JJEES

Jordan Journal of Earth and Environmental Sciences

JJEES (2024) 15 (3): 216-224
ISSN 1995-6681

The Development of Fine Precast Concrete Mix Using Local Materials

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Received September 23th, 2023; Accepted November 15th, 2023

Abstract

The imperative to enhance the quality of precast concrete is evident, with a particular focus on augmenting its physical and mechanical attributes by incorporating concrete admixtures. This research centers on the utilization of phosphate minerals and finely ground glass within concrete mixes, with substitution ratios ranging from 15% to 60% of fine sand within the mix. The investigation encompasses multiple facets, including examining material blending, assessing fresh concrete properties (slump), and evaluating both physical and mechanical characteristics of hardened concrete at 7-day and 28-day intervals, juxtaposed against the properties of a control concrete mix. The findings reveal several significant outcomes. Firstly, the incorporation of phosphate minerals leads to a remarkable increase in the slump of concrete, reaching 75mm, in stark contrast to the 20mm slump observed in the control mix. Conversely, introducing fine glass elevates the slump to 60mm while maintaining a constant water-to-cement ratio of 0.48 across all concrete mixtures. Furthermore, the density of the hardened concrete demonstrates notable variations. The control mix boasts a density of 2375kg/m3, whereas the phosphate minerals and fine ground glass result in reduced densities of 2258kg/m3 and 2100kg/m3, respectively, at the 7-day and 28-day intervals. In terms of compressive strength, the 7-day results indicate a decrease to 8MPa with the use of phosphate and fine ground glass minerals, compared to the 13MPa strength observed in the control mix. At the same time, the compressive strength increases to 21MPa for phosphate "Shedyah," compared to 20MPa for the control mix. Phosphate "Abiad" and fine ground glass yield compressive strengths of 15MPa and 16MPa, respectively, at the 28-day mark. Regarding tensile strength, the 7-day figures reveal 1.25MPa for the control mix, and the introduction of phosphate materials results in both increases and decreases, with values remaining similar to the control mix. Conversely, the 28-day tensile strength diminishes to 2.75MPa and 2.5MPa for "Shedyah" and "Abiad," respectively, in contrast to the 3.5MPa exhibited by the control mix. The use of fine ground glass materials results in a tensile strength of 1.8MPa. Lastly, the flexural strength of the control mix stands at 2.5MPa, a value that can be maintained with "Shedyah" phosphate but reduces to 2MPa when "Abiad" phosphate is introduced. Fine ground glass fines maintain a flexural strength of 1.5MPa at 7-day, compared to the 3.25MPa of the control mix, with subsequent fluctuations resulting in strengths of 2.75MPa for "Shedyah" phosphate, 2.5MPa for "Abiad" phosphate, and 2.25MPa for ground glass fines.

Keywords: *Phosphate, Fine Ground Glass, Concrete Mix, Mix Design*

1. Introduction

The construction industry is continuously evolving with a growing emphasis on sustainability and environmental responsibility. Fine precast concrete—a versatile and widely used construction material— has gained attention due to its potential for enhancing sustainability in the construction sector. Incorporating local materials, such as glass waste, into concrete mix design, is one approach that can reduce the environmental impact of concrete production. The addition of raw and natural materials is common in concrete mix production (Ghrair et al, 2022), while maintaining or even improving its performance characteristics (Smith & Brown, 2022). Furthermore, concrete is globally used as a building material for its economy, formability, durability, availability of components, and its suitability for use in a variety of environments, given its exceptional compressive strength competitively, compared to other popular building materials (Kizilkanat et al.2015, Sadrmomtazi et al.2018). Though concrete is weak in tensile strength, it could be improved using fibers or using natural mineral materials. This literature review explores the development and utilization of fine precast concrete mixtures using local materials such as phosphates raw material and fine waste glass bottles as supplementary material. The improvement in properties of the concrete mix is essential in construction work and concrete technology to improve the quality in compliance with concrete specifications of contract, approval, and satisfaction of construction work (Sarireh et al, 2021; Ghrair et al, 2018). Also, Kennouche et al., 2022 applied the use of plastic waste and its effect on concrete properties.

Several case studies and real-world applications have demonstrated the feasibility and effectiveness of

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incorporating glass waste and local materials into fine precast concrete. The use of industrial products is common in concrete-based fiber content (Iqbal et al., 2015).

According to Johnson & Green (2020), glass waste, typically sourced from post-consumer glass products or industrial waste, has been identified as a promising supplementary material for concrete. It can replace a portion of traditional aggregates, such as sand and gravel and, thus, reduce the demand for natural resources. The incorporation of glass waste also offers the advantage of diverting waste from landfills, contributing to waste management and recycling efforts. In addition, Gonzalez & Patel (2019) reported that various studies have proposed optimization techniques to maximize the benefits of using glass waste in fine precast concrete. This process includes optimizing the particle size distribution of glass waste, adjusting the cement content and considering other supplementary materials, such as pozzolans and chemical admixtures. Also, the use of Jordanian volcanic tuff in aggregate for the production of light-weight concrete (Dwairi et al., 2018).Phosphate-based materials, such as phosphor content or glass fine materials are employed in low temperature building conditions (Aliha et al., 2017). Also, Anderson and Patel (2021) introduced the use of phosphate raw materials in concrete for sustainable aspects and objectives.

