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Waste Reduction: A Tool for Materials Management on Building Construction Sites in Nigeria

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ABSTRACT

Waste generation on construction sites in Nigeria has been a problem, leading to both environmental pollution and economic losses. Appropriate control and management systems of such wastes have become necessary. The aim of this study was to assess waste reduction as a tool for materials management on building construction sites in Nigeria. The specific objectives of the study were: the determination of the sources of construction waste generation; methods of source reduction of construction waste used in the study area; determination of the level of impact of the source reduction method used in the study area. The study adopted the survey research design. Data obtained were analysed using Relative Importance Index (RII) and Rank. The study revealed that the aggregated levels of impact on a five-point scale for source reduction methods were 3.54, 3.69, 3.81, 3.16, 4.56 and 2.86 for design, procurement, materials handling, operations, residual and others, respectively. The Relative Importance Indices were 0.79, 0.84, 0.87, 0.68, 0.92 and 0.50 for design, procurement, materials handling, operations, residual and others, respectively. The ranks of design, procurement, materials handling, operations, residual and others were 4, 3, 2, 5, 1 and 6, respectively. It therefore concluded that the major sources of construction waste generation were: design, procurement, materials handling, operations, residual activities and others. The study recommended that: Contract documents should be checked for accuracies before use; Procurement methods should be adequate to avoid over-ordering, under-ordering and suppliers' errors; Tradespersons should receive adequate training in waste reduction methods before being engaged; Adequate functional equipment should be deployed and equipment maintenance culture should be adopted; Appropriate waste control and management plans should be made for all the construction processes; Safety should be enhanced to avoid accidents on the construction sites; Adequate security should be ensured to safeguard construction materials.

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1. Introduction

The construction industry contributes immensely to the development of any nation. Materials resource management is one of the biggest challenges in the performance of the construction sector. Most sectors consume material resources more than the amount originally calculated. In spite of the benefits of the construction sector, it is equally known for producing immense amounts of wastes [1]. The rapid boom in construction has led to increasing construction wastes in developing countries. Gray [2] reported that the industry in the UK contributes about 36 million tonnes of debris to landfills every year, which is estimated to be about 35% of the total waste produced in the UK; she also predicted that if the trend is left unchecked in the next six years, the UK landfill sites would have been exhausted. The construction sector produces huge waste leading to environmental contamination and CO_2 emissions. Reardon, Fewster and Hearkeness [3] reiterated that approximately 19 million tonnes of building and demolition waste was generated in Australia from 2008–2009. Out of this figure, 8.5 million tonnes (45%) went to landfill while 10.5 million tonnes (55%) were recycled. This implies that the ratio of disposed waste to recycled ones in Australia is high (0.81) and represents huge financial and resource deficit to the country.

Construction material waste is mostly considered to be the by-product generated and removed from construction, renovation and demolition sites of building and civil engineering structures. Material waste is inefficiency that results from the use of resources in larger quantities than those considered necessary in the production of building. Ghanim [4] categorized waste according to its source, i.e., the stage in which the root causes of waste occur. They further explained that waste does not just emanate from the application and use of materials in the construction site but also from the process preceding construction, such as material manufacturing, design, material supply, and planning as well. Hence management of waste should first consider the different sources of waste and the type of waste they generate, and then apply appropriate measures to minimize them from the root. Inappropriate material management causes waste and results in environmental damage and financial loss during the various construction stages [5].

Thurnau [1] prescribed some guidelines for construction waste management at the planning stage as follows: Specify waste reduction goals, targets, and documentation procedures within contracting documents; Identify materials that can be recycled or reused, and how those materials can be transported for such purposes (some of the recyclable materials are but not limited to ferrous and non-ferrous metals, cardboard paper, plastics, wood, concrete, gravel and other aggregates etc; Design building dimensions to correspond with standard material sizes, especially timber (this will reduce material wasted as wood accounts for nearly a third of all construction wastes; Order materials to optimally fit the requirements (avoid ordering excess materials to be delivered to the project site) since ideally, the construction program and material schedule will guide when, what and how much to order; Packaging should not be used only if it is essential; Negotiate with suppliers to buy back any unused supplies; Develop methods for storing materials that will reduce their susceptibility to damage; Estimate how much waste a project is likely to produce and what it will cost to remove that waste in a variety of ways, such as traditional garbage collection, recycling, salvage and reuse, etc; choose alternative methods of construction such as prefabrication, modularization, and off-site construction techniques as it is an effective way to design out waste [9]. Furthermore, an off-site production offers a better opportunity for the materials to be managed prior to leaving the factory and equally offers a much more efficient process to reduce the amount of waste sent to landfills.

Minimizing waste also requires effective material management and control. Oladiran [8] summarized material control measures as comprising the following: Avoidance of late design variations and design effective materials handling on site; specification should be to standard sizes to minimize cutting; Ensuring accurate scheduling of materials to programmed delivery dates; Documentation should set out size, quality and delivery form of materials for estimators' consideration; Procurement must specify quality, quantity, delivery time and method, and packaging; Effective communication should be ensured between suppliers and recipient; Preparation of effective planning programmes; Establish on sites procedures for the reception of goods and plan for storage in advance. Materials of high value have to be held off-site until the last moment; Effective procedures for issuing of material on site; Training of both management and other staff. Generally, various authors have unanimously suggested a waste reduction strategy summarized under the three Rs namely: reduce [10], re-use and recycle [9]. Similarly, the UK Waste and Action Resources Programme (WARP) cited in MBI [9] developed a waste hierarchy that advocates as follows: Reduce waste generation by proper planning, ordering to requirement, proper storage and handling; When it is absolutely difficult to reduce waste, products and materials can be reused either for the same or for different purposes; If this is impossible, value should be recovered from waste through recycling and composting or energy recovery from the waste. If none of these solutions is appropriate, then waste may be disposed of, using the best environmental option [9].

Waste minimization by reduction option is considered effective and efficient for C&D wastes as it reduces the cost of transportation and disposal [10]. Business Division [11] advised that the first step in cutting the amount of waste that ends up in landfills is to reduce the quantity produced. Reardon, Fewster and Hearkeness [3] suggested that one of the ways of reducing waste is to reduce resource consumption by building smaller houses that are better designed to suit the required need. This means that in design, additional parts that add no value to the building should be eliminated; in this way, precious resources that will be needed by future generations would be conserved and waste reduced. Also, the cost of waste transportation and disposal will be reduced as well. Other waste reduction measures as prescribed by Shant and Daphene [10] include: Encourage designs that produce less waste; Avoid over-ordering materials; Use standard sizes and quantities of materials to reduce off-cuts; arrange for materials to arrive on site to match the work stages, to limit the chances of them being damaged through bad storage; Ensure storage areas are secure, safe and weatherproof.

Skoyle and Skoyle cited in Ghanim [4] divided waste into direct waste which is the loss of materials arising from damage during handling or site application or which were lost during the building process and indirect waste which does not result from direct waste (physical loss of materials) but have monetary consequences. Indirect waste includes materials used for purposes other than that for which they were ordered like in the following cases [12, 13, 14]: Where materials are used for purposes other than those specified (substitution); Where materials are used in excess of those indicated or not clearly defined in contract documents, e.g. additional concrete in trenches, which are dug wider than was designed, because no appropriately sized digger bucket is available; Where materials are used for temporary site work for which no quantity or other allowances have been made in the contract documentation, e.g. tower-crane bases, site paths, temporary protection; Where materials are used in addition to the amount required by the contract owing to the contractor's own negligence.

In Nigeria, very little consideration is given to control the generation of material wastes, and this is blamed on low environmental awareness of construction waste in the country [5]. Poor waste management practices and treatment of the environment will not only lead to a degradation of water, air and land resources but also represent a big financial burden to current and future generations [6]. Furthermore, as about 30 to 70% of construction cost is consumed by materials [7], the need to reduce cost of construction through effective material management has become paramount more especially as Nigeria faces the period of economic recession. Although statistics are unavailable to quantify the amount of wastes generated on construction sites in Nigeria, a similar submission by Oladiran [9] confirms that materials wastes pervade the Nigeria's construction sites. If the material waste is not properly handled and managed on the project site, this will lead to financial crises, and eventually negatively impact the community and the environment. This has formed the focus of this study. The aim of the study was to assess waste reduction as a tool for materials management on building construction sites in Nigeria. The specific objectives of the study were: a). To determine the sources of construction waste generation; b). To determine the methods of source reduction of construction waste used in the study area and c). Determination of the level of impact of the source reduction method used in the study area.

