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Manufacturing and Characterization of Recycled Plaster of Paris from Waste Industrial Molds: Comparison of the Physical and Mechanical Properties with Pure Plaster of Paris at Distinct Drying Temperatures.

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Abstract

This research aimed to investigate the manufacturing and characterization of recycled Plaster of Paris (POP) from waste industrial mold. Plaster of Paris is one of the main raw materials and the main source of gypsum in many ceramic industries. Every year, ceramic industries release a large amount of waste, which is concerning for the environment. The manufacturing process involved the collection and processing of waste industrial mold in a cost-effective way. In this research, we aimed to identify the physical and mechanical properties of recycled POP compared to pure POP. The experiment started with collecting the waste mold, crushing, sieving, and drying at elevated temperatures (50°C, 70°C, 90°C, 110°C, and 130°C). We prepared two types of batches (70% of material with 30% water and 50% of material with 50% water) by mixing them and finding out the density, water absorption, compressive strength, flexural strength, and impact strength. The result showed that all samples of recycled Plaster of Paris at distinct drying temperatures almost had a similar performance rate to pure Plaster of Paris.

Keywords: Recycled Plaster of Paris, Waste Industrial Mold, Distinct Temperature, Mechanical Properties, Physical Properties.

1. Introduction

Plaster of Paris (POP) is a chemical substance referred to as gypsum plaster. The chemical name of POP is calcium sulfate hemihydrates ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$). POP is found in white color and is generally used for mold making, sculpting materials, and gauze bandages [1]. In the ancient era, this chemical was extensively mined from Montmartre in Paris district; that's why it's called Plaster of Paris [2].

In Bangladesh, POP is mainly used for making tableware and sanitaryware molds in ceramic industries like BISEF, Charu Ceramic Industry, DBL Ceramic Industry, AKIJ Ceramic, Paragon Ceramic, and RAK Ceramic Industry. This POP is also used for manufacturing cement in different ceramic industries. After using the POP mold, they are mainly disposed of as waste materials. There is no natural source of POP in Bangladesh. Every year, all the ceramic industries import POP from different countries. According to the Volza Grow Global (updated June 13, 2024) export report, Bangladesh imports a huge amount of Plaster of Paris from India in around 60000 quantities [3]. Also, Bangladesh imports huge amounts of Plaster of Paris from Thailand, South Korea, and China. There are approximately 177 Bangladesh importers from 115 suppliers in this country. Around 1668 shipment data entries were obtained from Volza Grow Global (updated June 13, 2024) [4]. Above this report, Bangladeshi ceramic industries spend huge amounts of money on importing Plaster of Paris.

Recycling Plaster of Paris is the proper way to reduce the import cost. Recycling is the process of collecting waste, or trash mold from dustbins to be reused as a new product. The first step of recycling is collection and processing. In the initial process, pieces of waste mold will be ground and crushed through a hammer or ball mill to get fine-grain powder. Then the powder dried at 150 °C for 1 hour in an oven or furnace [5]. Also, the water can be reduced from the waste mold by drying under sunlight and crushing the mold through a hammer, and finally sieving using 0.297 mm, then drying the powder in an oven at 150 °C for 1 hour [6].

In this research, The Plaster of Paris was recycled at a laboratory scale. The waste mold was collected from industries and crushed with a hammer. After sieving, a fine-grained powder was obtained. Finally, the powder was dried at elevated temperatures to find out the most suitable condition for recycling the Plaster of Paris from waste industrial mold.

2. Materials and Methods

2.1. Recycling Process of Plaster of Paris

This process required crushing the waste mold into fine-grained powder because of the new Plaster of Paris (NPOP) found in powder form. Waste mold was collected from ceramic industries and crushed with a hammer. A 1.25 mm mesh sieve was used to separate the fine-grained powder. The fine-grained powder was dried in an oven for 6.5 hours at 50°C, 5 hours at 70°C, 4 hours at 90°C, 3.5 hours at 110°C, and 2.5 hours at 130°C to reduce its moisture content. The drying period depended on the drying temperature and how long it took for the Recycle Plaster of Paris (RPOP) to set properly after 24 hours. **Fig. 1** shows the process of RPOP.