Adding fibers to a concrete mix enhances its mechanical qualities, such as strength when subjected to bending, tensile, and fatigue forces. Concrete's toughness, ductility, and non-linear behaviour are, thereby, improved by the fibers (Iqbal et al. 2015); Hannawi et al. (2016); Santarelli et al. (2014). In general, the fibers improve the crushing capacity of the members of the structure and stop micro cracks in concrete. As indicated that the use of local natural materials such as crushed and rounded aggregate in concrete production in Karak and Tafila area are shown in two studies on concrete mix. The first one is Sarireh, 2015-a. It uses local materials of crushed limestone aggregate and rounded valley aggregate for testing concrete properties, and the second one is Sarireh (2015-b) that uses the optimum percentage of volcanic tuff in concrete mix production. Also, the use of basalt aggregate materials in concrete mix production and improvements in concrete production and strength (Sarireh, 2017). In addition to the use of local materials of aggregate in concrete mix production in a national project in the twelfth governorates in Jordan (Sarireh and Al-Baijat, 2019-a). Also, the use of blast furnace slag in concrete mix production is considered an important improvement in concrete compressive strength, tensile strength, and flexure of material of concrete (Al-Baijat and Sarireh, 2019-a).

Fibers are randomly dispersed discrete components that are used to stop cracks from propagating or forming in concrete owing to external or internal stresses (Aliha et al. 2017 & Aliha, et al. 2018). Fibers play a key role in the post-cracking zone, and their inclusion could improve concrete's toughness and energy absorption capacity. Because a single fiber could only be successful in a single aspect dependent on fiber size and type, the total performance of concrete is improved by the addition of different fibers (Rooholamini et al. 2018).

It is difficult and expensive to improve cement through the addition of additives and needs advanced technical solutions (Sarireh, 2020). The current case study is concerned with adding admixtures directly to the concrete mix. In this study, three fine materials (phosphate Shedyah, phosphate Abiad, and fine glass) of similar size of sand in the concrete mix are tested and used as samples for density, compressive strength, tensile strength, and flexural strength of concrete, compared with the control concrete mix. The study aims to test the impact of adding phosphate Shedyah, Abiad, and fine ground glass materials to the physical and mechanical properties of precast fine concrete.

2. Research Methodology

This study includes the design and testing of fresh and hardened properties of precast fine concrete mix through using phosphate Abiad, Shedyah, and glass fines in replacement with the fine sand in concrete mix at percentages of 15, 30, 45, and 60%. It is an effective and innovative procedure to use different materials to improve the properties of fresh and hardened concrete. A former study was done to use Tripoli materials as cement replacement to produce concrete mix and test its fresh and hardened properties (Sarireh and Al-Baijat, 2019-b), and also, the use of Tripoli in the concrete mix in replacement with a sand component in the concrete mix (Al-Baijat and Sarireh, 2019-b).

For the fine concrete mix design, the mix contains only Addaseyah as the maximum size of aggregate (12-6mm), Semsemeyah (6-2 mm), and fine sand (2-0.6 mm). The new mixed materials of phosphate of Abiad, phosphate of Shedyah, and fine ground glass were replaced with the sand portion in the concrete mix.

Physical and chemical analysis of proposed materials was conducted, and specific volumes of proposed materials were prepared for the concrete mix at the designed ratios of materials. Also, w/c ratio is considered constant at 0.4 for all concrete mixes following the instructions of testing methodology (Ghrair et al., 2018).

112 samples of concrete cubes were prepared to test density (unit weight) and compressive strength of concrete on 7-day and 28-day periods, in addition to 96 samples of cylinders for tensile strength test conducted at 7-day and 28-day periods. Also, 96 beam samples were prepared for flexural strength test at 7-day and 28-day periods. Samples were prepared for control mix and other mixes of phosphate and fine ground glass materials 15, 30, 45, and 60% ratios. Also, the slump of each fresh concrete mix was tested (3) times and the average of slump values was calculated for all concrete mixes. Samples were kept in distilled water tank for curing at 18^{o}C temperature until testing times at 7-day and 28-day periods.

2.1 Cement

Cement is a material with adhesive and cohesive properties that allow it to bond with the components of the concrete mixture. Ordinary Portland Cement (OPC) Type I was used in the concrete mixes according to EN 197-1-2011 standards with 3.15 specific gravity. Table 1 shows the chemical and physical properties of the OPC used.

