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Performance of Groundnut Husk Ash (GHA) - Rice Husk Ash (RHA) Modified Concrete in Acidic Environment

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ABSTRACT
This paper presents the findings of an investigation on the compressive strength of concrete containing Groundnut Husk Ash (GHA) blended with Rice Husk Ash (RHA) and its resistance to acid aggression, as well as regression models of the concrete resistance in acidic environment. The GHA and RHA used were obtained by controlled burning of groundnut husk and rice husk, respectively in a kiln to a temperature of 600 ^oC, and after allowing cooling, sieved through sieve 75 µm and characterized. The compressive strength of GHA-RHA-Concrete was investigated at replacement levels of 0, 10, 20, 30 and 40 %, respectively by weight of cement. A total of seventy five 150 mm cubes of GHA-RHA-Concrete grade 20 were tested for compressive strength at 3, 7, 28, 60 and 90 days of curing. Also, thirty 100 mm cubes were exposed to attack from 10 % concentration of diluted solution of sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively and the concrete resistance was also modeled using Minitab statistical software to establish regression models. The result of the investigations showed that the compressive strength of the concrete decreased with increase in GHA-RHA content. However 15 % replacement with GHA-RHA was considered as optimum for structural concrete. The use of GHA admixed with 10 % RHA in concrete improved its resistance against sulphuric and nitric acids aggression. The average weight loss of GHA-RHA- concrete after 28 days of exposure in sulphuric acid and nitric acid were 11.6 % and 11.7 %, respectively as opposed to 22.4 % and 15.1 %, respectively for plain Portland cement concrete. The regression models of GHA-RHA-Concrete for resistance against sulphuric and nitric acids were developed with R^2 values of 0.668 and 0.655, respectively and were adequate for prediction of the sensitivities of pozzolanic activity of GHA-RHA in acidic environment.
Keywords - Concrete, GHA, model, resistance, RHA

I. Introduction

For a long time concrete was considered a very durable material requiring very little or no maintenance. Due to its high durability, concrete structures were erected even in highly polluted urban and industrial areas, harmful sub-soil water in coastal areas and other hostile conditions where other materials of construction have not been found suitable. Though compressive strength of concrete is a measure of durability to a certain extent, but it is not entirely true that strong concrete is always durable, owing to some failures observed of concrete of high compressive strengths due to environmental conditions [1].

The durability of concrete is an important property which significantly determines the service life of concrete structures [2]. According to [3], durability of concrete is its ability to resist chemical and physical attacks that lead to deterioration of concrete during its service life. These attacks include leaching, sulphate attack, acid attack, carbonation, alkali-aggregate reaction, freezing-thawing and abrasion.

Supplementary cementing materials have been found in literature to improve the mechanical and durability properties of concrete apart from the main benefits of saving natural resources and energy as well as protecting the environment through the use of the main mineral admixtures [4]. Reference [5] reported that apart from the cost benefit of use of pozzolanas with ordinary Portland cement, other advantages of pozzolanas include; improved workability, improved water retention / reduced bleeding, improved sulphate resistance, improved resistance to alkali aggregate reaction, low heat of hydration and enhanced long term strength. However, there are controversial results about the resistance to acidic attack on pozzolanic cements in technical literature. Acidic attack usually originates from industrial processes, but it can even be due to urban activity. According to [6], pozzolanic cement has better durability characteristics against acid attacks, but [2] and others claimed vice versa. It was however reported in [7] that the resistance to acid attack on pozzolanic concrete varies with the acid in consideration. The acidic attack on pozzolanic cement products is affected by the processes of decomposition and leaching of the constituent of cement matrix [8]. Acids react with alkaline components of the binder (calcium hydroxide, calcium silicate hydrates and calcium aluminate hydrates) lowering the degree of alkalinity.

The use of Groundnut Husk Ash (GHA) as a supplementary cementing material in concrete has been reported in [9], [10] and [7]. They suggested that up to 10 % GHA content could be used as a partial substitute of cement in structural concrete. It was also indicated in [7] that GHA improved the resistance of concrete against sulphuric acid degradation, but concrete containing GHA was more susceptible to nitric acid attack. The research on influence of GHA in concrete so far reported have showed some constraints in use of GHA as a cementing material and therefore there is need to research on the use of GHA blended with a more reactive waste material such as rice husk ash (RHA) to improve its suitability as a supplementary cementing material. RHA has been established to be of very high silicon dioxide content and is a very reactive pozzolana, suitable as supplementary cementing material [11] and [12]. This paper therefore sets out to investigate the resistance of GHA admixed with RHA in concrete in acidic environment.

