ASSESSMENT OF SOME MECHANICAL PROPERTIES FOR CONCRETE BASED ON ALUM SLUDGE AND METAKAOLIN

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Since concrete is a consistently reliable building material, its importance to all nations' economies cannot be overstated. However, the cement and concrete industries continue to generate massive amounts of waste which results in the emission of carbon dioxide which is one of the environmental issues. Therefore, reducing the amount of cement is important by partially replacing one of the waste materials. In this research; two municipal materials were used as alternatives for cement. It is considered available in quantities with appropriate price as compared to other mineral materials. In addition, this research was interest given to assess the strengths and durable behaviour of concrete production with these addition materials. The amount of metakaolin used is (1-15) wt% and alum (1-5) wt% of cement. The central composite design (CCD) method was used in conjunction with the response surface method to design concrete mixtures for this research and to analyse the results obtained from laboratory tests. An empirical model was given for compressive strength, bulk density and splitting tensile strength. All concrete specimens were cured after 7 and 28 days. The best results were found when metakaolin was used between (1-3) wt% and alum sludge between (1.6-3) wt% as mixed materials to produce concrete and as a partial replacement of cement.

Keywords: *Metakaolin; Alum sludge; Concrete; Minitab software; Compressive strength; Splitting tensile strength; Durability*

1. Introduction

The industry of construction is growing fast around the world. The huge growth in construction is driving an increase in the demand for building materials. Concrete is one of importance of the building materials used in the industrial countries. Even though cement, aggregates, and water are all integral constituents that must be used in the creation of concrete, the energy needed to produce cement makes it expensive and harmful to the environment. Too much of a challenge has been faced by the researchers to find varying alternatives or supplementary construction materials. These may be characterized by cheaper, recycled and environmentally friendly materials to manufacture concrete that is more durable, the life cycle of good strength that affects the cost of long-lasting it [1-4].

Metakaolin is one of the alternative building materials that is frequently used as a mineral admixture to assist concrete to have better properties, produce at a lower cost, and emit less CO_2 due to the creation of the cement that is used in its production [5, 6 and 7]. It is a natural pozzolainc material [8]. The main advantages of this material include its capacity to increase concrete strength and its high efficiency when used as a partial replacement for cement [5]. All experimental testing indicated that mortar's sulphate resistance had increased by around 30% and that concrete's compressive strength had increased by about 50%. Additionally, there has been a 40% reduction in energy use and CO_2 emissions [8, 9 and 10]. From the literature review, it has been found that metakaolin negatively influences the workability of concrete which decreases with increasing the replacement percentage of metakaolin until 15% due to its high fineness. It has also been found that the strength of metakaolin has been remarkably increased when replacing the cement with metakaolin from 10 to 15% compared to the poor effect of replacement ratios from 15 to 20% [11-15].

Therefore, the utilization of metakaolin as a supplementary cementitious material is considered beneficial in terms of environmental, technical and economic issues. Another alternative construction material in terms of reducing environmental impact and saving costs is alum sludge. This material is a final waste generated from the plant for drinking water treatment and is not considered a natural pozzolanic material. Because of differences in source water and chemical composition from one plant to the next, alum sludge is classified as a by-product material [16-18].

Over the last decades, the waste water treatment plant has increased and had a negative effect on the environment. Sludge is one of the main wastes that are difficult to dispose of in an environmentally friendly manner and produces a lot of pollution [19,20]. Much research has been done on the use of alum sludge in concrete to reduce the harmful effects of this sludge on the environment. As a result, it will lead to less cement being used while still producing concrete with acceptable durability.

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Previous research, for example, demonstrated that the amount of sludge used in the concrete mixture affects the strength and stiffness of the concrete [19-21]. Another study has shown that the sludge was subjected to heat treatment to reduce the harmful materials and obtain the best concrete results [21]. Sometime, it can use the sludge as partial replacement of sand or cement that depends on particles size of them. The previous study showed acceptable results for both replacements in different percentages [20]. Many researchers have examined how to use the sludge in the production of building and construction materials, for example, the production of brick, artificial aggregate, cement, and ceramics [22-26].

Some researchers have experimented with varying amounts of alum sludge as a partial replacement for cement to produce concrete with (2.5-15) % cement by weight. They found that the addition of it was between 6 to 7.5 % and improved the strength of concrete after 7 and 28 curing days [4, 16 and 27]. From the literature, a lot of research has shown reusing the sludge as a supplementary material for cement in concrete but very limited research has shown the use of metakaolin and alum sludge together in it.

