INFLUENCE OF ALUMINIUM POWDER IN MECHANICAL PROPERTIES OF CEMENT MORTAR

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Abstract. This study investigates the advancement of lightweight mortar that incorporates aluminium powder as an air-entraining agent to enhance its properties. The research aims to determine optimal mix proportions for achieving desired compressive strength, density, and water absorption characteristics of mortar mixes to which aluminium powder was incorporated in various ratios (0.6 % and 1.2 %) by weight of cement.The paper aims in creating aerated lightweight mortar, utilizing different ratios of aluminium powder with the goal of attaining a density lower than 1000 kg/m³. The experiment demonstrated about 55 % reduction in density with 1.2 % aluminium powder. The study evaluates the effectiveness of incorporating aluminium powder in reducing environmental impact and enhancing structural performance, highlighting its potential for sustainable construction practices. The findings contribute to the understanding of lightweight mortar technology and its applications in reducing the weight of building materials while addressing waste management challenges.

1.INTRODUCTION

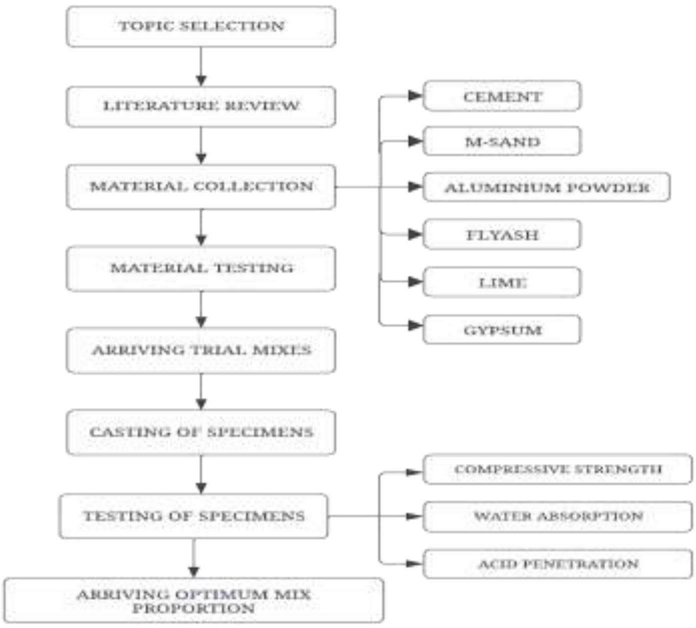
A mortar constitutes a binding substance created through mixing of cement, sand, and water, employed in construction for blending building materials together. Cement mortar enriches structural stability, functions as an adhesive, and helps in filling voids or gaps. Cement mortar hardens with time and becomes a firm aggregate structure as it cures [1]. Cement mortar is produced using various ratios that include 1:3 and 1:4. Freshly mixed materials give mortars a plastic consistency that makes it easy to use with trowels to smooth out the surface of walls or fill in masonry gaps during construction.

A lightweight mortar generally denotes a mortar blend that incorporates lightweight aggregate materials. Lightweight mortar usually has a density between 800 and 1600 kg/m³ depending upon the particular ingredients and proportions employed in the mixture. Some common natural lightweight materials include volcanic aggregate like scoria, pumice, perlite, vermiculite, clay, shale and Expanded Poly Styrene (EPS) [2]. These lightweight aggregates not just decrease the weight of concrete constructions, but it also enhances thermal conductivity. About 60 % to 90 % of total volume of lightweight concrete is pore space [3]. In this study, a lightweight mortar is produced by adding determined amount of aluminium powder along with cement, fine aggregate, flyash, lime and gypsum [4]. Besides utilizing lightweight materials, lightweight mortar can also be generated by incorporating foaming agents into the mortar mixture, which results in the formation of numerous distinct micro-voids. Additional chemical agents can be introduced to make the mortar expansive after placement. Aluminium powder is a key component employed to enhance the volume of the concrete.

