EFFECTS OF WASTE STEEL FIBRES ON THE MECHANICAL PROPERTIES OF MODIFIED SELF COMPACTING CONCRETE

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Abstract: Waste Steel Fibre (WSF) and Rice Husk Ash (RHA) were used in the production of Self Compacting Concrete (SCC). Seven variants of SCC mixes were prepared. The rheological and mechanical properties (Compressive Strength (CS) and Split Tensile Strength (STS)) of the SCC produced were examined. The results showed that the blocking ratio varied marginally while other fresh properties of the SCC with WSF compared favourably to the standard. The CS of the hardened control samples after 56 days of curing was 36.18 N/mm^2 while the CS of SCC with 15 % of RHA and 0.0 %-0.5 % of WSF, ranged from 37.04 - 43.64 N/mm^2 with the maximum CS at 0.4 % WSF addition. Similarly, the STS of SCC at 56 days improved with an increase in WSF content up to 0.4 % and decreased with further addition of WSF. The inclusion of WSF at the optimum level of 0.4 % addition had a better influence on the tensile strength of SCC thereby increasing the ratio of STS to CS.

Keywords: compressive strength, rice husk ash, self-compacting concrete, tensile strength, waste steel fibre

1. INTRODUCTION

Waste management is still a major concern for most countries around the world, and industrial pollution caused by such waste has indeed been reported to pose health risks to humans. Every day, massive amounts of solid waste are produced as a result of domestic and industrial activities, which are harmful to the environment. Considering the environmental issues that have been reported by researchers in the past, stringent and innovative ideas are been put in place by countries to mitigate this menace before it becomes unbearable [1, 2].

A typical case in point is metallic waste from various industrial processes. The ever-increasing amount of steel waste remains a concern. Despite efforts to use these materials as an important resource for manufacturing through recycling, the energy demand required to recycle a tonne of waste steel is rather alarming when considering the effects on the planet [3, 4]. Therefore, the efficient utilization of these largely abundant wastes is of importance to the development of a more sustainable circular economy for the material at large.

Concrete is easily recyclable, thus making it a viable option for incorporating metallic wastes. However, issues such as improper compaction, the difficulty of placing in heavily reinforced sections, high levels of noise pollution and the formation of honeycombs, all of which are thought to contribute to the material's failure in service, make it even more necessary to adopt a more efficient type of concrete.

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Therefore, the use of Self Compacting Concrete (SCC) provides a better avenue to address the shortfalls of conventional concrete [5]. SCC is a state-of-the-art concrete that is placed easily and consolidates in the absence of external agitation, it is both flowable and deformable and by these, it has revolutionized concrete placement [6-9]. Previously, the emphasis has been primarily on improving the wet properties of the concrete, such as its ability to easily fill moulds, manoeuvre obstacles, and resist segregation in densely reinforced sections [10-15].

Thus, using SCC in civil engineering applications has increased rapidly in the last three decades, especially in the construction of intricate structures [16]. Despite its broad range of applications, SCC, like conventional concrete, has low tensile strength after hardening; it is typically brittle and not tough. As a result, several scholarly articles have been published on the prospects of using fibres as reinforcement to improve tensile behaviour and other engineering properties relevant to the built environment [17-19].

Steel fibres, hybrid steel fibres, polyethene fibres, glass fibres, polypropylene fibres, polyester fibres, basalt fibres, polyvinyl alcohol fibres, coconut fibres, sisal fibres, polyolefin fibres, and banana pseudo-stem fibres are among the fibres used in improving the properties of SCC. The results of these studies have revealed that the presence of these fibres considerably improved some engineering properties of SCC such as; anti-cracking, reinforcing, and toughening [19]. However, when used in concrete, they can be quite expensive, resulting in a significant increase in the concrete unit cost [20].

Rice Husk Ash (RHA) is a by-product of the incineration of rice husk bark and is commonly used as a domestic source of fuel in developing countries. There are several available studies on the characteristics as well as mechanical properties of RHA when complimenting cement in concrete mixtures [21, 22]. The results of such investigations have demonstrated that there appears to be a consensus among various researchers on the most effective temperature of calcination (600 - 800 ºC) and quantity of replacement in cement binder (10-15 percent). At this temperature and quantity of ash in a controlled environment, the resulting material has demonstrated impressive pozzolanic properties, significantly improving the durability, strength, and cohesion of concrete [21-23].