Table 1. The Physical and Chemical Properties of OPC.

Chemical and physical properties	Percentages (%)
Silicon Oxide (SiO_2)	20.41
Aluminum Oxide (Al_2O_3)	4.51
Ferric Oxide (Fe_2O_3)	3.43
Calcium Oxide (CaO)	64.74
Magnesium Oxide (MgO)	1.99
Sulfur Trioxide (SO_3)	2.9
Potassium Oxide (K_2O)	0.52
Sodium Oxide (Na_2O)	0.32
Tricalcium Aluminate (C3A)	7.5
Chloride (Cl)	0.03
Loss On Ignition (L.O.I)	1.15
Specific Service Area	3550 cm^2/g
Initial Setting Time	155 min.

2.2 Aggregate and Sand

Since aggregates represent the majority of the volume of concrete, it is important to determine their physical properties, including size, shape, texture, porosity, absorption, moisture content, and bulking of fine components. These characteristics influence concrete strength and durability, as well as the water to cement ratio (w/c), which influences concrete quality.

According to the ASTM C33/C33M-16 standard, the aggregate was chosen based on the original rocks, specific gravity, and particle size. All aggregates were provided by the Jordanian Manaseer Group. The aggregate types used in the experiment were as follows:

Limestone is the source of medium aggregate, and it was used in this study with a maximum size of 9.5 mm (3/8 in.) and also passing sieve No. 4 (4.75 mm). The medium aggregate is known as Adaseyah and has a Sp.Gr. (dry) of 2.57, Sp.Gr. (SSD) of 2.55, Sp.Gr. (Apparent) of (2.65), bulk density of 1500 kg/m3, absorption of 2.5%, and abrasion of 29%. Table 2 shows specific gravity of used materials in concrete mix.

Table 2. Specific Gravity of Mixing Materials.

Material	Sp. Gr. (Dry)	Sp. Gr. (SSD)	Sp. Gr. (App)	Bulk Density	Absorption	Abrasion
Medium Aggregate	2.566	2.546	2.649	1500	0.025	0.29
Sand	2.616	2.629	2.65	1577	0.005	-----
Glass	2.67	2.58	2.69	1680	0.004	----

Fig. (1) presents the mixing materials that were used in fine concrete mixing design in current project. Ordinary and original materials include Addasseyah medium aggregate, Semsemeyah fine aggregate, and fine sand. And the new mixing materials include phosphate material from Abiad mining site that is close to Al-Hasa area in Tafila and Shedyah from Shedyah mining site in Ma'an, in addition to the fine ground glass by collecting waste glass bottles, cleaned and ground to sand gradation size. Also, phosphate materials were employed in fine precast concrete production as conducted by Smith and Greenfield, P. (2022).

Figure 1. Materials of Fine Concrete Mix Design.

For the quantities of mixed materials in concrete mix, Table 3 shows the quantity of concrete design for preparing mix 1m3 of concrete, in addition to the volume of cement and w/c ratio of the mix.

Table 3. Quantities of Mixing Materials of Fine Concrete Design.

Material	Gradation (mm)	Quantity Kg/m^3
Addaseyah	4-9.5	1,000
Semsemeyah	2-4	501
Sand	0.06-2	501
Cement	---	391
Water	---	190

**w/c ratio is 0.48*

The admixtures of Phosphate (Shedeyah and Abiad) and glass fine were mixed separately at ratios 15, 30, 45, and 60% in replacement with sand materials in the mix are presented in Table 4.

Table 4. Ratios and Quantities of Admixtures in Fine Concrete Mix Design.

Material	Quantity Kg/m^3	Admixture Ratio			
		15%	30%	45%	60%
Sand or Fines	501	75.15	150.3	225.45	300.6

2.3 Chemical Composition of Fine Ground Glass

A quantity of 15kg of glass was collected and ground to get the size gradation relevant to that of fine sand to be mixed at 15, 30, 45, and 60% ratios in the concrete mix. Table 5 shows the chemical composition of glass fines that was used in the concrete mix.

Table 5. Chemical Composition of Glass

Oxides	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O
%	70.4	1.9	1.2	10.3	14	0.4

2.4 Chemical Composition of Jordanian Phosphate

The chemical analysis of constituents in phosphate materials and their percentages are important as the materials will be used in substitution of fine sand. The required quantities are prepared from Jordanian phosphate from Shedyah and Abiad mining sites in the south of Jordan. Table 6 presents the chemical composition of Jordanian Phosphate in Abiad and Shedyah in Jordan.

