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Proceeding Paper

The Behavior of Pre-Treated Crumb Rubber and Polypropylene-Fiber-Incorporated Mortar Subjected to Elevated Temperatures †

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Abstract: Rubber is a waste product produced by the industrial sector in large quantities. Due to its non-degradable nature, it has been a serious threat to the environment. Thus, it is recommended to develop concrete or mortar containing rubber, so that it can save our environment, and it is economical too. Crumb rubber, when incorporated in mortar, reduces its strength, so it can be used along with some fibers to enhance its strength. This study examined the effect of elevated temperatures, i.e., 150, 300, 450, 600, and 750 °C, on mortar samples containing 5% crumb rubber replacement of fine aggregate by volume, and with the incorporation of 1% PPF. The findings indicated a rise in compressive strength up to 300 °C, followed by a subsequent decline. It was also observed that the weight loss of the samples increased with an increase in temperature.

Keywords: muffle furnace; polypropylene fibers (PP fibers); compressive strength; elevated temperature

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1. Introduction

Advancements in infrastructure have led to increased waste production from demolished structures and increasing population, including plastic and rubber tires [1]. These materials persist in the environment, causing environmental issues [2]. Tire reclamation is a major problem, with stockpiled scrap rubber tires posing fire hazards and potential breeding grounds for pests [3]. Alternative uses include fueling cement production, producing carbon-black in asphalt, or aggregates in cementitious composites. Replacing natural aggregates in cementitious composites with waste rubber tires could prevent environmental pollution and make it economically feasible [1]. However, CR's hydrophobic nature and surface sleekness cause weak matrix bonding [4–6]. Pre-treatment chemicals like lime, NaOH, and detergents can resolve this issue [7].

Researchers have studied cementitious materials incorporating recycled rubber tires (RRA) at elevated temperatures, finding reduced compressive and tensile strength. However, rubberized concrete remained strong at 200 °C and 400 °C [8–10]. Polypropylene fibers improve cement matrix mechanical traits after fire and exposure to extreme temperatures. They enhance the flexural strength and crack resistance but have a lower flexural strength and crack resistance than regular mortar [11–13].

There are no studies currently available that incorporate both crumb rubber and polypropylene fibers subjected to elevated temperatures. In this study, the behavior of pre-treated crumb rubber and PP-fiber-incorporated mortar subjected to elevated temperatures is assessed. Various proportions of crumb rubber have been employed as a replacement for fine aggregate and PP fibers are introduced in addition to the mortar. The main objective of this study is to use different pre-treatment methods and to find the optimum percentages.

The optimum PPFs are also checked. The collective effect of both optimal conditions is examined on the mechanical properties of the mortar specimens.

2. Research Methodology

Specimens underwent a 28-day curing period at room temperature and were tested for resistance to elevated temperatures (150 °C, 300 °C, 450 °C, 600 °C, and 750 °C) as shown in Figure 1. Samples were placed in a muffle furnace after 28 days of curing. The temperature increased at a rate of 5 °C/min and remained at the desired temperature for 30 min. The furnace then cooled down naturally.

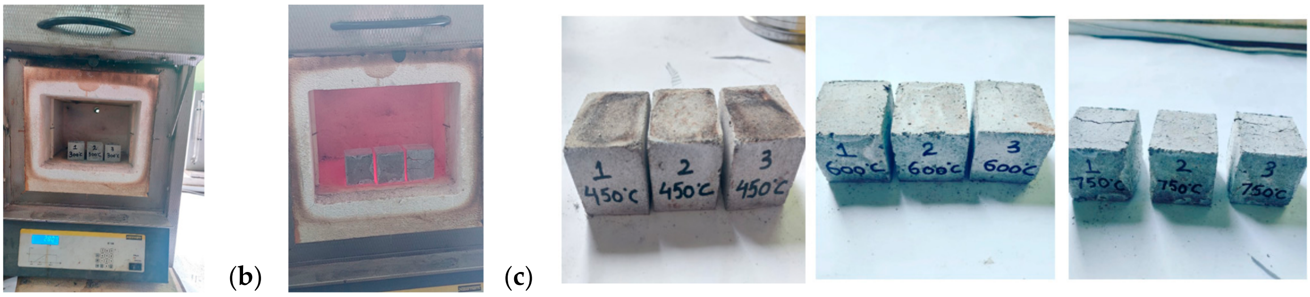
(a) (b) (c)