II. Materials and methods

2.1 Materials

Ordinary Portland cement manufactured in Nigeria as Dangote brand, with a specific gravity of 3.14 was used. The oxide composition of the cement is shown in TABLE 1. Sharp sand from river Challawa, Kano, Nigeria, with a specific gravity of 2.62, bulk density of 1899.50 kg/m^3 and moisture content of 2.50 % was used. The particle size distribution of the sand shown in Fig. 1, indicate that the sand used was classified as zone -1 based on [13] grading limits for fine aggregates. The coarse aggregate is crushed granite of nominal size of 20 mm with a specific gravity of 2.7, moisture content of 1.30 percent and bulk density of 1500.0 kg/m^3. The particle size distribution is also shown in Fig. 1.

Groundnut husk and rice husk were obtained from Yakasai village and Bunkure town, respectively, Kano State, Nigeria. The Groundnut Husk Ash (GHA) and rice husk ash (RHA) were obtained by a two-step burning method [14], where the husks were burnt to ash and further heating the ash to a temperature of about 600 ^oC in a kiln and controlling the firing at that temperature for about two and five hours, for GHA and RHA respectively, and the ashes were allowed cooling before sieving through 75 µm sieve. The GHA is of specific gravity of 2.12, bulk density of 835 kg/m^3 and moisture content of 1.60 %, while the RHA is of specific gravity of 2.03, bulk density of 368.50 kg/m^3 and moisture content of 2.0 %. The grain size distribution of GHA and RHA is shown in Fig. 1. The oxide composition of GHA and RHA was conducted using X-Ray Flouresence (XRF) analytical method and is shown in TABLE 1.

2.2 Methods

2.2.1 Concrete mix design

Concrete grade 20 was designed with a target mean strength of 33 N/mm^2, slump range of 10-30 mm, and a water-cement ratio of 0.55 for a mix proportion of GHA-Cement: Fine Aggregate: Coarse Aggregate of 1: 2.2: 3.9 by weight of cement. Five mixes were used, CMI-00 is the control mix and CMI-10, CMI-20, CMI-30 and CMI-40 are mixes containing GHA blended with 10 % RHA at combined replacement levels of 10, 20, 30, and 40 %, respectively.

2.2.2 Compressive strength test on GHA-RHA-Concrete

The compressive strength of GHA-RHA-Concrete was carried out in accordance with [15] for grade 20 concrete using the stated mix proportion. Samples were cast in steel moulds of 150 mm cubes and cured in water for 3, 7, 28, 60 and 90 days, respectively. A total of seventy five (75) samples were cast and at the end of every curing regime, three samples were crushed using the Avery Denison Compression Machine of 2000 kN load capacity and at constant rate of 15 kN/s and the average taken. The compressive strength behaviour is shown in Fig. 2.

2.2.3 Test of GHA-RHA-Concrete in Acids.

Grade 20 concrete with stated mix proportion was used to determine the influence of acidic environment on GHA-RHA-Concrete. Five mixes were used, CMI-00, CMI-10, CMI-20, CMI-30 and CMI-40. Concrete was mixed and cast in steel cube moulds of 100 mm during the casting of cubes for compressive strength test. A total of thirty (30) cubes were cast and cured in water for 28 days. At the end of every curing regime, three samples were air dried, then weighed before subjection in 10 percent concentration of diluted solution of sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively. The concrete cubes were weighed after subjection in acid environments at 7 days interval until the 28th day to determine the weight of the samples after the acid degradation. The behaviour of GHA-RHA-Concrete resistance to acidic environment is shown in Fig. 3 and 4.

