

OPTIMIZATION OF USED ENGINE OIL AS ADMIXTURE IN CONCRETE USING RESPONSE SURFACE METHODOLOGY

Ibrahim Mas'ud S., Hassan I., Mohammed A., Tumba M.G., Kashim U.M.
 Civil Engineering Department, Abubakar Tafawa Balewa University, Bauchi.

Corresponding author: imasud88@yahoo.com

Received 02 September 2024 Received in revised form 15 September 2024 Accepted 17 September 2024

Available online 23 September 2024

ABSTRACT

Maintenance of industrial machinery and automobile engines produces a large amount of Used Engine Oil (UEO) as waste. This waste oil is harmful to the environment, pollutes the land and kills the aquatic habitats. Used engine oil poured into household drains or directly onto the field will pollute fresh water by entering rivers and groundwater. Efforts are shifted to conversion of Used Engine Oil into useful material for concrete production as a replacement for SP430 superplasticizer. This research deals with optimizing Used Engine Oil in M20 grade concrete using response surface methodology. The oxide composition of UEO revealed 37% of SO_3 , 15.5% of CaO , 17.7% of ZnO , 9% of P_2O_5 . The research revealed that the workability of the concrete mixes were between medium and high. The control mix slump value was 50mm but when UEO and superplasticizer were used, the slump obtained were 54mm and 52mm respectively. Concrete samples were produced and strength properties were tested at 7, 14 and 28 days of curing by water immersion. The test result showed that water absorption decreased with increase in UEO. Compressive strength increased with increase in dosage and curing days. Also, there was gradual increase in flexural and splitting tensile tests with the increase in UEO. Model equations and optimal values of UEO concrete were generated by numerical optimization. The optimal value was 11.4ml of UEO at 28 days which gave compressive strength result of 26.7 N/mm², flexural strength 8.3N/mm², tensile strength 18.9 N/mm² and water absorption of 0.7%. Therefore, 11.4ml of UEO is recommended for use as superplasticizer in M20 grade concrete.

Keywords: Used Engine Oil, Superplasticizer, Compressive strength, Flexural strength, Optimization.

1. INTRODUCTION

The rapid increase in the world population and human activities have led to enormous generation of wastes [1,2,3]. Residue from manufacturing, agriculture and other activities with no economic benefits are regarded as wastes. In developing and under-developing countries of the world, wastes are generated everyday but its management and utilization are the main problems encountered daily [4,5]. For example, different industries power, steel and municipal waste industries generate different waste materials. These wastes can be converted to useful concrete material for sustainable environment [6].

It was revealed that an estimated of 389 million gallons of Used Engine Oil are recycled and re-used around the world. They also reported that only 45% of the total UEO generated around the world is collected for recycling while the remaining 55% is discarded. 40 % of all the re-used is improperly disposed of. Consistent maintenance of vehicles and industrial engines produce a large amount of Used Engine Oil [7]. The common contaminants in UEO are copper, zinc, lead, magnesium, chlorides, chromium, and arsenic [8]. Hence, it is necessary to dispose Used Engine Oil safely with applicable environmental regulations or convert it to a useable material.

Superplasticizer otherwise known as water reducers are widely used admixtures for concrete production. Flowability is an important property of concrete which makes it easier to handle and place without voids or air spaces. Superplasticizers are high range water reducers or chemical admixtures that help concrete to achieve high flowability.

Shatha [9] concluded in his research conducted that UEO acted as a chemical plasticizer in concrete and some construction industries used it as dispersants for aqueous mineral suspensions. This helps to modify properties of fresh and hardened concrete. Lubricant contains polluted heavy particles. Used-engine oil is more hazardous to environment and negatively impacts the male reproductive system [10]. Used engine oil poured into household drains or directly onto the field pollutes fresh water by entering rivers and groundwater.

Superplasticizer enhances the workability of concrete [11], [12] but compressive strength of concrete was decreased with increase of waste engine oil into the composition [12, 13].

