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Effect of Sand Particle Size (Grading) On Mechanical Strength and Durability of Epoxy Resin Mortar

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Abstract

This experimental study compares the properties of traditional cement mortar with epoxy resin-based mortars. In the resin mortars, Portland cement was entirely replaced with a blend of epoxy resin and hardener, used at a fixed ratio of 12.5% resin-hardener mixture to 87.5% aggregates by weight. Various aggregate types and sizes were investigated, including three grades of fine silica sand (fine: 0.063–0.63 mm; medium: 0.16–0.63 mm; coarse: 0.08–1.25 mm) and two grades of marble sand (fine: 1–4 mm; medium: 3–8 mm).

The study evaluates the mechanical performance (compressive and flexural strength), thermal insulation (via thermal conductivity), and durability of these mortars. Durability was assessed through changes in mass and compressive strength before and after exposure to hydrochloric and sulfuric acid solutions.

Results show that mortars made with marble aggregates exhibited slightly lower mechanical strength compared to those with silica sand. However, all epoxy resin mortars demonstrated significantly improved thermal insulation, with thermal conductivity values decreasing from 1.75 to 0.95 W/m·K. Acid resistance was also enhanced in all resin mortars, with the greatest degradation observed in hydrochloric acid and the least in sulfuric acid. Additionally, the reduced water absorption of resin mortars contributed to their improved durability.

Keywords : Epoxy resin, Hardener, thermal conductivity, mechanical strengths, durability.

Introduction

Cement, widely used in concrete and mortar, presents several well-documented drawbacks. These include environmental pollution during its production process, limited mechanical strength under flexural stress, and high susceptibility to chemical attacks. Such limitations highlight the need for alternative high-performance materials, especially in applications requiring enhanced durability and performance, such as industrial flooring and the rehabilitation of deteriorated structures like dams, walls, and pavements.

One promising solution is polymer mortar, a composite material comprising a polymeric binder, hardener, and mineral aggregates. The properties of polymer mortars—both in fresh and hardened states—are strongly influenced by factors such as the type and content of resin [1], the size and nature of the aggregates [2], and the bond quality between the resin and the aggregate surface.

In the fresh state, the workability of polymer mortars is primarily governed by the viscosity and content of the resin. Studies [1][2][3] have shown that increasing the resin content up to 12%, especially when combined with supplementary materials like fly ash, enhances both the fluidity and cohesion of the mixture.

Polymer mortars also significantly outperform traditional Portland cement-based mortars in terms of mechanical properties.

- **Compressive strength**: Mortars incorporating polyester or epoxy resins can exhibit compressive strengths 72% to 300% higher than that of conventional cement mortar, depending on the resin type and dosage [3][4][5].
- **Flexural and tensile strength**: These also increase with resin content, reaching values as high as 26 MPa in mortars containing 13–20% epoxy resin [6][7][8].

A further advantage of polymer mortars is their exceptional chemical resistance. Due to their low water absorption, they show strong durability when exposed to aggressive environments, including acids, alkalis, and salts. For instance, polyester-based mortars have shown no weight loss after immersion in hydrochloric and sulfuric acids [9], while traditional cement mortars have lost up to 50% of their initial mass under similar conditions.

2. Research Objective

This study aims to investigate the influence of aggregate type (silica sand and marble) and particle size on the performance of epoxy-based polymer mortars. Specifically, it evaluates their:

- **Mechanical properties** (compressive and flexural strength),
- **Thermal insulation capability** (via thermal conductivity), and
- **Durability**, assessed by acid resistance (mass and strength loss) and water absorption.

By replacing traditional Portland cement entirely with a mixture of epoxy resin and hardener, this research explores how different aggregate characteristics affect the suitability of polymer mortars for demanding applications.

Methods

Materials used

Poxy resin mortars were prepared using a polymeric matrix and aggregates:

Polymeric matrix: The polymeric matrix includes two components: a resin and a hardener, as given in Table 1. The resin is an epoxy resin based on Bisphenol A (BPA) and Epichlorohydrin (ECH)**.** The hardener contains primary aromatic amine and secondary aliphatic groups with a basicity of 2.3 meq/g.

Aggregate: Standard sand, three types of silica sand, and two types of marble aggregate from a quarry located in **Tebessa (Algeria)** were used (Figure 2). The three types of sand included:

- **Fine sand** [0.06–0.63 mm]
- **Medium sand** [0.16–0.63 mm]
- **Coarse sand** [0.08–1.25 mm]

While the two types of marble consisted of:

- **Fine marble** [1–4 mm]
- **Medium marble** [3–8 mm]

The physical characteristics of the sand are listed in Table 2. The CEN Standard Sand has a specific grain size distribution ranging between 0.08 and 2.00 mm.

Cement: The cement used is **Portland cement type CEM I 42.5**. The physico-chemical characteristics are given in Table 3.

Acid Solutions: Hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) solutions with a concentration of 5% were prepared in plastic boxes to investigate the acid resistance.