Table 6. Chemical Composition of Jordanian Phosphate

Phosphate Source	Na_2O	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	$Ti O_2$	MnO	Fe_2O_3
Abiad	0.0	1.23	0.56	29.17	0.09	54	0.02	0.02	0.3
Shedyah	0.0	1.17	0.48	29.54	0.1	52.7	0.04	0.03	0.29

2.5 Mixing and Sampling

The required wooden fair-face molds were prepared to cast the concrete mix properly. The molds were prepared in the specific dimensions for each test. Molds for concrete compressive test and density were prepared in (150x150x150mm) cubes, where cylindrical metal molds were considered for splitting the tensile strength of concrete, and wooden fair-face molds were prepared for the flexural strength of concrete. Fig. (2) shows the molds of sampling in the current Project.

(a) Molds of Concrete Compressive Strength (b) Molds of Flexural Strength (c) Molds of Tensile Strength

Figure 2. Molds of Concrete Samples

The mixing is done by hand in the work site for controlling the mix and other mixes with admixtures of Abiad and Shedyah phosphates and fine glass materials. Samples were taken as 6 samples for each parameter of physical and mechanical properties of concrete at 7-day and 28-day periods. Fig. (3) shows the mixing stage and quantity of concrete that was prepared each time.

2.5.1 Testing of Fresh Concrete Mix

One of the important test for fresh concrete is the slump test (ASTM C143) that is able to evaluate workability and the presence of humidity and its required levels, considering construction type and application. After mixing concrete ingredients, concrete ingredients including aggregate, sand, cement, and water are mixed for control mix design and other mixes for added materials, and concrete is poured in the frustum cone on (3), layers and each layer is compacted (25) strokes to evaluate the workability and consistency (humidity) of concrete, slump is measured to the nearest mm for concrete. Fig. (4) presents the mechanism of conducting slump test to concrete.

Figure 3. Mixing Operation for the Study of Concrete Properties

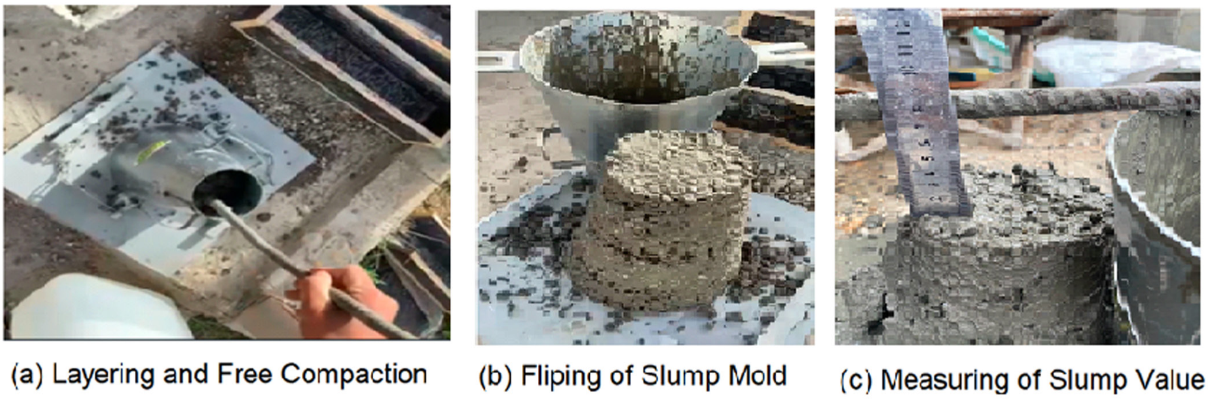

Figure 4. Slump Test for Fresh Concrete Mix

2.5.2 Sampling of Concrete Specimens

Cube samples (150x150x150mm) of 12 were taken to represent the test of compressive strength of control concrete mix and other mixes using Abiad phosphate and Shedyah phosphate and fine glass materials. 6 samples will be tested on 7-day, and other 6 ones will be tested on 28-day period. Samples of concrete are prepared according to ASTM C31/C31M-22, the standard practice for making and curing concrete test specimens in the Field. Fig. (5) shows the preparation of samples of concrete mix. Also, 12 samples were taken for splitting tensile strength in order to be tested on 7-day and 28-day periods. In addition, 12 samples were taken to test the flexural strength of concrete.