Beddu [14] studied the effect of used engine oil as an admixture in concrete durability. This was done according to British Standard and Malaysian Standard at water binder ratio of 0.55. The addition of UEO to concrete varied from 0.15 to 1 per cent of the weight of cement. The superplasticizer used was Sikamen N1. Concrete specimen with UEO as admixture was subjected to durability test such as porosity test and the effect at elevated temperature. The result showed that the addition of used engine oil to concrete was similar to that of adding an air-entraining admixture. Used Engine Oil improved workability and also reduced the porosity of concrete.

Response surface methodology (RSM) contains arithmetical and analytical methods for computing the correlation among independent measurable variables with one or more

responses [15]. RSM was used by many researchers to develop an optimization model that predict the compressive strength of concrete [16,17].

This study emerged out as a new technique where burned lubricant is utilized in concrete. This experimental study helped in understanding the behavior of concrete when burned lubricant are used as chemical admixture in concrete. Solving the problems of the rising cost of super-plasticizers and efficient utilization of hazardous waste like used engine oil are some of the major breakthroughs recorded in this research for use by professionals in concrete industries

2. RESEARCH METHODOLOGY

2.1 Materials

The materials used for this research work are Used Engine oil obtained from different service stations in Bauchi metropolis, coarse aggregate, fine aggregate, cement, superplasticizer (SP430)

2.2. Concrete Mix Design Using ACI method

ACI [18] was used for concrete mix design of grade M20 concrete. The mix proportion and w/c ratio were computed as follows: Cement 456kg/m³, fine aggregate 784 kg/m³, coarse aggregate 874 kg/m³ and water 205 kg/m³. 30 percent of the quantity of water obtained from the design was deducted and the result was used for the production of the sample specimens in order to determine the effect of UEO on concrete.

2.3. Experimental Design

The statistical software package was used for experimental design. In all, thirteen experimental runs were created by Design-Expert software 13 using the Central composite response surface methodology.

Table 1: Factor and Factor Levels of Mixture.

Factor	Units	Low	Middle	High
UEO	ml	3.8	7.6	11.4
Curing age	days	7	14	28

Table 2: Factor Combinations for Face –Centred Composite Design for Mixture

Run	Factor 1 A: (UEO) ml	Factor 2 B:C:A days
1	3.8	28
2	7.6	28
3	3.8	14
4	7.6	14
5	3.8	7
6	7.6	14
7	7.6	14
8	7.6	7
9	7.6	14
10	11.4	14
11	11.4	28
12	11.4	7
13	7.6	14

3. RESULT

3.1. Slump and Flow Value

Workability of concrete was conducted by slump test. It assessed the flowability, and fluidity of fresh concrete. A higher slump value indicates higher workability of concrete, while a lower value shows a lower workability. Table 3 below shows the result of slump flow tests of fresh concrete containing superplasticizer and used engine oil.

Table 3: Slump values

Dosage (ml)	SLUMP UEO	SLUMP SP
0	50	50
3.8	54	52
5.7	57	56
7.6	61	60
9.5	75	73
11.4	130	120

From Table 3, the control mix had a measured slump value of 50mm. When Used Engine Oil and Superplasticizer were used, the slump obtained were 54mm and 52mm respectively. Similarly, as the dosage of UEO and SP was increased, the slump value increased. In each of the sets of concrete, one of the mixes contained a 3.8 – 11.4 ml dosage of UEO and SP respectively. The addition of UEO caused an increase in the slump of all concrete mixes as compared to the measured slump of the related control mix. For comparing the effects of the UEO with the conventional superplasticizers, a contemporary group of samples were produced using a 3.8-11.4ml dosage of UEO and that of conplast SP 430 respectively. As shown in table 3, the effects of the superplasticizer and UEO on the slump of concrete were quite similar. The improvement of the slump of all concrete mixes due to UEO is attributed to the relatively high SO₃ content in UEO. Phosphate content usually cause retarding effects in fresh concrete. This result is in agreement with the conclusion of the research conducted by [13,14].

Table 4: Flow values of concrete mix

Dosage (ml)	SLUMP UEO	SLUMP SP
0	225	200
3.8	275	255
5.7	315	290
7.6	335	325
9.5	375	350
11.4	420	385

3.2 Compressive Strength Analysis by CCD

The compressive strength result of concrete made with UEO is shown in Table 5.