Aluminium powder is often produced by the atomization process from molten aluminium in order to be utilised in mortar [5]. This research focuses on the compressive strength of aluminium powder incorporated cement mortar at different proportions as a replacement with the weight of cement. The aluminium powder used was between the grain size of 50µm and 100 µm [6]. When aluminium powder is added to the mortar mix, it acts as an expanding agent [7]. It boosts the volume of the mortar, resulting in an expansion that can be 2 to 5 times greater than the original mortar volume. The hydration process involving aluminium powder involves vigorous reactivity with calcium hydroxide, a hydration agent, releases a significant quantity of hydrogen gas, which in turn creates more micro-voids within the mortar. The addition of aluminium powder to mortar leads to lessened strength and modulus of elasticity in addition to decreasing its density, making the concrete more brittle [2]. The fineness and amount of aluminium powder and the ratio of water powder determine how much the aeration reduces the density of concrete. When compared to traditional mortar, the density of lightweight mortar is far lower. The weight of aluminium powder is taken at different percentages (0.6 %, 1.2 %) to the weight of cement. The tests conducted for cubes are compressive strength test, water absorption. The compressive strength of the cubes were tested at the age of 7 days and 28 days. The water absorption for the cubes were tested on 28 days. The aim of the study is to determine the most effective mixture ratio, in accordance to the proportion of powder to sand. Lightweight mortar incorporating aluminium powder provides advantages such as fire resistance, sound and heat insulation, reduced environmental impact and improved sustainability [8]. It also addresses CO_2 emissions and soil degradation. The lightweight mortar is mostly useful for lowering dead load in structures [9].

The repurposing and recycling of industrial by-products and waste hold significant importance across all sectors [10]. Aluminium stands as one of the most frequently utilized building materials globally, leading to significant quantities of waste generated throughout its production process [11]. The amount of aluminium trash generated by various industrial products was estimated to be 2.7 million tonnes in 2017 [12]. Incorporating this waste into construction can effectively address the challenges presented by waste management. The increased level of air pollution through urban brick kilns presents a serious environmental risk. In reaction to dual challenges to safeguard the environment and to reduce the weight of building, the incorporation of aluminium powder in construction serves as a good method. The refining process utilized in aluminium production yields approximately 2 to 2.5 tons of solid waste per every 1 ton of aluminium manufactured. Industrial waste and by-product recycling and repurposing are incredibly important in any sector these days. So to reutilize the aluminium waste from industries, it is used as a lightweight material in order to diminish environmental impacts.

2.METHODOLOGY



3.LITERATURE REVIEW

R.K. Paikara and T.R. Gyawal (2023) have investigated about the impact of aluminium powder and powder-to-sand ratio on the physical and mechanical properties of lightweight mortar. The aim of the paper is to produce aerated lightweight mortar with a density of less than 1000 kg/m^3 by incorporating aluminium powder at different percentages. The percentage of cement varies from 0 % to 1.2 % to the weight of cement. It has three mixes M1, M2, M3 represented by water-powder ratios (W/P) and powder to sand ratios (P/S). The densities of M1, M2 mixes at 28 days were 1659 kg/ m^3, 1355 kg/ m^3 respectively and 961 kg/ m^3 and 944 kg/ m^3 for M3 mix. The compressive strength for 28 days for M3 were 7.63 MPa and 6.80 MPa with 0.6 % and 0.9 % of aluminium powder. M3 mix was suitable for achieving compressive strength and density.

Ayad S. Aadi et al(2021) have a detailed study on the mechanical properties of green mortar with aluminium wastes as substitute to sand. In this investigation, they have replaced natural sand by aluminium waste. The incorporation of aluminium waste varied from 0 % to 30 %. The size of aluminium waste was less than 4.75mm. The result showed that usage of aluminium waste less than 5 % gave the best strength with 20 MPa. The minimum density obtained was 1248 kg/m^3 with 30 % of aluminium waste. At 5 % and 30 % of aluminium waste, there is a sharp decrease in compressive strength. It suggested that usage of 5% aluminium powder in cement mortar can be used for structural application.

