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Studying of Mechanical Behavior of Waste Materials Modified Cement Mortar

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ABSTRACT

Large-scale environmental problems have been triggered by ceramic tiles from demolished buildings and animal bone waste. Therefore, optimizing their potential for reuse and recycling is an important goal of sustainable solid waste management. The primary objective of this study is to evaluate the feasibility of partial replacement of the fine aggregates in cement mortar with a combination of natural animal bone powder and industrial waste materials which is wall tiles ceramic powder. This study measures thermal and mechanical characteristics. Recycling construction waste is one of many ways to deny waste material from entering landfills and create new eco-friendly material that reduces energy consumption in buildings. Modified mortar cement specimens with 5% up to 25% mixtures were combined using a 1:3 ratio and a 0.5 W/C ratio to see how the ratios would affect the material's properties. The addition of a superplasticizer boosted the cement mortar's workability and compressive strength. The compressive strength, flexural strength, density, and thermal conductivity were evaluated for each mortar mixture ratio. Results showed that compared to regular cement mortar, cement mortar combined with 20% bone and ceramic powder wastes reached the optimal replacement percentage. Compressive strength increased by 54% and flexural strength by about 67%. At the 28-day mark, thermal insulation was lowered by 25%.It is concluded from this study that it is possible to use bone waste as a natural material with ceramic waste as an industrial material to modify the insulation and mechanical properties of cement mortar.

Keywords: Ceramic; tile; animal bone powder; waste materials; mortar; aggregates.

1. INTRODUCTION

Cement mortar is a mixture of materials with fixed proportions of cement, sand, and water widely used in building and construction [1]. However, the expanding demand for cement mortar and concrete has exhausted the materials' natural resources, which is particularly problematic given the rising cost of building supplies. By adding pozzolans and similar components to a mortar's recipe, the cement content may be lowered while maintaining the same level of mechanical strength, thereby substituting a substance whose production requires a great deal of energy. Ceramic and animal bone wastes are solid wastes that can be gained from construction demolition and are by-products. These waste materials can be used as mortar mixture materials [2-3]. So, recycling these waste materials as modified materials is essential [4]. Oluborode and Ayeni [5] studied the effect of cow bones as a partial substitution for coarse aggregates in the concrete mixture. The mixing proportion employed was (1:2:4), and the percentage replacements were 5% up to 20%. They were cured for 7 to 112 days. Compressive strength improved with age but diminished with increasing replacement percentage. Based on these findings, the authors suggest using up to 20% of cow bones instead of conventional coarse aggregates. Ogarekpe [6] studied the convenience of partial substitution for fine aggregate in concrete mixtures by scalding and mashing cow bones. The proportions of 10% to 50% substituted the fine aggregates of cow bones, considering the mixture proportions of (1:2:4) and (1:11/2:3) mix ratios at 28 days of curing age.

Fapohunda et al. [7] inspected the fitness of mashed cow bone as a partial exchange of sand for the

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concrete mixture. The results indicated that the specimens' compressive strength and density decreased with the increased mashed cow bone percentage. The results also showed that the compressive strength would increase when comparing sand with mashed cow bones up to 20%.

Anderson et al. [8] looked at what would happen if a coarse aggregate was replaced by three different types of broken ceramics in a concrete mix in ratios ranging from 20% to 100%. The study's findings suggest that waste ceramic might be used as a practical substitute material for natural coarse aggregate with only minor alterations to the material's mechanical characteristics.

Sanitary ceramic wastes were utilized in place of aggregates in cement-based mortars by Wioletta et al. [9]. The research also studied the effect on pore volume, consistency, plasticity, and the mechanical properties of the flexural and compressive strengths. The results indicated that the flexural and compressive strength improved by 20wt.% sanitary ceramic substitution of fine aggregate while decreasing shrinkage.

Ravindra et al. [10] replaced the sand with crushed waste ceramic in cement mortar. The study included a physical description, strength properties, and a comparison of ceramic-fine aggregates with natural sand. The results appeared that the substitution ratio of natural sand with 10% fine ceramic aggregate achieved an improvement.

Javed et al. [11] substituted the coarse aggregates in concrete with 25%, 35%, 50%, and 100% crushed animal bones. The results were compared with standard concrete. The findings showed that the normal aggregates substitution of approximately 50% of the crushed animal bones was quite favorable in the compressive strength tests, with no arrangement in the concrete mix ratio (1:1.5:3).