Table 1. Properties of epoxy resin and Hardener

Type	**Epoxy resin**	**Hardener**
Mixing proportion	2.5	1
Color	Colorless	Pale yellow
Specific gravity	1.13	1.05
Viscosity at 25°C (mPa.s)	550	400
Pot life (min)	20 min	
Hardening time at 25°C (h)	8 h	

Table2. Physical characteristics of silica sand and marble aggregate

Characteristics	Silica Sand			Marble Aggregate	
	Fine	Medium	Coarse	Fine	Medium
Bulk density (kg/m^3)	1730	1800	1935	1560	1420
Specific gravity	2.11	2.15	2.93	3.52	2600
Fineness modulus	2.16	2.98	3.8	5.9	8.7
Sand equivalent (%)	98	97	95	98	96
Total water absorption (%)	4	3.5	3.3	2.3	1.9

Figure 1. Used silica sand and marble aggregate

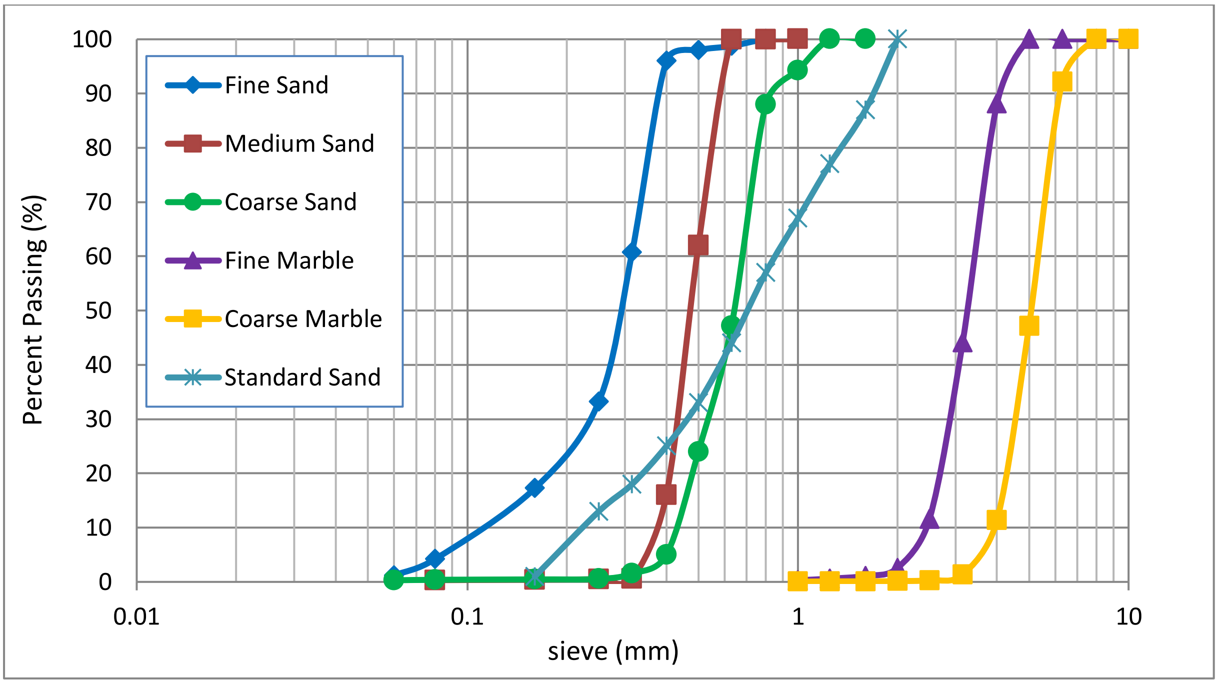

Figure 2. Particle size distribution curve of sand and marble aggregates

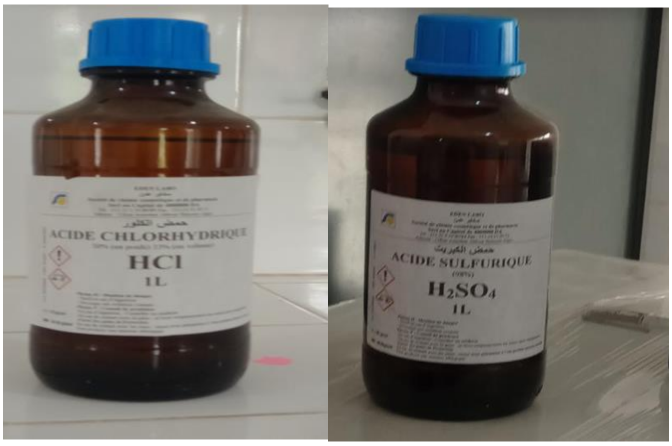

Figure 3. Hydrochloric acid (HCL) and sulfuric acid (H_2SO_4)

Formulation

Two types of formulations were used: cement mortar and five different epoxy resin mortars. These formulations were used to investigate mechanical strength, water absorption by capillary and total immersion, and resistance to acid solutions. The cement mortar was prepared with a sand-to-cement ratio of 3:1 and a water-to-cement ratio of 0.5 by weight.
The five epoxy resin mortar mixtures (see Table 3) were prepared by varying the size of aggregate:

- Three sizes of **silica sand**:
  - Fine sand (FS)
  - Medium sand (MS)
  - Coarse sand (CS)
- Two sizes of **marble**:
  - Fine marble (FM)
  - Medium marble (CM)

For all of these mortars, the combined epoxy resin and hardener constituted 12.5% by mass**,** and the epoxy resin-to-hardener mass ratio was fixed at 2.5. Table 3 summarizes the compositions of epoxy resin mortars.

