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Compressive Strength Prediction of Silica Fume mixed Concrete Soaked in Used Engine Oil with a Mathematical Model

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Abstract

The determination of strength properties i.e., compressive strength (CS) is essential to estimate the load at which the concrete members may crack especially in aggressive environment. The paper reports an experimental investigation on deterioration of used engine oil (UEO) soaked concrete with respect to its strength properties. Also, it is found that this deteriorating effect is lessened with partial replacement of silica fumes (SF). The CS analysis was done with a water-concrete ratio of 0.49 with nine percentage replacements of SF (0, 5, 10, 15, 20, 25, 30, 35, 40 and 45) with water curing and UEO soaking. The soaking in two different liquids was essential in order to throw light on the detrimental effects of UEO on the CS of concrete. The results of the experiments showed that 20% replacement of SF in concrete was optimum to attain maximum CS. A mathematical model based on Abrams' law has been developed to evaluate the strength characteristics of concrete subjected to UEO soaking. The developed model facilitates the prediction of CS based on curing time in water and soaking time in UEO and also the quantity of SF used. The accuracy of the developed model is evaluated and good agreements with the ground truth values are found.

Index Terms: Concrete, silica fumes, compressive strength, used engine oil, mathematical model.

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1. Introduction

Concrete structures usually comes in contact with petroleum products like diesel, petrol, used engine oil and so on, in places like petrol bunks, garages, storage tanks, etc. Either steel or concrete tanks is made use of for the storage of petroleum [1]. Owing to the corrosion hazards, concrete is advisable for storage of petroleum products over metallic products. Drastic decrease in compressive strength of concrete is seen in case of concrete specimen coming in contact with crude oil [2]. Many attempts have been made to increase the strength properties of concrete by the addition of pozzolans. In spite of this, it is seen that concrete quality degrades when it comes in contact with used engine oil (UEO). Hence, efforts to completely avoid or to lessen this degrading effect is crucial.

2. Related Work

Matti et al, [3] studied over a period of 3 years, the dynamic modulus of concrete for samples subjected to crude oil soaking. The strength properties of concrete was found to be decreased in this case. A comparison between the physico-chemical effect along oil and water showed that the polar molecules amongst hydrocarbon chain were detrimental to concrete. Water moles are basically tiny dipoles and when acted positively on concrete, it leads to the strengthening of concrete. Hydrocarbon chain is basically non-harmful and non-polar in nature, though issues are found in connection with the hydrophilic part of the problem [4].

An assortment of pozzolan proportions showed increase in strength properties of concrete. However, choosing the right pozzolan with optimum proportion for a specific platform (for instance UEO used in this study) is a very challenging issue. Efforts have been put in promoting the usefulness of industrial wastes or the by-products rich in silica as an admixture to cement. Mineral admixtures as finely ground siliceous material lacks cementitious properties, although reacts with excess Ca(OH)2 produced during hydration process. It then converts it to useful cementitious product like C-Si-H (Gel).

The strength properties of concrete are seen to be increased owing to the high pozzolanic activity and void filling of silica fumes. The process comprises of a pozzolanic reaction which converts weak Ca(OH)2 crystals into strong CaSiH (calcium silicate hydrate) gel. The process basically renders significant enhancements in compressive strength as reported in [5, 6,7,8]. In contrast to reference concrete, a significant enhancement in the strength properties is found for 20% replacement level (Fig. 1). The drop in excess Ca(OH)2 owing to the pozzolanic reaction enhances the durability of concrete by making cement paste more impervious and dense.

Petroleum products degrades the strength properties of concrete. As a result, the concrete structures are deteriorated easily in such an environment [9,10, 11,12,13,14,15]. Also, petroleum coming in contact with environment poses danger to water bodies [16]. This paper attempts to assess the degrading effect of a petroleum product on concrete and throws light on its minimization with the inclusion of silica fumes.

The rest of the paper is organized as follows. The closely related work is discussed in section II. Section III. briefs the materials and methods of the study. The results are discussed in section IV. The paper concludes in section V.

3. Materials and Methods

This section briefs the materials used for the study along with the methodologies adopted.