The impact of cement replacement with bone powder on the mechanical characteristics of cement mortar was examined by Kotb et al. [12]. From 5% to 15% of the cement weight was replaced by substitutes. When 5% bone powder was added to cement mortar, the tensile and compressive strengths increased significantly.

The incorporation of ceramic shards into concrete was investigated by Torgal and Jalali [13]. The results indicated that replacing 20% of the cement in the concrete mix increases durability performance. The results also showed that ceramic aggregates used in concrete perform better relative to oxygen permeability, capillary water absorption, compressive strengths, and chloride diffusion.

Torkittikul and Chaipanich [14] studied the influence of adding fly ash and ceramic wastes to cement mortar and concrete. The study indicated that the compressive strength of concrete modified by ceramic waste increased with ceramic waste content, which recorded an optimum percentage of 50% for the control concrete. It was an inevitable result of there being less concrete available for construction. By contrast, when ceramic wastes were introduced to the mix at a 100% rate, the strength of the fly-ash-compressive concrete increased.

By substituting 15% fine ceramic aggregate (FCA) and 30% coarse mixed aggregate (CMA) for the natural sand, Gonzalez-Corominas and Etxeberria [15] were able to produce high-performance concrete. The results showed that concrete with up to 30% FCA has mechanical and durability attributes comparable to or better than standard concrete. To the same extent as high-performance conventional concrete, concrete with up to 20% CMA had a compressive strength of 100 MPa. Concrete containing up to 50% CMA showed minimal corrosion risk after 180 days.

The use of bone powder as a partial substitute for regular fine aggregates was investigated by Ogarekpe et al. [16]. Construction expenses may be cut by as much as 10% by using fly ash as a cement substitute in concrete operations. It has been studied and compared how regular concrete's mechanical and physical qualities change when normal aggregates are substituted with crushed animal bones vs. the usual aggregates found.

The flexural behavior of bone-pulverized foam concretes is studied by Opeymi and Makine [17]. They utilized forty-two cubes specimens. The research used bone powder with a range of bone content percentages, from 0% to 10%, spread out throughout 1.5%, 3.5%, 4.5%, 6%, 7.5%, 9%, and 10.5%, in place of cement. The results suggest that bone could be used instead of cement to make aerated concrete. This would mean less use of nonrenewable resources and less environmental pollution.

This study explores the influence of incorporating two types of natural waste materials (animal bones) and industrial waste materials (wall tiles ceramic) to show additional impact in improving the mortar mixture by recycling bones and ceramic materials as partial substitutions for fine aggregate in cement mortar.

2. EXPERIMENTAL WORK

2.1 Materials

i. Cement: Iraqi Ordinary Portland Cement was utilized in this research to prepare thespecimens. It was stored in a dry area to avert the harmful influence of moisture on the cement. Table (1) and Table (2) present the physical and chemical properties of cement, and they were adjusted to IQS No.5/1984 (Iraqi Standard Specifications) [18].

Table 1. Composition of fine-aggregate and Portland cement.

Chemical Compound	% Cement	%Fine-Aggregates
Fe_2O_3	2.9	0.53
Cao	64.53	5.4
MgO	3.62	0.81
SiO_2	19.41	83.56
Al_2O_3	4.42	0.54
SO_3	0.92	2.57
Na_2O	-	-
LOI	4	5.56

Table 2. Ordinary Portland cement's physical characteristics.

Characteristics	Values
Specific surface area (Blaine) (m2/kg)	330 m^2/kg
Soundness (Autoclave)	0.09%
Compressive- strength	
7 days	34.6 Mpa
3 days	25.13 Mpa
The Setting time (Vicat),	
Final setting	3:08 hr:min
Initial setting	1:15 hr:min

ii. Fine aggregates: The Al Nabaey area provided the fine aggregate utilized in this investigation. Tables (1) and (3) describe the grading of fine aggregate that complies with No. 45/1984 Zone 3 Iraqi Specification standards [19].

Table 3. Fine aggregate Characteristics.