Consequently, commendable efforts have been made by researchers to use this reactive pozzolan in SCC, and the results obtained in such cases have been deemed satisfactory [10-14, 24-29]. Furthermore, the effects of other Supplementary Cementitious Materials (SCM) such as bagasse ash, fly ash, metakaolin, silica fumes, corn cob ash, sawdust ash, glass powder, coal bottom ash, ground granulated blast furnace slag, cement kiln dust, and limestone on the properties of SCC have been adequately studied, and such reports have opined that the workability, rheological stability of SCCs [30-34]. For example, [35] investigated the effectiveness of various SCMs on the engineering properties of steel fibre reinforced (SFR)-SCC mixtures, and the findings from the V-funnel and L-box were stated to be within defined limits. This report demonstrated that the presence of fibres had a significant impact on the tensile and flexural strengths of the concrete, with silica fume being the best among the group of SCMs evaluated and a 2 % steel fibre content was recommended to be the optimum in SCC. In another scholarly work, [36] used steel fibres ranging from 0 %-5 % in SCC with RHA and reported a corresponding increase in compressive strength of the concrete; results showed that samples tested after 7 days had an increase of 3-36 % while samples tested after 28 days had an increase of 3-34 %.

There has been no attempt to evaluate the influence of waste steel fibres derived from various industrial processes on the engineering qualities of SCC. As a result, the influence of WSF addition on the fresh and mechanical characteristics of SCC with a 15 % fixed RHA content was investigated in this study. With the incorporation of WSF in SCC, an attempt is made to understand how this addition will influence the resulting concrete, as well as serve as an opportunity to utilize the waste steel fibres in a more sustainable method that is friendly to the environment and less energy demanding than recycling.

2. EXPERIMENTAL SETUP

2.1. Materials

The cement used in this study was sourced from a local vendor in Osogbo, Osun State and corresponds to CEM II/A-L 42.5N. Rice Husk (RH) used was obtained from Inisha, Osun State, Nigeria.

The WSF used in this study was collected from the Mechanical Engineering workshop of Osun State University, Osogbo campus, where it was deposited in large quantities; these fibres are generated as waste products from the activities of using the lathe machine on high yield steels in the fabrication of tools and equipment.

After collection, the WSF was cut into 50 mm length with an aspect ratio of 100 they have a spiral-shaped deformed geometry with crimpled ends. Aggregates used were subdivided into coarse aggregates and fine aggregates. Pure Chem Conplast SP 430 was used as the High Range Water Reducer (HRWR) to achieve the desired flow in accordance with [37].

2.2. Methods

RH was sun-dried then burnt in an enclosed cylinder. After the first burning, the ashes were taken into the furnace to calcinate at 800 ºC for one hour. The resulting ashes were then milled further to obtain fine particles that will pass through the standard sieve No 200. Trial mixes were made to know the most suitable quantity of superplasticizer that will be needed, as too much of the superplasticizer may inhibit the production of strength and trigger bleeding of the concrete. Consequently, seven different mixes were produced and batching of the mix was done by weight following the guidelines by [38].

The water-to-binder ratio, superplasticizer, fine and coarse aggregate contents were kept constant for all the mixes. Cement was replaced with RHA at a weight replacement rate of 0 % and 15 % respectively. The mix without RHA and WSF served as the control sample, while other samples were modified with 15 % of RHA. Subsequently, WSF were added to the mix at different contents of 0.0 %, 0.1 %, 0.2 %, 0.3%, 0.4 % and 0.5 % respectively and thoroughly mixed until a uniform blend was obtained.

In preparation for the hardened tests, the SCC specimens were created by pouring thoroughly mixed fresh concrete into moulds. Table 1 shows the adopted mix ratio for casting the concrete samples. Slump flow, V-Funnel and L-Box tests were used to assess the filling ability, resistance to segregation and passing ability of the fresh SCC in compliance with [38]. A universal test machine (UTM) with a capacity of 2000 kN at a loading rate of 1.0 kN/s was used to conduct the compressive strength and splitting tensile strength tests. Each sample consisted of an average of three concrete specimens that were tested according to [39-43] at various curing ages of 7, 14, 28, and 56 days.