Nadia Tebbal and Zine El Abidine Rahmouni (2019) have examined the Enhancing the Mechanical capabilities of mortar through the valorization of aluminium waste under cycles of freeze-thaw. Aluminium waste was added with various proportions at 0 %, 5 % and 7.5 % by the weight of sand. Aluminium waste was obtained from aluminium doors and windows manufacturing units with size around 3 mm. The addition of 2.5 % of aluminium waste resulted in the maximum compressive strength of 16 MPa. This concluded that addition of aluminium minimizes its workability which in turn requires the use of water reducing admixtures. A good quality mortar is achieved with the incorporation of 5 % and 7.5 %.

Maciej Gruszczyński and Małgorzata Lenar (2020) have studied the endurance of mortars enhanced through the inclusion of amorphous aluminium silicate and silica fume. They have added Amorphous Aluminium Silicate in the percentage of 5 % and 10 % to the mass of cement. When compared to silica fume addition, in the utilisation of amorphous aluminium silicate, the water demand resulted in less increase. It concluded that the utilization of silica fume leads to increase in the demand for water of 30 % to 40 %, whereas usage of amorphous aluminium silicate lowers water demand of about 22 % to 32 %. Mortar with 5 % silica fume reached 22% decrease in water absorption and decrease in 30 % for 10 % silica fume. The reduction in water absorption reached 26% for 5% amorphous aluminium silicate and 33 % for 10 % amorphous aluminium silicate. The mortar with amorphous aluminium silicate has less water absorption than mortar with silica fume. The mortar with silica fume and amorphous aluminium silicate show increased compressive strength from 0.9 to 1.8 N/mm^2 and flexural strength from 0.2 to 0.6 N/mm^2 when compared to standard mortar.

Abdul Qader Nihad Noori et al (2021) have investigated on lightweight structural materials produced using aluminium scraps with cement mortar. They have used solid aluminium scraps to produce lightweight mortar to find their mechanical behaviour by adding it at different percentages (1 %, 2 %, 3 %, 4 % and 5 %). They included aluminium scraps as a substitute from the weight of sand. They have used the mix ratio as 1:2.73. The results indicated that as the addition of aluminium scraps increases, the decrease in compressive strength increases. The compressive strength varies from 40.33 to 78.95 % when the percentage of aluminium scraps increases.

E. Muthu Kumar, K. Ramamurthy (2015) have investigated the impact of aluminium powder's fineness and dosage on the characteristics of aerated concrete under moist curing. They have studied about the workability of the concrete, rate of aeration, compressive strength, dry density, water absorption. Aluminium powder with the fineness of C50 has high strength to density ratio and also has lower water absorption. As the fineness of aluminium powder increases the dry density reduces.

Dr. K. Chandrasekhar Reddy and S. Dinesh Kumar (2017) have investigated about the effect of fly ash and Aluminium Powder on Concrete. Aluminium powder is taken at different percentages of 5 %, 10 % and 15 % to the weight of cement. The outcomes showed that the concrete mix with 15 % fly ash and 0.25 % aluminium powder has higher flexural strength with 78.75 % than control mix. As the percentage of aluminium powder increases, the flexural strength decreases. The minimum density of 1714 Kg/m^3 is achieved when 10 % fly ash and 1 % aluminium powder is added which is 31 % less than control mix.

Rana Shabbar et al (2017) have investigated the Mechanical properties of lightweight aerated concrete with varying aluminium powder content. The weight of aluminium powder in added at different percentages of 0.25 % to 1 %. The results concluded that as the aluminium powder content increases, the compressive strength decreases. The highest compressive strength obtained was 32.3 N\$mm^2$ with 0.25 % aluminium powder which is less than control mix(53 N\$mm^2$). The highest flexural strength was obtained for control mix with 5.5MPa and it decreases with the addition of aluminium powder. The flexural strength with 0.25 %, 0.5 % and 0.75 % Aluminium powder was 4.6 MPa, 4.2 MPa and 3.7 MPa respectively. The highest modulus of elasticity was for control mix with 23 MPa and decreases as 18.9 MPa, 14.1 MPa and 9.7 MPa for 0.25 %, 0.5 % and 0.75 % aluminium powder. The dry density decreases with the addition of aluminium powder. The density for control mix was 2102 Kg/m^3 and decreases to 1841 Kg/m^3 for 0.25 % aluminium powder.

