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## IMPLEMENTATION OF FELDSPAR AS A PARTIAL REPLACEMENT MATERIAL IN CEMENT MORTAR (EXPLORATION AND APPLICATION)

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*This paper aims to explore and evaluate the use of Jordanian Feldspar as a natural resource partial replacement material for cement and sand in cement mortar. First, Al-Jaishia area was explored through a global positioning system (GPS) navigation to gather site samples of Feldspar raw material. Then, cement and sand were partially replaced by Feldspar with substitution ratios of 5%, 10%, 15%, 20%, and 25% for each. The study included the effect of cement replacement on normal consistency and setting time for cement paste. The water content along with initial and final setting times increased with the increment of cement replacement ratio. Moreover, mechanical properties (compressive, flexural, and residual compressive strengths) of cement mortar with cement and sand replacement were evaluated. The compressive and flexural strengths after 3, 7, and 28 days of curing were examined for both cement and sand replacement. While, residual compressive strength for cement replacement after 28 days was measured at elevated temperatures of 400°C, 600°C, and 800°C. The compressive and flexural strengths decreased by increasing the Feldspar replacement ratio for both cement and sand at all specimen ages. Whereas, heat resistance properties were improved by cement/Feldspar replacement. The best result for residual compressive strength was obtained at 15% replacement ratio and 400°C temperature.*

*Key words: Feldspar, cement mortar, compressive strength, normal consistency, setting time, Palestine grid*

### INTRODUCTION

Recently, building construction scientists have been looking for the optimum use of natural resources as a replacement material in cement mixture. One of the natural resources that can be used as a replacement material for both aggregate and cement is Feldspar. The majority of aggregates used in concrete come from metamorphic and igneous rocks that contain different ratios of Feldspar minerals. Due to their physical and mechanical properties, Feldspar minerals can be used as a substitution material for aggregates in concrete mixture. Moreover, using Feldspar as a replacement material for cement in concrete mixture can decrease the total cost of mixture since it can be easily found and extracted worldwide (especially in Jordan) in large quantities. In addition, utilizing Feldspar as a replacement material is an environmentally friendly alternative that decreases the amount of pollution caused by cement manufacturing.

Feldspar minerals are basic components of igneous, metamorphic, and sedimentary rocks [1] that have quite similar structures, chemical compositions, and physical properties. Common Feldspar minerals are composed of orthoclase ( $\text{KAlSi}_3\text{O}_8$ ), albite ( $\text{NaAlSi}_3\text{O}_8$ ), and anorthite ( $\text{CaAl}_2\text{Si}_2\text{O}_8$ ). Feldspar is a mineral that persists on both of Earth's continental crust and Earth's oceanic crust. On the Earth's continental crust, Feldspar exists as the main component of igneous rocks along with granite and

granodiorite rocks. While, on the Earth's oceanic crust, Feldspar is found in gabbro and basalt rocks as an important constituent. Jordan is a country rich in industrial rocks and minerals of different origins. Feldspar ores are one of the most plentiful ores available in large quantities in the southern part of Wadi Araba as well as the southwestern part of the southern mountainous deserts of Jordan. Five areas in the southern part of Jordan were investigated and indicated to be a good source for Feldspar production [2]. The areas are Wadi Mahloba (51 km north east to Aqaba city), Jabal Abu Al Ghoufran (18 km north east to Aqaba city), Wadi Hood Al-Sufun (7 km south to Aqaba city), Wadi Araba (5 km east to Aqaba airport), and Al-Jaishia (about 8 km east to Aqaba city). These five sample locations are illustrated in Fig. 1. The rocks in the study areas are part of the Precambrian Arabian Shield of Jordan which is locally called Aqaba Complex [3, 4]. The estimated amount of Feldspar reserves in Al-Jaishia, which is the area under study in the current research, exceeds 115 million tons [5].

Several materials have been exploited as a replacement material in concrete mixtures in the last decades. For instance, palm oil boiler clinker was used by [7] as a substitution material for natural fine aggregate in cement mortar. The compressive strengths of the mortar were enhanced after a curing period of 28 days. In addition,

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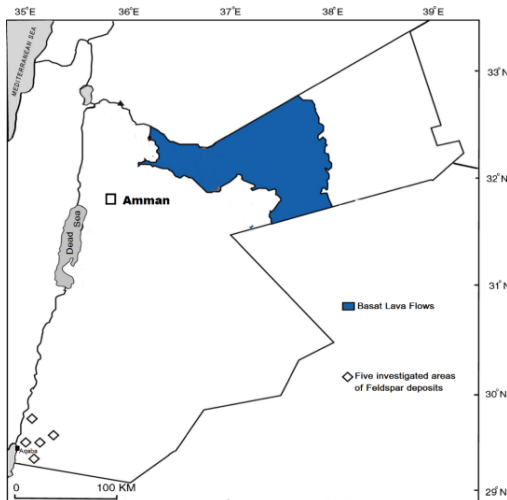


