength of REDMUD PPFRC

3. Split Tensile Strength Test Results

- **Split Tensile Strength Test for PPFRC:** In order to assess the improvement in ductility of concrete matrix due to the addition of PPFRC fibres. Split tensile strength was conducted for polypropylene fibre reinforced concrete (PPFRC). The concrete mix is prepared by adding polypropylene fibres at different percentages from 0.5% to 2.0% in 0.5% intervals. The split tensile strength tests were conducted on different curing periods of curing and results are compared with conventional concrete. The Split tensile strength of PPFRC are tabulated in Fig. 5. The split tensile strength characteristics of polypropylene fibre reinforced concrete exhibit a pattern, in which, values show a steady increase up to the point of addition of 1.5% polypropylene fibre. Beyond this threshold, with a 2% addition of polypropylene fibre, there is an observable decline in split tensile strength, indicating the importance of precise fibre content in optimizing this property. The trend has similar pattern at all curing periods.

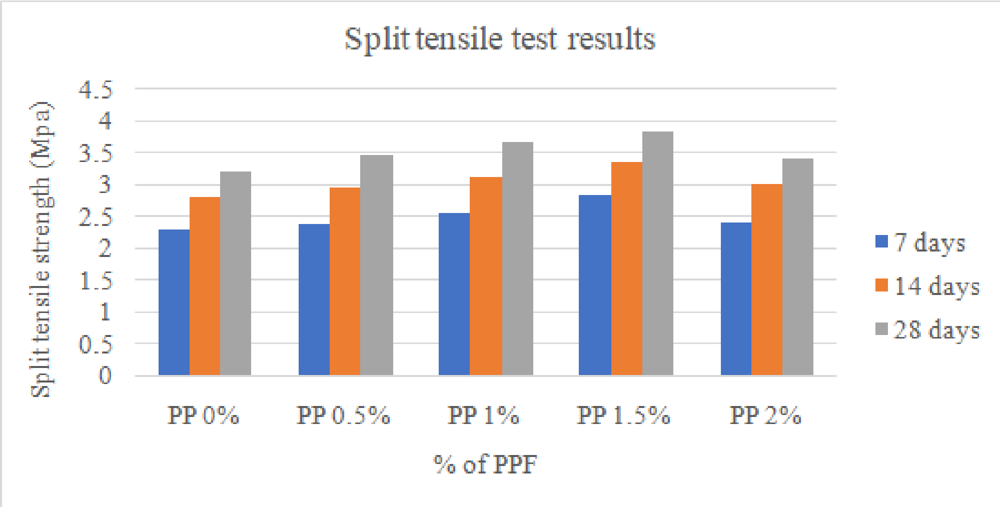

Figure 5: Variation of Split Tensile Strength of PPFRC

- **Split Tensile Strength Test For Redmud PPFRC:** Similar to the above case, split tensile strength was assessed for red mud polypropylene fibre reinforced concrete. The concrete mix is prepared by replacing cement with red mud at different percentages from 5% to 20% in 5% intervals and fly ash is also replaced for cement in 20%. Optimum percentage of polypropylene fibre 1.5% from table 7.5 is also added. The split tensile strength test is conducted on 7, 14 and 28 days of curing and compared with conventional concrete. The results are tabulated in Fig. 6. It can be seen that there is a similar trend is observed for red mud-infused Polypropylene Fibre Reinforced Concrete (PPFRC), with split tensile strength values experiencing growth up to a 15% replacement of cement by red mud. Beyond this percentage, split tensile strength begins to decline. Specifically, with a 15% replacement of red mud, there is a substantial 17.98% higher split tensile strength compared to conventional concrete after 7 days. This effect persists with an 18.96% increase after 14 days and a significant 17.85% higher split tensile strength after 28 days, highlighting the potential of red mud as a supplementary material for enhancing split tensile strength.

  The maximum split tensile strength is achieved through a carefully balanced combination of materials. The optimal mix entails a 15% red mud replacement, a 20% fly ash replacement, and the addition of 1.5% polypropylene fibre, resulting in the maximum split tensile strength for the concrete mixture.