2Methods and Materials

This study adopted the survey research design. Questionnaire surveys, interviews, and reviews of previous studies and related literature were employed in gathering the relevant data. Four hundred and eighty (480) of five hundred (500) questionnaires administered on contractors, consultants, and clients were retrieved. A five-point Likert scale was used to ascertain the level of impact of each source reduction method. These data were then analyzed using the relative importance index (RII) and ranks.

3. Results and Discussion

Results of this study are shown on Figures 1 and 2 and Table 1:

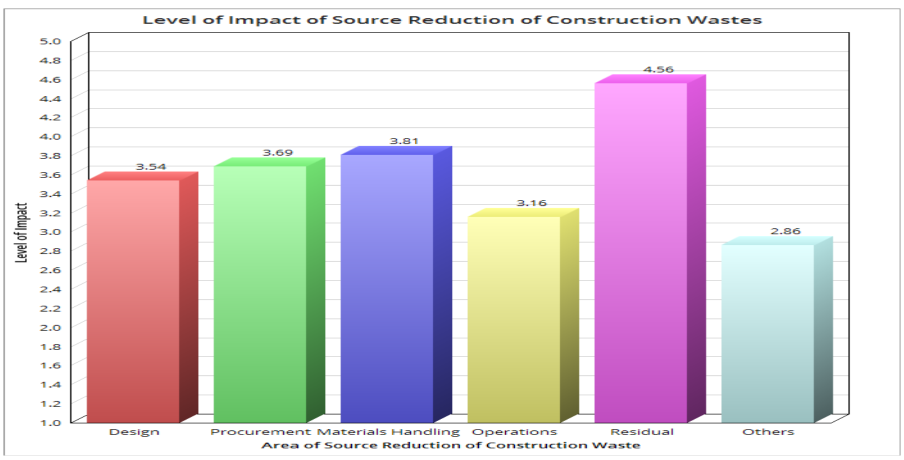

Fig. 1: Level of Impact of Source Reduction of Construction Wastes

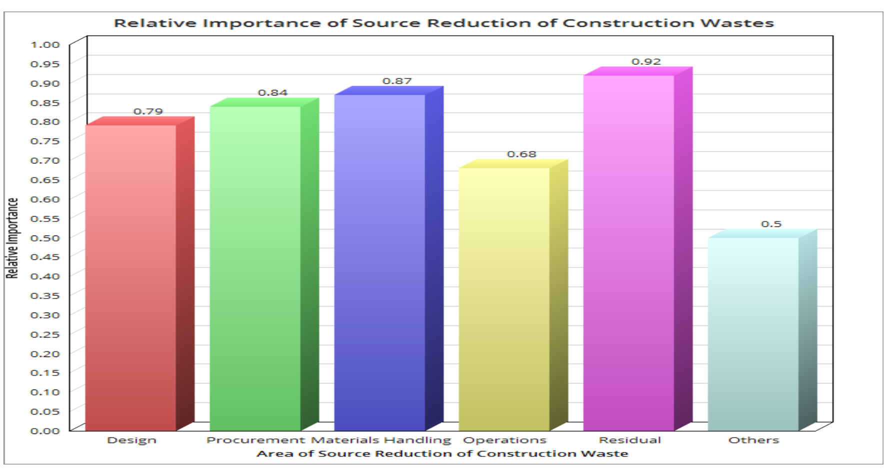

Fig. 2: Relative Importance Index of Source Reduction of Construction Waste

Table 1:
Source Reduction Method and Relative Importance Index (RII)

Source	Source Reduction Method	Likert Mean Score	Grande Mean Score	Relative Importance Index (RII)	Rank
Design	- Minimization of errors in contract documents - Checking completeness of contract documents at commencement of work - Minimization of changes in design	3.25 3.10 4.28	3.54	0.79	4
Procurement	- Avoidance of ordering errors (over ordering, under ordering and so on) - Minimization of suppliers' error	4.53 2.84	3.69	0.84	3
Material handling	- Minimization of damaged materials during transportation to the site/ on site - Use of appropriate storage to minimize damage or deterioration	3.42 4.20	3.81	0.87	2
Operation	- Minimization of errors by tradesperson or labourer - Use of highly functional equipment - Avoidance of work in inclement weather - Avoidance of accidents - Minimization of damages caused by subsequent trades - Use of correct materials to avoid replacement	4.15 2.60 3.20 2.45 2.73 3.80	3.16	0.68	5
Residual	- Minimization of conversion wastes from cutting uneconomical shapes - Minimization of off cuts from cutting materials to length - Avoidance of over mixing of materials for wet trades due to lack of knowledge of requirement - Avoidance of wastes	4.65 4.60 4.22 4.78			

	from application process		4.56	0.92	1
Other	- Checking criminal wastes due to theft - Implementation of on-site material control and waste management plan	1.52 4.20	2.86	0.50	6

As shown from the results (Figs. 1 and 2), the major sources of construction waste generation were: design, procurement, materials handling, operations, residual activities and others. Design wastes were observed to emanate from contract documents and changes in design. Procurement errors that generate wastes included over-ordering, under-ordering and supply errors. This is in line with the findings of Ginga, Ongpeng and Daly [15], Oluleye *et al.* [16]. Waste generation during materials handling, included damages during transportation and storage. Wastes generated from operations, were due to tradespersons' errors, equipment malfunctions, inclement weather, accidents, damages from subsequent trades and use of incorrect materials. This agrees with the findings by Purchase *et al.* [17] and Nawaz, Chen and Su [18]. Wastes generated from residual activities included cutting of uneconomical shapes, off-cuts from cutting materials to length, over-mixing of wet materials and application process. Other waste generation routes included criminal activities such as theft and lack of on-site waste control and management plan. This is also corroborated by the findings by Aslam, Huang and Cui [19] and Khoshand *et al.* [20].

Also from Figure 2, the aggregated levels of impact for source reduction methods were 3.54, 3.69, 3.81, 3.16, 4.56 and 2.86 for design, procurement, materials handling, operations, residual and others, respectively. This is similar to the findings of Aovisutthichai, Lu and Bao [21] which ranked design, procurement, and materials handling as 1, 2 and 3, respectively. The Relative Importance Indices were 0.79, 0.84, 0.87, 0.68, 0.92 and 0.50 for design, procurement, materials handling, operations, residual and others, respectively. The ranks of design, procurement, materials handling, operations, residual and others were 4, 3, 2, 5, 1 and 6, respectively. These findings also agree with those of Anaç *et al.,* [22].

4. Conclusion

This study assessed the various sources of construction waste generation; source reduction methods, their levels of impact, relative importance indices and ranks. From the findings, the most prominent sources of construction waste generation were from errors in design, procurement, materials handling, operations, residual activities and others.

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Effect of Elevated Temperature on Compressive Strength of Self-Compacting Concrete Produced with Rice Husk Ash

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ABSTRACT

Concretes have propensity of being exposed to conflagration from fire incidences and this can lead to collapse of buildings. This is the reason why attention is paid to the performance of concrete at elevated temperatures. Also, self-compacting concrete is an innovation that helps to overcome the problem of incomplete compaction which causes pores and reduces the strength of concrete. This research evaluates the effect of elevated temperature on compressive strength of rice-husk ash self-compacting concrete using central composite design. This study was limited to the use of rice husk ash to replace cement from 5% to 25% and superplasticizer used was varied from 0.5% to 2.5%. The compressive strength of concrete was assessed at 7days, 28days, and 90days at temperature of 25ᵒC, 100ᵒC, 300ᵒC and 500ᵒC. The analysis of variance and modelling of responses were done using CCD. The values for 7days compressive strength at 25ᵒC, 100ᵒC, 300ᵒC and 500ᵒC were 8.5N/mm^2, 9.2N/mm^2, 8.4N/mm^2, 4.1N/mm^2 respectively while the 28 days compressive strength at 25ᵒC, 100ᵒC, 300ᵒC and 500ᵒC are 30.5N/mm^2, 32.7N/mm^2, 25.7N/mm^2, 9.7 N/mm^2 respectively and finally, the 90 days compressive strength at 25ᵒC, 100ᵒC, 300ᵒC and 500ᵒC were 35.8N/mm^2, 37.1N/mm^2, 32N/mm^2, 13.8 N/mm^2 respectively. The optimal values of factors for highest concrete strength for SCC are 5% RHA and 1% superplasticizer. Low strength gain was observed at a temperature range of 25 to 100ᵒC. Between 100 to 200°C, strength loss was observed and attributed to the thermal swelling of the physically bound water which caused disjoint pressures. At 300°C to 500ᵒC, the results showed rapid reduction in strength. This research concludes that RHA can be used to produce SCC, and relative to the effect of mix proportions. Rice husk ash in self-compacting concrete helps to enhance concrete strength, enhances durability by resisting high temperature up to 300ᵒC.