Table 1. Mix ratio for casting.

Material	Control	SCC-1	SCC-2	SCC-3	SCC-4	SCC-5	SCC-6
Cement (kg/m^3)	450	382.5	382.5	382.5	382.5	382.5	382.5
Rice Husk Ash (kg/m^3)	0	67.5	67.5	67.5	67.5	67.5	67.5
Waste Steel Fibres (kg/m^3)	0	0	2.4	4.8	7.2	9.6	12.0
Water (kg/m^3)	200	200	200	200	200	200	200
Fine Aggregates (kg/m^3)	1270	1270	1270	1270	1270	1270	1270
Coarse Aggregates (kg/m^3)	685	685	685	685	685	685	685
Super Plasticizer	6.7	6.7	6.7	6.7	6.7	6.7	6.7

3. RESULTS AND DISCUSSION

3.1. Chemical composition of Cement and RHA

The elemental composition of the Cement and RHA used were determined using XRF analysis. The machine used was developed by Shimadzu Technologies with model No: EDXRF-702HS. The results obtained were compared with CEM II and IIA, ASTM C150-94 and ASTM C618 and presented in Table 2. In both cases, the results revealed that both materials were within the limits specified by the standards and the SiO_2 content of the RHA was notably high suggesting a highly reactive pozzolana.

3.2. Fresh properties of SCC

3.2.1. Effect of RHA on the fresh properties of SCC

When compared to the control specimen (i.e. SCC without RHA and WSF), the fresh characteristics of the SCC mix with 15 % RHA performed better in terms of filling ability and resistance to segregation, but the blocking ratio was lower.

The control sample's reduced ease of flow may be ascribed to the large amount of cement paste employed in the control sample, which would require more free water for hydration than the other mixtures with a considerably lower amount of cement. Authors such as [6, 10], have reported that the presence of RHA in SCC at replacement values ranging from 5-15 % provided satisfactory properties in accordance with EFNARC's guide, and because RHA has a higher surface area than cement higher levels of replacement values will ultimately hinder the flow properties when used in concrete.

Table 2. Chemical property of cement and RHA.

Compound	Cement	Remarks	RHA	Remarks
	weight %	CEM II and IIA (ASTM C150-94)	weight %	ASTM C618
Calcium Oxide (CaO)	63.01	SiO_2+ CaO ≥ 50.0 %	0.57	-
Silica (SiO_2)	20.17		80.86	SiO_2+ Al_2O_3+ $Fe_2O_3 \geq 70.0$
Alumina (Al_2O_3)	4.95	6.0 % Max	1.51	
Iron Oxide (Fe_2O_3)	3.07	6.0 % Max	0.53	
Magnesium Oxide (MgO)	1.96	6.0 % Max	4.20	-
Sulphur trioxide (SO_3)	1.08	-	0.12	4.0 Max
Titanium Oxide (TiO_2)	-	-	0.04	-
Potassium Oxide (K_2O)	1.14	-	1.69	-
Manganese (MnO)	-	-	0.52	-
Other Oxides	4.62	-	9.96	-
LOI	5.32	2.5-3.0	3.2	10.0 Max
S.G	3.14	3.15	2.54	-

3.2.2. Combined effects of RHA and WSF on the fresh properties of SCC

There were no visible problems while mixing since the fibres were dispersed equally in SCC mixtures. Table 3 shows the results of slump flow tests, V-funnel tests, and L-box tests performed on fresh SCC mixes with WSF. The slump flow test helps to ascertain the deformability of the SCC in the absence of any perceived blockages [17]. It was observed that the ease at which the fresh SCC flows horizontally falls within the limits (550-800 mm) specified by [38] and is also in good agreement with the previous study published by [44].

The slump flow decreased steadily as the WSF content increased, but saw a sudden spike at 0.3 % WSF before decreasing to 625 mm at 0.5 %. For all of the mixes, the flow times reported during the V-funnel test were between 16 and 19 s. Although, these findings were incongruent with the rise in WSF content, yet all of the SCC mixes filled their moulds without the need for external agitation. It can be seen from Figure 1 that there exist a considerably strong relationship between the V-funnel flow and the slump flow time (R^2= 0.7813) and a mathematical equation relating both parameters is presented as equation (1). This relationship is very similar to the works of [17, 45], where R^2 values of 0.74 and 0.96 were reported, respectively.