In this research, an attempt has been made to produce a concrete mixture from alum sludge and metakaolin as cement partials in different percentages and examine the main properties of concrete. This technique is beneficial to the environment by decreasing the waste that is disposed in landfills and it is also useful from the economic perspective by producing concrete with acceptable strength and durability.

2.Materials and Methods

2.1 The Materials Used

- Ordinary Portland cement type 1 was used in this study, produced by United Cement Company, known in the local market as Tasulujah Bazian.
- Fine aggregate (sand) and coarse aggregate (gravel) were used in this study with specific gravities of 2.5 and 2.65 respectively. The maximum size of the used gravel is 10 mm. The gradation of sand and gravel was shown in Tables 1 and 2.
- The superplasticizer used in this study was a high-performance superplasticizer based on polycarboxylic polymer, known as PC200, produced by Don Construction Products Ltd.
- Tap water was used throughout this work in mixing concrete without any additives.
- Iraqi metakaoline powder (off white color) obtained after thermal treatment at temperature 700°C for 1hr [27]. The specific gravity of this powder was 2.32, as shown in Table 3, which illustrates the chemical composition of used metakaolin powder.
- Alum sludge was obtained from Unity Water Station in Iraq. It was dried under the sunshine for 3 days, after that manually milled by using a steel hammer. Then, the powder dried in electric oven at 120°C for 3 hrs. Consequently, removed any impurities particles from this powder by using sieving technique (No.200). It is noteworthy, the sieved alum sludge powder was treated with 70% alcohol in order to murder the harmful bacteria. Finally, the wet alum sludge powder dried at 120°C for 1 hr. The resulted powder (off white color) has 2.34 as specific gravity. Table 4 represents the chemical compositions of resulted alum sludge powder.

Table 1

Gradation of sand

Opening size of sieve (mm)	**Passing %**	**Iraqi specification limits I.O.S.45/1984 Grading zone (2) [28]**
10	100	100
4.75	92.39	100-90
2.36	75.21	100-75
1.18	59.24	90-55
0.6	46.19	50-35
0.3	10.16	30-8
0.15	0.07	10-0

Table 2

Gradation of gravel

Opening size of sieve (mm)	**Passing %**	**Iraqi specification limits I.O.S.45/1984 (5/14 mm) [28]**
20	100	100
14	94.5	100-90
10	57.34	85-50
5	0	10-0

Table 3

Chemical Properties of metakaolin

Particles	**Content %**
SiO_2	51.77
Al_2O_3	35.50
Fe_2O_3	3.29
CaO	0.50
MgO	0.10
SO_3	0.06
Na_2O	0.09
K_2O	0.58
L.O.I.	5.45

Table 4

Chemical Properties of alum sludge

Particles	**Content %**
SiO_2	39.14
Al_2O_3	13.80
Fe_2O_3	8.06
CaO	16.3
MgO	2.68
SO_3	0.23
Na_2O	0.33
K_2O	2.02
L.O.I.	17.40

Table 5

Codes used in the CCD for factors (independent variables) and their real experimental values

Coded Level	Metakaolin (W %) X_1	Alum sludge (W %) X_2
-1.414	1	1
-1	3.050	1.586
0	3	8
1	12.95	4.414
1.414	15	5

Table 6

Coded levels utilized with their real values of metakaoline and alum sludge

Mix No.	Coded Variables		Real Variables	
	X_1	X_2	Metakaolin w%	Alum sludge w%
1	-1	-1	3.050	1.586
2	1	-1	12.95	1.586
3	-1	1	3.050	4.414
4	1	1	12.95	4.414
5	-1.414	0	1	3
6	1.414	0	15	3
7	0	-1.414	8	1
8	0	1.414	8	5
9	0	0	8	3
10	0	0	8	3
11	0	0	8	3
12	0	0	8	3
13	0	0	8	3

Table 7

The concrete mixes based on $1m^3$

Mix No.	Cement Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	Metakaolin %	Alum Sludge %	Water L/m^3	SP L/m^3	W/C
R	485	820	748	0	0	182.4	4.365	0.37
1	484.95	820	748	3.050	1.586			
2	484.85	820	748	12.95	1.586			
3	484.92	820	748	3.050	4.414			
4	484.82	820	748	12.95	4.414			
5	484.96	820	748	1	3			
6	484.82	820	748	15	3			
7	484.91	820	748	8	1			
8	484.87	820	748	8	5			
9	484.98	820	748	8	3			
10	484.98	820	748	8	3			
11	484.98	820	748	8	3			
12	484.98	820	748	8	3			
13	484.98	820	748	8	3			

2.2 Methods

The experimental design includes statistical design experiments, estimation of coefficients through a mathematical model with predicted response, and statistical analysis. Moreover, it can obtain the largest amount of information from a small number of experiments. In this study, Central Composite Design (CCD) was used. Two factors were chosen as independent variables, (wt. % of metakaolin and alum sludge additions). The dependent output response variables are compressive strength, bulk density and splitting tensile strength. All responses were fitted to a second quadratic model as shown in Eq. 1, and the model's adequacy was confirmed using analysis of variance (ANOVA).