Table 3. Component percentages for epoxy resin mortars

Designation	**Polymeric matrix (%)**		**Silica sand (%)**			***Marble***	
	Epoxy Resin	**Hardener**	**Fine Sand**	**Medium sand**	**Coarse Sand**	**Fine Marble**	**Coarse Marble**
ERMSF	9	3.5	87.5	0	0	0	0
ERMSM				87.5	0	0	0
ERM SC			0	0	87.5	0	0
ERM M	9	3.5	0	0	0	87.5	0
ERM C			0	0	0	0	87.5

2.3 Mix preparation

The mixing procedure for the epoxy resin mortars begins with drying the aggregate at 105°C for 24 hours. Then, the epoxy resin and hardener were mixed using an automatic stir in a container. Once the blend was homogeneous, the mortar was cast in 40 × 40 × 160 mm wood molds for 24 hours.

After demolding, specimens of epoxy resin mortars were divided into four groups. One group was cured in water at 23 ± 2 °C to assess the evolution of compressive and flexural strength at 7, 14, 21, 28, 56, and 90 days of curing. The second group was first cured for 28 days and then used to assess water absorption by capillarity and total immersion. The third group was cured for 90 days and used to measure thermal conductivity. The fourth group was cured for 28 days and then immersed for 90 days in 5% hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) solutions to assess acid resistance.

Figure 4. Drying aggregate,mixing procedures and molding

Figure 5. Epoxy resin mortar with silica sand (a: fine sand, middle sand, coarse sand)

Figure 6. Epoxy resin mortar with marble aggregate (Marble sand)

2.4 Testing

Workability

The workability of all mortar was tested using the slump cone test according ASTM C1437 standard test method. This involves filling the cone with a mixture, then removing it vertically and measuring the diameter of the spread material. The flow of mortars is expressed the diameter spread as a percentage of the original base diameter of the cone.

Flexural and Compressive strength

The mechanical strengths of cement mortar and all epoxy resin mortars were evaluated by measuring flexural and compressive strengths according to BS EN 196-1 standard [10]. Flexural strength was determined using a three-point bending test on 40 × 40 × 160 mm mortar prisms (Figure 4a). The compressive test(Figure 4b) was conducted on the halves of 40 × 40 × 160 mm mortar prisms that had previously broken in the flexural test.

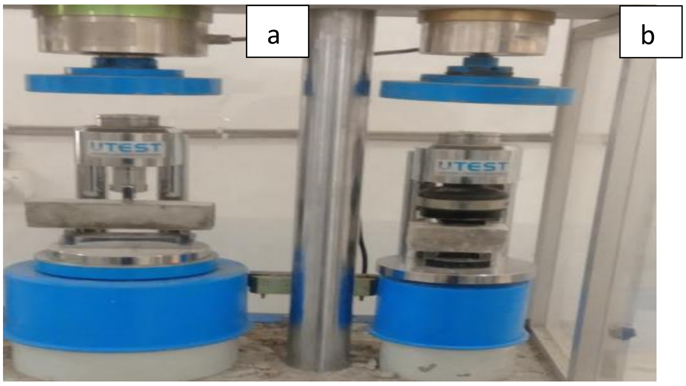

Figure 7. Flexural strength and Compressive strength devices for mortar

Capillary water absorption test

Capillary water absorption or sorptivity test was performed according to BS EN 13057 standards [11].At 28 days, prisms with dimensions of 40 × 40 × 160 mm were oven-dried at 105°C until their weight stabilized. To ensure uniaxial water absorption of the prisms, all sides except the one touching the water were sealed with epoxy resin.

After that, the prisms were placed in the water (Figure 8) with a depth of immersion of about 4 ± 1 mm.
The water absorption mass was measured regularly every 5 minutes until 90 minutes. The prisms were first wiped to remove any excess water from the suction surface and then quickly weighed (±0.01 g).The capillary water absorption is obtained by using the following equation:

$$Abs_{capil} = \frac{\Delta M}{A} \cdot \frac{1}{\sqrt{t}} \qquad (1)$$

Where ΔM: mass of water absorbed at time t (g), A: exposed area of the specimen (cm^2) and t : elapsed time (min).

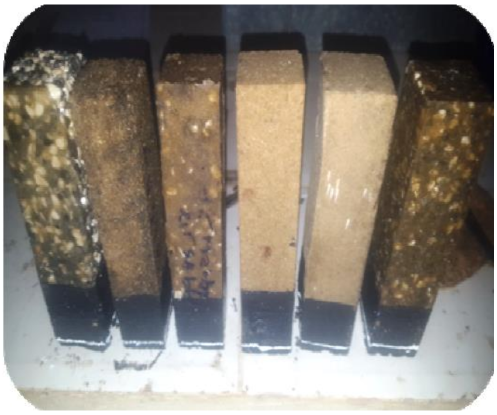

Figure 8. Water absorption by capillary test

Water absorption by total immersion test

Water absorption by immersion was tested at 28 days according to ASTM C642-97 standards [12].In this test, three specimens from cement mortar and mortars with dimensions of 4×4×16 cm were first dried in an oven at 105°C for 24 hours. After oven drying, the specimens were left to cool at room temperature and then weighed (Md) to give the oven dry mass. Thereafter, the specimens were immersed in water at 25°C for 24 hours. After immersion, the specimens were removed from the water, wiped with a damp cloth, and their mass after immersion in water was weighed again (Mw). The water absorption by immersion is given by the formula:

$$Abs_{immer}(\%) = \frac{M_w - M_d}{M_d}.100 \qquad (2)$$

Thermal Conductivity test

The thermal conductivity of cement mortar and epoxy resin mortars was determined by the hot-wire (parallel) method according to EN-993-15 standards [13].The measurement was carried out with a CT-Meter device equipped with a sensor wire for solid materials (Figure 6).