Figure 1: Location map of the Feldspar deposits existing in the southern part of Jordan adapted after [2, 6]

the utilization of sand waste marble dust as an additive in cement production was investigated by [8] and the obtained results were encouraging. Ones of the most popular materials that were used in concrete as replacement for cement are silica fume and fly ash [9]. The authors showed that the compressive strength increased when 10% of cement was replaced by Silica fume and Fly ash. Since Feldspar is a material rich in sodium and potassium, it was considered as a potential source of alkalis released into the concrete pore solution and contributed in activating the alkali–aggregate reaction [10]. The impact of the aggregate contents of quartz and K-Feldspar on the microstructure and mechanical properties of Geopolymeric bricks was studied by [11]. The results indicated that the compressive strength of Geopolymeric bricks did not remarkably affected by the aggregate contents of quartz and/or K-Feldspar. In [12], Mortars with different alkali-bearing Feldspar minerals released significant amounts of alkali ions. The study indicated that the mortars containing feldspar showed a steady state of alkali release during the age of specimens. In [13], the effect of replacing cement with Mica and Feldspar on rheological, mechanical, and durability of self-compacting mortars were investigated. The cement partially replacement ratios with Mica and Feldspar were 10, 20, and 30%. A little decrease in the mechanical properties was observed by Mica and Feldspar replacement. In [14], mineral and engineered Feldspars were used as a partial replacement of white cement. The replacement ratios were 15% and 25% of the cement weight. The results showed that the engineered Feldspar avoided the alkali-silica reaction effect regardless of its alkaline content. Furthermore, the thermal properties of the white cement were improved by adding Feldspar. In [15], Feldspar was examined as a partial and total replacement material for sand in white cement mortars. The thermal and optical properties of white cement mortar improved by replacing sand with Feldspar. However, the replacement degenerated the mortars resistance.

In this research, the Feldspar that exists in Al-Jaishia area was investigated as a partial alternative material for cement and sand in cement mortar. Al-Jaishia area was explored through Global Positioning System (GPS) navigation and samples of Feldspar raw material in this area were collected. Then, tests were carried out on both cement paste and cement mortar by partially replacing cement and sand with the collected Feldspar at different ratios. The properties of both fresh and hardened cement mortar were examined. This research paper will proceed as follows. First, a section is dedicated for the exploration of Feldspar. Then, the experiments for cement mortar are illustrated. Finally, results and discussion in addition to the conclusion are introduced at the end of paper.

### EXPLORATION OF FELDSPAR EXISTING IN AL-JAISHIA AREA

The coordinates of the four boarder points along with the center point of Al-Jaishia area (5x10.5 km) were taken out from the Natural Resources Authority (NRA) map provided by [16, 17], resulting in a total of five points (Fig. 2). In order to take the advantage of the semantic features (e.g.; roads, highways, mountains, ..., etc.) appearing Google Earth® software, these five points were located on Google Earth® software (Fig. 3). Then, a site GPS navigation for the Google Earth® points was performed using the GPS unit integrated in smartphone device and samples of Feldspar raw material were collected from different zones in Al-Jaishia area and taken to the lab for analysis.

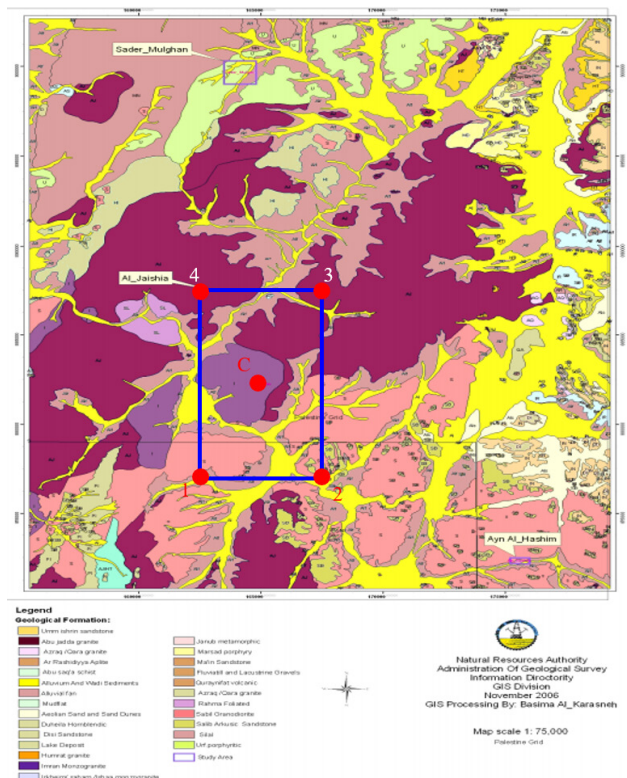


Figure 2: Compiled geologic map for Al-Jaishia area adopted after [16, 17]