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_{11}x_1^2 + b_{12}x_1x_2 + b_{22}x_2^2 \quad (1)$$

Where Y is the predicted response, X1 and X_2 are coded levels of the variables (metakaolin and alum sludge) % and (b_0, b_1, b_2, b_{11}, b_{12} …) are regression coefficients.

The equation for each property (compressive strength, bulk density and splitting tensile strength) is created to obtain three responses Y_1, Y_2 and Y_3 respectively. Thirteen experimental runs are required to use CCD of two independent variables with five different levels of each variable designated by the codes (-1.414, -1, 0, 1 and 1.414). The selected factors with the actual and coded levels according to the design are represented in Tables 5 and 6. The data was analyzed using Minitab V16 (Minitab Inc., PA, and USA) statistical and graphical software.

2.3 Mix proportions and specimen's preparation

The percentage of partial replacement for metakaolin and alum sludge used was within the range of (1-15) % and (1–5) % of the weight of cement respectively as shown in Table 7. The ratios of replacement for metakaolin and alum sludge were dependent on several studies that proved that these ratios were the best when used to produce the concrete [27, 29-31].

Two types of specimens have been used in this study. The bulk density, durability and the compressive strength were assessed for cubic specimens of 100x100x100 mm^3, while the splitting tensile strength was assessed for the cylindrical specimen's of100 x 200 mm^3.

All mixtures were done using manual mixing as followed the American specification (ASTM C-192-02) [32] until having a homogenous mixture. The alum sludge and metakaolin were added to the mix as a partial replacement of the weight of cement. After thoroughly mixing all materials, the first part of the mixing water was added to the mixture continuous mixing; thereafter, the superplasticizer was added. Finally, the second part of water was added. All mixtures have been casted in the molds and compacted by vibrating machines for 1 minute. Consequently, the specimens were de-molded and cured in water at room temperature up to 7 and 28 days.

2.4 Specimens testing

The bulk density of the hardened concrete cubic was determined by American specification (ASTM C652-13) [33]. The compressive strength test was carried out using E.L.E. international-2007/UK/A.D.R.-2000- standard machine-instrument. It was performed according to B.S. 1881: Part 116 (1989) [34]. Splitting tensile strength test was followed the American specification (ASTM C496-06) [35].

Durability test was performed according to (ASTM C 666, 2003) [36]. The type of durability test was freezing and thawing test. This test carried out by putting the cubes specimens from each concrete mix in the fridge freezer at temperature of (-17±1) °C for about 7 hours. These specimens were taken out of freezer and were placed in water at temperature (+17±1) °C for about 19 hours. This procedure of freezing and thawing was repeated for 8 cycles. To find out how these specimens would behave under these conditions, ultrasonic pulse velocity tests were performed on them both before and after freezing and thawing. This test was carried out in accordance with British standards (BS: 1881 part 203:1986) [37]. The ultrasonic device was designed to operate at a frequency of 55 kHz.

3.Results and Discussion

3.1 Bulk density results

Figure 1 illustrates the effect of curing time of studied mixes on the bulk density of concrete. From the results, it can be shown that the addition of metakaolin and alum sludge leads to a reduction in density for all curing times compared to the reference mix (R).

Although the metakaolin and alum sludge replacement percentages were small in comparison to the cement for mixes (1, 3 and 5), they contained the percentages of metakaolin and alum sludge (3.0503:1.5858) and 4.0503:4.414) (1:3) respectively. It can be seen that the resultant density of them was the best, see Table 7.

In contrast to what can be seen from the bulk densities of concrete results for mixes 2, 4 and 6 containing metakaolin and alum sludge (12.95: 1.586), 12.95: 4.414), and 15:3, respectively, it can be observed from the figure that the density has been dramatically decreased compared to other mixes. In addition, the values of concrete density for mixes (7, 8) were close and better than the density values for mixes (9-13).

3.2 Compressive strength results

Figure 2 shows the effect of curing time on the compressive strength of all mixes studied. It is noted that there is an acceptable increase in the compressive strength of the mixtures containing metakaolin and alum sludge for the mixes (1, 5) that contained (metakaloin: alum sludge) (3.050:1.586) (1:3) respectively. In contrast to the behaviour of mixes (4, 6) that contained (metakaloin: alum sludge) (12.95: 4.414) (15:3), where there was a significant decrease in compressive strength with the progression of the curing time. The values of the compressive strengths of mix (1 and 5) were (44.70 and 43.74) MPa respectively, while the values of the strengths of mix (4 and 6) were (2.13 and 2.10) MPa respectively after 28 days.