Table 1: Oxide Composition of OPC (Dangote Brand), GHA and RHA

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	MnO	BaO
OPC	18.0	3.10	4.82	68.37	1.48	0.35	0.32	1.82	0.35	0.03	0.16
GHA	20.03	2.00	4.03	13.19	1.82	38.80	-	1.08	0.68	0.20	0.31
RHA	75.30	2.73	2.30	2.34	0.37	4.70	0.53	0.63	0.16	0.37	0.10
Oxide	V_2O_5	P_2O_5	ZnO	Cr_2O_3	NiO	CuO	SrO	ZrO_2	Cl	L.o.I	
OPC	0.03	-	-	-	-	-	-	-	-	1.27	
GHA	0.03	1.90	0.08	0.03	0.01	0.10	0.20	0.22	0.26	8.02	
RHA	-	9.87	0.48	-	-	-	-	-	-	3.41	

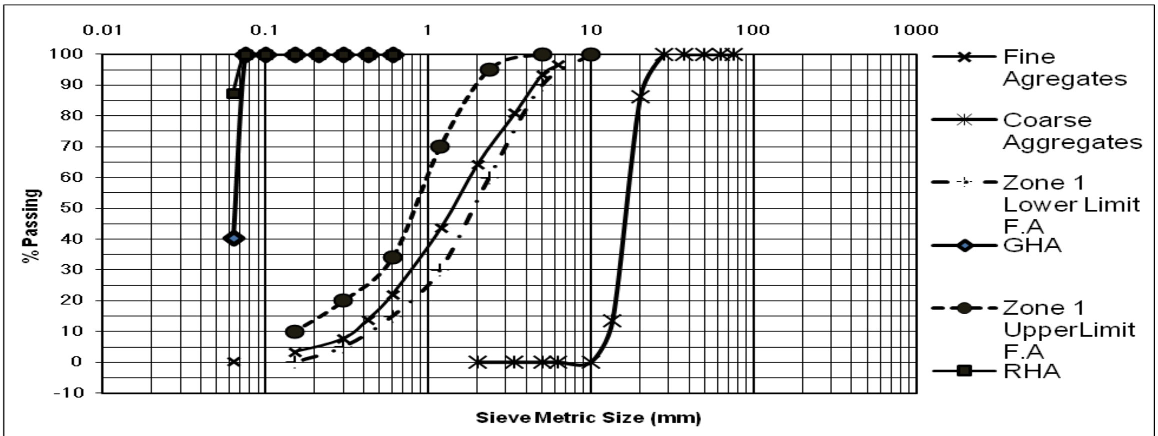

Fig. 1: Particle Size Distribution of GHA, RHA, Fine and Coarse Aggregates

2.2.4 Statistical Modeling of GHA-RHA-Concrete Resistance in Acidic Environment

Statistical models were developed from experimental data using MINITAB 11 software to predict resistance behavior of GHA-RHA-Concrete. The models were also used to analyze the sensitivities of pozzolanic activity of GHA admixed with 10 % RHA in the resistance to acid attack. In developing the resistance prediction models of the pozzolanic concrete, two effects were considered; influence of ash content and influence of duration of exposure on weight of concrete sample retained. The software generates model equations and graphs that would best fit the experimental data. A comparison is then made between the experimental data and data generated by the models and the error difference evaluated.

III. Analysis and discussion of results

3.1 Groundnut husk ash (GHA) and rice husk ash (RHA)

The oxide composition of Groundnut Husk Ash (GHA) and rice husk ash (RHA) indicate a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 26.06 and 80.33 %, respectively. This shows that the GHA is a low reactive pozzolana, while the RHA is very reactive [16]. The CaO content (13.19 %) in GHA also shows that it has some self cementing properties. The chemical composition of GHA also indicated a high content of K_2O (38.80 %) which may be a source of disruption in cement and concrete matrix. The high content of P_2O_5 (9.87 %) in RHA may adversely affect its reactivity.

3.2 Compressive Strength of GHA- RHA-Concrete

The compressive strength of GHA- RHA-Concrete shown in Fig. 2 indicated that compressive strength increase with curing age and decreased with increase in blended GHA- RHA content. The compressive strength of control samples was higher than that of samples containing combined GHA-RHA at all ages. The 28 days compressive strength of GHA-RHA-Concrete ranged from 46.0 – 84.6 % of control at GHA-RHA content of 10 – 40 %, with least compressive strength occurring at 40 % GHA content. It was however observed that the 28 days compressive strength of concrete with about up to 15 % GHA-RHA content exceeded the design characteristic strength and was considered as optimum percentage replacement.

The decrease in compressive strength of concrete with increase in GHA-RHA content would be due to dilution effect of Portland cement and weaker formation of C-S-H gel as a result of pozzolanic reaction of GHA-RHA [17].

