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Spent Foundry Sand as Partial Replacement of Fine Aggregate in the Production of Concrete

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Abstract: *An evaluation on the use of spent foundry sand (SFS) in the production of concrete has been carried out. The material SFS, was properly characterized and used in proportions of 0 %, 10 %, 20 %, 30 % and 40 % by weight of fine aggregate and cured under laboratory conditions for up to 90 days. The results obtained showed that the SFS used satisfied the ACI Code of practices on the use of SFS, and also has pozzolanic properties. The work also confirmed that SFS can substantially reduce the effects of absorption in concrete to about 8 % to 28 %, when cured for 90 days and at different replacement levels. This is good for durability of concrete. However, the compressive strength decreased as the replacement levels increased and performed optimally at 10 % replacement. Linear regression models developed on the experimental data are significant and adequate.*

Keywords: *Spent foundry sand, Water absorption, Compressive strength, Pozzolan, Linear regression*

I. Introduction

Spent foundry sand (SFS), is high quality silica sand that is a byproduct from the production of both ferrous and nonferrous metal casting and, its physical and chemical characteristics depend in great part, on the type of casting process and the industry sector from which it originates [1].

There are two basic types of foundry sand available, green sand (often referred to as molding sand) that uses clay as the binder material, and chemically bonded sand that uses polymers to bind the sand grains together. Green sand consists of 85-95% silica, 0-12% clay, 2-10% carbonaceous additives, such as sea coal, and 2-5% water. Green sand is the most commonly used molding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity. The carbonaceous additives prevent the “burn-on” or fusing of sand onto the casting surface. Green sands also contain trace chemicals such as MgO, K_2O, and TiO_2 [1].

Foundry waste sand has been found to be physically suitable for many applications but the long term environmental effects are not well known and documented. Therefore, understanding the characteristics of waste is fundamental to selecting, designing and implementing waste management solutions in the foundry industry. This will result in defensible engineering and regulatory decisions regarding beneficial use of spent molding sand while minimizing environmental impact and maximizing economics.

Many research works lately have been centered on the use of spent foundry sand (SFS) as a possible replacement of sand in concrete works. The reasons for that are tied to the beneficial characteristics of SFS. Other reasons proffered for its use are for areas where good quality sand is difficult to obtain.

Siddique and Sandhu [2], used waste foundry sand (WFS) in the study of self-compacting concrete (SCC), and used it to replace sand by percentage weight, in proportions of 0 to 20 %. Their investigations were on the compressive and splitting tensile tests. They concluded that WFS increased the strengths respectively and also improved the durability and permeability of the concrete samples.

Khatib et al [3], worked on concrete using WFS to replace sand in the proportions of 0 to 100 %, curing for 14, 28 and 50 days respectively, and concluded that replacing part of the sand with WFS decreased workability and that adequate strengths were achieved.

Saveria et al [4] investigated the performance of waste foundry sand in cement mortars and concrete production at different water-cement ratios. Their results showed that WFS can be used to produce structural mortar and concrete.

Kumar et al [5] used three (3) types of used foundry sand to replace fine aggregate in the evaluation of the compressive strength of concrete. The results obtained using the three (3) types of used foundry sand were compared with the natural sand. They attributed the strength loss in used foundry sand concrete mixtures to the presence of anti-binder in the form of very fine powder of carbon and clay. This, they say resulted in lack of contacts between the aggregates and cement paste.

The purpose of this work is to use SFS in proportions of 0 to 40 %, in replacing fine aggregate in concrete production, both in the fresh and hardened conditions. These will be cured for 3, 7, 28, 60 and 90 days, respectively, for the characterization and evaluation of SFS-Concrete.

II. Materials

The cement used for this work is Ashaka Portland cement conforming to BS 882 [6]. The Physical and Chemical properties of the cement are shown in Table 1.