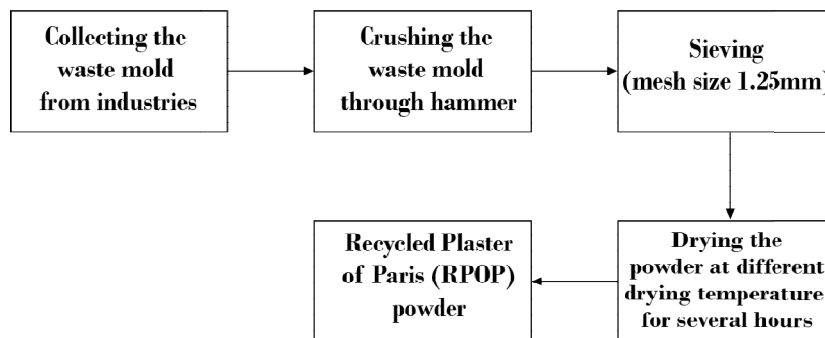


Fig. 1. Process of Recycled Plaster of Paris (RPOP)

2.2. Sample Preparation

Two types of batches (70% of material with 30% water and 50% of material with 50% water) were prepared by mixing them with water properly to achieve a hardened structure. The mixing process involved the continuous stirring of the Plaster of Paris (POP) and water using a mixing stick or spatula until a smooth, lump-free consistency was achieved, ensuring no dry spots remained. Firstly, the batches of New Plaster of Paris were prepared. The NPOP powder was poured into a container, and mixed with the water to equally spread across the water's surface. The prepared slurry was poured into foam dice. Also, a similar process was followed for RPOP powder, which had been dried at distinct drying temperatures (50°C, 70°C, 90°C, 110°C, and 130°C). To obtain accurate results, we tried to maintain almost equal length, width, and thickness for all the samples. In the research, six types of samples were prepared, as shown in **Fig. 2**.

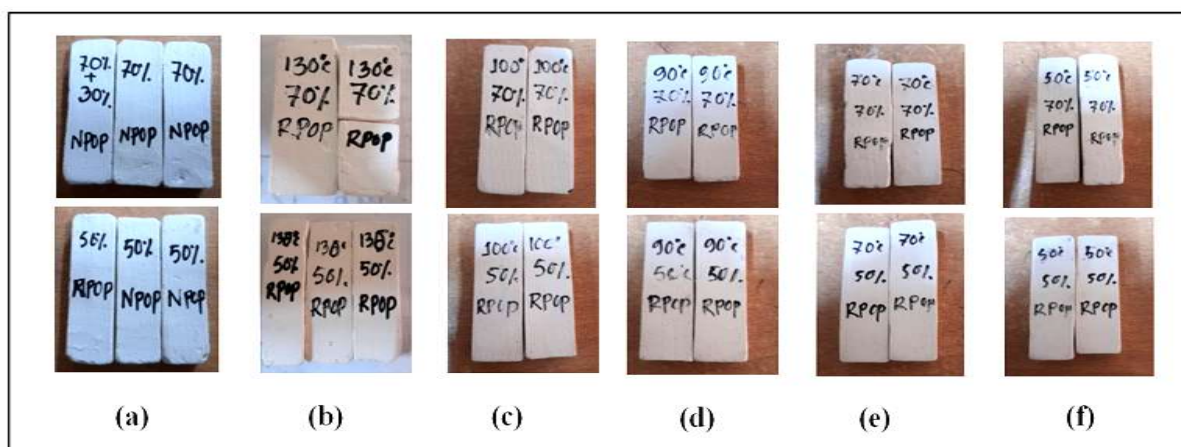


Fig. 2. (a) NPOP, (b) RPOP at 130°C, (c) RPOP at 110°C, (d) RPOP at 90°C, (e) RPOP at 70°C, and (f) RPOP at 50°C

2.3. Characterization

In this research, the density was measured using the Archimedes method. A measuring balance (Type: EJ-323A) with a specific density measurement setup was used for this experiment. Throughout the process, the mass of the sample was measured in air and water (temperature: 4 °C) with a measuring accuracy of ± 0.1 mg [7]. Fig. 3 shows the schematic principle of measuring density. The density of the sample was measured under consideration of the following equation (1):

$$\rho_s = \frac{m_a}{m_a - m_w} \times \rho_w \quad (1)$$

Where, ρ_s is the density of the sample, m_a is the mass in air, m_w is the mass in water, ρ_w is the density of water (1gcm^{-3}).