This behaviour can be explained by the fact that the use of metakaolin and alum sludge with high percentages has a reverse reaction that leads to a greatly reduced in compressive strength values. Unlike what happened when using low percentages of these materials with cement where good resistance can be obtained, both of them have acceptable properties to improve the strength of the concrete.

The strengths of the metakaolin and alum sludge-containing mixes (2, 3 and 7) were 12.95:1.586, 3.050:4.414, and 8:1, respectively, almost identical in terms of compressive strength, where the slightly increase about (22.05, 27.82, and 23.92) MPa, respectively. In addition, mixes 8 to 13 had approximately the same trend and slightly increased in the compressive strength values which ranged from 13.07 to 17.67 MPa after 28 days.

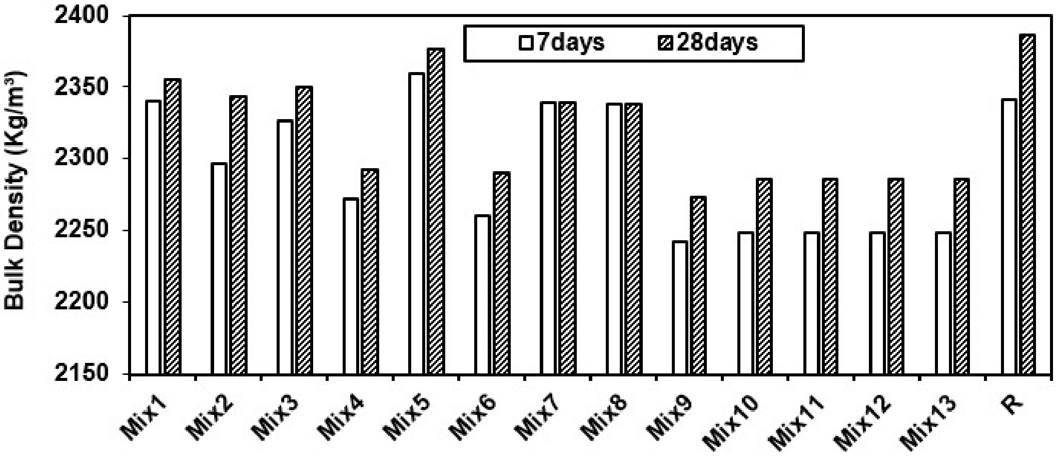


Fig. 1- Effect of curing time on the bulk density of concrete

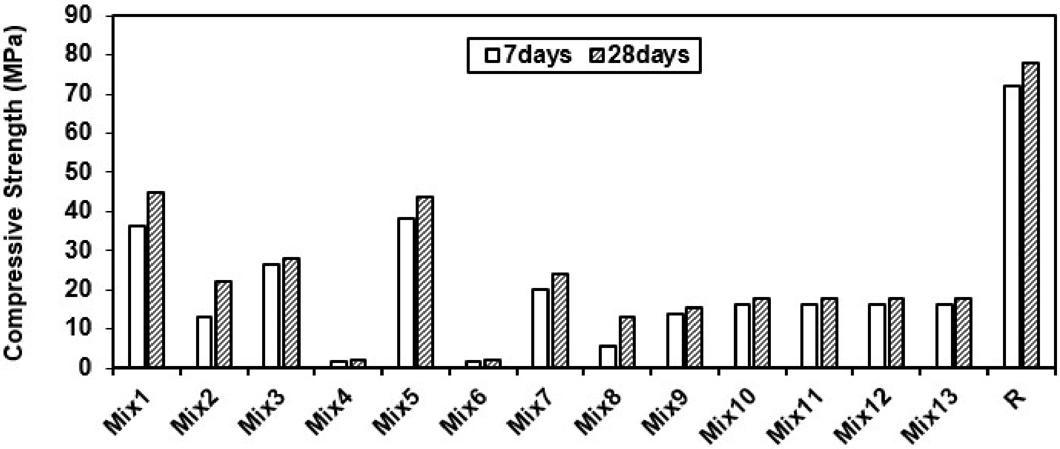


Fig. 2- Effect of curing time on the compressive strength of concrete

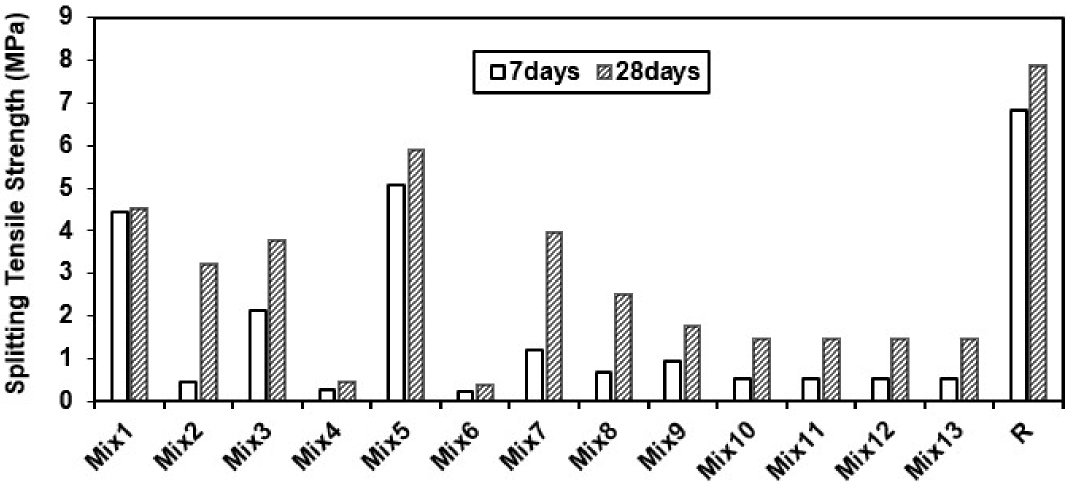


Fig. 3 - Effect of curing time on the splitting tensile strength of concrete

3.3 Splitting tensile strength results

As demonstrated in Fig. 3, the behavior of concrete's tensile strength for all mixes was about the same as that of its compressive strength.

It is clear that the effects of the metakaolin and alum sludge additions on strength resulted in mixes (1, 3, and 5) having acceptable strengths of around (4.54, 3.78, and 5.90) MPa at 28 days respectively. While mixtures (4, 6) had significantly decreased in tensile strength at 28 days, by around (0.47 and 0.40) MPa, respectively.