The fine aggregate is river sand with a maximum size of 4.46 mm, bulk density of 1688 kg/m^3, moisture content of 14.49 %, and a specific gravity of 2.68. The coarse aggregate was sourced from the quarry site in Bauchi, and has a maximum size of 20 mm, bulk density 1.714 kg/m^3, specific gravity 2.88, crushing value of 3.68 and an impact value of 10.48. The results of the sieve analysis of both the fine and coarse aggregates show they fall into zone 2 in the classification chart.

Table 1: Chemical and Physical Properties of OPC

Oxides	Ashaka PC
SiO_2 (%}	20.7
Al_2O_3 (%)	6.1
Fe_2O_3 (%)	2.3
CaO (%)	62.1
MgO (%)	1.2
Na_2O (%)	0.9
K_2O (%)	1.0
SO_2 (%)	1.6
P_2O_5 (%)	-
MnO (%)	-
Specific gravity	3.15
Ignition Loss (%)	1.00
Loose bulk density (kg/m^3)	1550
Specific surface Blaine (m^2/kg)	355
Moisture content (%)	-
pH value	-

Table 2: Sieve Analysis Results of Fine Aggregate and SFS

	Weight Passing		
Sieve	Fine Aggregate.	Foundry Sand (Present)	Foundry Sand [7]
5 mm	100	100	100
2,00 mm	93.00	93.00	95 – 100
1.18 mm	78.00	78.00	70 – 85
600 µm	43.80	43.80	40 – 75
300 µm	20.40	20.40	20 – 40
150 µm	8.20	8.20	10 – 25
75 µm	8.16	8.16	0 - 10
Receiver	0.00	0.00	0.00

The SFS was obtained from the National Metallurgical Institute, Jos, Plateau State, Nigeria. It is a waste from the production of both ferrous and non-ferrous metal castings. The SFS has a maximum size of less than 3.96 mm with a moisture content of 3.04 %, bulk density of 2589 kg/m^3 and a specific gravity of 2.39. Table 2 shows the results of the sieve analyses of the fine aggregate and SFS. The chemical properties of the SFS are shown in Table 3 and were carried out in the Laboratory of Ashaka Cement, Gombe, Gombe State, Nigeria.

Table 3: Chemical Oxide Composition of SFS Compared with Others

Constituents	Percentage (%)		
	Present	FHWA [1]	IJERA [6]
SiO_2	78.34	87.91	67.21
Al_2O_3	9.95	4.70	4.28
Fe_2O_3	2.14	0.94	7.32
CaO	2.64	0.14	0.15
MgO	0.41	0.30	0.23
SO_3	0.06	0.09	0.89
K_2O	1.14	0.25	0.46
Na_2O	0.15	0.19	0.48
P_2O_5	0.09	0.00	0.00
Mn_2O_5	0.05	0.02	0.12
TiO_2	0.78	0.15	0.15
SrO	-	0.03	0.19
LOI	2.47	5.15	16.25

III. Experiments

A mix proportion of 1: 1.71: 2.56: 0.52 was used for the work and the quantities of the materials per m^3 are shown in Table 4. The SFS used replaces the fine aggregate in the proportions of 0 %, 10 %, 20 %, 30 % and 40 % by weight of fine aggregate, respectively. A total of five mixes labeled M-0, M-10, M-20, M-30 and M-40 were prepared and cured for 3, 7, 28, 60, and 90 days respectively and the following experiments were carried out using the above mixes and curing regimes to evaluate the effects of partially replacing sand with SFS in producing concrete. The data collected for these evaluations are on the density, water absorption and compressive strengths

The compressive strength tests were carried out using cube moulds of 150 mm to cast the specimens and, a total of seventy five specimens were cast and cured for the specified periods of curing. At the end of each curing regime, three of each of the specimens was evaluated for the water absorption and density, before crushing to failure using an ELE model testing equipment, for the compressive strength. The results of the water absorption, density and compressive strengths of the concrete cubes are shown in Tables 5, 6 and 7.