Fig. 3. Archimedes Method for measuring mass in air and water.

The BS 7263 method was used to measure the water absorption due to its shorter duration [8]. Dry NPOP and RPOP samples of specific dimensions and known weights were dipped into water at room temperature. After 12 hours, the samples were removed from the water, and the weight of the wet sample was measured [9]. The water absorption (W) of the sample was measured by following equation (2):

$$w = \frac{w_w - w_d}{w_d} \quad (2)$$

Where, W_w is the weight of wet sample, W_d is the weight of dry sample.

The value of water absorption is expressed as a percentage of the dry weight of the sample [9].

A manual compressive testing machine was used for this test, with a capacity of 200 kN. During the test, each sample was placed between the upper and lower jaws, and the force was applied until it was broke. The twelve samples (rectangular shape) were tested, and the result was given by the following equation (3):

$$\sigma_{cs} = \frac{F}{A} \quad (3)$$

Where, σ_{cs} is the compressive strength of sample (Nmm^{-2}), F is the applied force (N), A is cross sectional area (mm^2) [10].

Three point bending method was used to determine the flexural strength of the sample. Sample was placed above the support beam and a cross head was conducted in air at room temperature using a universal testing machine according to IS 2333:1992 [11]. The flexural strength was calculated using the following equation (4):

$$\sigma_f = \frac{3FL}{bd^2} \quad (4)$$

Where, σ_f is the flexural strength of sample, F is the applied force (N), l is the length of support beam (mm), b is the width of sample (mm), d is the thickness of sample (mm).

Impact test was done according to the ASTM C368-88(1999) procedure [12] and the impact strength was calculated under consideration of the following equation (5):

$$I_s = \frac{12i}{t} \quad (5)$$

Where, I_s is the impact strength of the sample (psi), i is the average impact to produce initial failure (ft.lbf), t is the average thickness of sample at point of impact (inch).

3. Result and Discussion

3.1. Density

Fig. 4 presents the result of density at different drying temperatures. As the temperature increases, the volume of the substance will increase, leading to a reduction in density of the substance. For both batches, density decreases with increasing temperature [13]. In Fig. 4(a), at 130°C, the density (1.57 gcm^{-3}) is nearly the same as the NPOP density (1.58 gcm^{-3}). Moreover, in Fig. 4(b), at 130°C, the density (1.47 gcm^{-3}) is nearly the same as the NPOP density (1.48 gcm^{-3}). Up to expectation, 130°C is the optimum temperature for recycling the Plaster of Paris powder. Due to the water content, the density in Fig. 4(a) is higher than in Fig. 4(b). As the moisture content increases, it exhibits a larger pore size, resulting in a lower density [14], [15]. As a result, the variation is shown between the two batches.