Property	Fine-Aggregate
Bulk-specific-Gravity	2.64
Present- water-absorption	0.614
Apparent specific Gravity	2.690
Percent-wear loss Angeles abrasion	.....

iii. Bone powder: The bone powders were gained by crushing cow bones. They were washed and boiled in water; then, they were dried. Afterward, they would be appropriate for crushing to gain pulverized bone; the particles passed through a sieve (1.18) mm, replaced by sand. Table (4) indicates the chemical properties of the bone powder.

iv. Wall tiles ceramic: The wall tiles ceramic waste resulted from the building's demolition. It was crushed in the laboratory crusher and then milled to convert it into a fine powder to sieve it. The particles pass through the 1.18 mm sieve, substituted from the sand. Table (4) presents the chemical properties of the ceramic tiles.

v. Superplasticizer: Sikament FFN superplasticizers were utilized for 3% of the cement mass for all specimens. It reduces the mixture's water content and maintains operability. It increased the compression resistances.

vi. Water: Every mixing and curing step uses clean water.

Table 4. Chemical composition of Bone-Powder and Ceramic tiles.

Chemical compound	% Bone powder	% Ceramic tiles
MgO	1.3	3.6
CaO	52.45	3.64
Fe_2O_3	0.25	1
Al_2O_3	0.35	31
SiO_2	1.34	65
SO_3	0.41	-
Na_2O	1.6	1.41
LOI	1.2	-

2. 2 Mixture proportioning

The specimen preparation required a 1:3 mixture of Portland cement and fine aggregates and 0.5 w/c proportion, as given in Table (5). The developed samples were partially processed by replacing 5% to 25% of the fine aggregates with a mixture of animal bones and ceramic waste from wall tiles. The superplasticizers from Sikament FFN were utilized for the specimens at 3% of the weight of cement.

Table 5. Proportions of modified wastes –mortar- mixes.

%Mix Proportion BP%+CP% from sand		Cement (gm)	Sand (gm)	Bone Powder(gm)	Ceramic Powder(gm)	w/c
M0	0%	250	750	-	-	0.5
M1	2.5%+2.5%	250	712.5	356.25	356.25	0.5
M2	5%+5%	250	675	337.5	337.5	0.5
M3	7.5%+7.5%	250	637.5	318.75	318.75	0.5
M4	10%+10%	250	600	300	300	0.5
M5	12.5%+12.5%	250	562.5	218.25	218.25	0.5

3. Tests Methods

3.1 Compressive Strength

The experiments were performed following ASTM:C109M02 [20] employing (50 mm × 50 mm × 50 mm) testing cubes. They were tested using an ELE-Auto test, a compressive digital machine with a 200 KN capability. The test was conducted after 28 days of age.

3.2 Flexural Strength

The modulus of rupture was determined utilizing a (40 mm × 40 mm × 160 mm)prism manufactured in accordance with ASTM C348-14 standard [21]. Flexural strength is often stated as the rupture modulus (σ) in design regulations. This experiment demonstrates the advantages of material bends and breaks.

3.3 Density

The density of the cement mortar cubes was determined using the same method described in ASTM C188-17[22]: density = weight /volume.

3.4 Thermal Conductivity test

The ASTM C1058-03 and C177-10 US standards are utilized in this research to calculate the thermal conductivity coefficients (K) of cement mortar cubes [23]. The test employed the hot wire method, which measures the metal wire's temperature rise before thermal equilibrium. The temperature of the electric current was measured between models using two scales for every wire. The inspection equipment included (350 and 300) mm external and (300 and 250) mm internal cylinders. As thermal insulation, 5 cm-thick layers of glass wool separated the cylinders. A heater and brick cubes are on top of the cylinder. Thermal silicon was used to seal the cube's edges against heat loss. Temperature, current, and voltage were measured with a high-resolution multimeter (M890G) (i.e., the top of the device). Controlling the heater's voltage allowed the desired heat to penetrate the sample. The test lasted 8 hours. The readings came: Current and voltage are entering the heater. Fourier's Law was used to calculate K. According to the manufacturer's instructions, the temperatures gradually rose to 50°C and the maximum summer temperature for concrete. The current rose to 0.6 amps and the voltage to 3 volts.