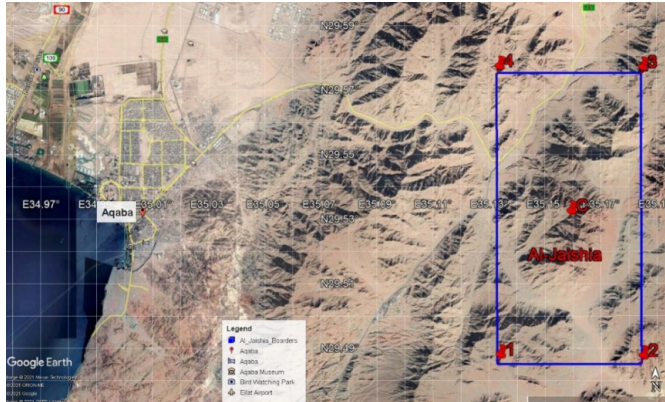


Figure 3: Al-Jaishia area on Google Earth® software

The points' coordinates were transformed from the Palestine Grid Projection coordinate system utilized in the Natural Resources Authority map [16, 17] to the WGS 1984 ellipsoid coordinate system used by Google Earth®. First, the point coordinates were transformed from the Palestine Grid Projection coordinate system to the Clarke 1880 (Benoit) ellipsoid coordinate system (the ellipsoid on which the Palestine Grid Projection is based) according to the parameters illustrated in Table 1. Then, a coordinates transformation was completed from the Clarke 1880 (Benoit) ellipsoid coordinate system to the WGS 1984 ellipsoid coordinate system according to the parameters shown in Table 2. A detailed explanation of the transformation process can be found in [18]. The coordinates of points in question in both of the Palestine Grid Projection coordinate system and the WGS 1984 ellipsoid coordinate system are listed in Table 3.

### EXPERIMENTS OF FELDSPAR REPLACEMENT

Two sets of experiments were performed in the current research and denoted as Set 1 and Set 2. For Set 1 of experiments, the tests were performed on cement paste. The normal consistency test was applied to measure the water content of specimens. Besides, the setting times for specimens were measured by applying the initial and final setting time tests. On the other hand, Set 2 of experiments was conducted on cement mortar. In this set of experiments, the mechanical properties of cement mor-

Table 1: Parameters of Palestine Grid projection adopted after [19, 20]

Parameter	Palestine Grid
Ellipsoid	Clarke 1880 (Benoit)
Semi-major Axis	6,378,300.789m
Inverse flattening	293.4663155389802
Projection Type	Transverse Cylinder
Projection Name	Cassini-Soldner
Latitude of Origin	31.73409694444445°
Central Meridian	35.21208055555556°
False Easting	170,251.555 m
False Northing	1,126,867.909 m
Scale Factor	1
Datum	Palestine_1923
EPSG Code	28191
Usage	Cadastral/Engineering

tar specimens were investigated though applying compression, flexural, and heat resistance tests. The details of all tests are explained in the following sub-sections.

### Materials

In this study, the primary components used for preparing both of cement paste and cement mortar specimens were cement, sand, and Feldspar collected from the site. Ordinary Portland Cement (OPC) produced by the AL-Manaseer Company was used based on [22]. Local sand was used for mix designs with saturated surface-dry (SSD) conditions conformed to the standard specifications stated in [23]. The size of used sand particles was determined as the size of particles passing through sieve #4 (4.75 mm) to sieve #200 (0.075 mm). The gradation curve of sand was obtained according to the standard [24] resulting in a fineness modulus of 2.50. Feldspar raw samples, which are ranged in size from medium to coarse grains [17], were obtained from Al-Jaishia area as described earlier. The Feldspar samples were washed and sieved. The sizes that passed from sieve #4

Table 2: Transformation parameters from Clarke 1880 (Benoit) ellipsoid to WGS 1984 ellipsoid adopted after [21]

Ellipsoid	$\Delta a$ (m)	$\Delta f$	$\Delta X$ (m)	$\Delta Y$ (m)	$\Delta Z$ (m)
Clarke 1880 (Benoit)	-163.790	-5.47E-05	-200	-53	282

Table 3: Points' coordinates for Al-Jaishia area

Point	Palestine Grid Projection		WGS 1984 Ellipsoid	
	Easting (m)	Northing (m)	Latitude	Longitude
C	165000	882250	29.527885409°N	35.158650331°E
1	162500	877000	29.480509148°N	35.132898184°E
2	167500	877000	29.480529839°N	35.184452213°E
3	167500	887500	29.575256370°N	35.184426460°E
4	162500	887500	29.575235599°N	35.132824377°E

(4.75 mm) and retained at sieve #100 (0.150mm) were used as partial replacement material for sand. Whereas, the sizes that passed from sieve #200 (0.075mm) were crushed by a ball mill and used as partial replacement material for cement (Fig. 4). The chemical composition and physical properties of both cement and Feldspar are summarized in Table 4 where it can be inferred that the component that has the highest percentage in cement is CaO (66.2%), whereas the main component of Feldspar is SiO<sub>2</sub> (71.4%). In addition, the gradation curves for sand and Feldspar are shown in Fig. 5.



Figure 4: Feldspar passed from sieve #200 (0.075mm) and crushed by ball mill (used as a partial replacement material for cement)

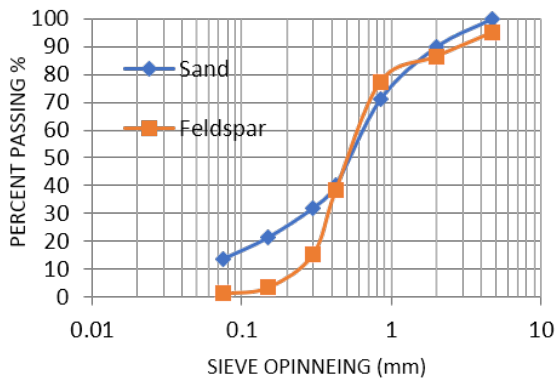


Figure 5: Grain Size Distribution for sand and Feldspar

### Specimen preparation

As mentioned earlier, two sets of experiments were performed. For Set 1, the control mix (0% cement/Feldspar replacement) was prepared and assigned as Control 1. Then, a ratio of the cement used in the cement paste was replaced by Feldspar at different ratios (5%, 10%, 15%, 20%, and 25%) resulting in five additional mixes (Mix 1 to Mix 5). The properties of mixes are shown in Table 5.