1. Introduction

Self-compacting concrete (SCC) is a unique concrete different from normal concrete because it can be laid and compacted without vibration or with minimal vibration [1]. The most significant characteristics of SCC are good passing ability, high flow ability, and high segregation resistance [1]. Concrete can be exposed to high temperature due to fire outbreak. This exposure which can lead to damage of structures despite not been a combustible material. Elevated temperature alters physical, chemical and mechanical properties of concrete. The elevated temperature is one of the most harmful effects that causes strength and durability problems in construction. This effect can cause permanent damage in construction and reduce the service life of concrete structures [2].

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Also, the environmental impact caused by cement is huge considering the energy used in production and the release of gasses that cause the depletion of the ozone layer [3]. There is rapid increase in the price of cement, yet the necessity for housing constructions needing this material keeps growing with growing in population, and thus, created a void to be filled by finding other binding materials.

Fire is considered as the most severe environmental conditions to which concrete structures may be subjected to during its service life. Venkatesh [4] defined fire resistance as the period during which a structural member exhibits resistance with respect to structural integrity, stability and temperature transmission. It is essential that concrete structural members when used in buildings should satisfy appropriate fire safety requirements as contained in building codes [5-7].

According to Kodur and Raut [8], concrete demonstrates an excellent fire resistance property when exposed to elevated temperature compared to any building material. Subjecting a structural member to a defined elevated temperature at a particular time will cause a predictable temperature distribution in the member as the temperature continue to increased, it causes deformations and property changes in the constituent materials of structural member. Durability of cement concrete is defined as its resistance to deteriorating agencies to which it may be exposed during its service life [9].

Rice husk Ash is considered as super-pozzolana because of its large amount of silicon oxide. It is one of the promising pozzolanic materials that can be combined with Portland cement for the production of calcium silicate hydrate (CSH) around the cement particles. The CSH is highly dense, less porous, and increases the strength of concrete against cracking and also improves the durability properties of concrete [10].

Fapounda *et al.,* [11] said that rice husk ash is one of the most suitable sources of pozzolanic material among agricultural wastes, available in large quantities and contains a relatively large amount of silica.

Seyed and Mojtaba [12] discovered the benefits resulting from using rice husk ash (RHA) in concrete production. The effects indicated a positive relationship between a 15% replacement of RHA and with increase in compressive strengths by about 20%. The peak level of strength and durability properties generally gain with an addition of up to 20%.

Dabai [13] conducted a research on compressive strength tests of mortar cubes. Cement was replaced by rice husk ash (RHA) and the mortar produced where cured at different ages of 3, 7, 14 and 28 days. The chemical analysis of the rice husk ash showed a high amount of silica 68%, alumina 1.01% and oxides such as calcium oxide 1.01% and iron oxide 0.78% responsible for strength, soundness and setting of the concrete. It contained a high amount of magnesia 1.31% which is responsible for the unsoundness. The result of the study showed that RHA can be used as substitute for cement 10% and 20% replacement at 28 days curing age.

Mohammed *et al.,* [14] studied the properties of SCC subjected to elevated temperature. Laboratory tests such as compressive strength, weight loss, and ultrasonic pulse velocity of SCC were subjected to 200°C, 400°C, 600°C, and 800°C elevated temperatures. At 800^{o}C elevated temperature, the result of residual compressive strength shows that SCC produced with the addition of the ternary blend at 10 % had a higher value of residual compressive strength of 27.3 % over the control specimens.

Toumi and Resheidat [15] identified and quantified surface cracking of concrete heated to different temperatures from 105 to 1250ºC. The result revealed that the properties of concrete were largely affected by temperatures beyond 500°C and were very feeble as temperatures exceeded 1000°C. The surface cracks' density, initial surface absorption and total porosity by boiling methods revealed a swift indication of concrete durability.

High temperature negatively affects the engineering properties and durability of concrete and it is one of the most harmful effects that cause permanent damages in structures. It reduces the service life of structure, causes causalities and affects the construction's sustainability [2].

Several works have been conducted on the use of rice husk ash as partial replacement of cement in concrete but subjecting the admixed concrete to high temperature to study its durability by fire resistance is limited. This study was limited to the use of rice husk ash from 5% to 25% and superplasticizer from 0.5% to 2%. The use of rice husk ash in self-compacting concrete helps to enhance concrete strength and resistance to high temperature up to 300°C.

2. Methodology

2.1 Materials

The materials used include cement, rice husk ash, fine aggregates, coarse aggregates and conmix superplasticizer. Portland limestone cement grade 42.5 based on BS 12 [16] was used for the study. Rice husk was collected from Rice mills plant in Sabo-kaura, Bauchi. It was burnt at a temperature 700°C for 2 hours and subjected to chemical analysis to determine its pozzolanic properties according to ASTM [17]. The resulting rice husk ash was passed through sieve of size 150µm to obtain the required fineness. It partially replaced cement in this study. The fine aggregate was obtained from a stream after Bayara, along Bauchi - Dass road. The coarse aggregate used was crushed stone of maximum size of 20mm, it was obtained from local suppliers in Bauchi. Conmix SP (superplasticizer) was procured from Kaduna and used for the production of concrete.

2.2 Concrete Mix Design

M35 grade of concrete was designed based on American concrete institute, (ACI) [18]. The mix ratio of 1:1.51:1.92:0.02 was designed and converted to SCC concrete mix of 1:1.89: 1.54:0.02 for cement, fine aggregate, coarse aggregate and superplasticizer respectively. The fine aggregate had 55% of total aggregates while coarse aggregate constitute only 45% of the total aggregate for making self-compacting concrete. This was done in accordance to EFNARC [1] requirements. Increasing the fine aggregates helps in passing and flowability properties of SCC EFNARC [1]. The mix design used for the production of concrete is shown in table 1.

Table 1
Self-Compacting Concrete Mix Design for M35 grade.

Component	Value
Minimum Strength	35 N/mm^2
Target Strength	43.7 N/mm^2
Cement Type	PC Grade 42.5
Maximum size of Aggregate	20mm
Water-cement ratio	0.4
Cement Content (kg/m^3)	500
Fine Aggregate Content (kg/m^3)	944
Coarse Aggregate Content (kg/m^3)	772
Water-content (kg/m^3)	200
Superplasticizer (kg/m^3)	10
Mix ratio	1 :1.89: 1.54:0.02

2.3 Response Surface Methodology

Experimental design was made by response surface methodology (RSM). Experimental runs were created by Design-Expert software 13 Central Composite Design response surface methodology for M35 grade SCC. The software was used to quantify the relationship between the controllable input parameters (factors) rice husk ash and superplasticizer and the obtained response surfaces. It was used for analysis, design, modelling and optimization of residual compressive strength of SCC.

3.0 Results and Discussion

3.1 7-days Residual compressive strength results of SCC

The residual compressive strength was determined at 7 days after concrete specimens were subjected to elevated temperature and the result is presented in table 2.