At 28 days, the specimens consisted of two mortar prisms with identical dimensions (4×4×16 cm) and the same formulation. Before performing the test, the specimens were placed in a drying oven at 60°C for 24 hours. To measure the thermal conductivity, a hot-wire sensor was inserted between the two mortar prisms.

Figure 9. Device of Thermal conductivity-meter

Results

Effect of sand size on workability

The workability of cement mortar compared to epoxy resin mortars containing different size abd types is shown in Figure 10. It indicates that the cement mortar was more workable than all epoxy resin mortar. For all epoxy resin mortars, it can be observed that there is a lower workability was observed for epoxy resin mortar containing marble as the size of [3-8].

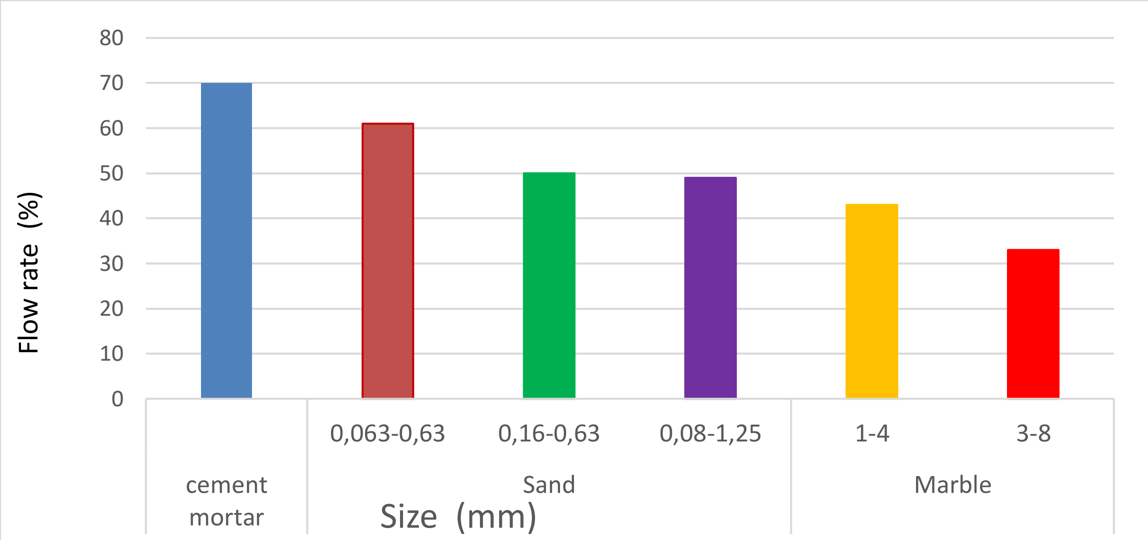

Figure 10. Influence of sand size on workability of epoxy resin mortar

Effect of sand size on bulk density

Figure 11presents the bulk density at 28 days for epoxy resin mortars prepared with three different sizes of sand and two sizes of marble aggregates. It can be seen that the marble aggregate increases the bulk density of epoxy resin mortars.

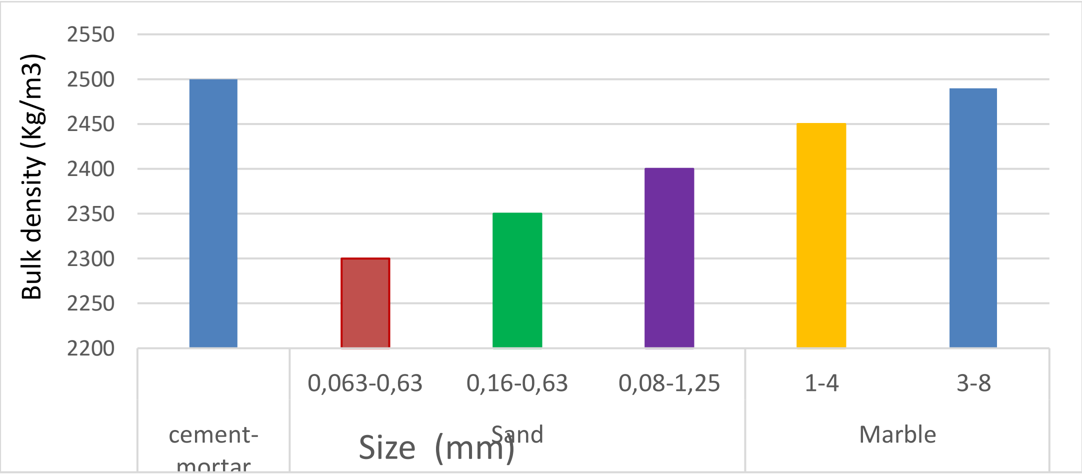

Figure 11. Influence of sand size on bulk density of epoxy resin mortar

Effect of sand size on compressive strength

Figure 12 illustrates the results of the compressive strength at 28 days for cement mortar and epoxy resin mortars prepared with three different sizes of silica-sand and two marble sand sizes. The compressive strength of all epoxy resin mortars is higher than that of cement mortar. It can be observed that there is a slight increase in the compressive strength as the grading size of the sand decreases.