Table 4: Mix Proportions for the SFS-Concrete

Mix No.	Cement (kg/m^3)	Fine Agg. (kg/m^3)	SFS (kg/m^3)	Coarse Agg. (kg/m^3)	Water (kg/m^3)	Water-Cement
M-0	404	690	0.00	1036	210	0.52
M-10	404	621	69	1036	210	0.52
M-20	404	552	139	1036	210	0.52
M-30	404	483	207	1036	210	0.52
M-40	404	414	276	1036	210	0.52

Table 5: Water Absorption of SFS-Concrete

Mix No.	Water Absorption (%)				
	3 d	7 d	28 d	60 d	90 d
M-0	10.3	11.7	12.5	13.4	14.0
M-10	8.1	10.4	11.7	12.3	12.9
M-20	7.0	9.7	10.2	11.5	12.3
M-30	6.3	8.7	9.5	10.4	11.1
M-40	5.6	8.4	8.8	9.4	10.1

Table 6: Density of SFS-Concrete

Mix No.	Density (kg/m^3)				
	3 d	7 d	28 d	60 d	90 d
M-0	2757	2769	2833	2893	2906
M-10	2370	2438	2529	2702	2773
M-20	2430	2507	2551	2735	2788
M-30	2492	2587	2638	2638	2666
M-40	2558	2637	2702	2759	2707

Table 7: Mortar Compressive Strength of SFS-Concrete

Mix No.	Compressive Strength (kN)				
	3 d	7 d	28 d	60 d	90 d
M-0	17.1	21.4	25.3	25.7	26.0
M-10	18.0	19.0	20.9	23.0	24.0
M-20	15.9	16.5	18.8	19.6	21.0
M-30	15.3	16.0	17.0	18.5	18.8
M-40	14.8	15.7	16.0	17.2	17.8

IV. Discussion of Results

The SFS used has a specific gravity of 2.39 and is within the specified range of 2.39 – 2.55, specified by ASTM [8], bulk relative density of 2589 kg/m^3, as compared to the values (2590 kg/m^3), given by ASTM [9], and a moisture content of 3.04 %, satisfying ASTM D 2216 [10]. From Table 2, the grain size distribution is very uniform, with approximately 72 % of the material between 0.6 mm and 0.15 mm (No. 30 and No. 100) sieve sizes. Eight percent is smaller than 0.075 mm (No. 200) sieve. These values are within the specified values of ASTM C 144 [7]. The variability of the specific gravity has been attributed to the variability in fines and additive contents in different samples [11].

Table 3 shows the chemical properties of the SFS used for this work. It shows that the silica content is approximately 78 % which is high enough. The SiO_2 + Fe_2O_3 and Al_2O_3 add up to approximately 90 % and greater than the 75 % specified by ACI, for a pozzolanic material and therefore, SFS can be classified as a pozzolanic material. The pozzolanic index of SFS as calculated using the ASTM C 311[12] standard is 79 %.

The slump of SFS-concrete decreases as the proportions of SFS increases and thus the workability. This may be due to the void filling action of the waste foundry sand as it is finer than the fine aggregate, which gives a high cohesion to the mix. Mix with increase in waste foundry sand content tends to become harsh, sticky and stiff [13]. The density of SFS-concrete is a normal weight concrete as shown in Table 6, and increases as the SFS replacement level increased.

Figure 1(a and b), shows the effect of replacing part of the sand with SFS on the water absorption. The figure shows there is a decrease in water absorption as the SFS replaces fine aggregate and the percentage increase at 90 days of curing ranged from 8 % to 28 % of the control at the same curing age. It has been reported in the literatures that SFS has low absorption and is non plastic and that the absorption values obtained vary widely, which can be attributed to the presence of binders and additives [14]. Water absorption and porosity are important indicators of the durability of hardened concrete. Reduction of water absorption and porosity can greatly enhance the long term performance and service life of concrete in aggressive service environments. Decreased porosity also benefits the compressive and flexural strengths of concrete, as a fundamental relationship exists between porosity and strength of solids.