For Set 2, the control mix (0% cement/Feldspar replacement and 0% sand/Feldspar replacement) was prepared and assigned as Control 2. Two groups of specimens for cement mortar were prepared. In the first group of specimens (Group 1), Control 2 along with five ratios (5%, 10%, 15%, 20%, and 25%) for cement/Feldspar replacement were used. While, in the second group (Group 2), Control 2 along with five ratios (5%, 10%, 15%, 20%, and 25%) for sand/Feldspar replacement were used. The proportion of cementitious material to fine aggregate to water for Control 2 was set as 1: 2.75: 0.485 according to [25]. The two groups of specimens are illustrated in Table 6 and Table 7.

### Tests Procedure

After completing the specimen preparation, experiments for Set 1 and Set 2 were performed. In the cement paste set of experiments (Set 1), cement/Feldspar replacement was investigated. Normal consistency test and setting time tests were carried out on Control 1 and Mix 1 to Mix 5. The normal consistency test was conducted using the Vicat apparatus according to [26] to measure the normal consistency of the cement paste specimen. As indicated in the aforementioned reference, the normal consistency is defined as the amount of water required for the Vicat plunger (10mm in diameter) to penetrate the cement paste specimen by 10 mm in 30 seconds. For initial and final setting time tests, the Vicat apparatus was used according to the testing standard indicated in [27]. The initial setting time is defined as the time required for a Vicat testing needle of 1 mm diameter to penetrate the specimen by 25 mm. Whereas, the final setting time is

Table 4: Properties of consumed materials

Chemical properties (%)	SiO <sub>2</sub>	CaO	MgO	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	Fineness Modulus	Density (g/cm <sup>3</sup> )
Cement (OPC)	17.38	66.2	0.02	9.69	---	0.86	---	1.12	---	3.15	3
Feldspar	71.4	1.04	0.37	1.03	13.9	0.85	5.30	4.90	0.03	2.80	2

Table 5: Cement/Feldspar ratios of mixes used for cement paste experiments (Set 1)

Mix Number	Cement Content (g)	Cement/Feldspar Replacement (%)	Feldspar Content (g)
Control 1	300	0	0
Mix 1	285	5%	15
Mix 2	270	10%	30
Mix 3	255	15%	45
Mix 4	240	20%	60
Mix 5	225	25%	75

the time required for no penetration of the Vicat testing needle into the specimen.

In cement mortar set of experiments (Set 2), three tests were performed: compression test, flexural test, and heat resistance test. The compression test was carried out at room temperature (20°C - 24°C) according to [25] using cubes 50 x 50 x 50 mm in size. The flexural test was performed at room temperature by loading a simply supported prism beams of size 40 x 40 x 160 mm at their mid-spans according to [28]. Finally, for heat resistance test, the residual compressive strength was observed for specimens at elevated temperatures of 400°C, 600°C, and 800°C according to [29].

Two groups of tests were completed for the Set 2 experiments. For Group 1 of the tests (cement/feldspar replacement), both compression and flexural tests were carried out on different mixes (Control 2 and Mix 6 to Mix 10) at specimen ages of 3, 7, and 28-days. Heat resistance test was conducted on the same mixes (Control 2 and Mix 6 to Mix 10) at a specimen age of 28-days. Whereas, for Group 2 of tests (sand/feldspar replacement), compression and flexural tests were executed on different mixes (Control 2 and Mix 11 to Mix 15) at specimen ages of 3, 7, and 28-days. It should be noted that, for all tests performed for Group 1 and Group 2, the obtained results represent the average results for three specimens.

## RESULTS AND DISCUSSION

### Cement paste

In this sub-section, the results obtained for Set 1 (cement paste) of experiments are illustrated. Normal consistency tests were conducted to calculate the amount of water content in the cement paste corresponding to the different ratios of cement/Feldspar replacement (see Table 8 and Fig. 6). The table and figure depict that the value of water content increased by the increment of cement/Feldspar replacement ratio. Concerning setting time tests, as shown in Table 9 and Fig. 7, both initial and final setting times increased by the increment of cement/Feldspar replacement ratio. The reason behind the above results is that the ordinary Portland cement (OPC) has two components (C<sub>3</sub>A and C<sub>3</sub>S) that control amount and temperature of hydration reaction and setting time. Accordingly, when replacing the cement by other material (Feldspar), the amount of these two components (C<sub>3</sub>A and C<sub>3</sub>S) decreases and results in increase of the water content and both of initial and final setting times. Furthermore, comparing to cement particles, Feldspar particles absorb high amount of water in the mixture owing to their fine composition.