Thus, epoxy resin mortars with finer sand have higher mechanical strengths. For example, the compressive strength of silica sand with size of [0.06-0.63], [0.16-0.63], and [0.08-1.25] are 68, 65, and 63 MPa, respectively. While, the compressive strength of marble sand with size of [1-4] and [3-8] are 61 and 59 MPa, respectively.

This trend is attributed to improved packing density and reduced porosity associated with finer sand particles.

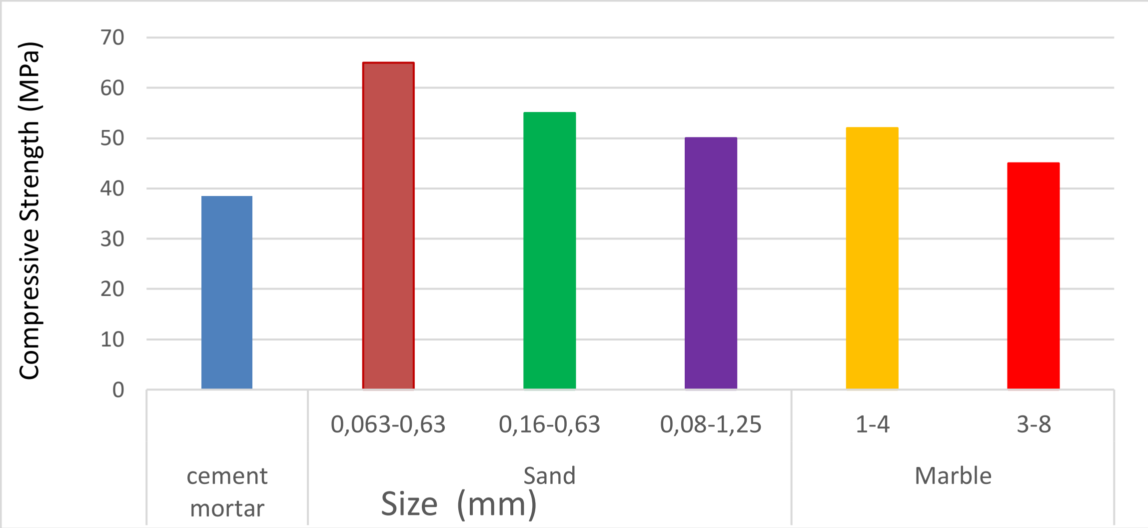

Figure12. Influence of sand size on compressive strength of epoxy resin mortar

Effect of sand size on flexural strength

Figure 13illustrates the results of the flexural strength at 28 days for cement mortar and epoxy resin mortars prepared with three different sizes of silica-sand and two sizes of marble-sand.The flexural strength of all epoxy resin mortars is higher than that of cement mortar.

For all epoxy resin mortars, it can be observed that there is a slight increase in the flexural strengths as the size of the sand decreases. For silica sand, the flexural strength corresponding to silica sand with size of [0.06-0.63], [0.16-0.63], and [0.08-1.25] are 22, 20, and 19 MPa, respectively. For marble sand sizes of [1-4] and [3-8], the flexural strength are 17.5and 16 MPa, respectively. Similar results were shown by Jung et al. [4], who found an increase in strength as the sand became finer.

Compared to cement mortar, the high increase in flexural strength in epoxy resin mortars may be related to the high tensile strength of the epoxy resin, which reaches up to 30 MPa.