Table 5: Compressive strength result

Run	Factor 1 A:UEO ml	Factor 2 B:C:A Days	Response 1 Compressive strength N/mm ²
1	3.8	28	21.3
2	7.6	28	22.3
3	3.8	14	14.7

4	7.6	14	15.6
5	3.8	7	9.6
6	7.6	14	15.6
7	7.6	14	15.6
8	7.6	7	10.7
9	7.6	14	15.6
10	11.4	14	16.6
11	11.4	28	27.2
12	11.4	7	10.5
13	7.6	14	15.6

Table 6: ANOVA for compressive strength result

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	289.3	3	96.42	159.24	< 0.001
A-(U.E.O)	14.96	1	14.96	24.70	0.0008
B-C.A	269.8	1	269.80	445.56	< 0.001
AB	6.86	1	6.86	11.32	0.0083
Residual	5.45	9	0.6055		
Lack of Fit	5.45	5	1.09		
Pure Error	0.000	4	0.0000		
Cor Total	294.72	12			

Table 6 shows analysis of variance (ANOVA) for compressive strength of concrete produced with UEO. The Model F-value of 159.24 indicates that the model is significant. P-values less than 0.05 indicate model terms are significant. In this case A, B, AB are significant model terms. The R-Squared is 0.9815, the Predicted R² of 0.9393 is in reasonable agreement with the Adjusted R² of 0.9753, and the difference is less than 0.2. The model equation for the compressive strength

$$\text{Compressive strength} = 7.63602 + -0.144737 * \text{UEO} + 0.375455 * \text{C.A} + 0.0322234 * \text{UEO}(\text{C.A})$$

.....(1)

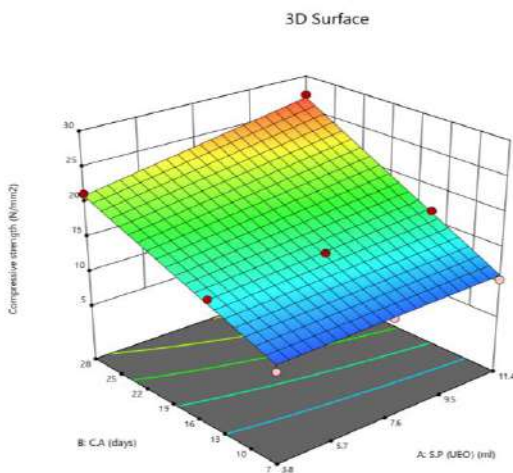


Figure 3: 3D Response Surface Graph of Compressive Strength, UEO and C.A

Figure 3 shows the 3-D surface and elucidates the correlation between the dependent variables (responses) and the independent variables (factors). The graph shows an increase in compressive strength as dosage of UEO and curing age increase. The development of strength was steady as the dosage and curing proceeded, but more pronounced at ages of 14 days to 28 days. The result agrees with the results of [12] and [13].

Table 7: Actual and Predicted Value for Compressive Strength

Run Order	Actual Value	Predicted Value
1	21.30	21.03
2	22.30	23.91
3	14.70	14.06
4	15.60	15.22
5	9.60	10.57
6	15.60	15.22
7	15.60	15.22
8	10.70	10.88
9	15.60	15.22
10	16.60	16.39
11	27.20	26.78
12	10.50	11.19
13	15.60	15.22

3.3 Analysis of Flexural Strength Result

Table 8: Flexural strength result of U.E.O.

Run	Factor 1 A:S.P ml	Factor 2 B:C.A days	Response 2 Flexural strength N/mm ²
1	3.8	28	7.12
2	7.6	28	7.69
3	3.8	14	5.87
4	7.6	14	6.58
5	3.8	7	5
6	7.6	14	6.58
7	7.6	14	6.58
8	7.6	7	5.1
9	7.6	14	6.58
10	11.4	14	6.97
11	11.4	28	8.3
12	11.4	7	6.22
13	7.6	14	6.58