Table 2: Residual Compressive Strength of SCC Subjected to Elevated Temperature at 7 Days (N/mm^2)

Run	A: RHA (%)	B: SP (%)	25^o	100^o	300^o	500^o
C	0	2	11.7	12.5	11.6	4.5
1	15	0.5	7.2	7.8	7.6	3.4
2	25	0.5	6.8	7.3	7.0	2.8
3	25	2.5	6.0	6.5	6.1	1.8
4	15	1.5	6.8	7.5	7.1	2.6
5	15	1.5	6.8	7.5	7.1	2.6
6	15	1.5	6.8	7.5	7.1	2.6
7	15	1.5	6.8	7.5	7.1	2.6
8	15	1.5	6.8	7.5	7.1	2.6
9	5	1.5	7.9	8.6	8.4	4.2
10	15	2.5	6.5	7.1	6.9	2.8
11	25	1.5	6.4	7.1	6.1	1.3
12	5	2.5	7.5	8.0	7.7	3.5
13	5	0.5	9.1	9.7	8.8	4.3

C stands for control

Table 2 shows the residual compressive strength of SCC specimens subjected to 25^{o}C, 100°C, 300°C, and 500°C elevated temperatures. The compressive strength of all the concrete increases from 25^{o}C to 100^{o}C but decreases with an increase in exposure to elevated temperature at 300°C and 500°C. At 25°C, the residual compressive strength ranges from 6.0 to 9.1 N/mm^2. At 100°C exposure to temperature, the residual compressive strength ranges from 7.1 to 9.7 N/mm^2. At 300°C exposure to temperature, the residual compressive strength ranges from 6.1 to 8.8 N/mm^2. At 500°C temperature, the residual compressive strength ranges from 1.3 to 4.3N/mm^2. The decrease in strength could be as a result from dehydration of calcium silicate hydrate, making cement to lose its binding properties. The elevated temperature causes decrease in compressive strength with increased distortion of the concrete material at high temperature because cracking effects are accelerated and thereby resulting to low strength of the concrete at high temperatures. The reduction in strength at elevated temperature from this study was in agreement with the findings reported by Iffat and Bose (2016) and Mohammed *et al.,* (2021).

Table 3: Analysis of Variance for Residual Compressive Strength at 7days

Parameter	25^{o}C		100^{o}C		300^{o}C		500^{o}C	
	F-value	P-Value	F-value	P-Value	F-value	P-Value	F-value	P-Value
Model	66.19	< 0.001	59	< 0.001	64	< 0.001	27	< 0.001
A= RHA	215	< 0.001	198	< 0.001	253	< 0.001	47	< 0.001
B = SP	74	< 0.001	69	< 0.001	57	0.022	7	0.022

AB	7.36	0.03	8	0.02	-	-	-	-
A^2	22.7	0.002	17	0.0046	-	-	-	-

The analysis of variance results presented in Table 3 showed that the response surface regression models reaches a reference significant level ($p < 0.0001$), and the lack of fit is insignificant in all cases. The response surface models therefore fit well with real situation and can ably predict the effect of elevated temperature on residual compressive strength SCC at 7 days. The factors in the RSM model have a significant influence on the residual compressive strength of SCC, and the order of influence is A (dosage of RHA) > B (dosage of SP). Response surface for residual compressive strength subjected to 25^0 at 7days is presented in Figure 1.

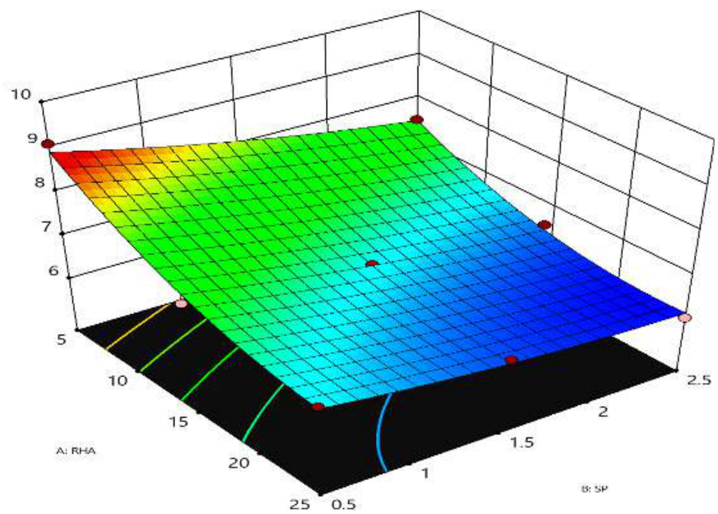

Fig. 1: *Response surface for Residual Compressive Strength subjected to 25^0 at 7days.*

The steep gradient of the response surface suggests the more pronounced effects of RHA on residual compressive strength of concrete at 7 days. From the diagram, it is evident that the higher the level of replacement, the higher is the reduction in strength. The values of compressive strength at 25^oC at 7days ranges from 6.4 to 8.1 N/mm^2. The relationship between the forecast and the experimental values (Predicted and Actual) shows that the values are closely distributed. The correlation between the actual and predicted values is very good and the regression model coincides with the test data. The relationship between the forecast and the experimental values (Predicted and Actual) shows that the values are distributed comparatively on a straight line. The reduction in strength at elevated temperature recorded was in agreement with the findings reported by Iffat and Bose (2016) and Mohammed *et al.*, (2021).

The model describing 7-days Residual Compressive Strength subjected to 25^oC is given by the equation 1.

$$7\text{-}day\ Residual\ compressive\ strength\ at\ 25^0 = 10.56 - 0.245A - 1.184B + 0.02AB + 0.004\,A^2 + 0.122\,B^2 \quad \ldots(1)$$

Figure 2 shows the response surface for residual compressive strength subjected to 100^0 at 7days.

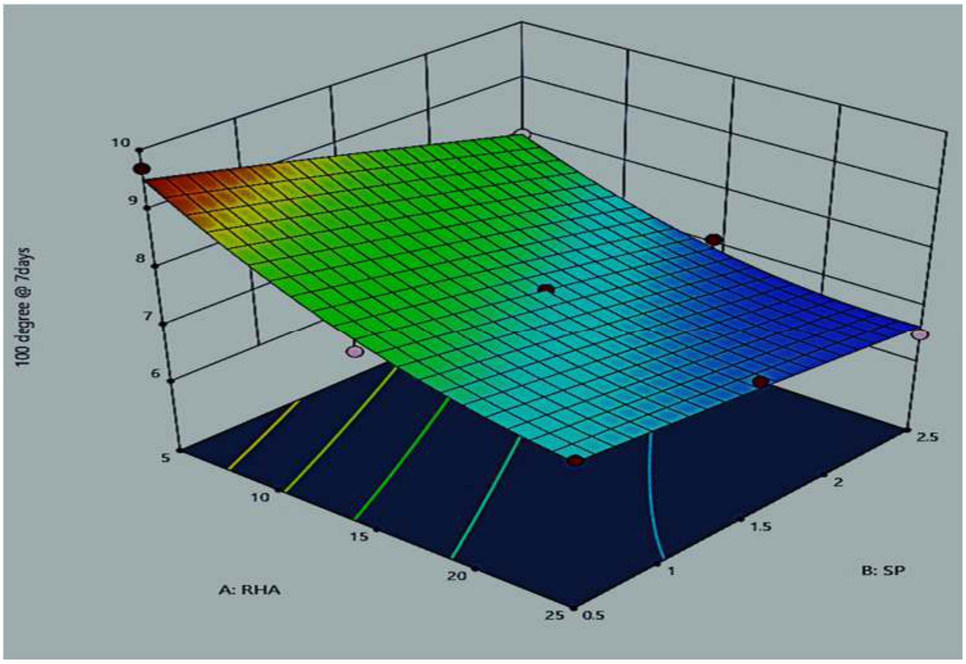

Fig. 2: Response surface for Residual Compressive Strength subjected to 100^o at 7days.

The experimental results are in good agreement with the predicted. The values of compressive strength at 100^{0}C at 7days ranges from 6.5 to 9.7 N/mm^2. The model describing Residual Compressive Strength subjected to 100^{0}C at 7days is given by the equation.

$$7\text{-}day\ Residual\ Compressive\ Strength\ at\ 100^0C = 10.98 - 0.2396A - 0.829B + 0.023AB + 0.0039A^2 - 0.014B^2 \quad \ldots (2)$$

The response surface for residual compressive strength subjected to 300^o at 7days is shown in Figure 3.