Table 8: Results for normal consistency test

Mix Number	Cement/Feldspar Replacement (%)	Water Content (g)	W/C (%)
Control 1	0	84	28%
Mix 1	5%	93	31%
Mix 2	10%	102	34%
Mix 3	15%	105	35%
Mix 4	20%	111	37%
Mix 5	25%	120	40%

Table 6: Cement/Feldspar ratios used for cement mortar experiments (Set 2/Group 1)

Mix Number	Cement Content (g)	Sand Content (g)	Water Content (g)	Water/Cementitious Material (%)	Cement/Feldspar Replacement (%)	Feldspar Content (g)
Control 2	300	825	145.5	48.5	0	0
Mix 6	285	825	145.5	48.5	5%	15
Mix 7	270	825	145.5	48.5	10%	30
Mix 8	255	825	145.5	48.5	15%	45
Mix 9	240	825	145.5	48.5	20%	60
Mix 10	225	825	145.5	48.5	25%	75

Table 7: Sand/Feldspar ratios used for cement mortar experiments (Set 2/Group 2)

Mix Number	Cement Content (g)	Sand Content (g)	Water Content (g)	Water/Cementitious Material (%)	Cement/Feldspar Replacement (%)	Feldspar Content (g)
Control 2	300	825	145.5	48.5	0	0
Mix 11	300	784	165.4	48.5	5%	41
Mix 12	300	743	185.8	48.5	10%	83
Mix 13	300	701	205.6	48.5	15%	124
Mix 14	300	660	225.5	48.5	20%	165
Mix 15	300	619	245.4	48.5	25%	206



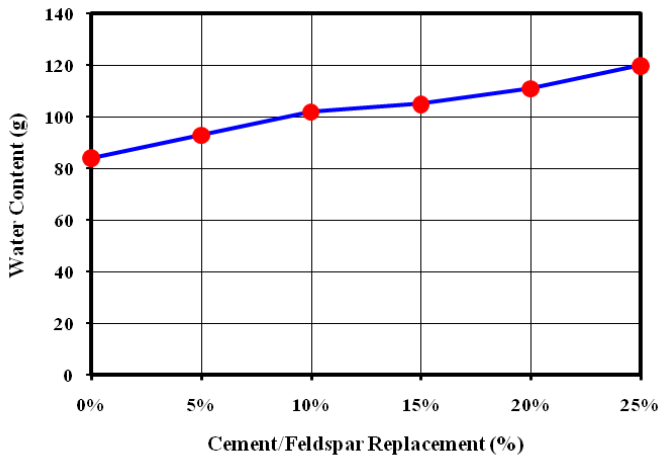


Figure 6: Water content versus cement/Feldspar replacement percentage

Table 9: Initial and final setting times

Mix Number	Cement/Feldspar Replacement (%)	Initial Setting Time (min.)	Final Setting Time (min.)
Contro l1	0	45	144
Mix 1	5%	47	149
Mix 2	10%	51	155
Mix 3	15%	54	161
Mix 4	20%	56	163
Mix 5	25%	60	167

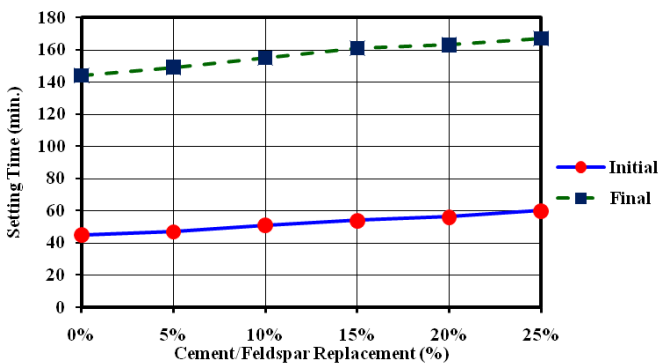


Figure 7: Setting time versus Feldspar percentage

### Cement mortar

For Set 2 (cement mortar) of experiments, compression, flexural, and heat resistance tests were performed for Group 1 of the specimens (cement/Feldspar replacement), while only compression and flexural tests were conducted for Group 2 of the specimens (sand/Feldspar replacement).

### Cement / Feldspar replacement

The results obtained for the compression tests conducted on Group 1 (cement/Feldspar replacement) are shown in Fig. 8, while results for flexural tests are shown in Fig. 9. The figures reveal that the best results at all

ages of the specimens for both compressive and flexural strengths were obtained for Control 2 (0% cement/Feldspar replacement). Results then deteriorated by increasing the replacement ratio. The reason, according to [13], is that when the Feldspar is added to the cement mixture it absorbs a part of the existing water needed to complete the hydration process which thereby results in drying the mixture and causes a reduction of strengths. As observed during the experiments, the percentages of reduction of both compressive and flexural strengths obtained at different replacement ratios comparing to that obtained for Control 2 (0% cement/Feldspar replacement) improved by increasing the age of specimen from 3 to 28 days. For instance, at 3-days age of specimen, the percentages of reduction of compressive strength were 22, 40, 44, 48, and 51% for 5, 10, 15, 20, and 25% replacement ratios, respectively. Whereas, at 28-days age of specimen, the percentages of reduction of compressive strength were 9, 16, 30, 31, and 35 % for 5, 10, 15, 20, and 25% replacement ratios, respectively. This is due to the high pozzolanic reaction of Feldspar developed gradually by the reactive amorphous SiO<sub>2</sub> content of Feldspar [7].