Priya chetry et al (2018) have investigated on the impact of aluminium and marble waste powder on the concrete's performance. In this paper, they have used 0 %, 0.25 % and 0.50 % of aluminium powder to the weight of cement. The substitution of 2.05 % and 0.5 % of aluminium powder was 27.23 MPa and 24.59 MPa respectively .The replacement of sand with 10% marble powder showed increased compressive strength with 35.08 MPa. With the replacement of combination with 10 % marble powder and 0.25 % aluminium powder, the compressive strength was 32.15 MPa and 29.41 MPa for 10 % marble powder and 0.5 % aluminium powder.

Aadil Hameed et al (2021) have investigated the effect of aluminium waste powder on the strength properties of cement mortar. They have used aluminium waste powder as a substitute of cement at various percentages ranged from 2.5 % to 10 %. They have studied the results of flowability, density and compressive strength. The flowability result indicated that the increase in aluminium waste powder decreases the flowability of mortar. The increase in addition of aluminium waste powder increased the density of the mortar. The density of mortar with addition of aluminium waste powder was lesser than the control mix. The compressive strength of control mix was greater than the cement mortar with aluminium waste powder. It was found that 2.5 % of aluminium waste powder as the optimum dosage with compressive strength of 12.8 MPa at 28 days which is 22 % less than the control mix.

Joel Hemanth (2006) has investigated the Compressive strength and microstructural properties of lightweight high-strength cement mortar reinforced with eloxal. The eloxal particles used at different percentages were 20 %, 30 % and 40 %. The addition of eloxal decreases the setting time and increases the strength. It showed that increase in curing days increased the compressive strength. The highest compressive strength developed was 68.9 MPa with 700 kg/m3 containing 40 % wt dispersoid.

Arvind K. Suryavanshi and R. Narayan Swamy (2002) have studied the development of lightweight mixes using ceramic microspheres as fillers. The densities obtained varied from 550 kg/m^3 to 1220 kg/m^3. As the amount of aggregates increased, water absorption also increased which lowered the water absorption resistance. The results showed that decrease in density reduced the compressive strength.

Ali J. Hamad (2014) has studied the about the materials, production, properties and application of aerated lightweight concrete. Aluminium powder was added at 0.2 % to 0.5 % to the weight of cement. At the age of 7 day, the concrete without silica has obtained 70 % to 75 % of 28 day strength. The increase in mass density increases the strength. At a mass density of 700 kg/m^3, the compressive strength increases to 17 % and at a mass density of 1100 kg/m^3, the compressive strength increases to 20 %.

M.Shyam Sundar et al (2021) have studied on flyash based concrete with aluminium as partial replacement of cement. In this study, the replacement level of flyash remained constant at 25 % and amount of aluminium ranged from 5 % to 15 %. Tests were conducted on unit weight, compressive strength and ultrasonic pulse velocity of concrete. The rise in weight of aluminium increases the slump value and rise in percentage of aluminium increased the strength properties of concrete.

Mr. M. Gunasekaran et al (2016) have studied about the development of lightweight concrete by using autoclaved aerated concrete. The aluminium powder was taken at 0.25gm to 1gm to the weight of concrete. The compressive tests gave maximum strength of 6.9 MPa with lime and 5.5MPa without lime. The least water absorption was 15.43 % with lime and 15.97 % without lime. The minimum density obtained was 1364.6 kg/m^3 with lime and 1393.1 kg/m^3 without lime.

Rana Shabbar et al (2018) have investigated the porosity and water absorption of aerated concrete with varying aluminium powder content. Aluminium powder was used at percentages of 0.25 % and 1 % to the weight of cement. The increase in aluminium content decreased the bulk density due to the formation of large porosity. The decrease in density increased the water absorption at all ages.