A regression analysis on the water absorption data using Minitab 15 Software shows that a linear model of the form: $wa = a_1 + b_1x + cx_1$, can be used to represent the statistical behavior of SFS-concrete, where, the constants a, b and c are given as 9.75; - 0.937 and 1.08, respectively. The variables, x and x_1, are SFS replacement levels (%) and age of curing, respectively. The standard deviation and correlation factor (r^2) are 2.148 and 48.1 %, respectively. The correlation shows that the interaction of the SFS and age is approximately 48 %. The relevance of the model chosen has a p value equal to 0.000, which is very significant. The normality and scatter plots on the data collected are shown in Figures 2 and 3, respectively, and confirm that the linear model chosen as relevant.

The compressive strength development of SFS-concrete is shown in Figure 4 (a and b). Figure 4a shows that as SFS replacement level increases, the compressive strength decreases. This is in conformity with past works on SFS [13] and best performance was at 10 % SFS replacement. Figure 4b shows that the SFS replacement level increases as the age of the SFS-concrete increased, showing that hydration process is in progress. The behavior of the compressive strength can also be represented regressionally as: $f_{cr} = a_2 + b_2x + c_2x_1$, where, a_2, b_2 and c_2 are constants with the values of 20.3, - 1.76 and 1.37, respectively, x and x_1 are as defined above, and are significant with *p* values equal to 0.000 and an interaction value of approximately 83 % ($r^2 = 83.4$ %). From Figures 5 and 6, it is seen that the regression model chosen is significant and perfectly describes the SFS-concrete behavior with a P-value of 0.000 from the variance analysis.

Relations between the compressive strength and the water absorption on one hand and the water absorption and slump on the other hand have been developed. The linear regression model for the cube compressive strength and water absorption is given as $fcr = -5.22 + 2.35\ wa$, with standard deviation (s) of 1.094 and correlation factor (r^2) of 93.5 %. The interpretation of this relationship shows that the constants are not significant with a *p*-value of $0.262 > 0.05$, while water absorption and regression model are significant with *P*-values of $0.007 < 0.05$. The relationship between the cube compressive strength (f_{cr}) and the water absorption and slump on the other hand: $f_{cr} = -17.3 + 5.03wa - 0.773x_3$, where x_3, is the slump. The constants, water absorption (*wa*) and slump (x_3) are not significant with *P*-values > 0.005 while, the regression model with a *P*-value of 0.038 is significant.

V. Conclusions

An evaluation on the use of SFS in the production of concrete has been carried out and the following conclusions are reached on the usefulness of using such materials for concrete production.

i. The characterization of the SFS shows that it is an adequate material for concrete production. The physical and chemical properties are within the ranges given by the American codes of practice for waste foundry sand utilization.

ii. SFS has pozzolanic properties and can reduce water absorption by approximately 8 % to 28 % at 90 days of curing. With this property, the durability of the concrete is enhanced and also the material SFS will perform well as a hydraulic barrier.

iii. Addition of SFS in concrete reduces the workability of the concrete and therefore, there will be need to use this material with a plasticizer that will enhance the workability of the concrete and encourage higher replacement levels.

iv. The values of the density production of SFS-concrete achieved show that it can be classified as a normal weight concrete.

v. The compressive strength of SFS concrete decreases with increase in the replacement levels and the best behavior is at 10 % replacement. This is in conformity with previous works.

vi. The work has established linear regression relations of the compressive strength of SFS-concrete with the water absorption and slump. The regression parameters show that the models chosen to represent these behaviors are significant.

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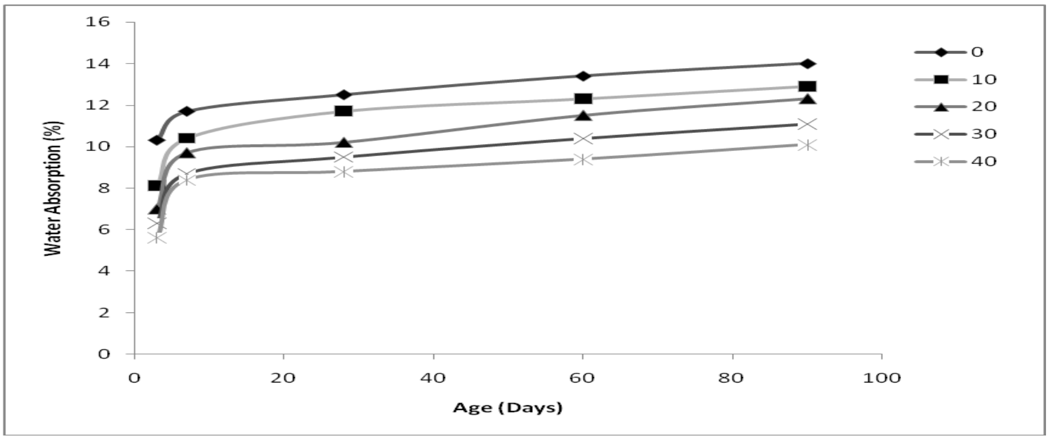