3.3 Effect of Acids on GHA-RHA-Concrete

The effect of 10 % concentration of sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively on GHA-RHA-Concrete shown in terms of weight retained in Fig. 3 and 4, showed that concrete with GHA admixed with 10 % RHA offered better resistance to deterioration by H_2SO_4 and HNO_3 than Ordinary Portland cement concrete. The average weight loss of GHA-RHA-concrete after 28 days of exposure in sulphuric acid and nitric acid were 11.6 % and 11.7 %, respectively as opposed to 22.4 % and 15.1 %, respectively for plain Portland cement concrete. It was also observed that GHA-RHA-Concrete offered enhanced resistance to H_2SO_4 and HNO_3 aggression than GHA-Concrete as was reported in [7].

The improvement in resistance to H_2SO_4 attack of GHA-RHA-Concrete over control could be adduced to pozzolanic reaction of combined GHA and RHA and reduction in C_3A in the blended cement concrete, as well as less soluble calcium sulphate salt formed from acid attack [18]. The better resistance to HNO_3 aggression of GHA-RHA-Concrete over control may also be as a result of pozzolanic reaction of GHA and RHA which reduced the $Ca(OH)_2$ available for reaction with nitric acid. The improvement in resistance to H_2SO_4 and HNO_3 of GHA-RHA-Concrete over GHA-Concrete can also be attributed to better pozzolanic reaction of RHA than that of GHA.

The results have also shown that Sulphuric acid (H_2SO_4) is more aggressive to plain Portland cement concrete than Nitric acid (HNO_3), while GHA-RHA-Concrete was more resistant to sulphuric acid than nitric acid.

3.4 Regression Models for GHA-RHA-Concrete Resistance in Acidic Environment

The regression model equations for GHA-RHA-concrete weight retained in H_2SO_4 and HNO_3 environments are given in (1) and (2), respectively.

M_{SO4} = 94.50 + 0.15GR – 0.46 E …………… (1)

M_{NO3} = 99.24+ 0.05 GR – 2.76 E …………… (2)