Abhijitsinh Parmar et al (2015) have investigated about lightweight concrete using EPS beads and aluminium powder. The highest strength obtained was 5.51 N/mm^2 at the age of 28 days. The lowest density achieved was 712.48 kg/m^3. The highest strength was achieved at lowest density.

R. Vijayalakshmi and R.Rajeswari (2018) have studied on the characteristics of lightweight concrete using aluminium powder and aluminium dross. In this study, they have used 5 %, 10 % and 15 % of aluminium powder and dross to the weight of cement. The lowest density was obtained at 10 % of aluminium powder. Highest compressive and split tensile strength was obtained as 43.15 N/mm^2 and 1.42 N/mm^2 at 28 days with 10% aluminium dross. The highest water absorption was 3.12 % with 10 % aluminium powder.

4. MATERIALS USED

The experiment was conducted with the readily available materials, with the objective of creating lightweight mortar cubes with sustainable materials. The materials used were cement, fine aggregate, aluminium powder, flyash, gypsum and lime.

4.1 Cement

The cement utilized was Ordinary Portland Cement of 53-grade. It acts as a binding material which binds all the materials together. Some of the chemical components present in cement are iron oxide, silica, magnesium oxide, sulphur trioxide. The specific gravity of cement is 3.15.

4.2 Fine aggregate

The experiment utilized locally sourced m-sand with specific gravity of 2.56. Sieve analysis for fine aggragate was performed according to Indian standards. Manufactured sand may contain higher quantities of micro fine particles than natural sand [13].

4.3 Flyash

Flyash used was fine, grey coloured powder added to increase the amount of powder materials. It was obtained from nearby cement manufacturing units.

4.4 Aluminium powder

Aluminium powder used in the investigation was bought from Coimbatore metals. It is generally used as a air entraining agent along with other materials to produce lightweight mortar [14]. The aluminium powder was fine, smooth metallic powder confirming to IS 438-2006 was used. Aluminium reacts with alkalis present in lime which produces hydrogen gas resulting in formation of voids.

5.MIX PROPORTION

The main purpose of the experimental study was to determine appropriate mix proportions to attain suitable 28 days compressive strength, density and water absorption [15]. The water to cement ratio 0.5 was maintained consistently for all the mixes. The amount of aluminium powder was kept at 0.6 % to the weight of cement. In mixes with aluminium powder and control , the mortar mix proportion adopted was 1:3 and constant for all the mixes. The same amount of fine aggregate and other powder materials were utilized for all blends. Control mix was also prepared for 1:3 mix proportion. AP0 denotes the control mix and AP1 denotes the mix with 0.6 % aluminium powder.

Table 1 represents the quantity of materials taken for each mix. Initially, the dry components(cement, fine aggregate, aluminium powder, flyash, lime and gypsum) were mixed. Dry mixing was carried out for a duration of two minutes to achieve uniform dispersion for each ingredient. Following that, wet mixing was performed for a minute by adding water during the process [12]. Then it is mixed by adding water gradually until a homogeneous mix is formed [11]. The molds (70.6x70.6x70.6mm) were filled by mortar mix in three layers. Each layer was given 25 blows using a damping rod. The top surface of the mortar was levelled and smoothened using a trowel. A total of 3 cubes were made for a single batch. After 24 hours, any surplus mortar that had overflowed was carefully trimmed using a sharp knife to ensure the exact dimensions of the cube. The specimens were demolded, weighed and cured in water until it is tested.

MIX ID	CEMENT (gm)	FLYASH (gm)	M-SAND (gm)	LIME (gm)	GYPSUM (gm)	Al POWDER (gm)
AP0	230	0	690	0	0	0
AP1	230	190	380	110	10	1.4
AP2	230	190	380	110	10	2.8

TABLE 1

Fig.1 Lightweight mortar test specimen

Fig.2 Compressive strength test

6. RESULTS AND DISCUSSION

The addition of water to the dry mixture initiated the generation of air bubbles while mixing. This led to a volume expansion of the mortar, even within the mixture itself. When the mortar was filled into the mold upto two third of its height, it continued to generate air bubbles, expanding in volume and eventually overflowing from the mold after few minutes. After 24 hours, air voids can be seen on the surface of the specimen.