A moderate value of V-Funnel and T_{500} flow time indicates a concrete that is moderately plastic and suggests an acceptable filling rate. As shown in Table 3, the results of the blocking ratio obtained from the L-box test demonstrate that there was a substantial reduction in the blocking ratio between the control sample and samples containing RHA and WSF. Only SCC-1 and SCC-4 correspond to the limitations of (0.8-1.0) provided by [38] Lower blocking ratio values are common for SCCs with a high proclivity for segregation, and the shape of steel fibre may have had a role in the current development. However, because the variance is minimal, samples that fall short of the limitations can still be used in SCC with caution [35, 46].

Table 3. Rheological properties of RHA modified SCC with varying percentages of waste steel fibres.

	Slump Flow		V-funnel	L-box
Specimen	Average D(mm)	T_{500} (s)	T(s)	Blocking ratio (h_2/h_1)
Control	540	4.2	19.1	0.9
SCC-1	665	3.5	17.2	0.85
SCC-2	660	2.7	16.1	0.76
SCC-3	658	2.6	16.2	0.78
SCC-4	678	3.1	17.3	0.85
SCC-5	655	2.3	16.1	0.77
SCC-6	625	3.1	16.4	0.79

Taking the overall results of the fresh properties into account, it can be seen that adding waste steel fibres to SCC with 15 % RHA as a partial replacement for cement has no significant effect on the rheological properties as the fibre content increases except for the blocking ratio which was slightly hampered but can still be accommodated in practice.

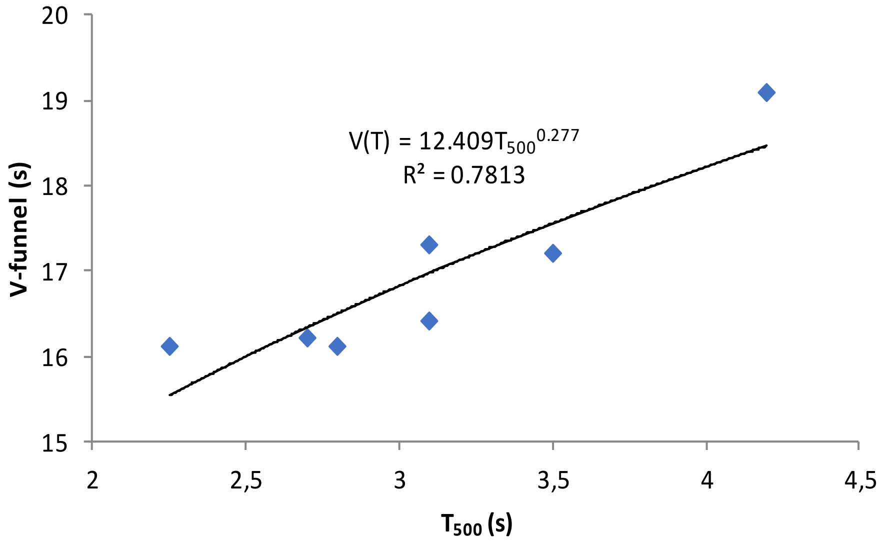

Fig. 1. V-funnel flow values against the flow time from the slump flow.

Funnel flow values against the flow time from the slump flow are given in equation (1).

$$V(t) = 12.409\, T^{0.277} \tag{1}$$

where V(t) is the V- funnel flow time and T is the time taken in seconds for the fresh SCC to cross the 500 mm diameter mark on the board.

3.3. Hardened properties of SCC

3.3.1. Effect of RHA on the compressive strength of SCC

The pozzolanic behaviour of RHA was evident in the results obtained, a detailed result of the compressive strength is shown in Figure 2 which represents the plot of compressive strength values against an increasing percentage of WSF for 7, 14, 28 and 56 days. It can be seen that the strength of the concrete mix increased with the age of curing across the board. The percentage increment in strength between the control and the SCC mix with 15 % of RHA only across the ages of curing was 7.41 %, 7.07 %, 4.00 % and 4.42 % for 7, 14, 28 and 56 days respectively.