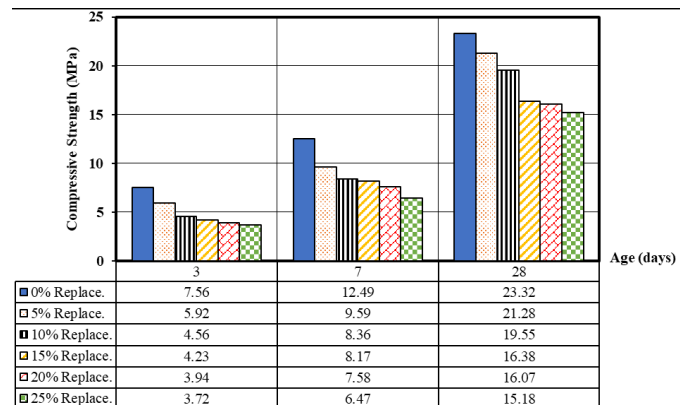


Figure 8: Compressive strengths for cement/Feldspar replacement

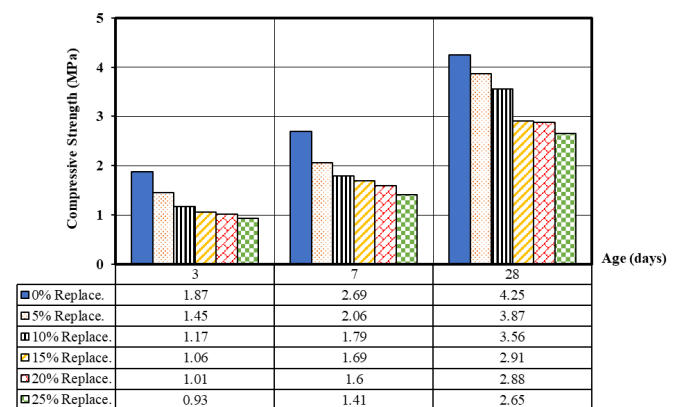


Figure 9: Flexural strengths for cement/Feldspar replacement

The results obtained for heat resistance tests at elevated temperatures of 400, 600, and 800°C are demonstrated in Fig. 10. As can be concluded from the figure, the residual compressive strength at all elevated temperatures

increased from the 0% cement/Feldspar ratio (Control 2) to 15% ratio (Mix 8). At 400°C elevated temperature for instance, the percentages of increasing of residual compressive strength with respect to Control 2 were 3, 5, 19% for 5, 10, 15% cement/Feldspar replacement ratios, respectively. By contrast, the residual compressive strength decreased from 15% ratio (Mix 8) to 25% ratio (Mix 10) at all elevated temperatures. Referring back to Table 4 to analyze the trend of results from 0% to 15% ratios, we notice that the fineness moduli of cement and Feldspar are 3.15 and 2.80, respectively. This means that the particle size of Feldspar is finer than that of cement and, by consequence, Feldspar has a specific surface area higher than cement. As reported in [30], the decrease in particle size (increase in specific surface area) results in the increment of water absorption capacity. Additionally, the lower thermal conductivity coefficient of Feldspar results in higher thermal resistance [13] which leads to the increment of residual compressive strength. In contrary, from 15% to 25% replacement ratios, the Feldspar works as a filling material (not binder material) resulting in the decrease of residual compressive strength. In general, the best results at all replacement ratios were obtained for 400°C and then became worse when increasing the temperature to 800°C as the Calcium-Silicate-Hydrate (C-S-H) bonding is broken after reaching such high temperatures.

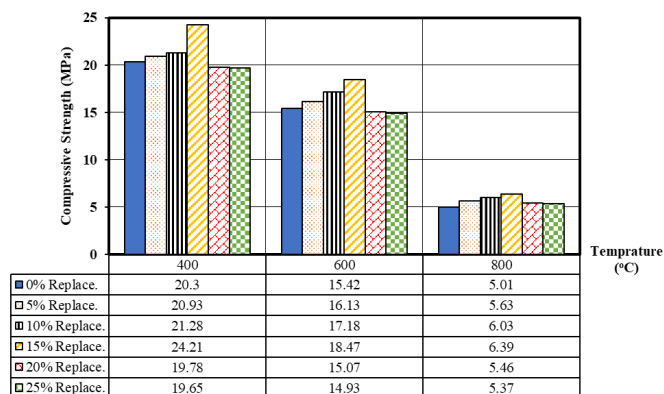


Figure 10: Residual compressive strength test results for Cement/Feldspar replacement