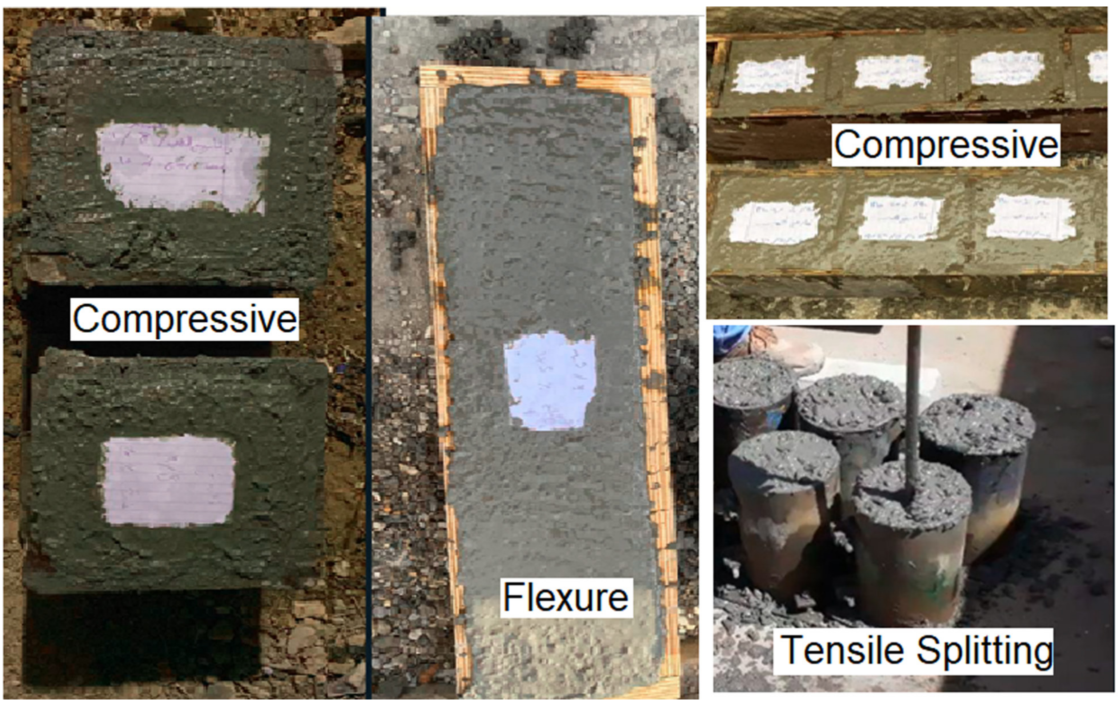

Figure 5. Samples of Concrete Mix for Compressive, Flexural, and Tensile Strengths

2.5.3 Curing and Testing of Concrete Samples

Samples of concrete, when prepared, were kept 24 hours in molds to insure drying process. Then, they were dismantled and kept in distilled water for curing up to 7-day and 28-day periods in order to be tested for density, compressive, tensile, and flexural strengths for control mix and all other mixes were made by Abiad phosphate, Shedyah phosphate, and glass fine materials. Fig. (6) presents the curing of concrete samples for 7-day and 28-day periods until testing samples.

Figure 6. Curing of Concrete Samples

After curing of samples for 7-day and 28-day periods, six samples are weighed and tested for compressive strength. After 28-day, other six samples were also weighed and tested for compressive strength. The weight is used to calculate density of concrete at 7-day and 28-day periods. Fig. (7) shows the compressive strength test of concrete. Also, the shape of failure or fracture of cube specimen is shown to be ideal for all samples.

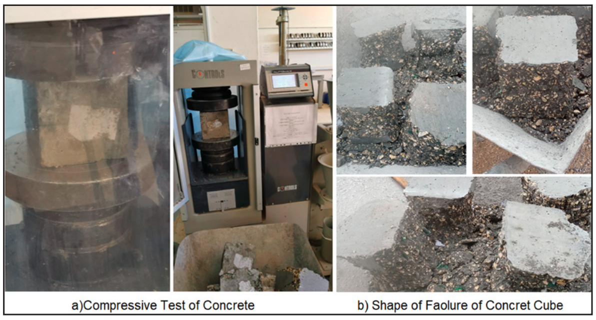

Figure 7. Compressive Strength Test and Shape of Failure for Cube Specimens.

Also, similar numbers of samples are tested for tensile and flexural strengths of concrete on 7-day and 28-day periods when cured for the same periods respectively. Fig. (8) shows the test of tensile and flexural concrete strength.

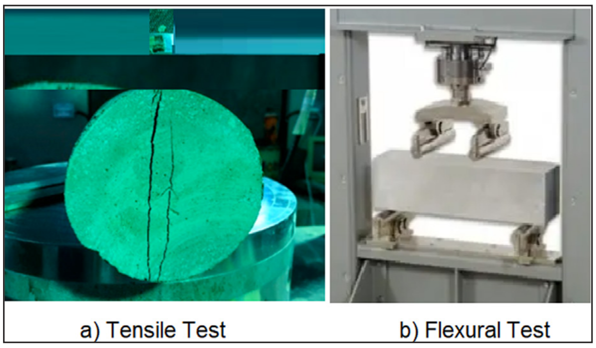

Figure 8. Tensile and Flexural Tests of Concrete.

3. Results and Discussion

3.1 Slump Test of Fresh Concrete

Slump value is an important property for concrete that the workability of concrete is measured using slump value at fresh state, in addition to other tests such as flow table and VB-Time. Figure (9) presents the slump values for control concrete mix, and other concrete mix of Phosphate Abiad, Phosphate Shedya, and Glass fine at the mixing ratios 15, 30, 45, and 60% in concrete mix. Fig. (9) presents the value of slump for the concrete mix on different ratios of phosphate materials from Abiad and Shedyah mining and glass fines during mixing.