Figure 1. (**a**) Samples placed in a muffle furnace, (**b**) samples after heating at excessive temperature, and (**c**) samples after being taken out from the muffle furnace.

Mix Design

This study employed a mix design of 1:2.75 (cement to aggregate ratio) as per ASTM C39 shown in Table 1. Cubes with dimensions of 50 mm × 50 mm × 50 mm were prepared for the samples. To enhance compressive strength, 5% lime-treated crumb rubber replacement and 1% PP fibers were added. Crumb rubber replacement was performed by volume, and the optimum concentration of treated lime with PP fibers is referred to as PPFL.

Table 1. Mix design for the PPFL samples.

Samples	Mix Ratio	Cement (g)	Sand (g)	W/C ratio	Water (g)	CR (mL)	PPF (g)
PPFL (Compression)	1:2.75	500	1306.25	0.48	240	50	7.158

3. Experimental Procedures

3.1. Treatment of CR with Lime, NaOH, and Water

Crumb rubber underwent pre-treatments to enhance its mechanical properties. For lime treatment, a 10% lime solution was used, and the crumb rubber was immersed in it for 24 h. It was then washed and sun-dried. NaOH treatment involved dipping the crumb rubber in a 10% NaOH solution for 24 h, followed by washing and sun-drying. Water treatment included boiling the crumb rubber for 24 h, after which it was dried.

3.2. Polypropylene Fibers (PP Fibers)

PP fibers were added to balance out the reduction in mechanical properties, and the inclusion of PP fibers increased the strength.

3.3. Compressive Strength and Weight Loss

To calculate the weight loss, the initial weight of the samples was recorded after a 28-day curing period. The final weight was measured after subjecting the samples to elevated temperatures and collecting them from the oven. The formula for weight loss is

$$Weight\ loss = \frac{initial\ wt. - final\ wt.}{initial\ wt.} \times 100 \quad (1)$$

4. Results

Weight Loss and Compressive Strength

Table 2 illustrates that weight loss increases with higher muffle furnace temperatures, indicating sample crack development and disintegration. The highest weight loss of 8.97% is observed at 750 °C, while the lowest is 1.087% at 150 °C. Initially, the compressive strength is lower at 150 °C, increases at 300 °C due to melted crumb rubber releasing hydrostatic pressure, and then decreases again. This study's maximum compressive strength is 25.597 MPa at 300 °C, while the minimum is 5.64 MPa at 750 °C.

Table 2. Weight loss and compressive strength of mortar samples at elevated temperature.

Sample No	Muffle Furnace Temp	Weight before Elevated Temp	Weight after Elevated Temp	Compression Test	Weight Loss (%)
1	150 °C	269.93 g	266.99 g	20.56 MPa	1.08%
2	150 °C	271.69 g	268.69 g	19.78 MPa	1.10%
3	150 °C	277.15 g	274.14 g	21.08 MPa	1.08%
1	300 °C	279.58 g	264.64 g	24 MPa	5.34%
2	300 °C	276.78 g	262.45 g	25.87 MPa	5.18%
3	300 °C	274.03 g	259.54 g	26.92 MPa	5.28%
1	450 °C	269.2 g	252.69 g	16.52 MPa	6.13%
2	450 °C	277 g	258.95 g	17.56 MPa	6.51%
3	450 °C	279 g	261.16 g	18.36 MPa	6.39%
1	600 °C	276 g	252.18 g	13.16 MPa	8.63%
2	600 °C	279.76 g	255.19 g	13.32 MPa	8.78%
3	600 °C	278.95 g	254.46 g	12.28 MPa	8.77%
1	750 °C	275.93 g	259.81 g	5.6 MPa	7.84%
2	750 °C	276.68 g	250.28 g	4.12 MPa	9.54%
3	750 °C	277.62 g	251.17 g	7.2 MPa	9.53%