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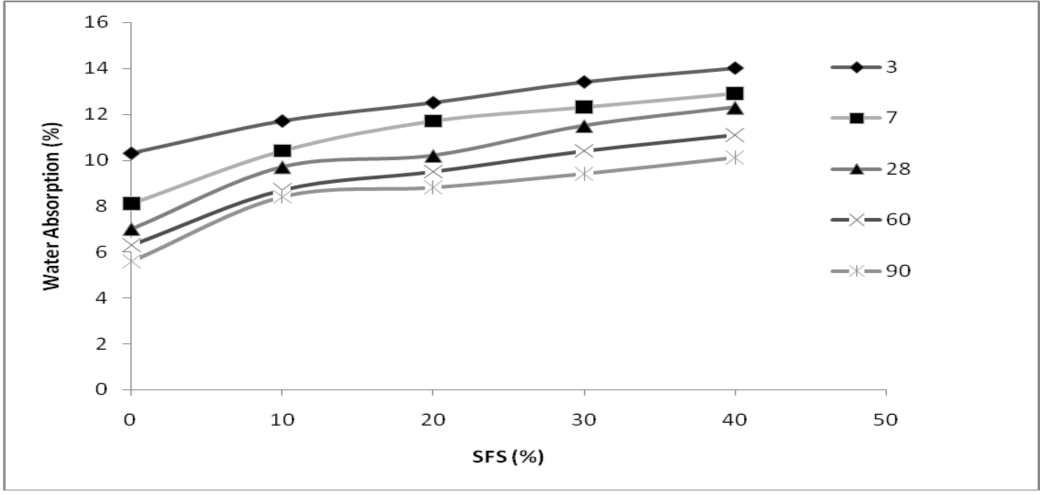


(b)