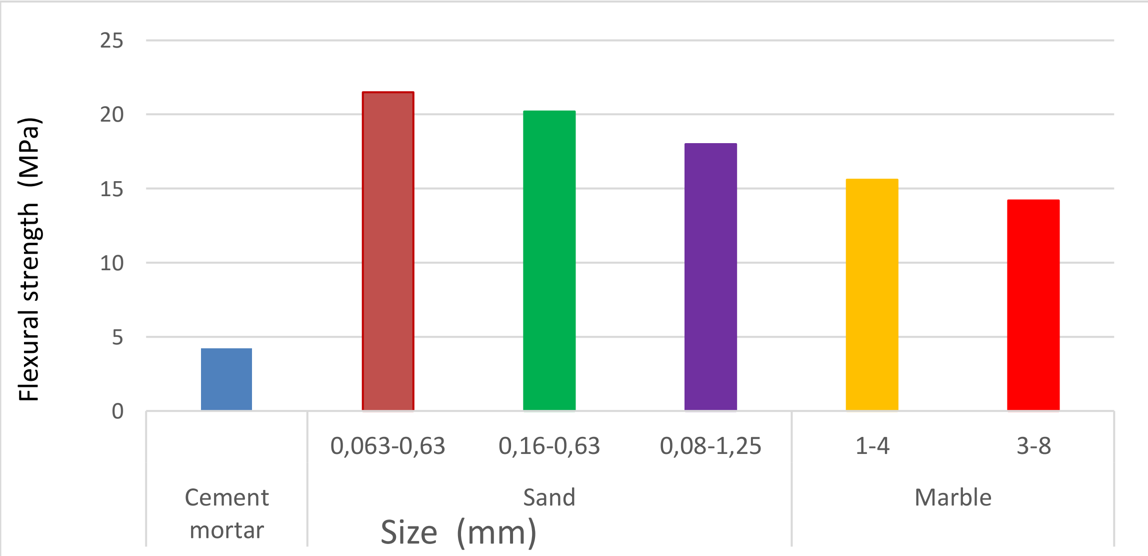

Figure 13. Influence of sand size on flexural strength of epoxy resin mortar

Effect of sand size on capillary water absorption

The water capillary absorption of cement mortar and epoxy resin mortars prepared with three different sizes of silica sand and two sizes of marble aggregates is presented in Figure14. It can be seen that the water capillary absorption of cement mortar is higher that than of all epoxy resin mortars. This is attributed to the higher porosity and capillary absorption of the cement matrix.

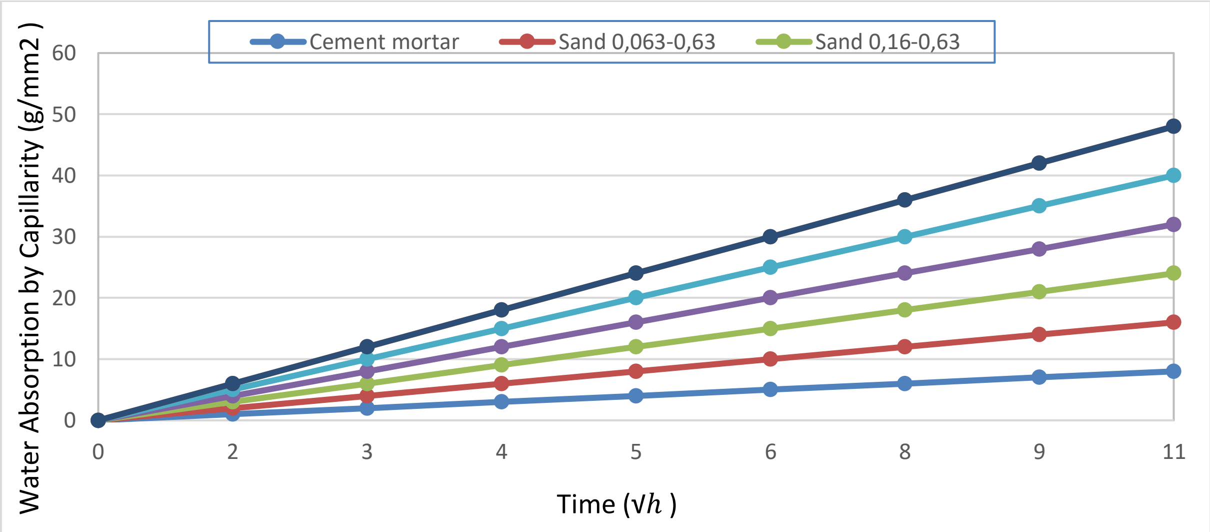

Figure 14. Influence of sand size on capillary water absorption of epoxy resin mortar

Effect of sand size on water absorption by immersion

The water absorption by immersion of both cement mortar and epoxy resin mortars prepared with three different sizes of silica sand and two sizes of marble aggregates is summarized in Figure 15. It is found that epoxy resin mortars do not absorb water, while the cement mortar absorbs 11.5% of its weight. Also, the water absorption of cement mortar is due to its porosity. However, the non-absorption in resin mortars can be attributed to the impermeability of epoxy resin.