At 28 days, the tensile strengths of mixes (2 and 7) were approximately 3.21 and 3.98 MPa respectively. When compared to the strength results for mixes from (8 to13), the lowest values at 28 days dropped between 2.51 and 2.47 MPa.

3.4 Analysis of variance (ANOVA)

Table 8 illustrates the experimental results for all mixes studied by using variance analysis (ANOVA). Consequently, Tables (11, 12 and 13) present the findings. The experimental results are used to build the regression model equations

Table 8

The matrix design along with the experimental results

Exp. No.	Independent variables				Responses(dependent variables)					
	Coded		Real							
	X_1	X_2	Meta Kaolin w%	Alum wt%	Y_1 Exp.	Y_1 Predicted	Y_2 Exp.	Y_2 Predicted	Y_3 Exp.	Y_3 Predicted
1	-1	-1	3.050	1.586	44.77	42.206	2355	2355.306	4.54	4.851
2	1	-1	12.95	1.586	18.86	14.477	2344	2330.547	3.21	2.735
3	-1	1	3.050	4.414	27.82	29.651	2350	2363.953	3.78	4.455
4	1	1	12.95	4.414	2.13	2.138	2293	2293.194	0.47	0.360
5	-1.414	0	1	3	43.74	43.728	2377	2367.021	5.9	5.248
6	1.414	0	15	3	2.1	4.666	2290	2299.479	0.4	0.857
7	0	-1.414	8	1	24.46	28.841	2339	2348.399	3.98	4.128
8	0	1.414	8	5	13.07	11.237	2338	2328.101	2.52	2.169
9	0	0	8	3	15.27	16.399	2273	2281.600	1.77	1.606
10	0	0	8	3	17.67	16.399	2286	2281.600	1.47	1.606
11	0	0	8	3	15.73	16.399	2279	2281.600	1.65	1.606
12	0	0	8	3	16.22	16.399	2290	2281.600	1.55	1.606
13	0	0	8	3	17.1	16.399	2280	2281.600	1.59	1.606

Table 9

Analysis of variance for compressive strength Y1

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Metakaolin X1	1	1525.85	1525.85	171.97	0.000
Alum X2	1	309.88	309.88	34.93	0.001
X1X1	1	105.76	105.76	11.92	0.011
X2X2	1	23.05	23.05	2.60	0.151
X1X2	1	0.01	0.01	0.00	0.972
Pure Error	4	3.88	0.97		
Total	12	2015.79			