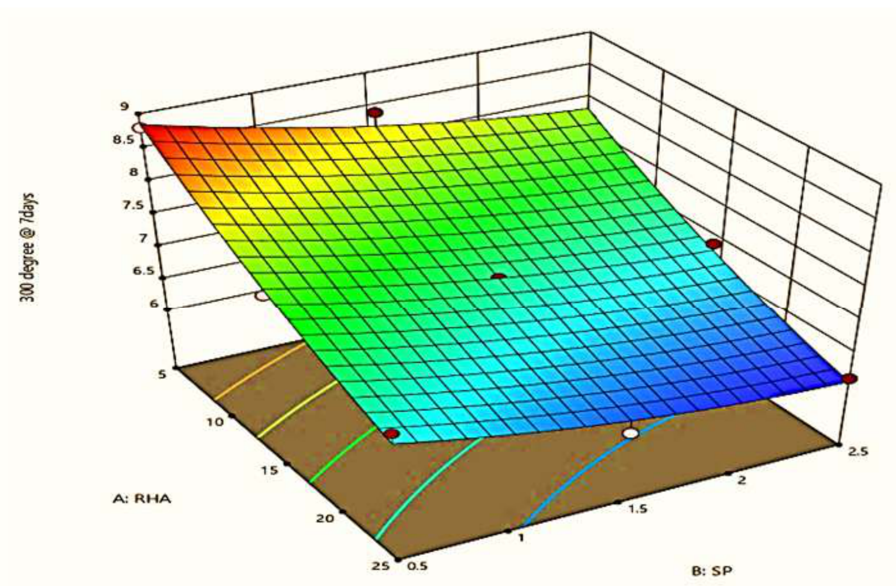

Fig. 3: Response surface for Residual Compressive Strength subjected to 300^o at 7days.

The actual values of Compressive strength at 300°C at 7days ranged from 36.1 to 8.89 N/mm². The variation of 7day compressive strength is a function of RHA and it is presented by the 3D surface. The model describing Residual Compressive Strength subjected to 300°C at 7days is given by the equation (3).

$$7\text{-}day\ Residual\ Compressive\ Strength\ at\ 300^0C = 9.9875 - 0.1475A - 0.975\,B + 0.005AB + 0.0015A\hat{}2 + 0.15B\hat{}2 \quad ...(3)$$

Figure 4 shows the response surface for residual compressive strength subjected to 500° at 7days.

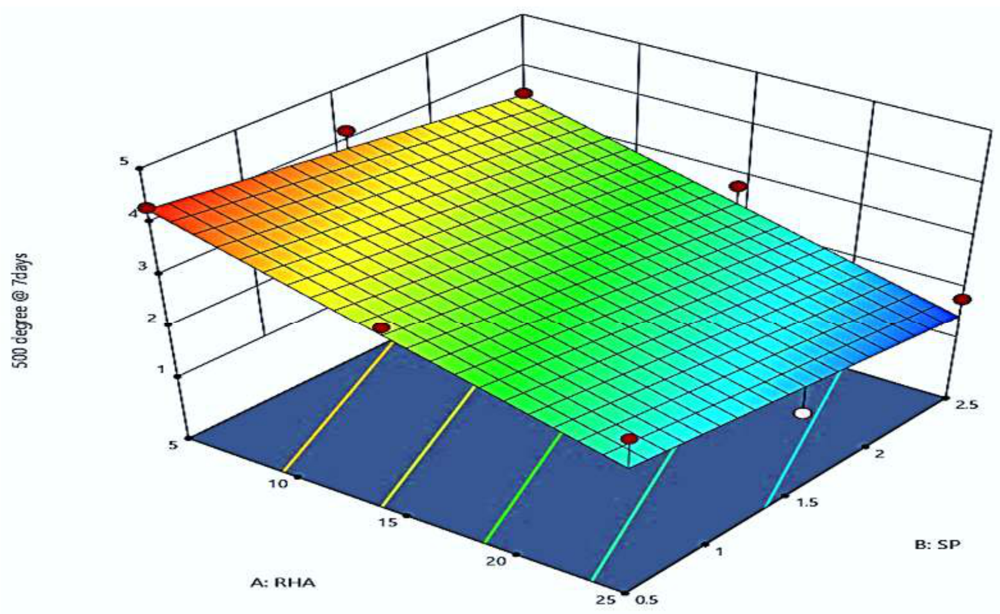

Fig. 4: Response surface for Residual Compressive Strength subjected to 500° at 7days.

The model describing Residual Compressive Strength subjected to 500°C at 7days is given by the equation (4).

$$7\text{-}day\ Residual\ Compressive\ Strength\ at\ 500^0C = 4.979 - 0.102A - 0.4B \quad ...(4)$$

3.2 28-days Residual compressive strength results of SCC

Table 4: Residual Compressive Strength of SCC Subjected to Elevated Temperature at 28 days. All the results are in N/mm².

Run	A:RHA (%)	B: SP (%)	25°	100°	300°	500°
Control	-	2	31.2	33.4	29.5	11.1
1	15	0.5	25.1	28.1	21.7	8.5
2	25	0.5	20.4	24.4	15.8	7.4
3	25	2.5	20.1	23.5	15.6	7.2
4	15	1.5	26.2	28.2	22.1	9.0
5	15	1.5	26.2	28.2	22.1	9.0
6	15	1.5	26.2	28.2	22.1	9.0
7	15	1.5	26.2	28.2	22.1	9.0
8	15	1.5	26.2	28.2	22.1	9.0

9	5	1.5	31.1	33.4	25.6	9.6
10	15	2.5	22.8	26	18.7	8.8
11	25	1.5	22.3	25.1	18.7	7.5
12	5	2.5	26.3	29.4	22.4	9.2
13	5	0.5	28.9	31.5	24.3	9.8

Table 4 shows the residual compressive strength of SCC specimens subjected to 25^{o}C, 100°C, 300°C, and 500°C elevated temperatures. The compressive strength of all the concrete increases from 25^{o}C to 100^{o}C but decreases with an increase in exposure to elevated temperature at 300°C and 500°C. At 25°C, the residual compressive strength ranges from 20.1 to 31.1 N/mm^2. At 100°C exposure to temperature, the residual compressive strength ranges from 23.5 to 33.5 N/mm^2. At 300°C exposure to temperature, the residual compressive strength ranges from 15.6 to 25.6 N/mm^2. At 500°C temperature, the residual compressive strength ranges from 7.2 to 9.8 N/mm^2. The decrease in strength could be as a result from dehydration of calcium silicate hydrate, making cement to lose its binding properties. The elevated temperature causes decrease in compressive strength with increased distortion of the concrete material at high temperature because cracking effects are hastened and thereby resulting to low strength of the concrete at high temperatures. The reduction in strength at elevated temperature from this study was in agreement with the findings reported by Guo and Chi, (2011), Iffat and Bose (2016) and Mohammed *et al.,* (2021).

Table 5: Analysis of variance for Residual Compressive strength at 28 days.

Parameter	25^{o}C		100^{o}C		300^{o}C		500^{o}C	
	F-value	P-Value	F-value	P-Value	F-value	P-Value	F-value	P-Value
Model	114	< 0.001	69	< 0.001	81.3	< 0.001	57.33	< 0.001
A= RHA	569	< 0.001	301	< 0.001	316	< 0.001	253.8	< 0.001
B = SP	27.87	0.0011	17.3	0.0043	16.7	0.0047	1.50	0.02601
AB	8.18	0.0243	-	-	-	-	1.44	0.269
A^2	-	-	-	-	-	-	12.43	0.0096
B^2	107	< 0.001	27.6	0.0012	53.9	0.0002	6.39	0.0393

The Analysis of variance results presented in table 5 showed that the response surface regression models reaches a highly significant level ($p < 0.0001$), and the lack of fit is insignificant in all cases.

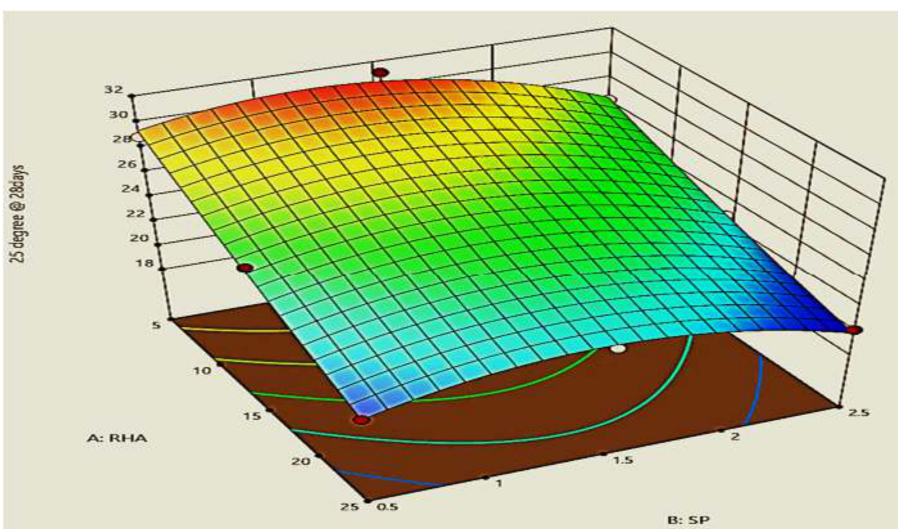

Fig. 5*: Response surface for Residual Compressive Strength subjected to 25^{0} at 28days.*

Journal of Civil Engineering
Volume XX, Issue 16 (2024) 19 - 34

The response surface models therefore fit well with real situation and can ably predict the effect of elevated temperature on residual compressive strength SCC at 28 days. The factors (RHA and SP) in the RSM model have a significant influence on the residual compressive strength of SCC. Figure 5 shows the response surface for residual compressive strength subjected to 25^0 at 28days.