Given the trend herein observed, the influence of RHA on the CS was more significant at the early days of curing than was observed for the later ages of curing. Considering the works by other authors the trend herein observed can be validated. For instance, [47] used RHA at replacement values of 10 and 20 % in SCC and reported an increase in strength of up to 41 % when compared with conventional concrete after 180 days of curing. Elsewhere, [24, 48-49] concluded that 15 % of RHA gave optimum compressive strengths in SCC after 28 days and it was as a result of the chemical reaction between RHA, calcium hydroxide and water which produced silicates of stronger microstructure.

3.3.2. Combined effects of RHA and WSF on the compressive strength of SCC

After 7 days of curing, the average compressive strength of the control SCC was 25.19 N/mm^2, while the compressive strengths of concretes with 15 % of RHA and WSF content of 0.0 %, 0.1 %, 0.2 %, 0.3 %, 0.4 % and 0.5 % were 27.06 N/mm^2, 28.72 N/mm^2, 28.52 N/mm^2, 28.89 N/mm^2, 27.54 N/mm^2 and 26.28 N/mm^2 respectively. It was observed that the concrete sample with 15 % RHA and 0.3 % WSF had the highest compressive strength with a value of 28.89 N/mm^2.

The 14 days compressive strength of the control sample increased by 13% (28.58 N/mm^2), while that of the SCC modified with RHA were 30.60 N/mm^2, 30.55 N/mm^2, 31.78 N/mm^2, 32.48 N/mm^2, 34.52 N/mm^2 and 33.76 N/mm^2 for WSF inclusion of 0.0 %, 0.1 %, 0.2 %, 0.3 %, 0.4 % and 0.5 % respectively. It was observed that the concrete sample with 15 % RHA and 0.5% WSF had the highest compressive strength value at this age.

For the 28-day compressive strengths, the control sample had a compressive strength of 34.52 N/mm^2 while other samples with 15 % RHA and WSF at varying proportions ranging from 0.0% - 0.5% are 35.90 N/mm^2, 35.55 N/mm^2, 36.23 N/mm^2, 35.03 N/mm^2, 41.28 N/mm^2 and 39.30 N/mm^2.

Up until the 56th day, the concrete samples showed an appreciable increase in compressive strengths for all the samples tested, while the percentage change in the strength of the control was 4.8 %, those of other samples were 5.2 %, 4.2 %, 9.5 %, 16.6 %, 5.7 % and 7.1 % for SCC with 15 % RHA and WSF at varying proportions ranging from 0.0% - 0.5 % at an increment of 0.1%. This shows that the addition of RHA and WSF had a significant effect on the compressive strength of SCC at later days of curing and became more pronounced between 0.2 % - 0.5 % WSF content. Previous researchers have differing opinions on how much the addition of fibres affects the compressive strength obtained; for example, [50] reported a 25 % increase in strength while [17] reported a 4 % increase; however, there is general agreement that the presence of the fibre improves the compressive strength, which is the case in this study.

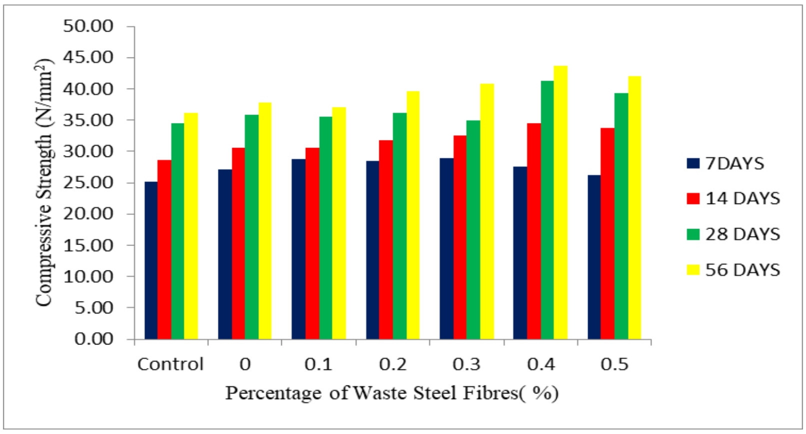

Fig. 2. Compressive strength of concrete at varying percentages of waste steel fibres.