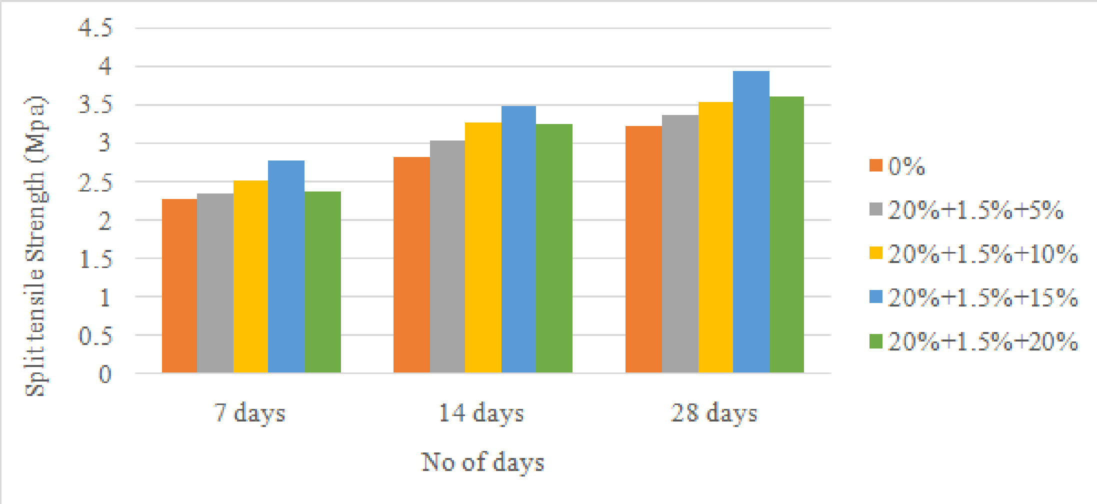

Figure 6: Variation of Split Tensile Strength of Red mud PPFRC

4. Flexural Strength Test Results

- **Flexural Strength Test for PPFRC:** Flexural strength of concrete mix is prepared by adding polypropylene fibres at different percentages from 0.5% to 2.0% in 0.5% intervals was also measured. 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. The addition of polypropylene fibres into reinforced concrete has a notable impact on flexural strength. It demonstrates a consistent increase in flexural strength, reaching its peak at a 1.5% addition of polypropylene fibre. However, beyond this point, as the addition of polypropylene fibre rises to 2%, there is a diminishing effect on flexural strength.

  Remarkably, the enhancement in flexural strength with the introduction of 1.5% polypropylene fibre is noteworthy. After 7 days, there is a remarkable 23.8% increase in flexural strength compared to conventional concrete. This trend continues with a 20.58% increase after 14 days and a 17.31% boost after 28 days, showcasing the lasting impact of this fibre on the concrete's flexural strength.

Table 4: Variation of 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

- **Flexural Strength Test For Redmud PPFRC:** Similarly, the flexural strength test was assessed for red mud polypropylene fibre reinforced concrete. The concrete mix is prepared by replacing cement with red mud at different percentages from 5% to 20% in 5% intervals and fly ash is also replaced for cement in 20%. Optimum percentage of polypropylene fibre 1.5% from table 7.7 is also added. The flexural strength test is conducted on 7, 14 and 28 days of curing and compared with conventional concrete. The results are tabulated in Table 5. There is a distinct trend in flexural strength for red mud-infused Polypropylene Fibre Reinforced Concrete (PPFRC), It exhibits a substantial rise in flexural strength up to a 15% replacement of cement by red mud, after which flexural strength begins to decrease. Specifically, with a 15% replacement of red mud, there is a remarkable 21.15% increase in flexural strength compared to conventional concrete after 7 days. This effect persists with a 19.4% increase after 14 days and a notable 15.85% boost after 28 days, highlighting the potential of red mud as a supplementary material in enhancing flexural strength. The maximum flexural strength is achieved through a carefully balanced combination of materials. The optimal mix involves a 15% red mud replacement, a 20% fly ash replacement, and a 1.5% addition of polypropylene fibre, resulting in the maximum flexural strength for the concrete mix.