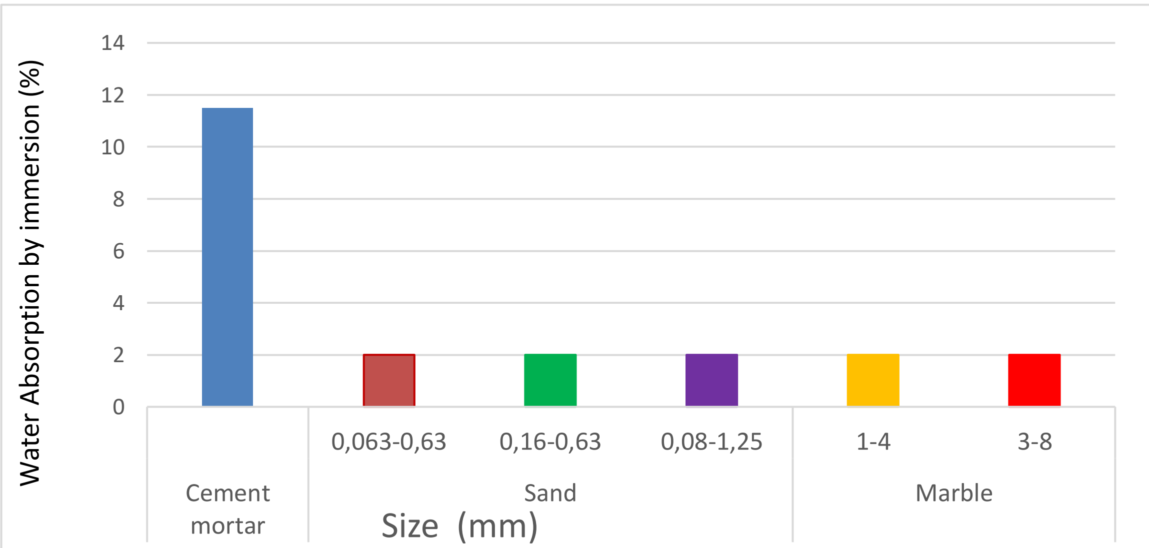

Figure 15. Influence of sand size on water absorption by immersion of epoxy resin mortar

Effect of sand size on Acid resistance

The behavior of mortars immersed in acid solutions has been studied by measuring the mass and compressive strength losses. Figure 16 shows the mass loss of the mortars after 90 days of immersion in aggressive solutions. It was found that all epoxy resin mortars has a good resistance under both $H_2SO_4$and HCl acid solutions. it was observed that all epoxy resin mortars have almost zero loss of mass. This can be explained by the impermeability of epoxy resin to the acid solutions. However, the mass loss is greater for cement mortar and is significantly higher in H_2SO_4solutionscompared to that of cement mortar immersed in 5%HCL solutions.

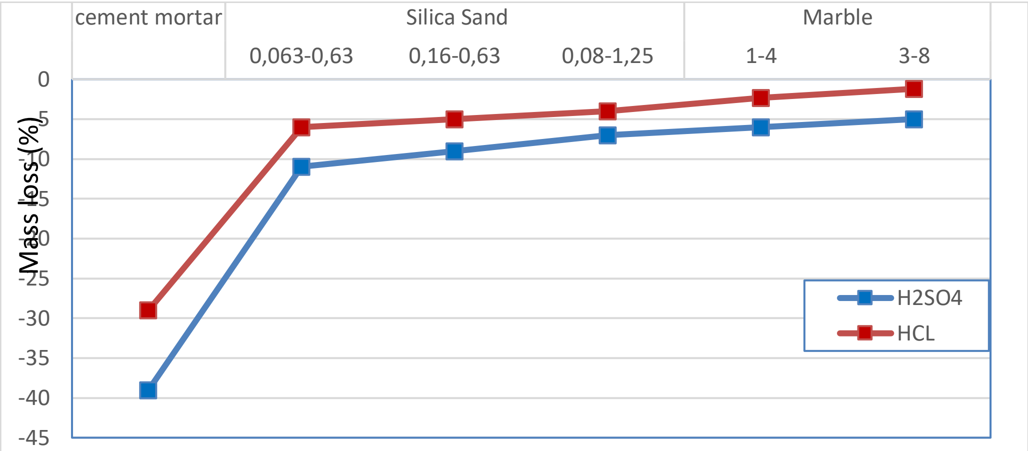

Figure 16. Mass loss of mortar immersed in acid solution at 90 days

Figure 17 and 18 shows the mass and compressive strength loss of cement mortar and all epoxy resin mortars when exposed to HCL and H_2SO_4 solutions. It was found that the resin mortars exhibited no significant loss in compressive strength, compared to cement mortar, which is very vulnerable to acid solutions. The loss in compressive strength was more significant in H_2SO_4 solution than in HCL solution. In addition, the improvement in durability of epoxy resin mortar increased when the size sand became finer.