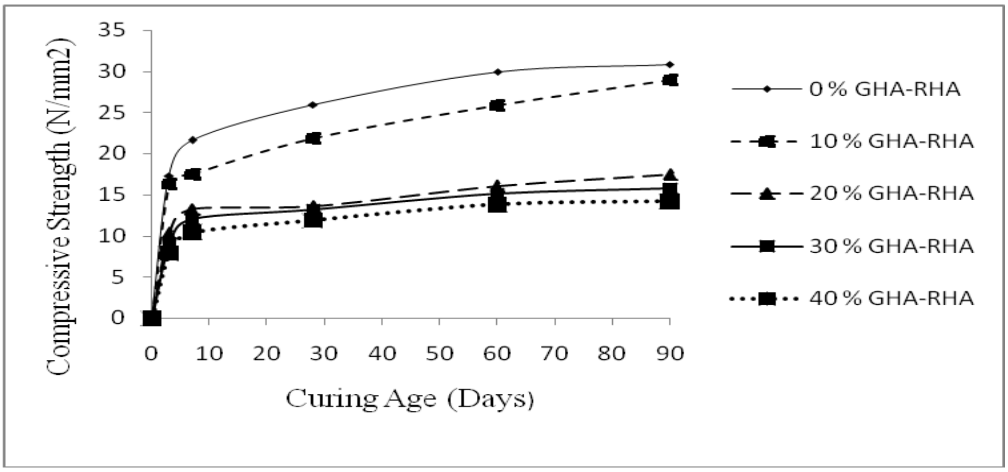

Fig. 2: Compressive Strength Development of GHA-RHA-Concrete Grade 20

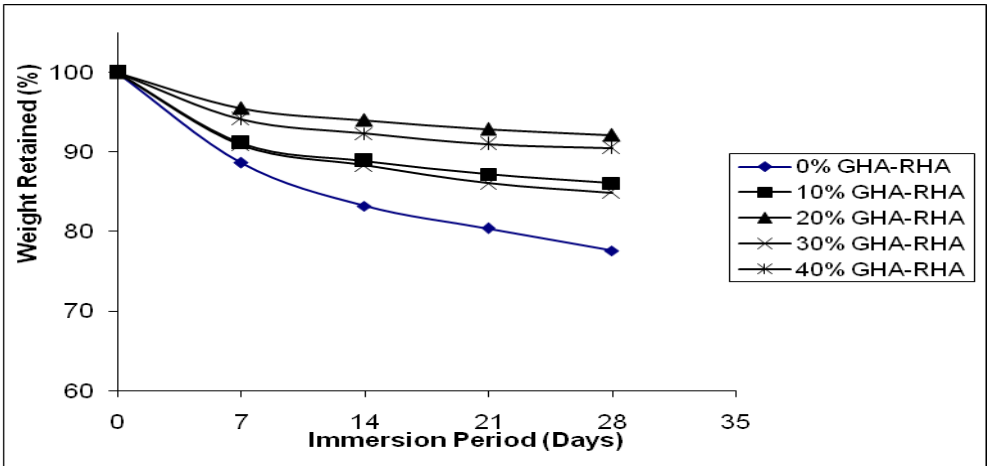

Fig. 3: Weight of GHA-RHA-Concrete Retained after Exposure in H_2SO_4 environment

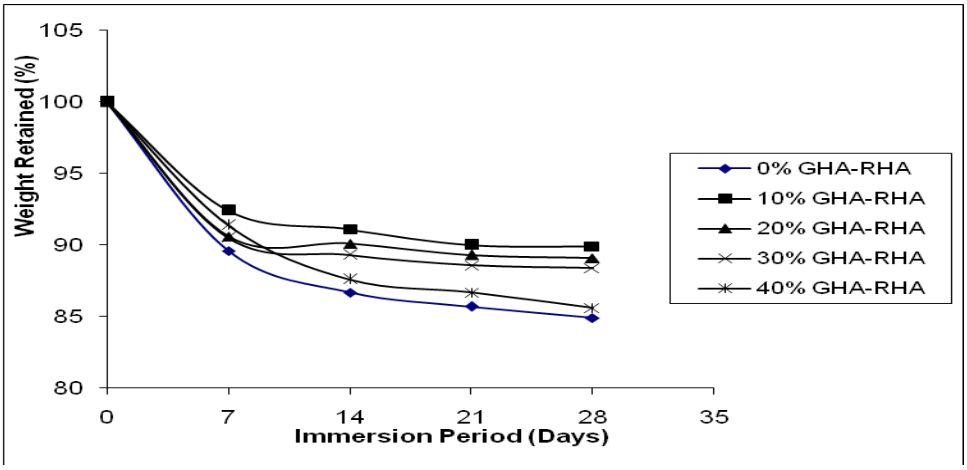

Fig. 4: Weight of GHA-RHA-Concrete Retained after Exposure in HNO_3 environment

Where; $M_{SO4,}$ $M_{NO3,}$ is concrete weight retained in H_2SO_4 and HNO_3, respectively, GR and E are GHA-RHA content at 0, 10, 20, 30, 40 % replacement and exposure duration of 0, 7, 14, 21, 28 days of samples, respectively.

At 0.05 level of significance, from the regression analysis, P-value = 0.000 for both GHA-RHA content and exposure duration in H_2SO_4, and shows that both variables are highly significant ($P < 0.05$) signifying that the variation in the concrete weight retained in H_2SO_4 is caused by GHA-RHA content and exposure duration. In the case of GHA-RHA concrete exposed in HNO_3, at 0.05 level of significance, P-value = 0.842 and 0.000 for GHA-RHA content and exposure duration, respectively. This shows that exposure period is highly significant ($P < 0.05$) while GHA-RHA content is not significant ($P > 0.05$) signifying that the variation in the concrete weight retained is caused mainly by exposure duration in HNO_3 while the effect of GHA-RHA content is marginal.

The coefficient of determination, (R^2) of the models is 66.8 % and 65.5 %, for weight retained in H_2SO_4 and HNO_3, respectively. This indicates that the variation of concrete weight retained is significantly dependent on the variations of GHA-RHA content and exposure duration in H_2SO_4, but and less dependent on GHA-RHA content in the case of exposure in HNO_3. The residual and normality plots (Fig. 5 and 6; 7 and 8) were drawn for the GHA-RHA-concrete weight retained in H_2SO_4 and HNO_3, respectively to further examine how well the models fit the data used. It was observed that there were few large residuals [19] and [20] and limited apparent out-lier [21]. This confirms that the models are adequate for prediction of the sensitivities of pozzolanic activity of GHA admixed with 10 % RHA in acidic environment.