6.1 Density

Aluminium powder was incorporated in the mortar with the aim of achieving a density less than 1000 kg/m^3. The density of mortar with incorporation of 0.6 % aluminium powder was found to be 1839 kg/m^3 at 7 days and 1854 kg/m^3 at 28 days. While the density of mortar with 1.2 % aluminium powder was 1569 kg/m^3 at 7 days and 1583 kg/m^3 at 28 days. There was a gradual decrease in density when employing aluminium powder at 1.2 %. The density of control mix at 7 days was 2294 kg/m^3 and 2256 kg/m^3 at 28 days. An increase in the amount of powder materials (cement, lime and gypsum) resulted to the decrease in density. Test results showed that aluminium powder reacts more effectively than sand in mortars with higher proportion of powder materials.

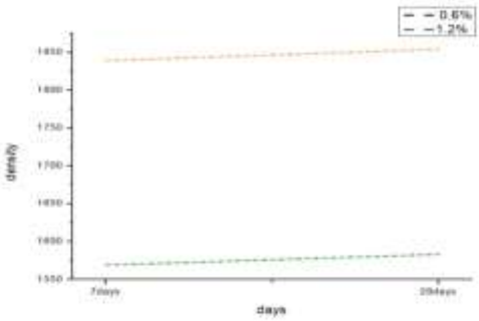


Fig.3 Density

6.2 Compressive strength

The compressive strength of lightweight mortar with the incorporation of 0.6 % of aluminium powder was 8.3 N/mm^2 at 7 days and 9.39 N/mm^2 at 28 days. With the addition of 1.2 % of aluminium powder, the compressive strength was found to be 7.6 N/mm^2 and 7.8 N/mm^2 at 7 days and 28 days respectively. In the control mix, without the addition of aluminium powder, the compressive strength was obtained at 12.57 N/mm^2 at 7 days at 22.73 N/mm^2 at 28 days. The compressive strength exhibited a decrease with a rise in the percentage of aluminium powder increased.

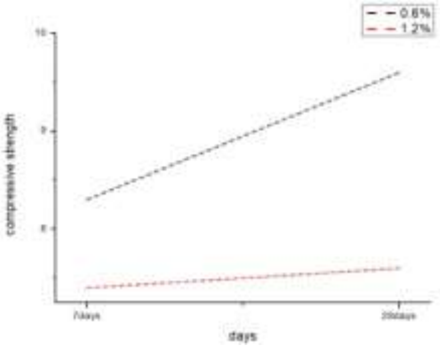


Fig.4 Compressive strength

6.3 Water absorption

The water absorption of mortar with 0.6 % aluminium powder was observed to be 25 % and 28 % for 1.2 % aluminium powder at the age of 28 days. The test results showed that increase in water absorption was observed with the increase in powder content, even without changing the aluminium powder content.

7. CONCLUSION

The study highlights the significance of lightweight mortar development, particularly focusing on the incorporation of aluminium powder to enhance mortar properties. Through experimentation and analysis, the research identified optimal mix proportion to achieve desired compressive strength, density, and water absorption. The findings revealed that the addition of aluminium powder lead to a remarkable decrease in density and compressive strength with benefits such as enhanced volume expansion and reduced environmental impact. Key conclusions drawn from the experiment are

1. The effectiveness of aluminium powder was greater with higher powder to sand ratio.
2. The 28-day density with 0.6 % and 1.2 % aluminium powder was 17 % lesser and 29 % lesser than the control mix respectively.
3. The water absorption rates were recorded at 25 % for 0.6 % aluminium powder and 28 % for 1.2 % aluminium powder.
4. The 28-day compressive strength with addition of 0.6 % and 1.2 % aluminium powder was 9.39 N/mm^2 and 7.8 N/mm^2.
5. From the conducted experiments, the optimum strength was obtained with the addition of 0.6 % aluminium powder.

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