Table 10

Analysis of variance for bulk density Y2

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Metakaolin X1	1	4561.9	4561.87	34.53	0.001
Alum X2	1	412.0	412.05	3.12	0.121
X1X1	1	4639.5	4639.52	35.12	0.001
X2X2	1	5581.3	5581.26	42.25	0.000
X1X2	1	529.0	529.00	4.00	0.085
Pure Error	4	173.2	43.30		
Total	12	15474.9			

Table 11

Analysis of variance for splitting tensile strength Y3

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Metakaolin X1	1	19.2817	19.2817	83.50	0.000
Alum X2	1	3.8388	3.8388	16.62	0.005
X1X1	1	3.6367	3.6367	15.75	0.005
X2X2	1	4.1374	4.1374	17.92	0.004
X1X2	1	0.9794	0.9794	4.24	0.078
Pure Error	4	0.0501	0.0125		
Total	12	32.5955			

(second-order polynomial) that relate the response. As a result, three equations for compressive strength, bulk density and splitting tensile strength have been obtained.

Where
Y1: Compressive Strength (MPa), Y2: bulk density (kg/m^3), Y3: Splitting Tensile Strength (MPa)

The p-values for the coefficients in regression analysis reflect whether these relationships are statistically significant. A low p-value (<0.05) indicates that they are statistically different from zero at the 95% confidence level. Therefore, coefficients' p-values (<0.05) are statistically significant. Tables (11, 12 and 13) provide the F and P values for all linear, quadratic and interaction effects of the parameters. The smaller the value

Table 12

Summary of the response regression analysis

Responses	**R^2 (%)**	**Adjusted R^2 (%)**	**Predicted R^2 (%)**	**SD**
Y1	96.92	94.72	79.16	2.979
Y2	94.02	89.76	63.71	11.494
Y3	95.04	91.50	65.59	0.481

of P, the bigger the magnitude of F and thus the more significant the corresponding coefficient term. The coefficients for the linear effect of the factors metakaolin (p=0) and alum sludge (p=0.001) for the compressive strength are significant, as shown in Table 9. The interaction between the variables metakaolin and alum sludge was not significant (p=0.972).Moreover, the quadratic effect of metakaolin (p=0.011) is significant, whereas it is less so for alum sludge.

For bulk density Table 10, the coefficients of all the effects of the factors were significant except for the linear effect of alum (p=0.121) and the interaction between the variables kaolin and alum (p=0.085). While the results for splitting tensile strength were all significant, except for the interaction between the variables kaolin and alum (p=0.078), as shown in Table 11.

The regression equations in uncoded units are given in Eqs. (2), (3) and (4).

1- Compressive strength (Y1) = $70.48 - 5.360\,X1 - 9.92\,X2 + 0.1591\,X1^2 + 0.910\,X2^2 + 0.008\,X1X2$ ……… (2)

2- Bulk density (Y2) = $2490.9 - 16.76\,X1 - 76.9\,X2 + 1.054\,X1^2 + 14.16\,X2^2 - 1.643\,X1X2$ …… (3)

3- Splitting tensile strength (Y3) = $9.25 - 0.574\,X1 - 2.238\,X2 + 0.02951\,X1^2 + 0.3856\,X2^2 - 0.0707\,X1X2$ ………. (4)

The ANOVA for the three properties showed that the second-order polynomial model Eqs. (2), (3), and (4) is highly significant and adequate to represent the actual relationship between the response and variables, with high coefficients of determination (R^2 = 96.92 %, 94.02 %, 95.04 %) for Y1, Y2, and Y3, respectively, as shown in Table 12. These results indicate that the three properties could be described well by the predicted model.

3.5 Plots of the 3D response surface and contours

The three regression equations (2), (3), and (4) are presented by 3D response surface and contour plots, as shown in Figs.4, 5 and 6.

It can be seen from Fig. 4 that there is a sharp decline in the compressive strength values with increasing ratios for the metakaolin additive, while there is a slight increase in the compressive strength value for alum sludge.

The contour plot shows the best limits for the replacement percentages of metakaolin and alum sludge, which ranged up to 2% of metakaoline and up to 1.8% of alum sludge, which contributed good strength to the concrete.

From Fig 5 it can be observed more clarification of the results. The bulk density was increased with decreasing the replacement percentage of metakaolin and alum sludge.