IV. Conclusion

i) GHA is a low reactive pozzolana, while the RHA is more reactive as indicated in the combined SiO_2, Al_2O_3 and Fe_2O_3 content of GHA and RHA of 26.06 and 80.33 %, respectively.

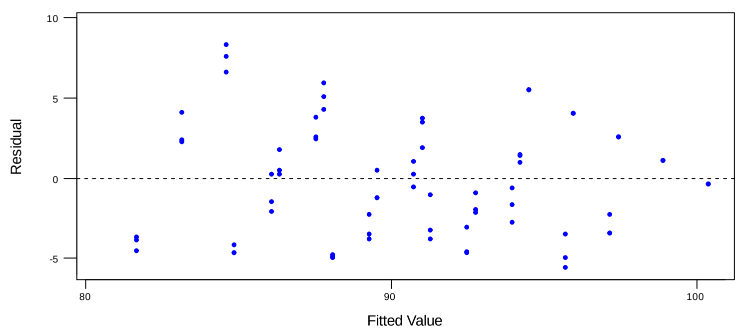

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Fig. 5: Residual Vs Fitted values for Weight Retained of GHA-RHA-Concrete in H_2SO_4

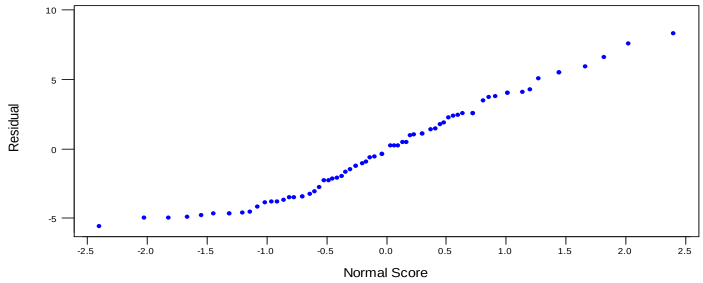

Fig. 6: Normal Probability of Residuals for Weight Retained of GHA-RHA-Concrete in H_2SO_4

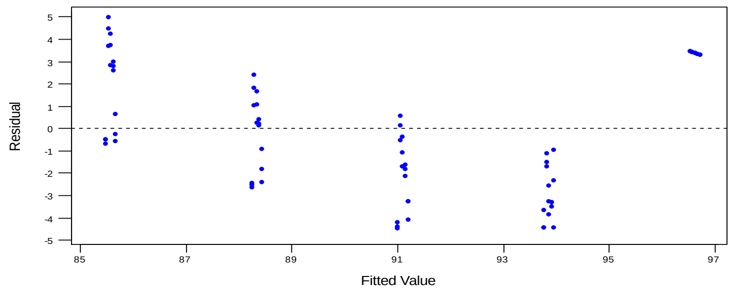

Fig. 7: Residual Vs Fitted values for Weight Retained of GHA-RHA-Concrete in HNO_3

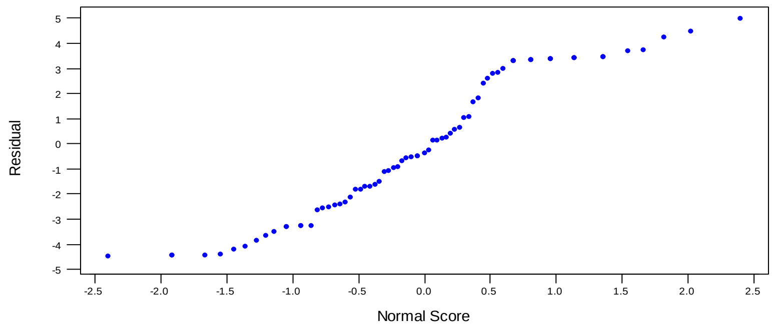

Fig. 8: Normal Probability of Residuals for Weight Retained of GHA-RHA-Concrete in HNO_3

ii) The compressive strength of concrete decreased with increase in GHA-RHA content. However, 15 % would be considered as the optimum percentage replacement to act as a retarder suitable for hot weather concreting, mass concrete and long haulage of ready mixed concrete.

iii) GHA-RHA improved the resistance of concrete against sulphuric and nitric acids aggression.

iv) The regression models for GHA-RHA-Concrete weight retained after exposure in H_2SO_4 and HNO_3 with R^2 values of 0.668 and 0.655, respectively were adequate for prediction of the sensitivities of pozzolanic activity of GHA admixed with 10 % RHA in acidic environment.

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