The model describing Residual Compressive Strength subjected to 25^0C at 28 days is given by the equation.

$$28\text{-}day\ Residual\ Compressive\ Strength\ at\ 25^0C = 29.7 - 0.552A + 5.78B + 0.058AB + 0.0025A^2 - 2.503B^2 \quad \ldots(5)$$

The response surface for residual compressive strength subjected to 100^0 at 28days is shown in Figure 6.

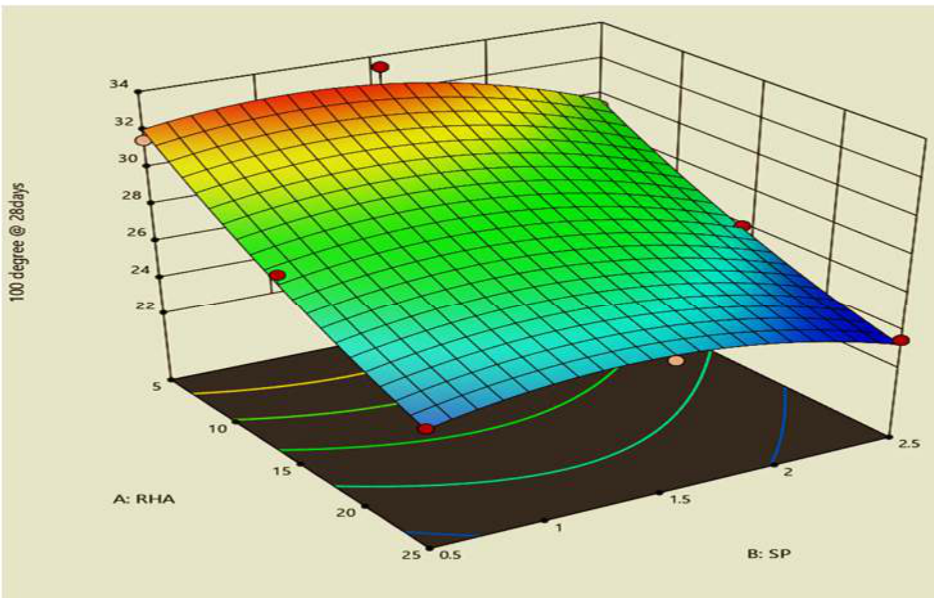

Fig. 6: Response surface for Residual Compressive Strength subjected to 100^0 at 28days.

The model describing Residual Compressive Strength subjected to 100^0C at 28 days is given by the equation (6).

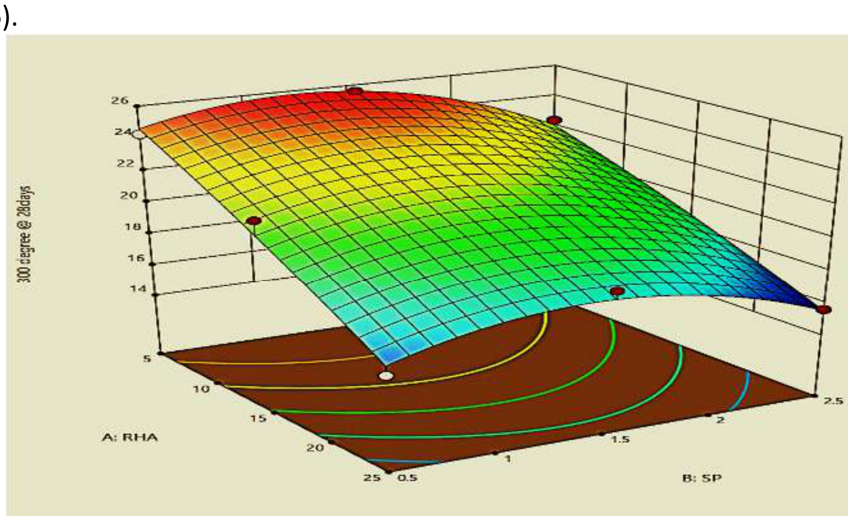

Fig. 7: Response surface for Residual Compressive Strength Subjected to 300^0 at 28days.

$$28\text{-}day\ Residual\ Compressive\ Strength\ at\ 100^0C = 33.419 - 0.584655A + 3.45345\ B + 0.03\ AB \quad ...(6)$$

The response surface for residual compressive strength subjected to 300^0 at 28days is shown in Figure 7.

The model describing Residual Compressive Strength subjected to 300^0C at 28 days is given by the equation (7).

$$28\text{-}day\ Residual\ Compressive\ Strength\ at\ 300^0C = 24.24 - 0.344A + 5.26B + 0.043AB - 0.003A^2 - 2.25B^2 \quad ...(7)$$

The response surface for residual compressive strength subjected to 500^0 at 28days is shown in Figure 8.

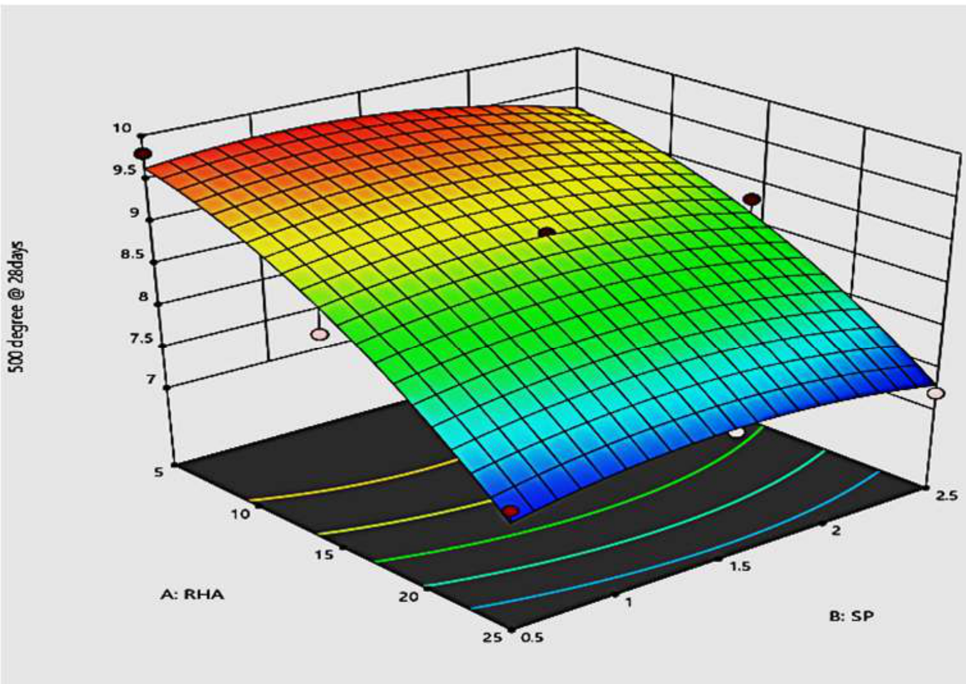

Fig. 8: Response surface for Residual Compressive Strength subjected to 500^0 at 28days

The model describing Residual Compressive Strength subjected to 500^0C at 28 days is given by the equation.

$$28\text{-}day\ Residual\ Compressive\ Strength\ at\ 500^0C = 9.582 - 0.017A + 0.527B + 0.01AB - 0.004A^2 - 0.253B^2 \quad ....(8)$$

3.3 90-days Residual compressive strength results of SCC

Table 6 shows the residual compressive strength of SCC specimens subjected to 25^oC, 100°C, 300°C, and 500°C elevated temperatures. The compressive strength of all the concrete increases from 25^oC to 100^oC but decreases with an increase in exposure to elevated temperature at 300°C and 500°C. At 25°C, the residual compressive strength ranges from 32.6 to 36.7 N/mm^2.