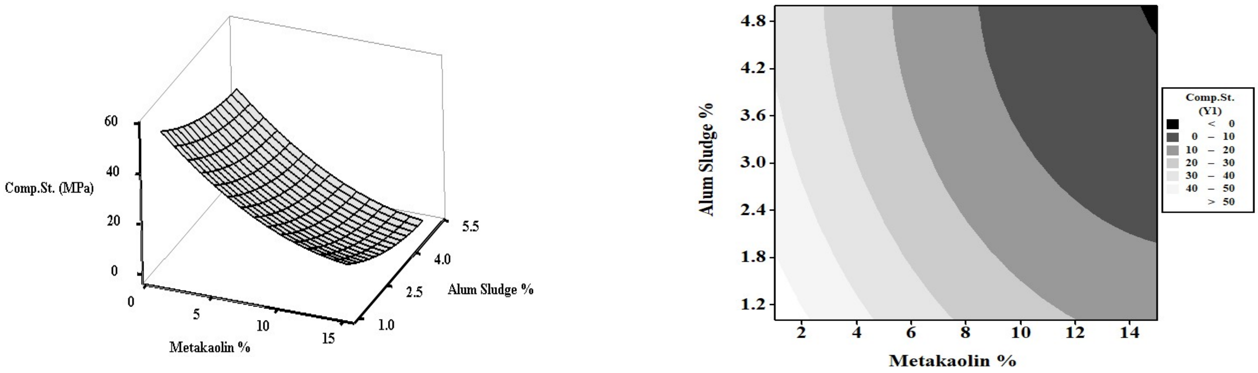
The contour plot shows the area that gives a low density when the percentages of addition of metakaolin are between 8 to 13 and the alum sludge percentages are between 2.7 to 4. This agrees with mixes 4, 6, and 9.

Figure 6 presents the effect of the replacement percentage of metakaolin and alum sludge on the splitting tensile strength. It can be seen that strength values reduced with increasing in the proportions of metakaolin and alum sludge as shown in 3D surface plot. In the contour plot, it can be observed that the area represented by the smallest triangle at the bottom and top on the left of the figure showed the best results of replacement percentages of about 2.5% of metakaolin with 1.6% of alum sludge, and 2% of metakaolin with 4.4% of alum sludge respectively.

3.6 Durability results

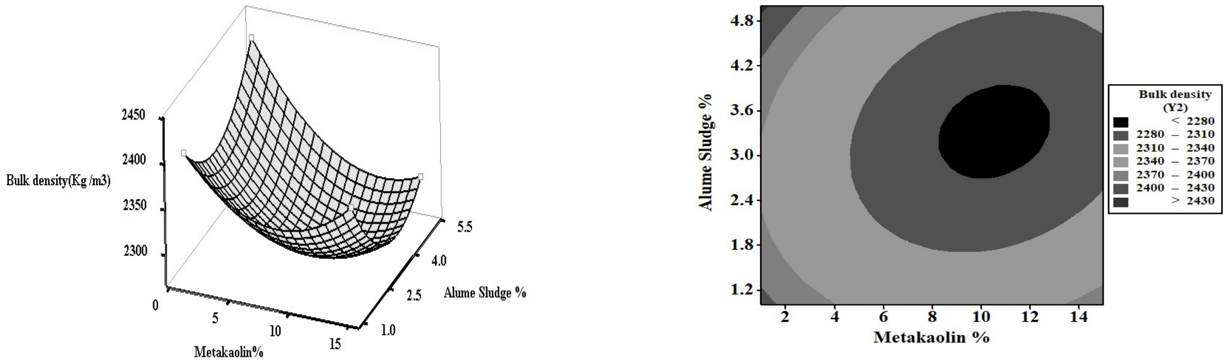
In this research, this test was used to determine the durability of concrete after 4 and 8 cycles of freezing and thawing. From Fig. 7, it can be seen that the pulse velocity of mixes (1, 3 and 5) is higher than mixes (4 and 6) before and after subjecting to cycles of freezing and thawing. The results showed decline in pulse velocity after subjecting the samples to cyclic freezing and thawing. Where the decline of pulse velocity was increased with increasing the number of cycles compared that of no cycles. The decrease of ultrasonic pulse velocity of mix (2 and 7) at 4 and 8 cycle was approximately similar to that mixes from 8 to 13.

This may be happened due to the shrinkage and expansion phenomena that was subjected to the samples during cycles of freezing and thawing. This caused the generation of stresses resulting from changing the volume of water in their pores inside the specimens, leading to a negative effect on the pulse velocity. This deterioration was clear that can be observed especially on mix (4 and 6).