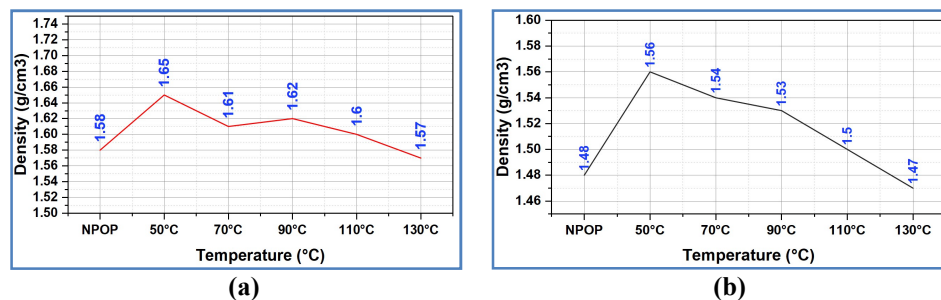


Fig. 4. Density at different drying temperatures (a) 70:30 Batch (b) 50:50 Batch

3.2. Water Absorption

All the samples were dried at 60 °C for 3 hours before the water absorption test to remove the residual moisture from the sample. As shown in Fig. 5, the percentage of water absorption decreases with increasing temperature for both batches. Due to the high volume of water, the bond between the particles will decrease, and the fraction of voids will increase [16]. For Fig. 5(a), less amount of water only 30% was used. It shows a lower water absorption value than in Fig. 5(b), where 50% of water is used. The hardness of Plaster of Paris depends on the quantity of water used [10]. Due to the lower use of water in 70% of the material with a 30% water batch, a more stable structure was achieved than in 50% of the material with a 50% water batch.

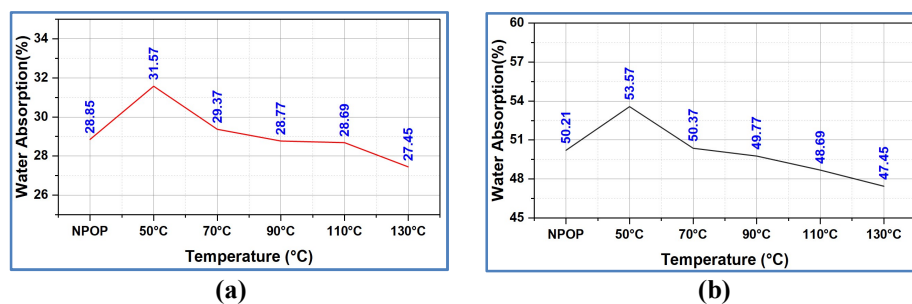


Fig. 5. Percentage of water absorption (a) 70:30 Batch (b) 50:50 Batch

3.3. Compressive Strength

Fig. 6 shows the result of compressive strength for both batches. As the temperature increases, the compressive strength will decrease. For both batches, the highest compressive strength was obtained at the optimum temperature of 90 °C because of optimum crystallization. Depending on the temperature, Plaster of Paris shows hemihydrates activity, varied dehydration characteristics, and physical properties [16], [17]. Fig. 6(a) shows that all the samples have the highest compressive strength than Fig. 6(b) because of the volume of water. When the volume of water increases, the bond between the particles decreases and shows a lower compressive strength [10]. From Fig. 6(a), at 130 °C, almost similar compressive strength (6.94 MPa) was obtained to NPOP (6.89 MPa). Also for Fig. 6(b), at 130 °C, almost similar compressive strength (4.85 MPa) was obtained to NPOP (4.82 MPa).

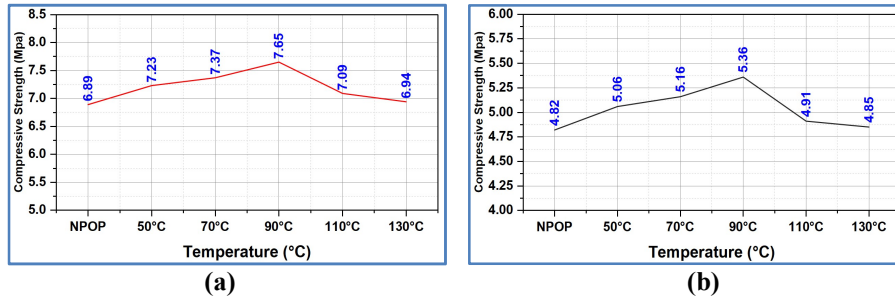


Fig. 6. Compressive Strength at different drying temperatures (a) 70:30 Batch (b) 50: 50 Batch

3.4. Flexural Strength

According to Fig. 7, the flexural strength at a drying temperature of 130 °C has the highest value at 21.7 psi for a ratio of 70:30 batch and 18.44 psi for a ratio of 50:50 batch. Also, both of Fig.7 show that the flexural strength increases with increasing temperature due to proper crystallization. For both batches, almost a similar value was obtained at 130 °C to NPOP. But the batch with a ratio of 70:30 shows better flexural strength than the batch with a ratio of 50:50 due to the high water content. As the water content increases, the bonding between the particles will decrease, reducing the flexural strength, which also shows in compressive strength analysis [10], [18].