Table 5: Variation of Flexural Strength for Red Mud 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

IV. CONCLUSIONS

Based on the present experimental study using red mud and fly ash incorporated into concrete as partial substitutes for cement, alongside the induction of polypropylene fibres, the following conclusions are drawn:

1. The workability of concrete decreases with an increasing percentage of red mud.as well as polypropylene fibres.

2. Compressive strength in Polypropylene Fibre Reinforced Concrete (PPFRC) reaches its peak at a 1.5% addition of polypropylene fibres and hence can be considered as optimum.

3. Split tensile strength and flexural strength in PPFRC also exhibit maximum performance at a 1.5% addition of polypropylene fibres. The ideal percentage of polypropylene fibres in concrete is 1.5% of the total weight.

4. Compressive strength in red mud polypropylene fibre reinforced concrete is highest at a 15% replacement of cement with red mud and 20% utilization of fly ash as a cementitious material, combined with 1.5% polypropylene fibres. Similarly, split tensile strength and flexural strength in red mud polypropylene fibre reinforced concrete achieve their maximum potential under the same conditions.

5. The optimal replacement percentage for red mud in concrete is 15%. In total, 35% of cement is substituted by red mud and fly ash (20% + 15%). The utilization of red mud and fly ash, both industrial waste materials, in construction helps reduce cement production and mitigates the challenges of waste disposal, thereby minimizing environmental pollution and proving to be cost-effective.

REFERENCES

[1] Kolli.Ramujee (2013), "Strength Properties Of PolypropyleneFiber Reinforced Concrete". International Journal of Innovative Research in Science,Engineering and Technology(ISO 3297: 2007 Certified Organization)Vol. 2, Issue 8, August 2013.
[2] Shwetha P C , Praveena K , Ajith B.T ,Chandrashekhar A (2015),"Experimental Study on Partial Replacement of cement by Fly Ash with Glass Fibre Reinforcement".International Journal of Engineering Research & Technology (IJERT)ISSN: 2278-0181IJERTV4IS050988 Vol. 4 Issue 05, May-2015.
[3] Vinit Kumar Singh, Vikas Srivastava, V.C Agarwal, Alvin Harison (2015), " Effect of Fly Ash as Partial Replacement of Cement in PPC Concrete ". International Journal of Innovative Research in Science, Engineering and Technology. Vol. 4, Issue 7, July 2015.
[4] Prof. Mahadeva M, Dr. D L Venkatesh Babu, Sharmila H C,(2017), "Soil Stabilization using RiceHusk",6th international conference on emerging trends in engineering,technology,science and management(ICETETSM-17),ISBN978-93-86171-70-2.
[5] Sabarish K.V., R. Venkat Raman, R. Ancil, R. Wasim Raja, P. Selva Surendar (2017)"Experimental Studies on Partial Replacement of Cement with Fly Ash in Concrete Elements" International Journal of Civil Engineering and Technology (IJCIET),Volume 8, Issue 9, pp. 293–298.
[6] Khuito Murumi and Supratic Gupta(2019) "Experimental Investigation on Viable Limit of Fly Ash Utilization in Concrete" Jordan Journal of Civil Engineering, Volume 13, No. 2, pp. 235-249
[7] Mahadeva M, M T Prathap Kumar, Lohith N R, Hrithik J, Sachin and Siriwanth Kumar, (2020), "Retrofitting of RC Beams Using Coir Textile Reinforced Mortar", Journal of Ceramics and Concrete Sciences, -ISSN: 2582-1938, Volume-5, Issue-1, http://doi.org/10.5281/zenodo.3750611
[8] Rajiv T, Mahadeva M., Avinash M. S, Manjula S. Bai (2020), "Performance of Copper Slag on Strength Properties as Partial Replacement of Natural River Sand in Self-Compacting Concrete" Journal of Construction and Building Materials Engineering, ISSN: 2581-6454,Volume-6, Issue-1,http://doi.org/10.5281/zenodo.3687532.
[9] Rudraswamy M P, Dr. B.R Patagundi, and Dr. K.B Prakash(2020) "An Investigation on The Shrinkage Characteristics of Hybrid Fibre Reinforced Concrete Produced by Using Fibres Of Different Aspect Ratio" International Journal of Advanced research in engineering and technology, Vol-11, Issue 3, pp. 19-28.