4. Results and Discussion

4.1 The Compressive Strength

Figure 1 shows that the substitution developed the compressive strength with bone powder and ceramic powder alone in addition to the bone/ceramic powder mixture. The improvement in compressive strength is relatively minimal when adding bone and ceramic powder compared to the bone/ceramic powder mix. When ceramic powder and bone mix are combined up to 20%, the compressive strength increases by around 54.47% after 28 days. The superfine component pozzolanic reactivity of the ceramic powder aggregate influences this increase in strength. SiO_2 reacts with alkalis to form a cementitious product that develops the strength of mortar cement by filling in gaps and raising the density of the mortar, as well as acting as an accelerator for the hydration of cement [13]. In addition, 25% bone and ceramic powder in mortar reduce its compressive strength. Cement mortar's poor bonding of its components causes it to be higher than the reference mix and lower than the control. Balaha et al. [24] and Wioletta et al. [9] concur with this finding by modifying the compressive strength properties of cement mortar using bones and ceramic powder, respectively. The compressive strength of the ceramic and bone powder composite is shown in Figure 1.

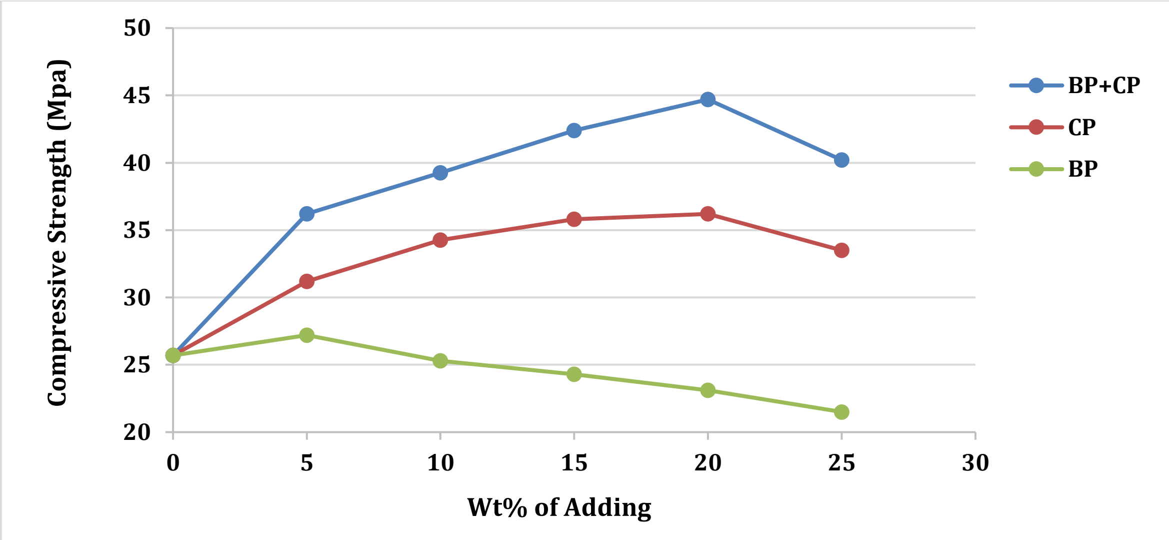

Figure 1. Compressive strength for fine aggregate replacement by bones powder, ceramic powder, and bones/ceramic powder mix at 28 days.

4.2 The Flexural Strength

Figure 2 displays the findings of the flexural strength tests, which indicate that the flexural strength outputs of bone powder and ceramic powder alone have a modest impact on outcomes. The flexural strength increases by increasing the bones/ceramic powder mix proportions from 5% to 20%. The rate of growth at 20% of the bones and ceramic powder mix is 67% at 28 days. An apparent pozzolanic reaction occurred within this time frame. They decreased as the mix's ceramic/bone powder amount increased since the inclusion of waste materials slowed the bonding process between the aggregates and the cement paste. Possible explanations for this behavior include the fact that the plasticity of fresh mortar is reduced due to the presence of the waste components, which prevents air voids from escaping during compacting and weakens the interfacial transition zone [11]. These results agree with those found by Ravindra R et al. [12] and Wioletta et al. [9] by improving flexural strength properties of cement mortar using bones and ceramic powder, respectively.