3.1. Materials

3.1.1. Cement and Silica Fume

In this research work, 43 grade ordinary Portland cement (OPC) is used for all the concrete mixes. The cement used is fresh and has no lumps. Cement's testing is carried on as per IS: 8112-1989 standards. The specific gravity of cement is found to be 3.15.

Silica fume used in the experimentation is obtained from Elkem laboratory, Navi Mumbai. The chemical properties of silica fume and cement used are given in Table 1. Table 2 gives the detailed physical properties of cement used.

Table 1. Chemical Compositions of Ordinary Portland cement (OPC) and Silica Fume

Composition (% by mass)	**OPC**	**Silica fume**
Silica (SiO2)	20.2	93.4
Alumina (Al2O3)	4.7	0.42
Iron oxide (FeO3)	3	0.52
Calcium oxide (CaO)	61.9	1.91
Magnesium oxide (MgO)	2.6	-
Sodium oxide (Na2O)	0.19	0.25
Potassium oxide (K2O)	0.82	0.79
Sulfur trioxide (SO3)	3.9	0.34
Loss on ignition	1.9	2.3
Specific surface area (m2/kg)	453[a]	13,000[b]

a Determined using Blaine's air permeability apparatus.
b Obtained from the manufacturer of silica fume.

Table 2. Physical properties of ordinary Portland cement

Particulars	**As per standard**	**Experimental result**
Fineness	Not less than 225 m2/kg	308 m2/kg
Soundness		
By Le-Chatelier Expn. (mm)	Not more than 10 mm	1.5 mm
By Autoclave Expn. (%)	Not more than 0.8	0.07
Initial	Not less than 30	180
Final	Not more than 600	250
Compressive strength (MPa)		
3 days	Not less than 23	36
7 days	Not less than 33	46
28 days	Not less than 43	60

3.1.2. Fine Aggregates

Locally available sand collected from the bed of river Krishna is used as fine aggregate. Sand is having a fineness modulus 2.38 and conformed to grading zone-II as per IS: 383-1970 specification. Sieve analysis of fine aggregate is given in Table 3 and physical properties tested for fine aggregate are given in Table 4. The specific gravity of fine aggregate is found to be 2.64.

Table 3. Sieve Analysis of fine Aggregate (IS: 383-1970)

IS Sieve size	Weight retained (grams)	Cumulative weight retained (grams)	Cumulative % weight retained	Cumulative % passing	Grading Zone II
10	0	0	0	100	100
4.75	5	1	5	95	90-100
2.36	44	45	9	91	75-100
1.18	30	75	15	85	55-90
600 μm	50	125	45	55	35-59
300 μm	185	310	72	28	8-30
150 μm	120	430	92	8	0-10
Pan	70	500		-	-
Total	500gm	-	238	-	-

Table 4. Physical Properties of fine Aggregate (IS: 2386-1963)

Properties	Results	Permissible limit as per IS: 2386-1963
Organic impurities	Colorless	Colorless /Straw Color/Dark Color
Silt content	0.7%	Should not be more than 6-10%
Specific gravity	2.64	Should be between the limit 2.6-2.7
Bulking of sand	16%	Should not be more than 40%
Moisture content	0.65%	-

3.1.3. Coarse Aggregates

Aggregates used for the study have fineness modulus of 1.9. The sieve analyses of coarse aggregate are presented in Table 5 while the physical and mechanical properties of the coarse aggregates are presented in Table 6.

Table 5. Sieve analysis of coarse aggregate (IS: 2386-1963)

IS sieve size	Weight retained (grams)	Cumulative weight retained (grams)	Cumulative % weight retained	Cumulative % passing	ISI permissible limit
20 mm	0	0	0	100	100
12.5 mm	0	0	0	100	85-100
10 mm	1860	1860	93	7	0-20
4.75 mm	93	1953	97.65	2.35	0-5
Pan	47	2000	-	-	-
Total	2000	-	190.65	-	-

Table 6. Physical and Mechanical Properties of Coarse Aggregate (IS: 2386-1963)

Properties	**Results**	**Permissible limit as per IS: 2386-1963**
Impact value	15.50%	Should not be more than 30% used for concrete
Crushing value	25.00%	Should not be more than 30% for surface course and 45% other than wearing course
Specific gravity	2.90	In between range 2.6-2.8
Moisture content	0.16%	-

3.1.4. Sand

Locally available sand of specific gravity 2.64 and coarse aggregates of (d max = 20 mm) were utilized.