Figure 1: Water Absorption of SFS-Concrete

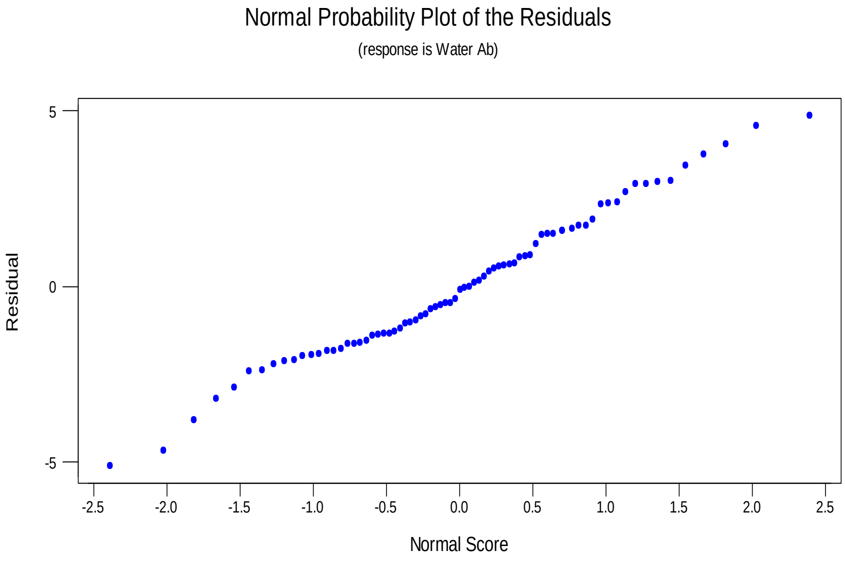


Figure 2

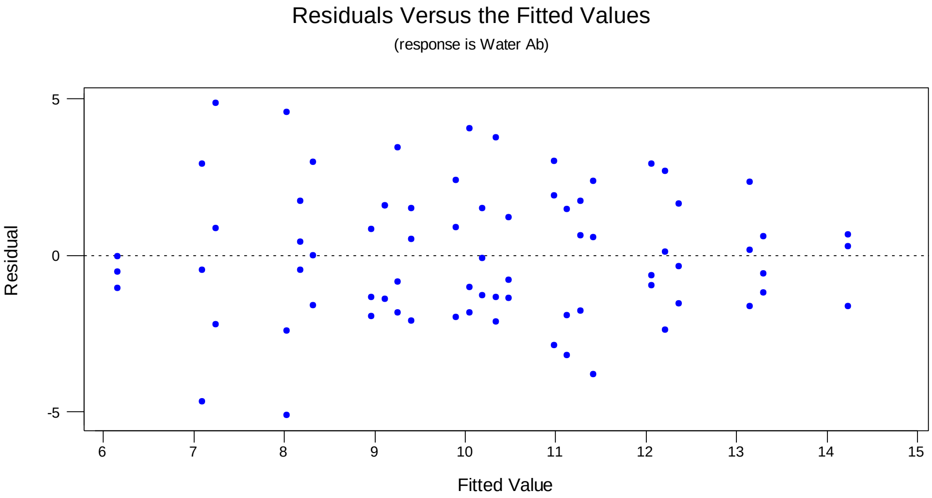
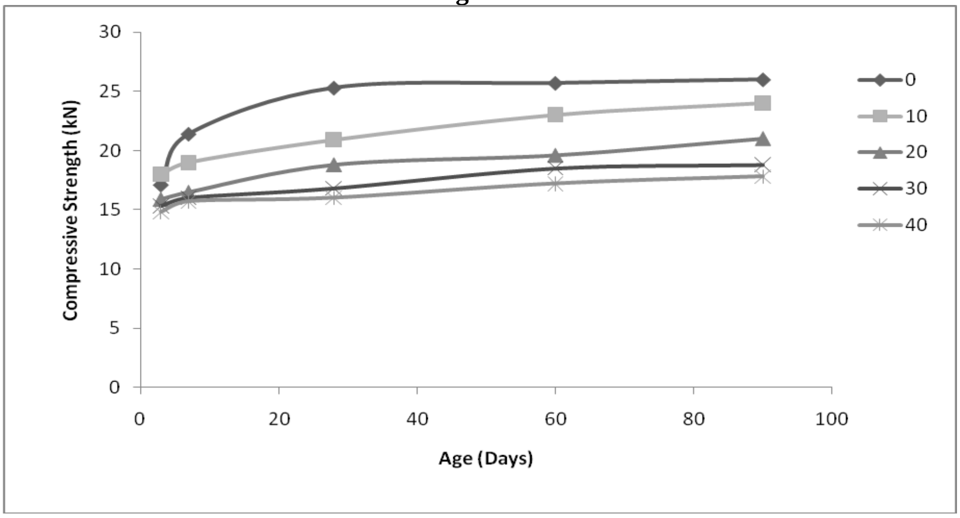