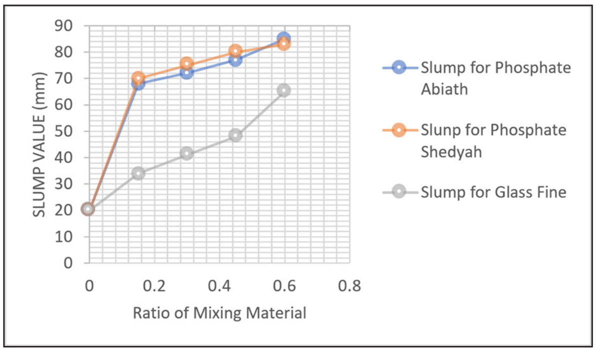

Figure 9. Slump Test of Fresh Concrete.

3.2 Density and Unit Weight of Hardened Concrete

Density and unit weight of concrete are both the most important properties of concrete to test and determine the type of concrete such as to be light weight, normal, or heavy weight concrete. Figure (10) presents the density of concrete at 7-day age of concrete when different materials are mixed in replacement with fine sand in concrete mix. Materials included Phosphate Abiath, Phosphate Shedyah, and Glass Fine materials mixed at once. Fig. (10) presents the density of concrete using the phosphate and glass fines in concrete.

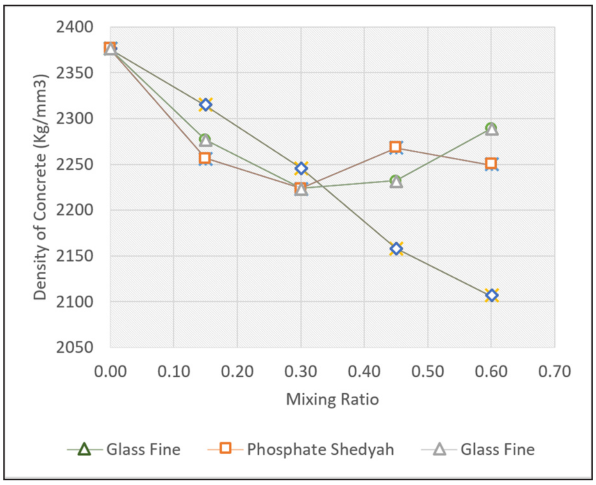

Figure 10. Density of Hardened Concrete at 7-day Period.

Also, it is necessary to evaluate density of concrete at 28-day period. The density of concrete at 28-day period is presented in Fig. (11).

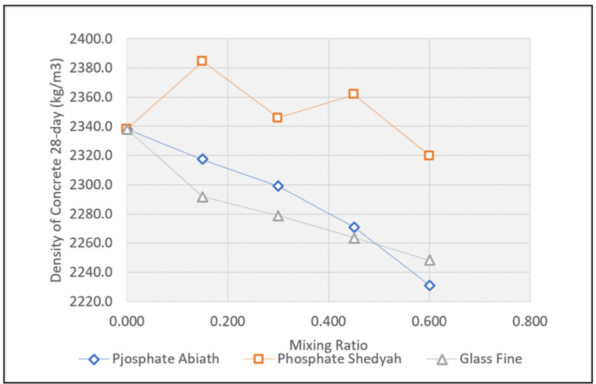

Figure 11. Density of Hardened Concrete at 28-day Period.

Also, Fig. (12) presents the unit weight of concrete using phosphate materials and glass fines material that were used in concrete mix.

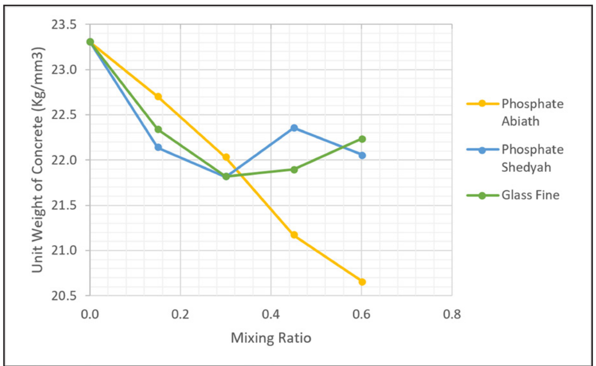

Figure 12. Unit Weight of Concrete at 7-day Period.

Fig. (13) presents the unit weight of concrete that was evaluated on 28-day period of concrete in the current project. The unit weight is an important property of concrete that is used in calculating the dead load of structures during design and evaluating of loads and structures.