3.1.5. Water

Clean potable water taken from the city sources is utilized exclusively for both during concreting and curing processes.

3.1.6. Used engine oil

Properties of used engine oil are shown in the Table 7. The engine oil used for soaking the concrete specimens is taken from automobile service station. Properties of used engine oil are shown in the Table 7.

Table 7. Properties of used engine oil

Properties	**Results**
Kinematics viscosity at 40 ℃	111.32
Kinematics viscosity at 100 ℃	17.83
Viscosity index	99
Flash Point, ℃	230
Pour Point, ℃	-10
TBN	-
Sulfated ash, wt %	4.5
Specific gravity	0.928

3.2. Methods

The specimens were separated into two categories (Group A and B). Group A specimens were left without any interruptions in water itself for another 90 days. Simultaneously, the Group B specimens were immersed in UEO for the same interval of time. Both the specimens were tested for their respective compressive strengths as per IS specifications. Both the classes of specimens were tested for their strength properties performed on 7th, 14th, 28th, 40th, 52nd and 90th days. Silica fume mixed concrete was used with two variants in the assessment of strength properties, few samples were water cured (designated as Group A samples) and the rest were soaked in UEO (Group B samples). 189 concrete beams with varying proportions of silica fume admixture were cast and water cured for 28 days. On the 28th day, 3 cubes from the 9 samples (with different percentage of silica fume ranging between 0- 45%) were taken and their respective compressive strength was measured. Totally 27 out of 189 samples were tested here. Then, 135 samples were soaked in the UEO (Group B) and the remaining 27 samples were water cured (Group A). At specific intervals (14, 28, 40, 52, 90 days) the compressive strength strengths of Group B specimens were assessed. In case of Group A, the test was conducted for the 28th and 90th day only (the reason being, most of the hydration takes place within 28 days and later the changes in compressive strengths are marginal).The compressive strengths of both the Groups A and B were compared against their corresponding time intervals. Entire concrete cube with its shape intact was used for compressive strength analysis by using Compressive Testing Machine (CTM). The compressive strength of the entire samples is summarized in Fig. 1.

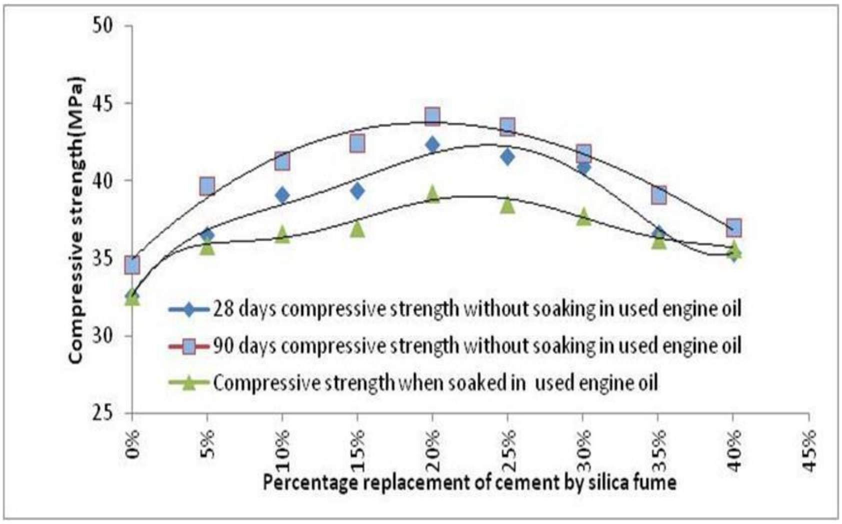

Fig.1. Compressive Strength of Concrete Mixed with Silica Fume. Note the Variations in Compressive Strengths Due to Soaking in used Engine Oil.