Figure 3



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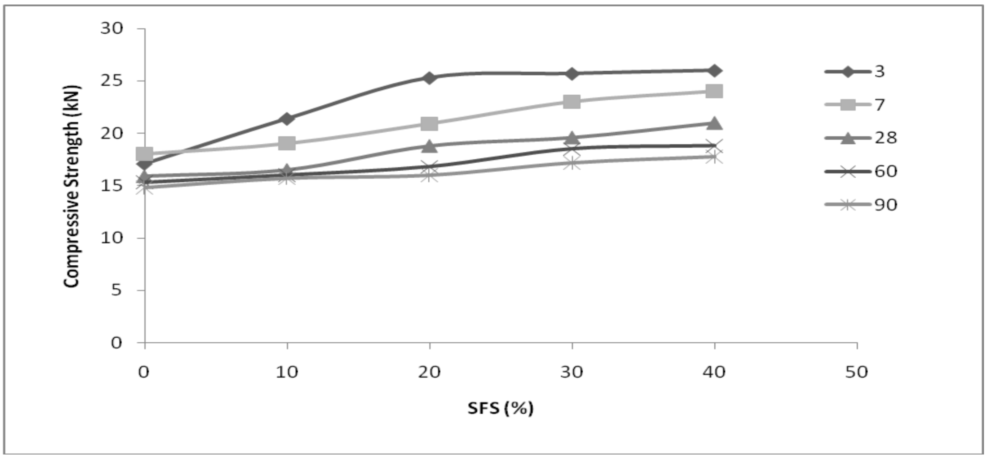

(b)

Figure 4: Compressive Strength of SF-Concrete

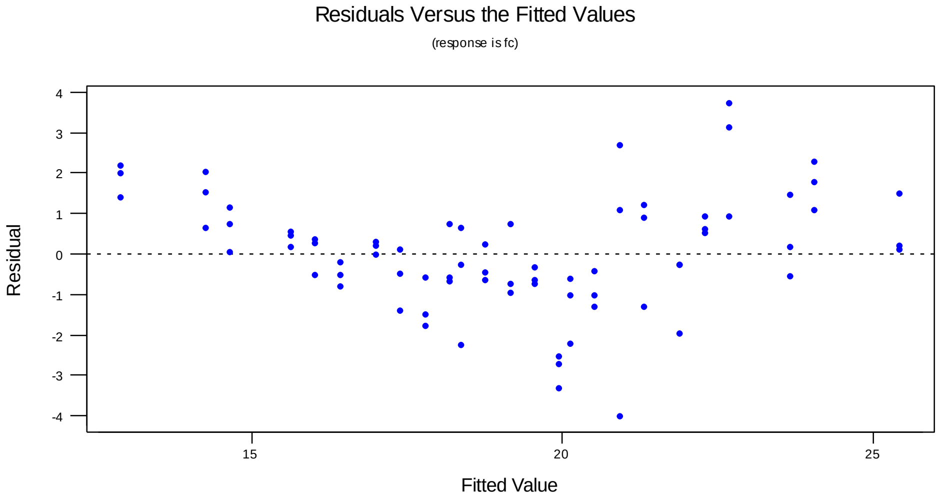

Figure 5

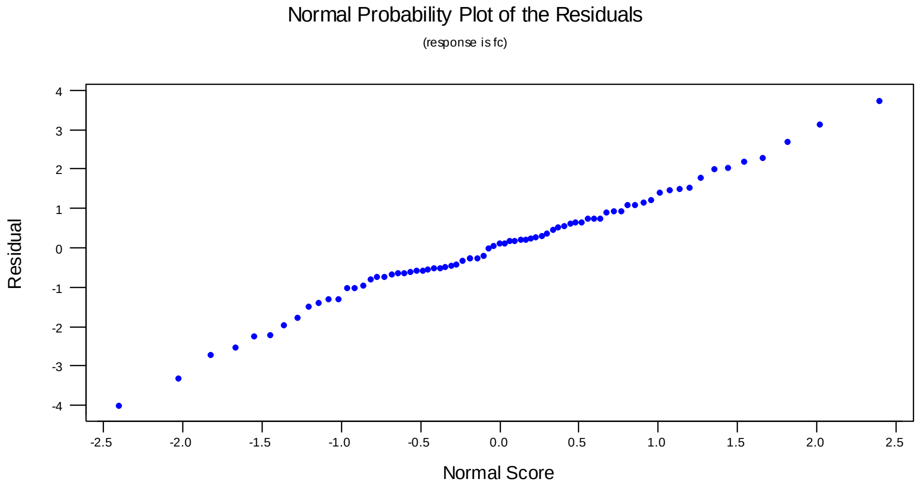

Figure 6