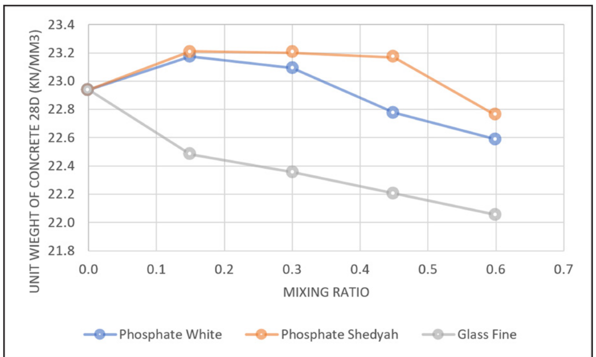

Figure 13. Unit Weight of Concrete at 28-day Period.

3.3 Compressive Strength

Compressive strength also is an important for concrete at the hardened state and is tested using cubic or cylinder molds. The cubic molds (15x15x15 cm) were used for testing and evaluating of compressive strength of concrete. Fig. (14) presents the compressive strength of concrete mix using phosphate materials and glass materials at 7-day age.

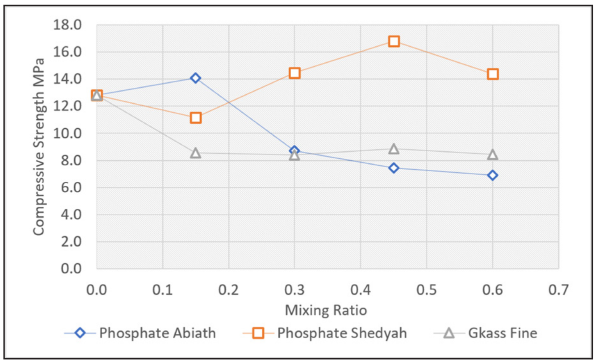

Figure 14. Compressive Strength of Concrete at 7-day Period.

Also, to follow the development of strength the compressive strength in concrete is evaluated at 28-day period. Fig. (15) presents the compressive strength of concrete at 28-day age of concrete.

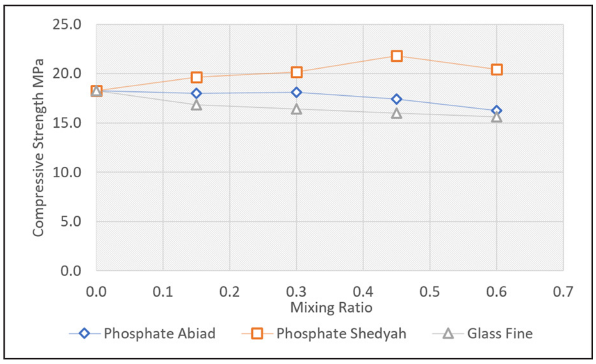

Figure 15. Compressive Strength of Concrete at 28-day Period.

3.4 Tensile Strength by Splitting

Tensile strength is an important property of concrete as the concrete can afford a minimal tensile strength when subjected to tension stresses in beams and slabs and columns. Fig. (16) presents the tensile of concrete, using phosphate and glass fine materials at 7-day period.

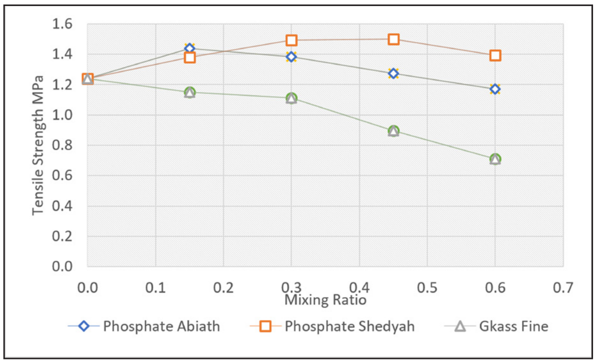

Figure 16. Tensile Strength of Concrete at 7-day Period.

The tensile strength of concrete is another indication on the quality of concrete and the improvement of concrete strength in general, Additional tests need to be made to adopt a decision that the concrete of good or specific quality. Fig. (17) presents the splitting tensile strength at 28-day age of concrete.

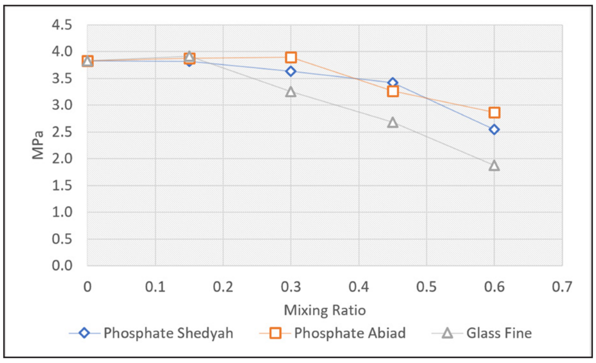

Figure 17. Tensile Strength of Concrete at 28-day Period.