4. Results and Discussions

The experimental results can be better explained using a mathematical model. The primary factors affecting the compressive strength of concrete in our study are water, SF, UEO and curing/soaking time. We deal with each of the factors individually by using regression analysis and modeling. Fig. 2 gives a brief idea of the modeling process involved.

According to Abrams' law, the compressive strength and water-to-cement ratio follows an inverse relationship given by equation 1 [8].

$$fc = A / B^{((}w / c)) \tag{1}$$

Where A and B are the constant coefficients and w/c denotes water-to-cement ratio. The curing time of water affects the compressive strength and obeys a logarithmic relation governed by equation 2 [8],

$$fc = b + a\log(t) \tag{2}$$

Where a and b are constant coefficients. When applied to our study, equation 2 can be rewritten as equation 3 (with no SF taken, see Fig. 3),

$$fc = 0.5545\,\log(t) + 28.292 \tag{3}$$

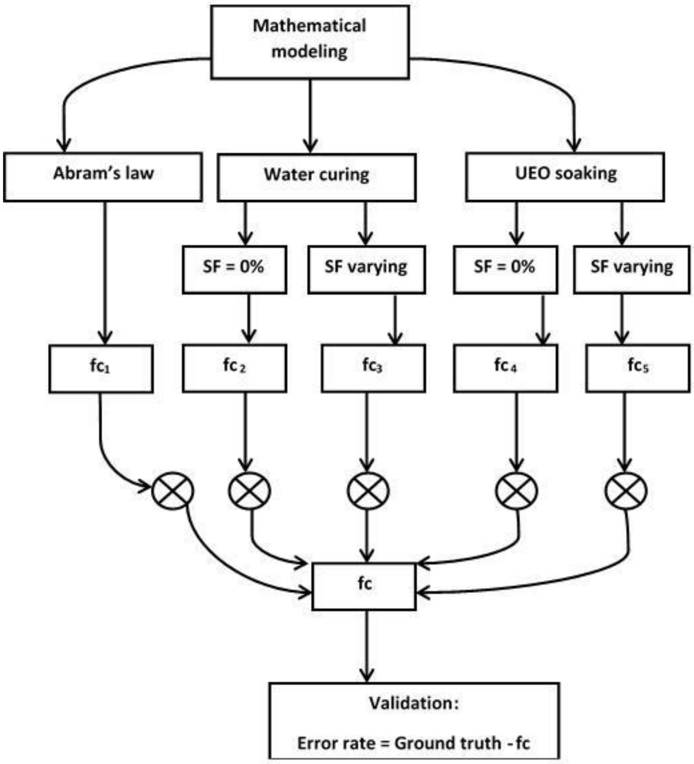

Fig.2. Depiction of Overall Workflow

Based on the principles of regression we derive a two-degree equation (equation 4) for the compressive strength based on the varying percentages of SF used (*s*) with water curing time kept constant (for 90 days).

$$Rfc = Cfc - Gfc \quad fc = -0.0196s^2 + 0.8167s + 35.217 \tag{4}$$

On similar grounds, we derive the relation for UEO soaking of concrete with 0% SF to study the effect of soaking time (*t*) of concrete in UEO (equation 5).

$$fc = 0.0000t^2 - 0.017s + 32.384 \tag{5}$$

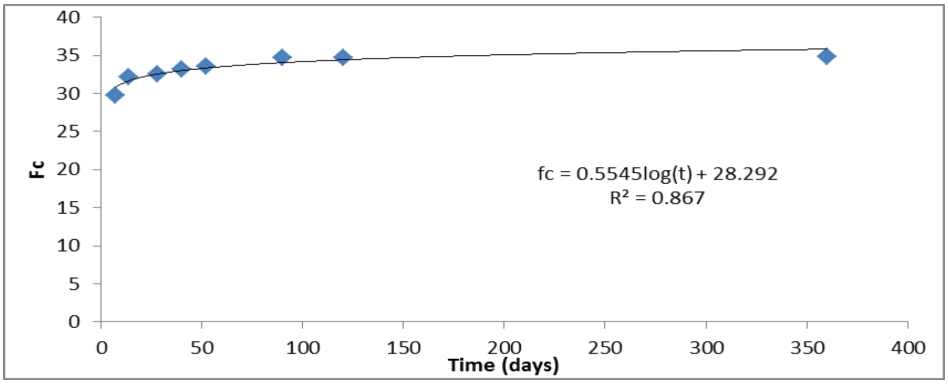

Fig.3. Relationship between Compressive Strength with time of Curing in Water (days)