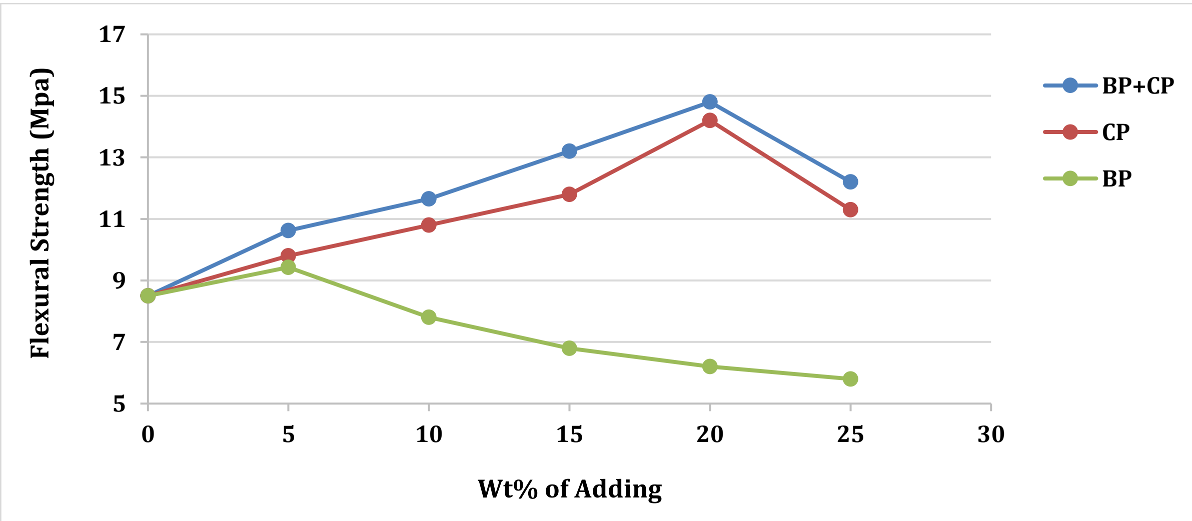

Figure 2. Flexural strength for fine aggregate replacement by bones powder, ceramic powder, and bones/ceramic powder mix at 28 days.

4.3 Density test

As seen in Figure 3, the mortar density fell as the percentage of additions increased to include both bone powder and ceramic powder alone, in addition to the bone and ceramic powder combination. The additions of bone and ceramic powders have lower specific gravities than the fine aggregate; therefore, density is often inversely proportional to a replacement. This may suggest that the waste materials aid the formation of the C-S-H gels in the pozzolanic reaction in the mortar. Density also tends to drop as mortar waste is replaced with new materials. It is likely because the more significant proportion of additives binding with the sand particles creates voids inside the cubes, reducing the mortar's density. The results are consistent with those of Silva et al. [25] and Vejmelková et al. [26] by decreasing the density of cement mortar using bones and ceramic powder.

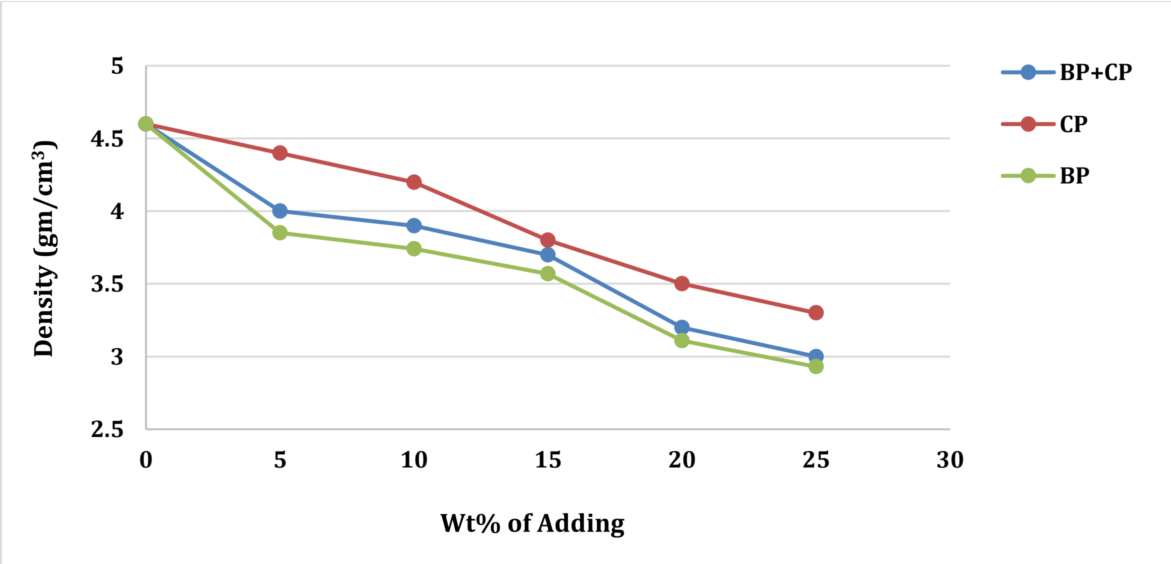

Figure 3. Density for fine aggregate replacement by bones powder, ceramic powder, and bones/ceramic powder mix at 28 days.