3.5 Flexural Strength

Flexural strength, also, is an important property for the concrete specially for beams and slabs to resist flexural stresses and for columns to resist buckling. Fig. (18) and Fig. (19) present the flexural stresses in concrete using phosphate and glass fine materials 7-day and 28-day periods.

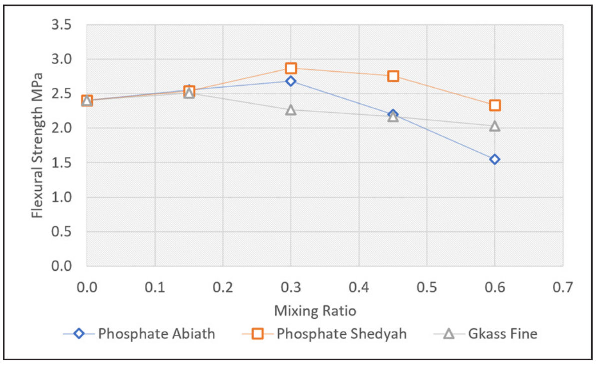

Figure 18. Flexural Strength of Concrete at 7-day Period.

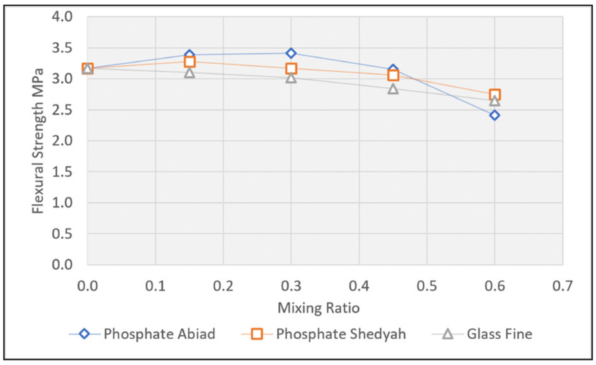

Figure 19. Flexural Strength of Concrete at 28-day Period.

4. Conclusion

According to the findings of the study, the following conclusions can be highlighted:

1. Using phosphate materials from Abiad and Shedyah sources can increase slump value up to 70-80mm, compared to 20mm for control mix, without increasing of w/c ratio (0.4) to maintain the increase in compressive strength of concrete mix.
2. Also, slump value is increased from 35mm to 65mm using glass fines in concrete mix.
3. Density of control mix at 7-day is 2375 kg/m^3, and density is decreased to 2275-2250 kg/m^3 when Shedyah and Abiad materials of phosphate, while it could be decreased into 2100 kg/m^3 when glass fines materials are used at 7-day period. While the density at 28-day could be maintained using Shedyahm, it still decreases using Abiad and glass fine materials. Similar conclusions could be elicited on unit weight of concrete.
4. The compressive strength of the control mix is 13 MPa, while it was decreased to 8 MPa using phosphate of Shedyah and glass fines.
5. Compressive strength at 28 days can be maintained, using phosphate of Shedyah up to 21 MPa compared to the compressive strength of control mix that maintained 20 MPa while it was decreased to 15MPa and 16MPa using glass fine and phosphate of Abiad respectively.
6. The tensile stress of the control mix is 1.25MPa at 7-day, while it is increased and decreased again to maintain this strength using phosphate from Abiad and Shedyah, and it is decreased all the time using glass fine materials.
7. Tensile strength of control mix is 3.75MPa at 28-day period, while it is maintained by Shedyah and Abiad to decrease to 2.75 and 2.5MPa respectively. And it is decreased using glass fine materials to 1.8MPa.
8. The flexural stress of the control mix is 2.5MPa and could be maintained using Shedyah phosphate at 2.5MPa. It could also be decreased to 2MPa using Abiad Phosphate. By using glass fines, the flexural stresses is maintained on 1.5MPa at 7-day.
9. The flexural strength is 3.25MPa of the control mix and starts to increase but to decrease to 2.75 for Shedya, 2.5 for Abiad, and to 2.25 to glass fines.

5. Recommendations

1. It is recommended to use materials that can help in reducing water/cement ratio and increase strength or do not affect strength adversely.
2. It is recommended to use phosphate materials and glass fines up to 20% to increase and improve the slump of the concrete mix.
3. It is recommended to use phosphate from Shedyah and/or Abiad sources up to 20% by replacing fine sand in concrete mix to keep strength parameters accepted.
4. It is recommended to expand and apply the research widely to prove the results and generalize them clearly.

Acknowledgement

The researchers would like to direct their acknowledgements and thanks to the staff in the laboratories of concrete in Tafila Technical University, in Mu'tah University, The Southern Engineering laboratory in Karak, and the staff of Laboratory of Karak General Work Directorate. Also great thanks are granted to the students in Civil Engineering Department in Tafila Technical University: Ahmad Al Huwian, Omar Al Rubaihat, and Mohammad Saqrayreh for their efforts in fulfilling the current research.

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