Finally, we derive the relation for compressive strength of concrete with UEO soaking for different variations of SF for 90 days of soaking time (see equation 6).

$$fc = -0.0119s^2 + 0.5197s + 32.844 \tag{6}$$

The overall relationships can be combined with considered variables as follows,

$$fc = \frac{A}{B^{\left(\frac{W}{C}\right)}} + F \times log\left(-0.0119s^2 + 0.5197s + 32.844\right) \times \left(0.5545\,log\left(t\right) + 28.292\right)^C$$

$$\times \left(-0.0196s^2 + 0.8167s + 35.217\right)^D$$

$$\times \left(0.0000t^2 - 0.017s + 32.384\right)^E$$

$$\times \left(-0.0119s^2 + 0.5197s + 32.844\right)^F \tag{7}$$

$$log\left(fc\right) = log\left(A\right) - log\left(B\right) \times \left(w/c\right)$$

$$+ C \times log\left(0.5545\,log\left(t\right) + 28.292\right)$$

$$+ D \times log\left(-0.0196s^2 + 0.8167s + 35.217\right)$$

$$+ E \times log\left(0.0000t^2 - 0.017s + 32.384\right)$$

$$+ F \times log\left(-0.0119s^2 + 0.5197s + 32.844\right) \tag{8}$$

where A, B, C, D, E and F can be determined with multiple linear regressions.

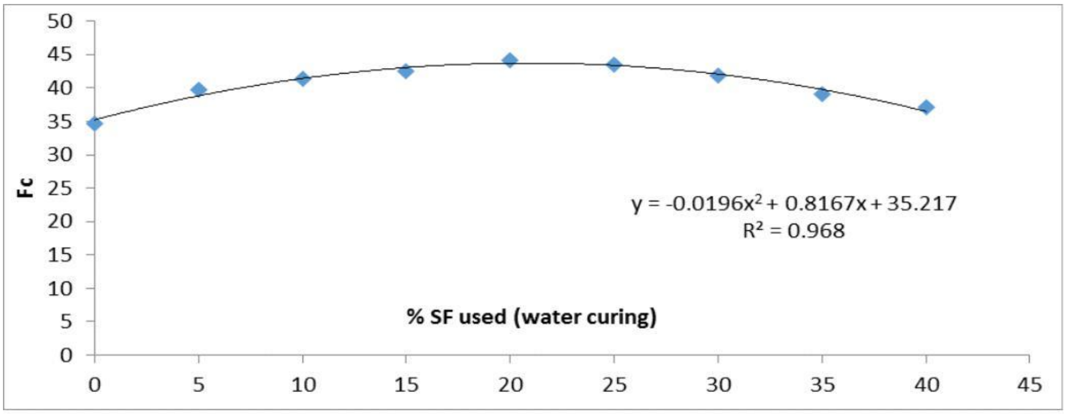

Fig.4. Relation between SF used and Compressive Strength (Water Curing for 90 days)