4.4 Thermal conductivity

Thermal conductivity is defined as the ability of mortar to allow temperature to pass through it. Thermal conductivity has a positive relationship with density. When density is low, so is thermal conductivity.. Adding bone powder, ceramic powder, and a blend of bone and ceramic powder, all increased the heat conductivity of the mortar (see Figure 4). There was a decrease in heat conductivity, with rates ranging from 24% for the bone powder to 48% for a bone/ceramic powder combination to 53% for ceramic powder at a ratio of 25%. This finding demonstrates the compounds' effective thermal insulating properties. This finding agrees with Vejmelková et al. [26] by decreasing the thermal conductivity of cement mortar.

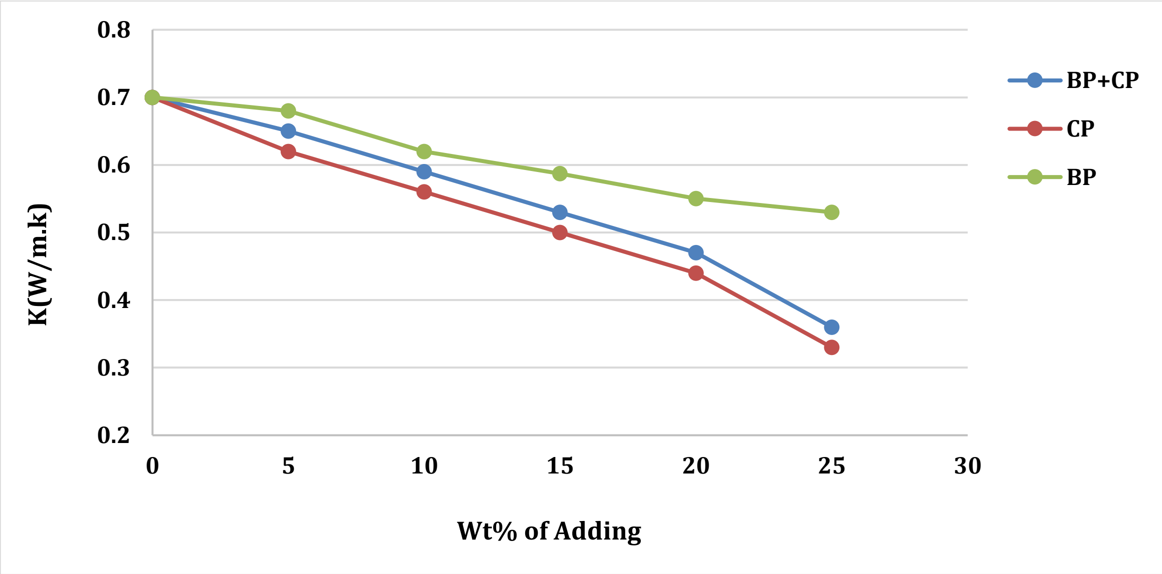

Figure 4. Thermal for fine aggregate replacement by bones powder, ceramic powder, and bones/ceramic powder mix at 28 days.

5. Conclusions

This research appears that the mechanical properties of the mortar cement had been improved by substituting the mixed (ceramic and bone powder) wastes for fine aggregates. The primary inferences drawn from the comparison of traditional cement mortar with waste-modified cement mortar in experimental settings are as follows:
1-The mechanical properties of cement mortar could be enhanced by using the ceramic and bone powder mixture.
2- The optimum proportion of ceramic and bone powder replacement mixture was 20% over this proportion, and the results of the modified cement mortar tests began to decrease.
3- An improvement in compressive strength resulted from the combination of ceramic and bone powder. The highest increase was obtained for samples containing 20% of the combination, which was approximately 54.47%..
4-The flexural strength of the modified mortar cement at 20% replacement was higher than the reference samples by about 67%.
5-Using ceramic and bone powder mix remarkably decreased the density.
6-The thermal conductivity reduced by about 24% by adding a bone powder, 48% by adding the mixed bone and ceramic powder, and 53% by adding ceramic powder compared to the reference mix.

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