Table 9: ANOVA for Flexural strength

Source	Sum of Squares	Df	Mean Square	F-value	p-value
Model	9.74	5	1.95	65.45	< 0.0001
A-S.P(UEO)	2.00	1	2.00	67.31	< 0.0001
B-C.A	7.68	1	7.68	258.27	< 0.0001
B ²	0.34	1	0.335	11.26	0.0122
Residual	0.21	7	0.03		
Lack of Fit	0.21	3	0.07		
Pure Error	0.00	4	0.00		
Cor Total	9.94	12			

Table 9 shows the ANOVA for flexural strength of concrete. The Model F-value of 65.45 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. A, B, B² are significant model terms. It is seen from the analysis that R² is 0.9791 showing that the correlation between the actual and predicted values is very good and the regression model coincides with the test data. The Predicted R² of 0.8714 is in reasonable agreement with the Adjusted R² of 0.9641. The adjusted R² indicates that the model can explain response value change of 96 %. The model equation for the flexural strength is given below

$$F.S = 2.94203 + 0.107713 * UEO + 0.236112 * C.A + -0.000107411 * UEO (C.A) + 0.00312828 * (UEO)^2 + -0.00364337 * (C.A)^2 \dots\dots(2)$$

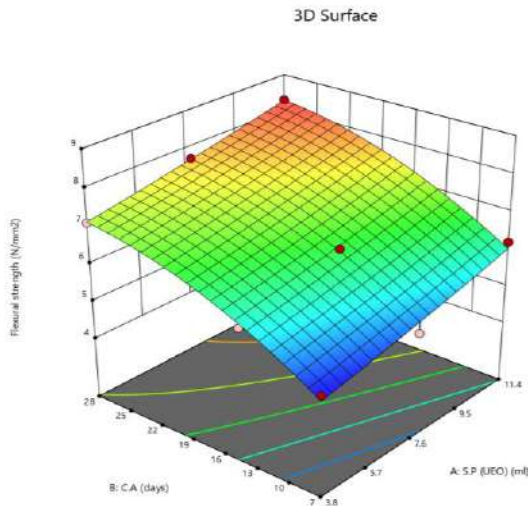


Figure 6: Three-Dimensional Surface image of Curing age, UEO and flexural strength
Figure 6 show the influence of UEO and C.A on flexural strength of concrete. The higher the curing age and dosage replacement, the higher the flexural strength of concrete.

Table 10: Actual and Predicted Value of Flexural Strength

Run Order	Actual Value	Predicted Value
1	7.12	7.14
2	7.69	7.67
3	5.87	5.98
4	6.58	6.52
5	5.00	4.87
6	6.58	6.52
7	6.58	6.52
8	5.10	5.41
9	6.58	6.52
10	6.97	7.15
11	8.30	8.30
12	6.22	6.04
13	6.58	6.52

3.4 Analysis of Split Tensile Strength

Table 11: Split Tensile strength result

Run	Factor 1 A:S.P ml	Factor 2 B:C.A days	Response 3 Split Tensile Nmm ²
1	3.8	28	10.3
2	7.6	28	11.3
3	3.8	14	7.11
4	7.6	14	8.41
5	3.8	7	7.11
6	7.6	14	8.41
7	7.6	14	8.41
8	7.6	7	6.93
9	7.6	14	8.41
10	11.4	14	15.5
11	11.4	28	18.9
12	11.4	7	11.6
13	7.6	14	8.41

Table 12: ANOVA for Split Tensile

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	149.23	5	29.85	87.18	< 0.0001
A-UEO	79.20	1	79.20	231.34	< 0.0001
B-C.A	36.51	1	36.51	106.63	< 0.0001
AB	3.17	1	3.17	9.27	0.0187
A ²	23.02	1	23.02	67.23	< 0.0001
Residual	2.40	7	0.3424		
Lack of Fit	2.40	3	0.7988		
Pure Error	0.0000	4	0.0000		
Cor Total	151.63	12			

Table 12 shows the ANOVA for tensile strength of UEO concrete. The Model F-value of 87.18 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. In this case A, B, AB, A² are significant model terms. The R² is 0.9842, the Predicted R² of 0.8501 is in reasonable agreement with the Adjusted R² of 0.9729. The model equation for the tensile strength.