Table 6
Residual Compressive Strength of SCC Subjected to Elevated Temperature at 90 days. All the results are in N/mm^2

Run	A: RHA (%)	B:SP (%)	25^o	100^o	300^o	500^o
C	-	2	36.1	37.5	31.0	12.7
1	15	0.5	36.5	37.9	33.0	13.2
2	25	0.5	32.6	33.5	28.6	12.8
3	25	2.5	33.1	34.3	28.8	12.7
4	15	1.5	36.7	38.1	33.2	13.4
5	15	1.5	36.7	38.1	33.2	13.4
6	15	1.5	36.7	38.1	33.2	13.4
7	15	1.5	36.7	38.1	33.2	13.4
8	15	1.5	36.7	38.1	33.2	13.4
9	5	1.5	36.1	37.5	32.7	14.0
10	15	2.5	36.4	37.8	32.9	13.3
11	25	1.5	33.0	34.2	28.5	12.8
12	5	2.5	36.4	37.4	32.0	13.9
13	5	0.5	35.2	36.4	31.3	13.6

At 100°C exposure to temperature, the residual compressive strength ranges from 33.5 to 38.1 N/mm^2. At 300°C exposure to temperature, the residual compressive strength ranges from 28.6 to 33.2 N/mm^2. At 500°C temperature, the residual compressive strength ranges from 12.7 to 14 N/mm^2. The elevated temperature causes decrease in compressive strength with increased distortion of the concrete material at high temperature because cracking effects are hastened and thereby resulting to low strength of the concrete at high temperatures.

Table 7
Analysis of Variance for Residual Compressive strength at 90days

Parameter	25^oC		100^oC		300^oC		500^oC	
	F-value	P-Value	F-value	P-Value	F-value	P-Value	F-value	P-Value
Model	137	< 0.001	125.6	< 0.001	93.7	< 0.001	192.6	< 0.001
A= RHA	306	< 0.001	258	< 0.001	185	< 0.001	896	< 0.001
B = SP	9.67	0.0171	8.62	0.022	1.16	0.3169	7.87	0.0263
AB	2.78	0.1396	0.18	0.685	0.6806	0.4366	21.0	0.0025
A^2	286	< 0.001	272	< 0.001	216.8	< 0.001	0.000	1.0000
B^2	3.54	0.1018	5.94	0.0449	3.37	0.1092	32.63	0.0007

Analysis of variance results presented in table 7 showed that the response surface regression model reaches a highly significant level ($p < 0.0001$), and the lack of fit is insignificant in all cases. The response surface models therefore fit well with real situation and can ably predict the effect of elevated temperature on residual compressive strength SCC at 90 days. The factors (RHA and SP) in the RSM model have a significant influence on the residual compressive strength of SCC.

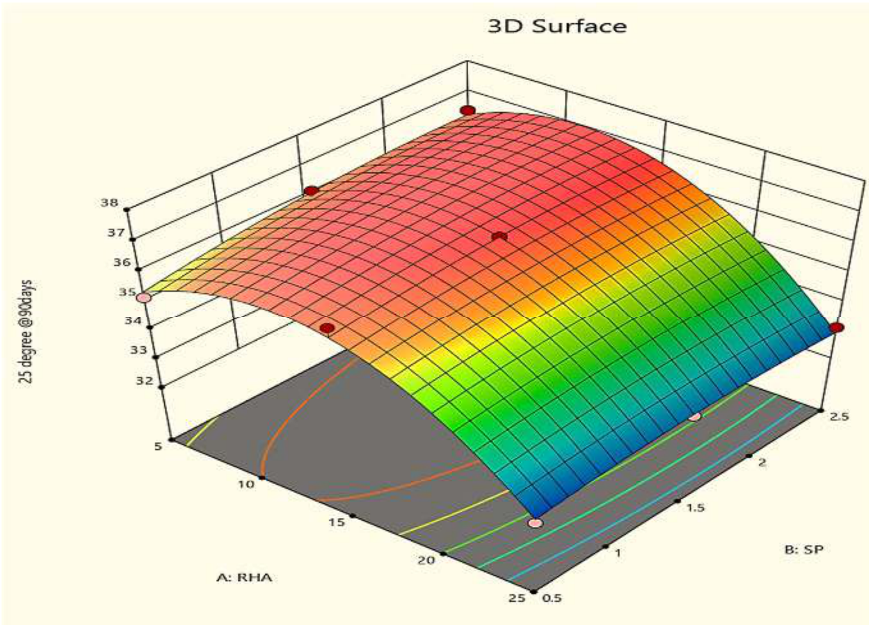

Fig. 9: Response surface for Residual Compressive Strength subjected to 25⁰ at 90 days.

The model describing Residual Compressive Strength subjected to 25⁰C at 90 days is given by the equation (10).

$$90\text{-}day\ Residual\ Compressive\ Strength\ at\ 25^0C = 32.8 + 0.52A + 1.24B - 0.02AB - 0.02A\char`^2 - 0.24B\char`^2 \quad ...(9)$$

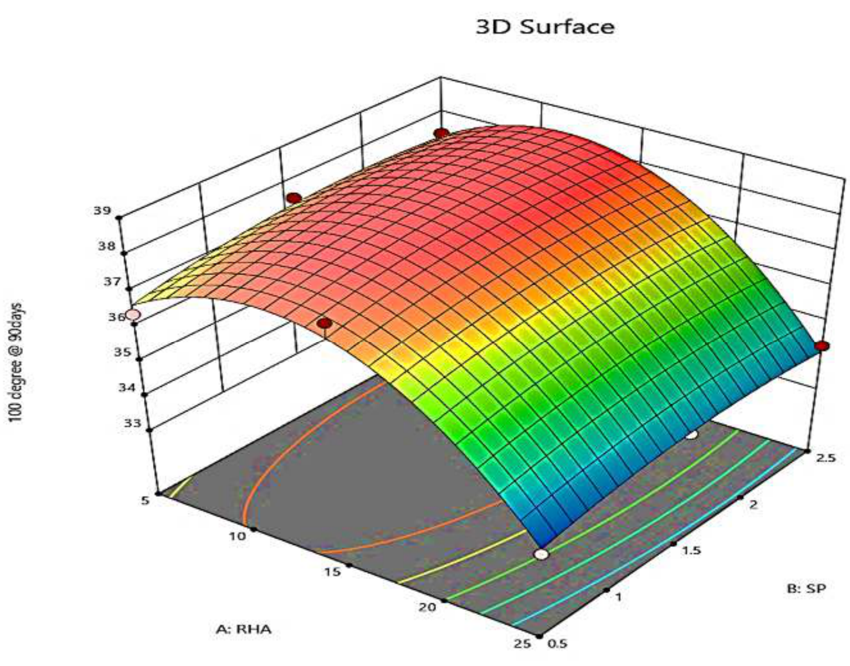

Fig. 10: Response surface for Residual Compressive Strength subjected to 100⁰ at 90days.

The model describing Residual Compressive Strength subjected to 100^{o}C at 90 days is given by the equation.