### Sand / Feldspar replacement

For Group 2 (sand/Feldspar replacement), compression and flexural tests were conducted on different specimens. The obtained results for compression and flexural tests are shown in Fig. 11 and Fig. 12, respectively. The figures reveal that the best results for both compressive and flexural strengths were obtained for Control 2 (0% sand/Feldspar replacement). Then, results disintegrated via the increase of sand/Feldspar ratio from 0% to 25%. We call back Fig. 5 (Grain Size Distribution for sand and Feldspar) in order to analyze this disintegration of results. Fig. 5 depicts that the particle size of sand is finer than that of the used Feldspar. Moreover, as mentioned earlier, the fineness modulus for sand was 2.50 whereas the fineness modulus for Feldspar was 2.80. As the

particle size increased, both compressive and flexural strengths decreased. This is in agreement with the results obtained by [31]. Replacing sand with Feldspar led to weakening the bonding between the surface of Feldspar particles and the other components of cement mortar and, thereby, reducing the compression and flexural strengths [13]. It should be emphasized for future work, that the mechanical and chemical activation methods should be applied to the cement mortar specimens in order to improve their performance for both cement and sand replacements. However, this is out of the scope of this research. Similar to the results behavior illustrated in the above sub-section (for cement/Feldspar replacement experiments), the increase of specimen's age from 3 to 28 days enhanced the values of both compressive and flexural strengths. At 3-days age of specimen, the percentages of reduction of compressive strength comparing to Control 2 were 6, 24, 38, 41, and 48% for 5, 10, 15, 20, and 25% replacement ratios, respectively. While, at 28-days age of specimen, the percentages of reduction of compressive strength were 5, 16, 17, 21, and 26 % for 5, 10, 15, 20, and 25% replacement ratios, respectively.

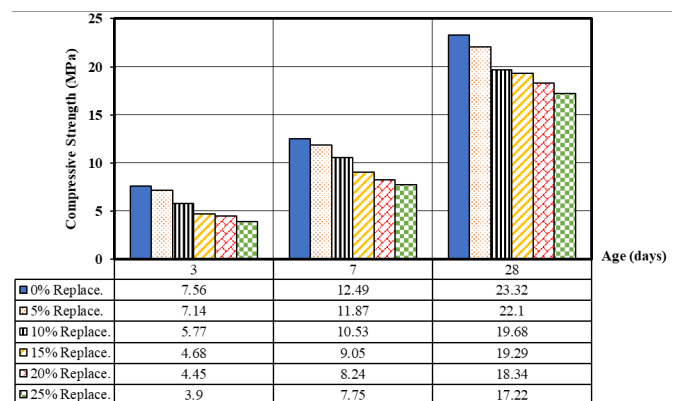


Figure 11: Compressive strengths for sand/Feldspar replacement

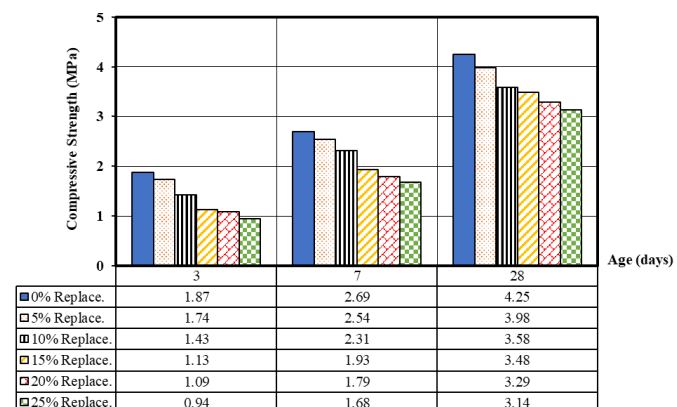


Figure 12: Flexural strengths for sand/Feldspar replacement

### CONCLUSIONS

This research explored and evaluated Feldspar as a partial replacement material for each of cement and sand in cement mortar. The study also was extended to investi-



gate the properties of cement paste relevant to cement/Feldspar replacement. Results showed that the increase of cement/Feldspar replacement ratio from 0% to 25% led to an increment of the water content, initial setting time, and final setting time for cement paste specimens. Additionally, for cement mortar specimens, the compressive and flexural strengths decreased by increasing each of cement/Feldspar and sand/Feldspar replacement ratios from 0% to 25% at all specimen ages. Residual compressive strength for the cement mortar at all elevated temperatures grew up by increasing the cement/Feldspar ratio from the 0% to 15%. Then, the residual compressive strength decreased back by increasing the ratio from the 15% to 25%. The best result for the residual compressive strength was obtained at 15% cement/Feldspar replacement ratio and 400°C elevated temperature. This reflects the positive impact of cement/Feldspar replacement on the ability of cement mortar to resist the possible high temperatures and, as a consequence, improve its durability.

#### DISCLOSURES

The authors have no relevant financial interests in the manuscript and no other potential conflicts of interest to disclose.