Figure 2a indicates the behavior of compressive strength over temperature. From 150 °C to 300 °C, the compressive strength increases, but after increasing the temperature further, it decreases gradually. This shows that the compressive strength is ideal at 300 °C. Figure 2b shows that in the initial stage of increasing temperature, there is a sharp increase in weight loss, but further temperature increases have a small impact on weight loss. By increasing the temperature from 150 °C to 300 °C, the weight loss rises to 5%, but a further increase of 150 °C causes a 1–2% weight loss.

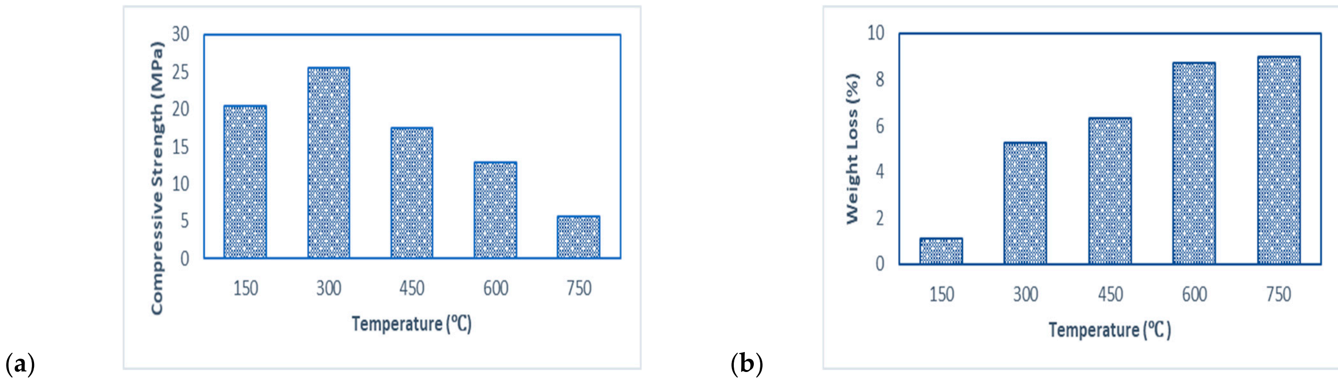


Figure 2. (**a**) Compressive strength values at elevated temperature. (**b**) Weight loss at elevated temperature.

5. Conclusions

This study concludes that

- Among the four treatments, lime treatment was found to be most effective, while water treatment yielded the worst results.
- The optimum percentage of crumb rubber replacement was found to be 5%, while the optimal PPF addition percentage was 1%.
- Rubberized-polypropylene-fiber-reinforced mortar can be exposed to temperatures up to 300 °C because, after this temperature, the compressive strength started decreasing.
- Initially, the strength increased from 150 to 300 °C. This may be due to the melting of CR, which may act as a paste. Also, with increasing temperature, hydrostatic pressure is generated, which acts against the load.
- The higher the temperature to which the sample is exposed, the greater the weight loss.
- The substitution of sand with CR had a significant impact on compressive strength, with a decrease observed as the proportion of CR increased. The results obtained in this study conclude that rubberized-polypropylene-fiber-reinforced mortar can be used in false facades, interior construction, road barriers, sideways, crash barriers around bridges, etc.

6. Recommendations

This study is inadequate to comprehend the actions of rubber-based cement composites and fiber-infused cementitious composites at high temperatures in a systematic manner. Further investigation is required to examine the mechanism and impact of the two additional fibers in the process.

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