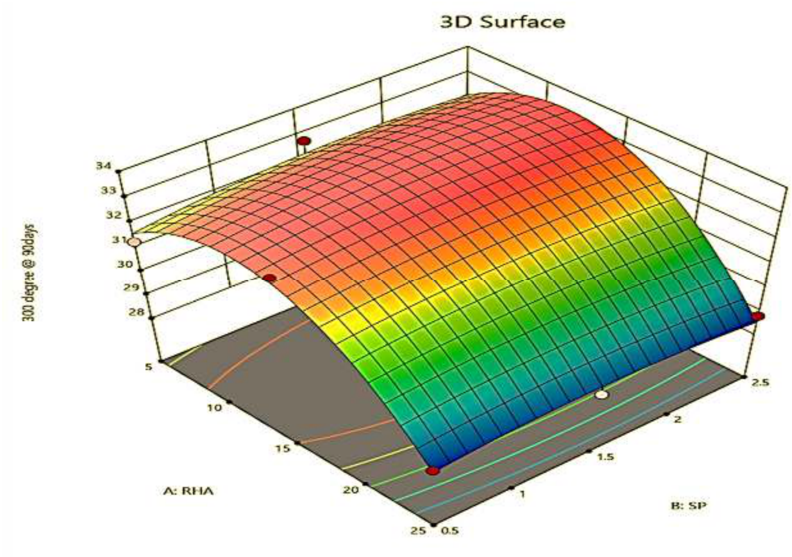

Fig. 11: Response surface for Residual Compressive Strength subjected to 300^{o}C at 90 days.

$$90\ -days\ Residual\ Compressive\ Strength\ at\ 100^{0}C\ =\ 33.9\ +\ 0.56A\ +\ 1.40B\ -\ 0.005AB\ -0.023A^2\ -0.347B^2. \quad ...(10)$$

Table 44: Actual and Predicted values of Compressive strength at 300^{o}C at 90days

The model describing Residual Compressive Strength subjected to 300^{o}C at 90 days is given by the equation (11).

$$90\ -days\ Residual\ Compressive\ Strength\ at\ 300^{0}C\ =28.48\ +\ 0.656A\ +\ 1.32B\ -\ 0.0125\ AB\ -0.027A^2\ -0.34\ B^2 \quad ...(11)$$

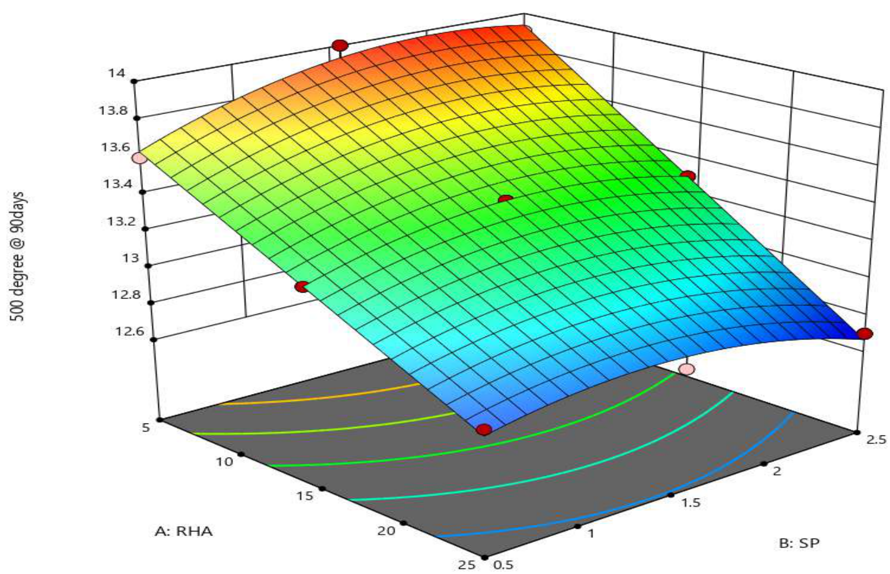

Fig. 12: Response surface for Residual Compressive Strength subjected to 500^{o} C at 90 days.

The model describing Residual Compressive Strength subjected to 500^{0}C at 90 days is given by the equation (12)

$$90\text{-}day\ Residual\ Compressive\ Strength\ at\ 500^0C\ = 13.56 - 0.038A\ +\ 0.65\ B\ -\ 0.01\ AB\ +\ 2.371E{-}17A^2\ - 0.15\ B^2 \quad ....(12)$$

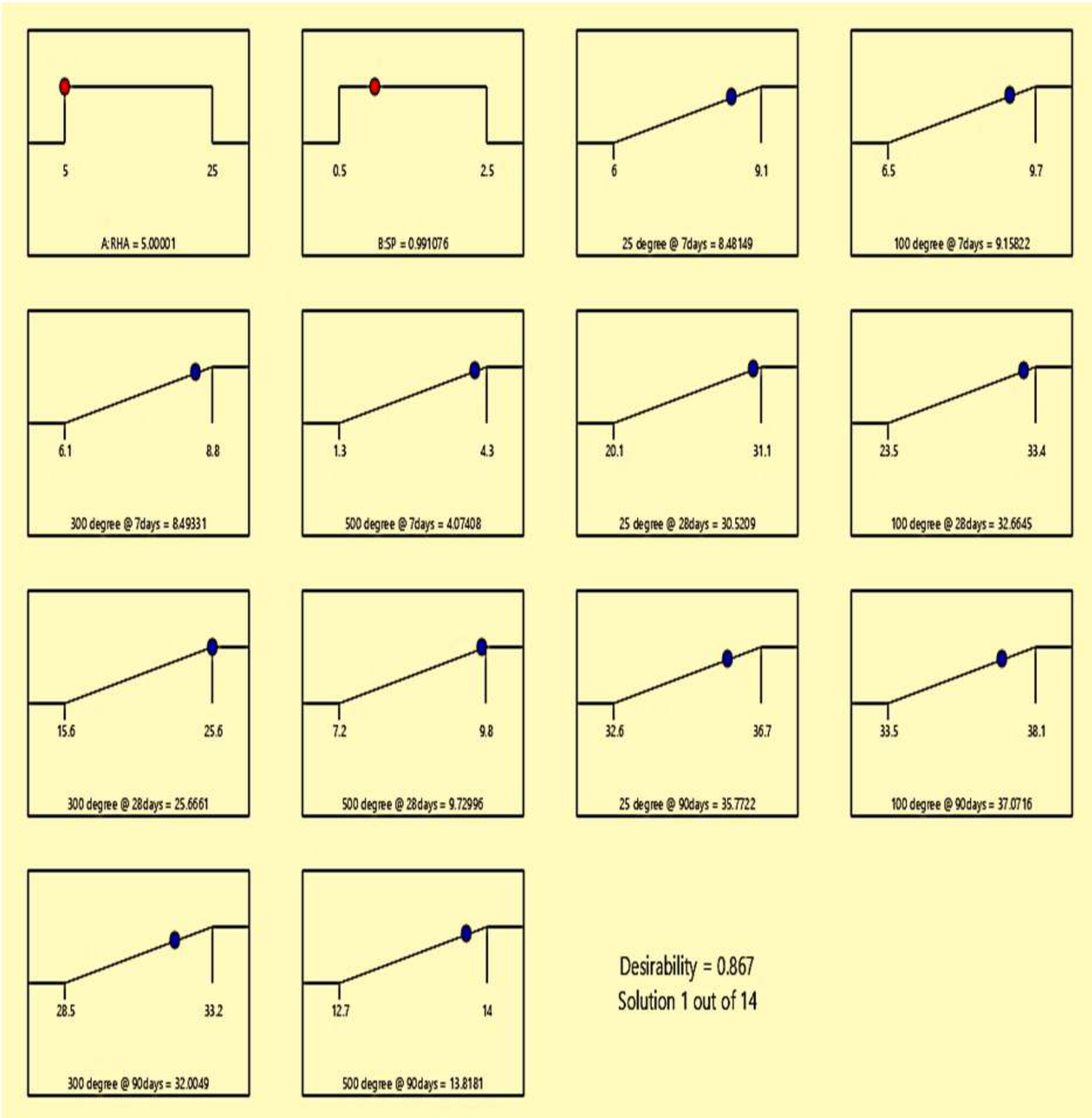

Fig. 13: Ramp plot showing the optimal values for responses.

4.0 Conclusion

Fire is a severe environmental condition which concrete structures may be subjected to during its service life. It is essential that concrete structural members when used in buildings should satisfy appropriate fire safety requirements and also demonstrate an excellent fire resistance property when exposed to elevated temperature compared to any building material. The use of rice husk ash produces concrete that is more economical, durable, workable and effective**.** It helps in proper waste management and lessens the environmental disposal burden. This study was limited to the use of rice husk ash from 5% to 25% and superplasticizer from 0.5% to 2%. Rice husk ash in self-compacting concrete helps to enhance concrete strength and durability by resisting high temperature up to 300^{o}C. The residual compressive strength of concrete reduced as concrete was subjected to increase in temperature. The reduction strength may be due to disruption of the interfacial zone, high dehydration of the calcium hydroxide and increase in water vapour generated. Concrete in the temperature range of 25°C to 100°C showed little strength gain. Between 100 and 200°C, the strength loss that occurred is attributed to the thermal swelling of the physically bound water which caused disjoint pressures. Beyond 300°C to 500^{o}C, the results showed rapid reduction in strength. The longer the duration of heating before testing, the larger the loss in strength. Relative to the effect of mix proportions, concrete made with siliceous rice husk ash losses less strength compared to concrete made with Portland cement.

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