$$T.S = 11.8053 - 2.45774 * UEO + 0.122037 * CA + 0.0219253(UEO) CA + 0.199912 (UEO)^2 + -0.00153569 (C.A)^2 \dots\dots(3)$$

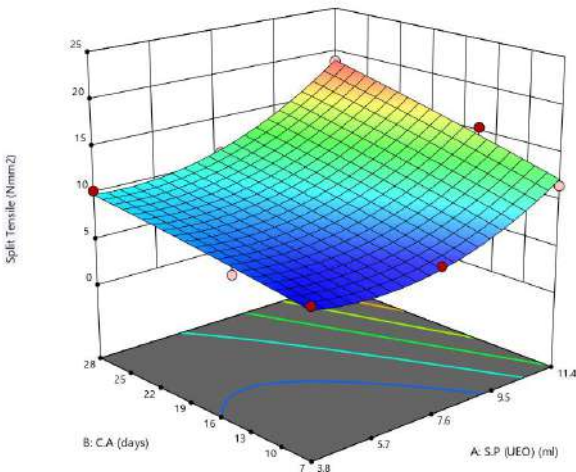


Figure 8: Three-Dimensional Surface Image of Split Tensile, Curing Age and U.E.O

Table 13: Actual and Predicted Value of Tensile Strength

Run Order	Actual Value	Predicted Value
1	10.32	9.90
2	11.26	11.55
3	7.11	7.93
4	8.41	8.41
5	7.11	6.71
6	8.41	8.41
7	8.41	8.41
8	6.93	6.62
9	8.41	8.41
10	15.51	14.67
11	18.85	18.98
12	11.59	12.30
13	8.41	8.41

3.5 Analysis of Water absorption

Table 14: Water Absorption result

Run	Factor 1 A:S.P ml	Factor 2 B:C.A days	Response 4 Water Absorption %
1	3.8	28	1.34
2	7.6	28	0.74
3	3.8	14	1.45
4	7.6	14	0.84
5	3.8	7	1.25
6	7.6	14	0.84
7	7.6	14	0.84
8	7.6	7	0.64
9	7.6	14	0.84
10	11.4	14	0.83
11	11.4	28	0.73
12	11.4	7	0.62
13	7.6	14	0.84

Table 15: ANOVA for Water Absorption

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.8412	5	0.1682	56585.06	< 0.0001
A-S.P	0.5645	1	0.5645	1.9E+05	< 0.0001
B-C.A	0.0150	1	0.0150	5044.97	< 0.0001
AB	0.0001	1	0.0001	32.43	0.0007
A ²	0.2446	1	0.2446	82262.45	< 0.0001
B ²	0.0751	1	0.0751	25263.86	< 0.0001
Residual	0.0000	7	2.9E-06		
Lack of Fit	0.0000	3	6.9E-06		
Pure Error	0.0000	4	0.0000		
Cor Total	0.8412	12			

Table 15 shows the ANOVA for water absorption analysis. The Model F-value of 56585.06 implies the model is significant. The P-values less than 0.05 indicate model terms are significant. In this case A, B, AB, A², B² are significant model terms. The R² is 1.00, the Predicted R² of 0.9998 is in reasonable agreement with the Adjusted R² of 1.0000; i.e. the difference is less than 0.2. The model equation for Water Absorption is given in equation 4.

$$W.A = 2.09 - 0.4(U.E.O) + 0.06C.A + 0.0001(U.E.O) * C.A + 0.021 * (U.E.O)^2 - 0.0017 * (C.A)^2 \dots (4)$$

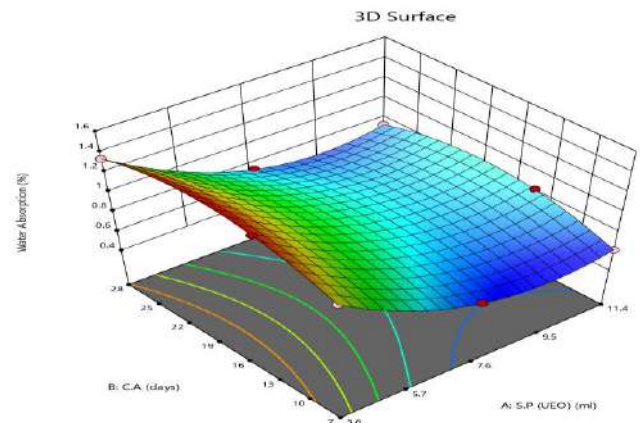


Figure 10: Three-Dimensional Surface Image of Water Absorption, Curing Age and U.E.O