In order to validate the above equation, we find the residuals given in equation (9), where fc is the compressive strength, *t* is the time of soaking/curing, w/b is water to cement ratio and s is the percentage of SF used. Applying logarithms on both sides, we have,

$$log(fc) = log(A) - log(B) \times (w/c)$$

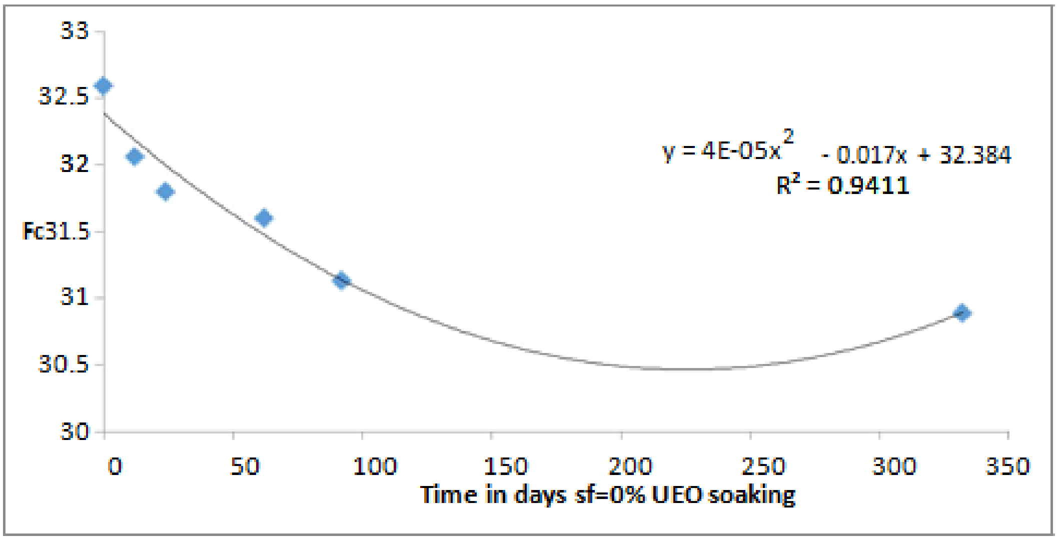

Fig.5. Relation between Compressive Strength and Concrete (with 0% SF) in UEO Soaking.

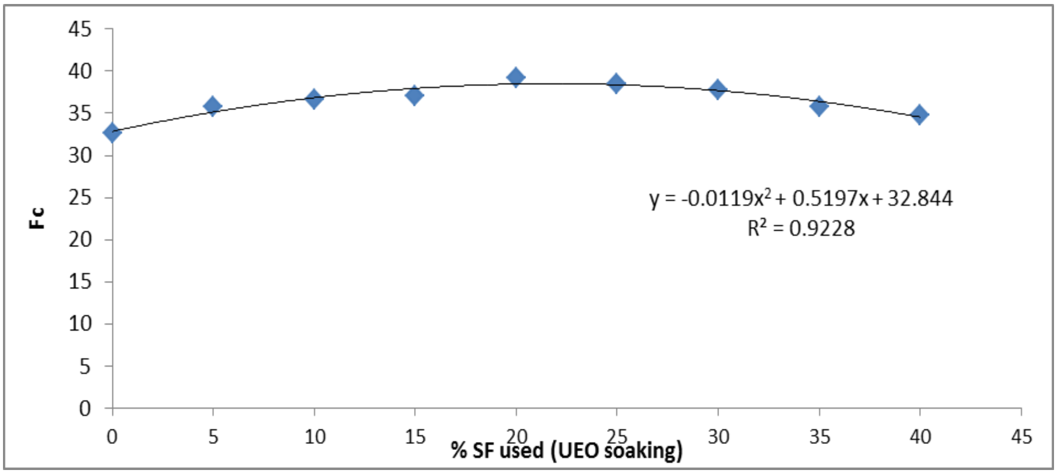

Fig.6. Relation between Compressive Strength and SF used (90 days UEO soaking)

$$Rfc = Cfc - Gfc \tag{9}$$

where *R* corresponds to the residual values obtained after taking the difference of calculated values (*C*) and the ground truth (observed values) *G* of the compressive strength *fc*. The residuals are plotted in Fig. 7. This diagram shows that the maximum percentage error in the predicted values of *fc* ±2%.