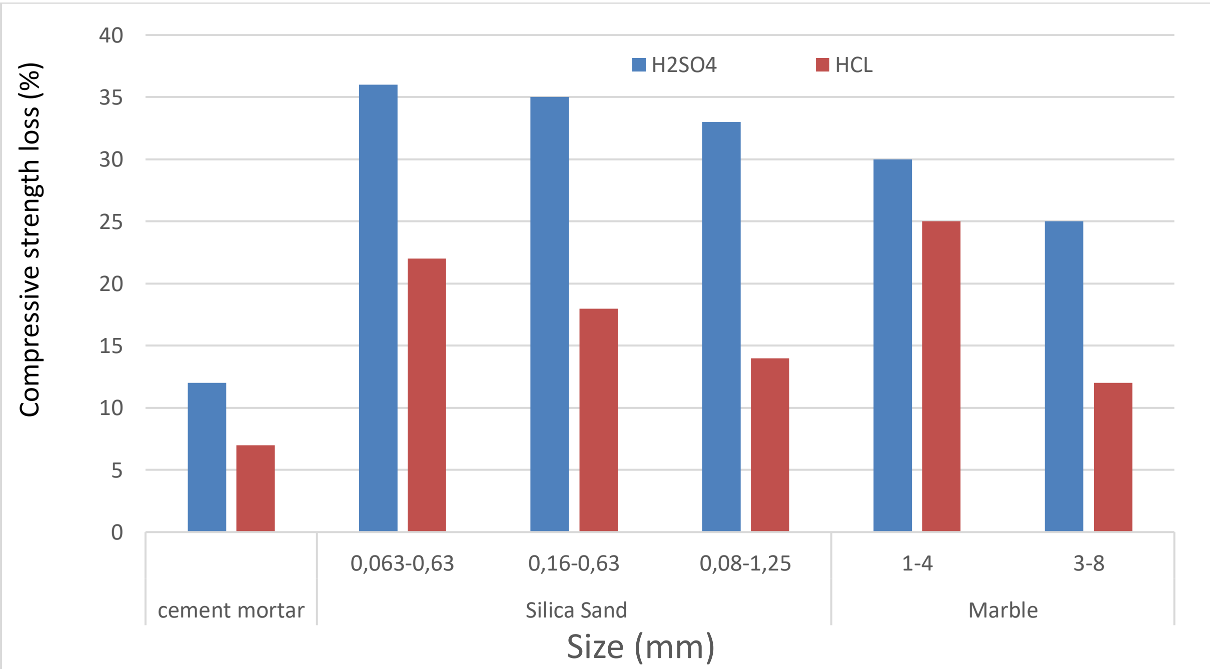

Figure 17. Compressive strength loss of mortar immersed in acid solution at 90 days

Effect of sand size on thermal conductivity

Figure 19 shows the comparison of thermal conductivities between cement mortar with the epoxy resin mortars prepared with three different sizes of silica sand and two sizes of marble sand. Results illustrate that the thermal conductivity of all resin mortars is lower than that of cement mortar.

The thermal conductivity of cement mortar is 1.75 W/m·K, whereas the thermal conductivities of epoxy resin mortars with silica sand sizes of [0.06-0.63], [0.16-0.63], and [0.08-1.25], and marble sand sizes of [1-4] and [3-8] are 1.02, 1.02, 1.07, 0.98, and 0.97 W/m·K, respectively. This difference can be attributed to the low conductivity of epoxy resin, estimated at 0.3 W/m·K.

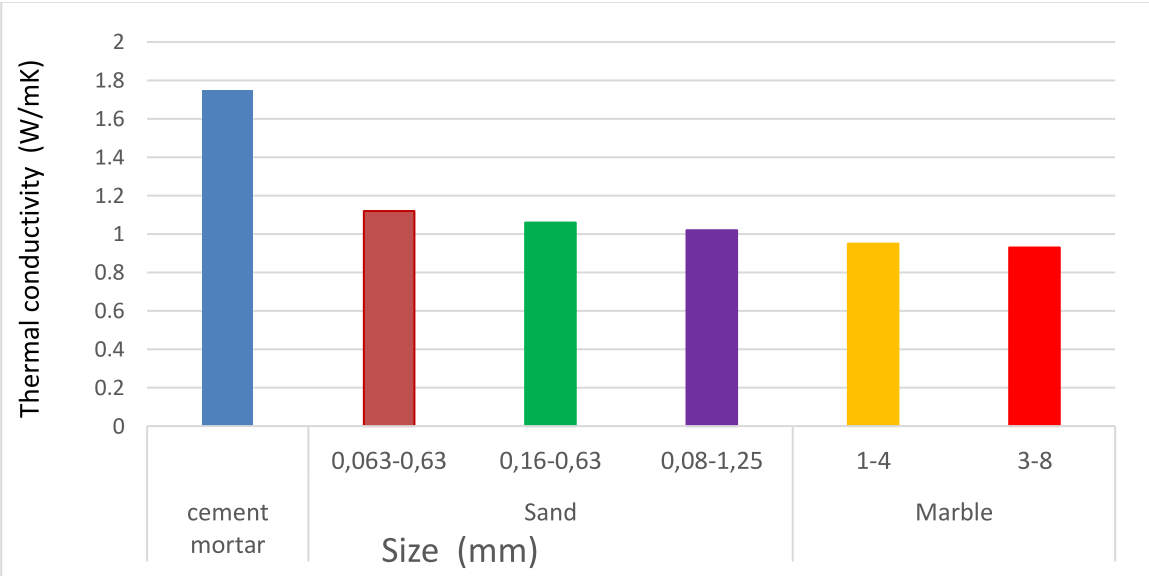

Figure 19. Influence of sand size on thermal conductivity of epoxy resin mortar

Conclusion

The present paper investigated the effect of sand particle size of epoxy resin mortars on mechanical strengths, water absorption, thermal conductivity, and the resistance to the HCl and H_2SO_4 acids. Based on the experimental results, the following conclusions can be drawn:

1- Finer sand significantly reduced the workability of the epoxy resin mortar.
2. Epoxy resin mortar with a single aggregate gradinghas a low mechanical strength.

3- Epoxy resin mortar containing fine sand have the lowest compressive and flexural strengths.
4- The combined grading of the 5 sizes of aggregates (three silica sand and two marble) offered the highest tensile bending strength (19.80Mpa).
5-Regardless of the size and type of sand, epoxy resin mortars has no water absorption ability.
6-Epoxy resin mortar has a high resistance to HCl and H_2SO_4acid solutions than the cement mortar.
7-Epoxy resin mortar exhibit high performance in comfort, since the thermal conductivity decreased.

Limitations of the research and recommendations for future research

This study has limitations because it focused on the study of epoxy resin mortars with just one size of sand and found a slight improvement in mechanical strengths. For future studies, we hope to study the effect of combining more one size of sand in order to enhance the mechanical strength and durability properties.

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