Table 16: Actual and Predicted Value of Water Absorption

Run Order	Actual Value	Predicted Value
1	1.34	1.34
2	0.74	0.74
3	1.45	1.45
4	0.84	0.84
5	1.25	1.25
6	0.84	0.84
7	0.84	0.84
8	0.64	0.64
9	0.84	0.84
10	0.83	0.83
11	0.73	0.73
12	0.62	0.62
13	0.84	0.84

3.6 Numerical Optimization of UEO Concrete.

The goals that were set for each response are presented in Table 17

Table 17: Goals used for numerical optimization.

	Goal	Lower Limit	Upper Limit
A: SP (UEO)	is in range	3.8	11.4
B: Curing Age	is in range	7	28
Compressive strength	maximize	9.6	27.2
	maximize	5	8.3
	maximize	6.93	18.85
	minimize	0.62	1.45

The automatic optimization function of Design-Expert software version 13 indicates that the optimal values of the factors for highest concrete strength for UEO concrete are presented in figure 12 below.

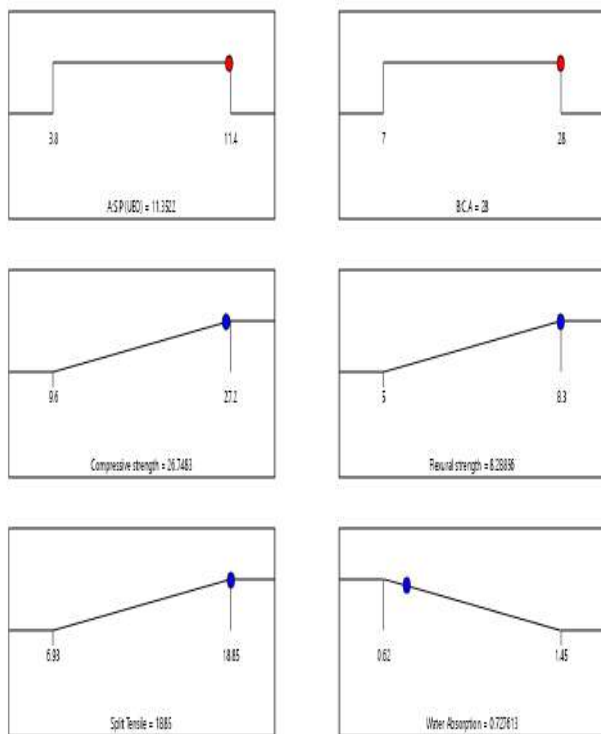


Figure 12: Ramp plot showing the optimal values for response.

4. CONCLUSION

The following conclusions are made after the findings in this research,

(1) Utilization of Used Engine Oil (UEO) resulted in a significant variation in the performance of Portland limestone concrete during its fresh state. UEO decreases the initial setting time and increases the consistency of Portland limestone concrete. The control mix had a measured slump value of 50mm but when engine oil and superplasticizer were used, the slump values obtained were 54mm and 52mm

respectively. Similarly, as the dosage of UEO and SP was increased, the slump value increased.

(2) Numerical optimization revealed the optimal values of UEO in concrete. The optimal value revealed 11.4ml of UEO at curing age of 28 days, compressive strength of 26.7 N/mm², flexural strength of 8.3N/mm², tensile strength of 18.9 N/mm² and water absorption of 0.7 %.

REFERENCES

[1] Khatib, J., Jahami, A., Baalbaki, O., Elkordi, A., Bakri, A., and Alaina, R. (2020). Performance of Concrete Containing Waste Plastic Straw Fibers. *BAU Journal Science & Technology*, 1(2020) 1-10.