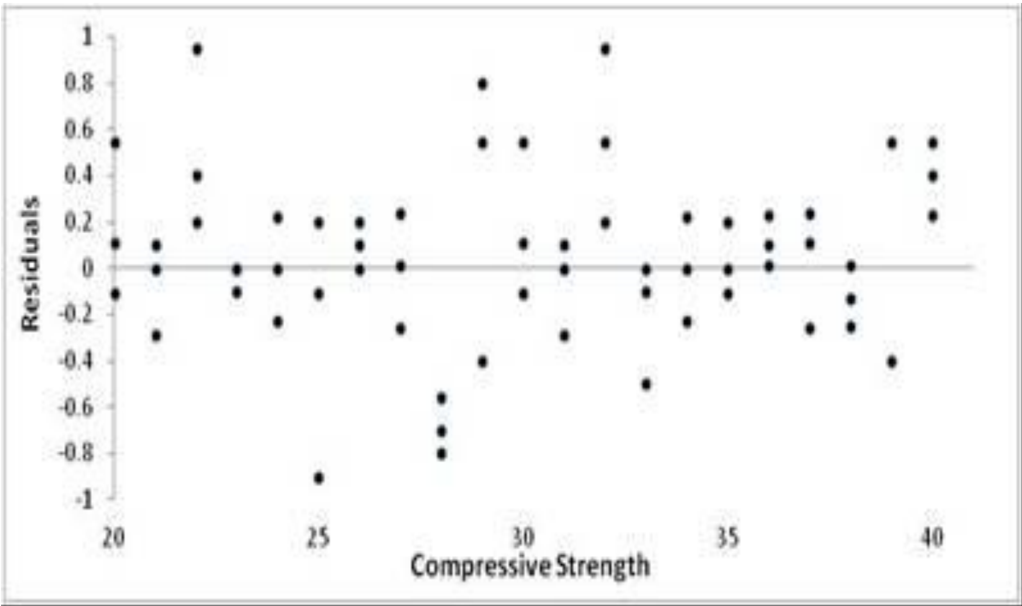

Fig.7. Residuals for Compressive Strength (equation 9)

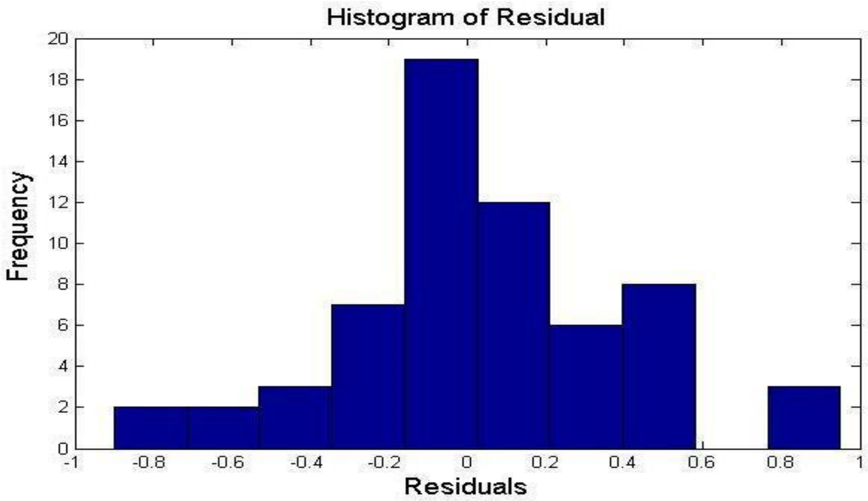

Fig.8. Histogram of Residuals Computed for the Residuals (equation (9)).

Fig. 8 shows the histogram for the residuals computed (Average±SD: 0.0502±0.3709). It can be observed that the mean and maximum values of the residuals in the histogram lie near zero.

5. Conclusions and Future Scope

The degree of degradation of UEO on concrete with respect to compressive strength were assessed and found that the negative effect on strength properties were considerably less for silica fume mixed concrete. Thus, it aids in the use of industrial waste product to reduce pollution. The mathematical model designed for the prediction of compressive strength of concrete soaked in used engine oil was in good agreement with the ground truth. As a future scope we would like to extend our model to incorporate different pozzolans and soaking time in different petroleum by-products into our model.

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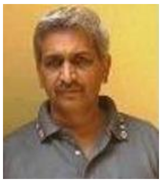

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