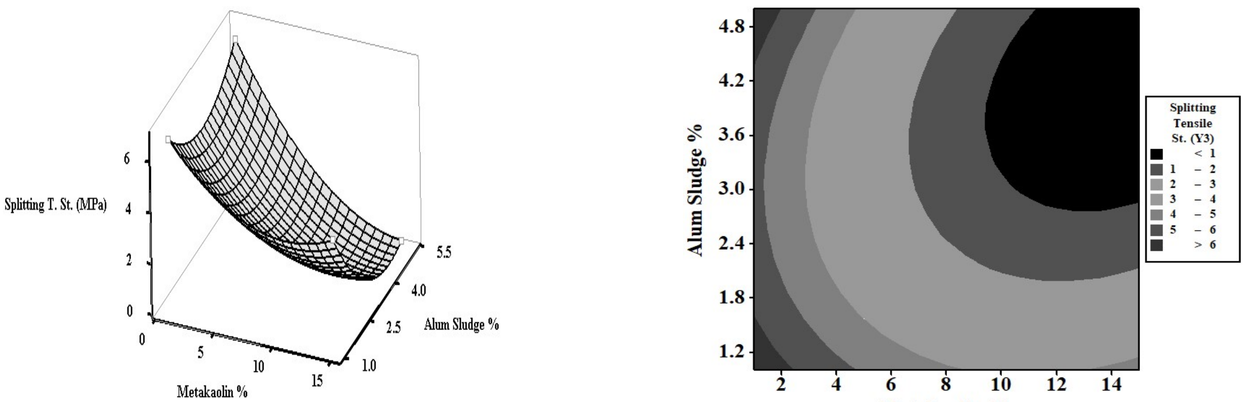
(a) (b)

Fig. 4- (a) 3D response surface and (b) contour plots of compressive strength (Y1) between alum sludge and metakaolin



(a) (b)

Fig.5- (a) 3D response surface and (b) contour plots of bulk density (Y2) between alum sludge and metakaolin



(a)

(b)

Fig. 6 - (a) 3D response surface and (b) contour plots of splitting tensile strength (Y3) between alum sludge and metakaolin

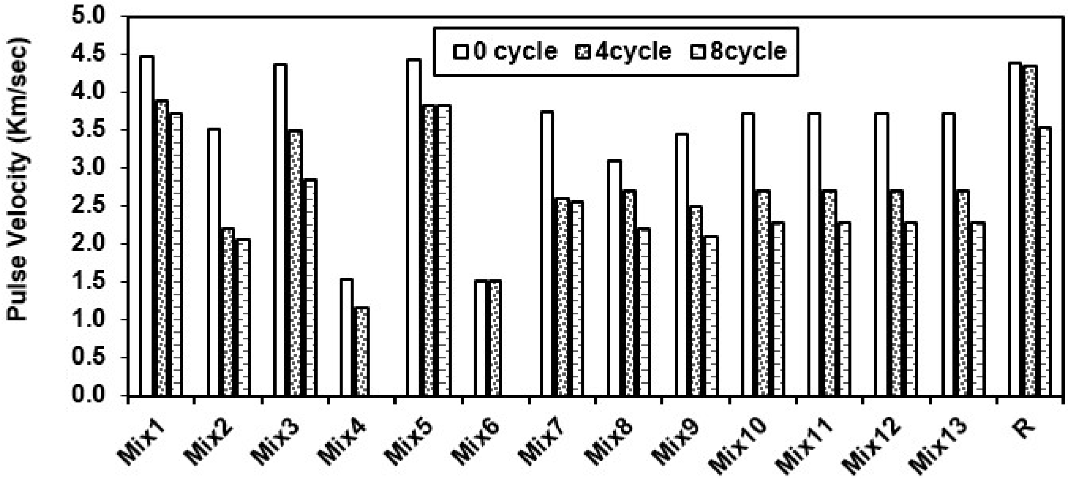


Fig. 7 - Effect of durability cycles on pulse velocity of concrete

4. Conclusions

Overall, the results of the laboratory experiments can be concluded as follows:

1- When increasing the replacement percentages of cement, the addition of alum sludge and metakaolin combined for the production of concrete had a detrimental impact.

2- The best mixes based on the overall results tests were mixes (1, 3, and 5), which contained the percentages of metakaolin and alum sludge (3.0503:1.5858), (3.0503:4.414), and (1:3), respectively. While the poorest mixes given the worst result were mix (4, 6) that contained the percent of (metakaolin: alum sludge) (12.95:4.414) (15:3) respectively.

3- It can be deduced that the ideal replacement percentages for metakaolin and alum sludge by weight of cement were (1.6–3) % and (1-3%) respectively. When combined, these percentages produced concrete with performance that was acceptable.

4- The behavior of mixes (2 and 7) with a percentage of (metakaolin: alum sludge) (12.95:1.586) and (8:1), respectively, is almost identical to that of mixes from (8 to13) for all findings test.

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