[2] Adetoye Olunmi A., Sani Aliyu and Ibrahim Hassan: Suitability of using Marble Dust Powder and Rice Husk Ash in Production of Self-Compacting Concrete: A Review. *International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)*. 6(2023). 2551-58 DOI:10.15680/IJMRSET.2023.0609001

[3] Afolayan Taiye J., Adetoye Olunmi A., Sani Aliyu: A Review on the Effect of Pozzolanic Properties of Metakaolin in Concrete. *International Journal of Research Publication and Reviews*, 3(2022) 1383-1388

[4] Adetoye, O., Olamoju, R.O., and Afolayan, T. Partial Replacement of Coarse Aggregates with Plastic Waste in Paver Blocks. *Journal of Sustainability and Environmental Management*, 2(2023) 92- 97.

[5] Baalbaki, O, Elkordi, A, Ghanem, H, Machaka, M., and Khatib, J. M.: Properties of concrete made of fine aggregates partially replaced by incinerated municipal solid waste bottom ash. *Academic Journal of Civil Engineering*, 37(2019), 532-538.

[6] Charbaji, M.; Baalbaki, O.; Khatib, J. M.; Elkordi, A.: Characterization of Fly Ash Originated from Lebanese Municipal Solid Waste Plant. *International Congress on Engineering and Architecture, Turkey*.1565-1576, November 2018.

[7] Qurashi, I. and Swamy, A. Viscoelastic Properties of Recycled Asphalt Binder containing Waste Engine Oil. *Journal of Cleaner Production* 182(2018)992-1000 doi: 10.1016/j.jclepro.2018.01.237.

[8] Animashaun, L., Yekinni, A. and Warren, B. Used Oil Re-Refining Techniques in Nigeria-Economic Benefits. 2016, 6(2). Available at: <http://www.ejournalofscience.org>.

[9] Shatha Sadiq Hussien, "Using of Industrial Waste as a Green Chemical Admixture in Concrete", *Kufa Journal of Engineering*, 7(2016)104- 114.

[10] Thompson and W. Darwish. "Environmental chemical contaminants in food: review of a global problem," *J Toxicology* .v2019; 2019: 2345283.

[11] Liu, S., Peng, A., Wu, J. and Zhou, S. Waste engine oil influences on chemical and rheological properties of different asphalt binders. *Construction and Building Materials* 191*(2019) 1210–1220. doi: 10.1016/j.conbuildmat.2018.10.126.

[12] Giridhar "Impact of waste engine oil in concrete composition" *International Journal of Current Engineering and Scientific Research*. ISSN (print): 2393-8374, (online): 2394-0697, 4(2017)12-19

[13] Salahdein Asadey "Effects of Used Engine Oil as a chemical admixture in concrete" *International Journal of Energy and Sustainable Development* 3(2018) 38-43

[14] Beddu, S., N. Shafiq, M. Nuruddin, and N. Kamal. Effects of used engine oil as an admixture in concrete durability. *Current Journal of Applied Science & Technology*, 15(2016)1-10

[15] Khed, V.C.; Mohammed, B.S.; Liew, M.; Zawawi, N.A.W.A.(2020): Development of response surface models for self-compacting hybrid fibre reinforced rubberized cementitious composite. *Constr. Build. Mater.* 232(2020) 117191.

[16] Abubakar Sabo Baba, Auwal Abdullahi Umar, Aliyu Abubakar, Terlumun Adagba: Application of Response Surface Methodology in Predicting and optimizing the properties of Concrete containing Ground Scoria and Metakaolin blended Cement in Concrete. *Journal of Civil Engineering Frontiers* 4(2016) 19 –26

[17] Sani Aliyu, and Adetoye Olubunmi: Optimization of Self-Compacting Concrete Incorporating Granite Dust and Rice Husk Ash Using Response Surface Methodology. *KIU Journal of Science, Engineering and Technology*. 3(2024)39-46.<https://doi.org/10.59568/KJSET-2024-3-1-04>.

[18] American Concrete Institute Committee 221.1- Reapproved 2009, Standard practice for selecting proportions for Normal, Heavyweight and Mass Concrete, an ACI Standard.