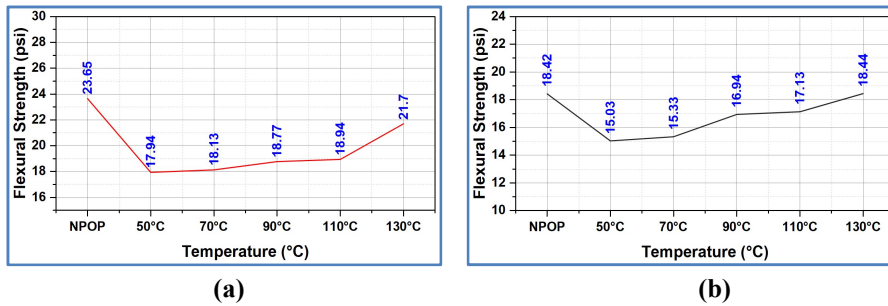


Fig. 7. Flexural Strength at different drying temperatures (a) 70:30 Batch (b) 50: 50 Batch

3.5. Impact Strength

Fig. 8 shows the impact strength for both batches. As temperature increases, the impact strength will increase because at low temperatures sometimes materials show brittleness properties and reduce the impact strength, which is also similar to the flexural strength [19]. Up to expectation, at optimum 130°C, a higher value of impact strength was obtained. Fig. 8(a) shows at optimum temperature 1.87 psi impact strength was obtained, which is nearly the same as the NPOP impact strength of 2.07 psi. Moreover, Fig. 8(b) shows at optimum temperature 1.38 psi impact strength was obtained, which is nearly the same as the NPOP impact strength of 1.59 psi. A linear relationship is shown between the flexural strength and impact strength. As flexural strength increases, the impact strength will also increase [20].For this reason, a better impact strength is obtained in a 70:30 batch than in a 50:50 batch.

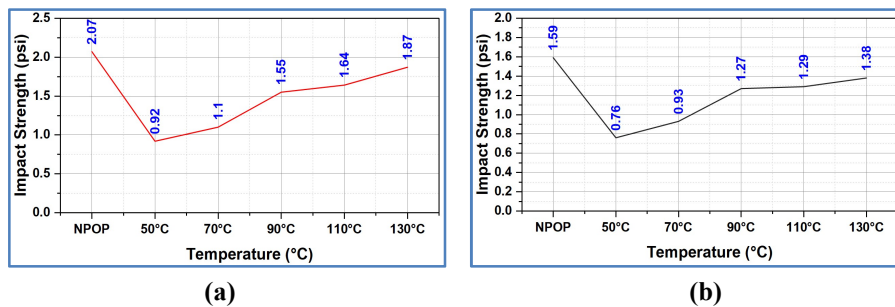


Fig. 8. Impact Strength at different drying temperatures (a) 70:30 Batch (b) 50: 50 Batch

4. Conclusion

In conclusion, this research demonstrates that the recycled Plaster of Paris (RPOP) derived from waste industrial mold exhibits physical and mechanical properties comparable to those of pure Plaster of Paris (POP). The use of distinct drying temperatures for extended duration confirms the result that all these temperatures can be used in the process of recycling. The findings indicate that 130°C is the optimum temperature to recycle the Plaster of Paris. At this temperature, RPOP exhibits almost the same physical and mechanical properties as NPOP for both batches. However, the 70:30 ratio batch yields a better result than the 50:50 ratio batches. Moreover, the choice between the two batches depends on the specific requirements of the application. If a stronger, thicker, and faster setting time is needed, the 70:30 ratio batch is more suitable, while if a more fluid, easily workable, and longer setting time is needed, the 50:50 ratio batch is more suitable. To improve the binding quality of RPOP, the addition of a small amount of calcium sulfate hemihydrates is recommended. Thus, this research confirms that it is possible to recycle the Plaster of Paris from waste industrial mold.

5. Reference

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