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#### REFERENCES

1. Feldspar, W. i.. Retrieved from Industrial Minerals Association of North America, from [https://www.imana.org/page/what\\_is\\_feldspar](https://www.imana.org/page/what_is_feldspar),(2017).
2. Shakrou, O., Rabba, I., Sadeq, A., Sahawneh, J., Madanat, M. (2014). Mineral status and future opportunity. Feldspar. Ministry of Energy and Mineral Resources.
3. Bender, F. (1975). Geology of the Arabian Peninsula. Geol. Surv. Prof. Paper, 560.
4. McCourt, W., Ibrahim, K., Abdelhamid, G., Barjo. (1990). The geology, geochemistry and tectonic setting of the granitic and associated rocks in the Aqaba and Araba complexes of southwest Jordan. Amman
5. Khoury, H. N. (2019). Industrial rocks and minerals of Jordan: a review. Arabian Journal of Geosciences, vol. 12, no. 1, 12-20.
6. Shakrou, O., Tarawneh, K., Jamal, D. (2010). Exploration, evaluation and investment opportunities of feldspar ore deposits in Jordan. 6th Jordanian International Mining Conference. Amman.
7. Kamolchanok, K., Danupon, T. (2021). Compressive strength and durability performance of mortar containing palm oil boiler clinker aggregate, rice husk ash, and calcium bentonite. Journal of Applied Engineering Science, vol. 19, no. 1, 193 - 203, DOI: 10.5937/jaes0-27580.
8. Berdoudi, S., Hebhou, H., Djebien, R. (2017). Valorization and recycling of quarries waste as an addition in cement. Journal of Applied Engineering Science, vol. 15, no. 2, 122-127, DOI:10.5937/jaes15-12743
9. Khoso, S., Shahzaib, K. J., Aziz, A. A., Hussain, K. Z. (2016). Experimental investigation on the properties of cement concrete partially replaced by silica fume and fly ash. Journal of Applied Engineering Science, vol. 14, no. 3, 345-350, DOI:10.5937/jaes14-11116
10. Locati, F. e. (2010). Na<sub>2</sub>O, K<sub>2</sub>O, SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> release from potassic and calcic-sodic feldspars into alkaline solutions. Cement and concrete research, 1189-1196, DOI: org/10.1016/j.cemconres.2010.04.005
11. Tian, L., Feng, W., Ma, H., Zhang, S., Shi, H. (2017). Investigation on the microstructure and mechanism of geopolymer with different proportion of quartz and K-feldspar. Construction and Building Materials, vol. 147, 543-549, DOI.org/10.1016/j.conbuildmat.2017.04.102
12. Constantiner, D., Diamond, S. (2003). Alkali release from feldspars into pore solutions. Cement and Concrete Research, vol. 33, no. 4, 549-554, DOI. org/10.1016/S0008-8846(02)01001-3
13. Khoshkbijari, R., Samimi, M., Mohammadi, F. (2020). Effects of Mica and Feldspar as partial cement replacement on the rheological, mechanical and thermal durability of self-compacting mortars. Construction and Building Materials, vol. 263, 120149, DOI. org/10.1016/j.conbuildmat.2020.120149
14. Enríquez, E., Torres-Carrasco, M., Cabrera, M., Muñoz, D., Fernández, J. (2021). Towards more sustainable building based on modified Portland cements through partial substitution by engineered feldspars. Construction and Building Materials, vol. 269, 121334, DOI.org/10.1016/j.conbuildmat.2020.121334
15. Torres-Carrasco, M., Enríquez, E., Terrón-Menoyo, L., Cabrera, M., Muñoz, D., Fernández, J. (2021). Improvement of thermal efficiency in cement mortars by using synthetic feldspars. Construction and Building Materials, vol. 269, 121279, DOI.org/10.1016/j.conbuildmat.2020.121279

16. Rabba, I. (1991). The geology of the Al Quwayra area. Amman: NRA.
17. Tarawneh, K. e. (2012). Exploration And Evaluation Investment Opportunities of Feldspar Ore in Jordan. Geology and Geophysics, 80-86.
18. International Hydrographic Organization. (2008). User's Handbook on Datum Transformations Involving WGS 84 (3rd ed.). International Hydrographic Bureau MONACO.
19. Younis, G. (2020). The Effect of Using Multiple Coordinate Systems and Datum Transformations on the Calculated Coordinates in Palestine. Bulletin of Geography. Physical Geography Series, vol. 19, 31-41. DOI: <http://dx.doi.org/10.2478/bgeo-2020-0008>
20. Gavish, D. (2010). A Survey of Palestine under the British Mandate, Routledge Studies in Middle East History. 1920-1948.
21. Al-Bayari, O., Sadoun, B. (2011). Vertical datum and coordinate systems in Jordan. International Journal of Information Technology Communications and Convergence, vol. 1, no 4, 444-454. DOI: 10.1504/IJITCC.2011.044645.
22. ASTM C150, C.-2. (2020). Standard Specification for Portland Cement.
23. ASTM C778-00. (2000). Standard Specification for Standard Sand. West Conshohocken: ASTM International.
24. ASTM C33, C.-1. (2018). Standard Specification for Concrete Aggregates. West Conshohocken: ASTM International.
25. ASTM C109 / C109M-20b. (2020). Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.
26. ASTM, C187-04. (2004). Standard Test Method for Normal Consistency of Hydraulic Cement. West Conshohocken: ASTM International.
27. ASTM C191-08. (2019). Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle. West Conshohocken: ASTM International.
28. ASTM C348-20. (2020). Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. West Conshohocken: ASTM International.
29. CEN/TC 104. (2009). EN 12390-3, Testing hardened concrete-part 3: compressive strength of testing specimens. Brussels.
30. Newman, A. (1983). The specific surface of soils determined by water sorption. Journal of soil Science, vol. 34, 23-32. DOI: [10.1111/j.1365-2389.1983.tb00809.x](https://doi.org/10.1111/j.1365-2389.1983.tb00809.x)
31. Han, J., Cho, J., Kim, S., Park, Y., Lee, J. (2020). Characteristics of CO<sub>2</sub> and Energy-Saving Concrete with Porous Feldspar. Materials, vol. 13, no. 18, 4204-4220, DOI: [10.3390/ma13184204](https://doi.org/10.3390/ma13184204).

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