3.3.3. Effect of RHA on the split tensile strength of SCC

The split tensile strength of the concrete samples was also evaluated at 7, 14, 28 and 56 days of curing and the results obtained are as shown in Figure 3. Apart from the 14 day tensile strength which had a slight reduction in tensile strength, concrete samples with 15 % of RHA had better tensile strength, suggesting that the presence of RHA in the mix had a positive effect on the tensile properties of the concrete. In the study by [51], the authors explained that such occurrence is possible in situations where the curing conditions were not properly controlled and could affect the outcome of the experiment. On the effect of RHA on SCC, [12, 49] both share a common perspective on how RHA influences the tensile strength of concrete and have reported in their studies that while RHA improved the tensile strength, the percentage improvement was much lower than that obtained with compressive strength and this is similar to the trend observed in this study.

3.3.4. Combined effects of RHA and WSF on the split tensile strength of SCC

All samples tested were within the standard values of the split tensile strength (STS) (2 N/mm^2–5 N/mm^2) as specified by [37]. The results showed a more steady increase in strength unlike the compressive strength results and the significance of the WSF was more pronounced than it was observed in compressive strength. The average tensile strength obtained for the control sample at 7 days was 2.69 N/mm^2, while that of concrete samples with RHA as a partial replacement for cement and steel fibre at 0.0 %. 0.1 %, 0.2 %, 0.3 %, 0.4 %, 0.5 % were 2.82 N/mm^2, 2.96 N/mm^2, 3.24 N/mm^2, 3.02 N/mm^2, 3.44 N/mm^2 and 3.07 N/mm^2 respectively.

It was observed that concrete samples with 0.4% of WSF had the highest tensile strength. Further increase in strength was recorded after 14 days and 28 days of curing as shown in Figure 3; it was observed that the increase in the percentage of the WSF affected the tensile strength of the concrete significantly in both cases.

After 56 days of curing, the STS of the control sample had improved by 0.68 % over the previous age of curing, while the SCC with 0.4 % WSF had the best STS. However, it was also discovered that the 56-day STS for 0.1, 0.2, 0.3, and 0.5 % Waste Steel Fibres was lower than the 28-day STS, implying that the curing condition or the orientation of the fibres in the concrete could have been the likely reason for the results obtained. In general, samples of concrete with WSF performed better than those without, with an improvement in tensile strength of 3.33 %, 5.18 %, 8.88 %, 12.59 %, 29.98 %, and 24.80 % for 0.0 % - 0.5 % of WSF, respectively. Although the percentage improvement recorded was a little lower than that reported by [52] and [53], this can still be considered beneficial to the concrete when used in situations where tensile strength is of interest.

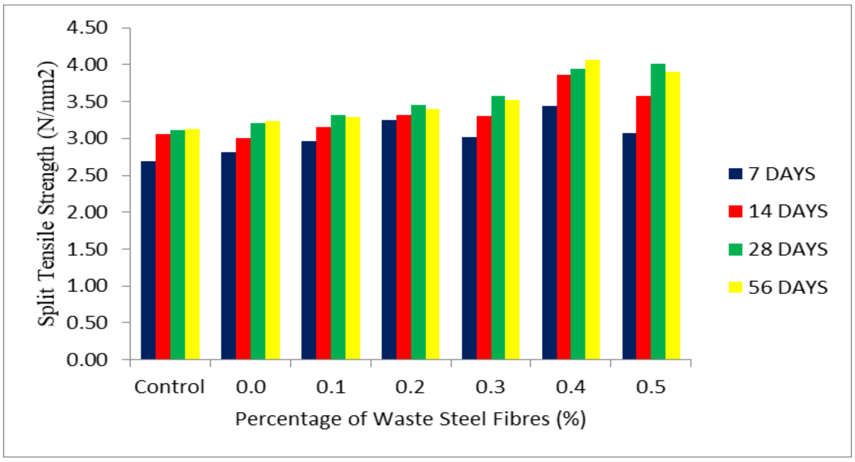

Fig. 3. Split tensile strength of concrete at varying percentages of waste steel fibres.

The importance of fibres in bridging micro-cracks and arresting the propagation of macro cracks has been reported by [17] and the trend observed in this study further attest to this because crack control in concrete plays an important role in the behaviour of the concrete especially when in distress. As seen in Figure 4, there is a considerate correlation (R^2= 0.922) between the two strength properties that are of interest after 56 days of curing and is represented as equation (2) in this paper.

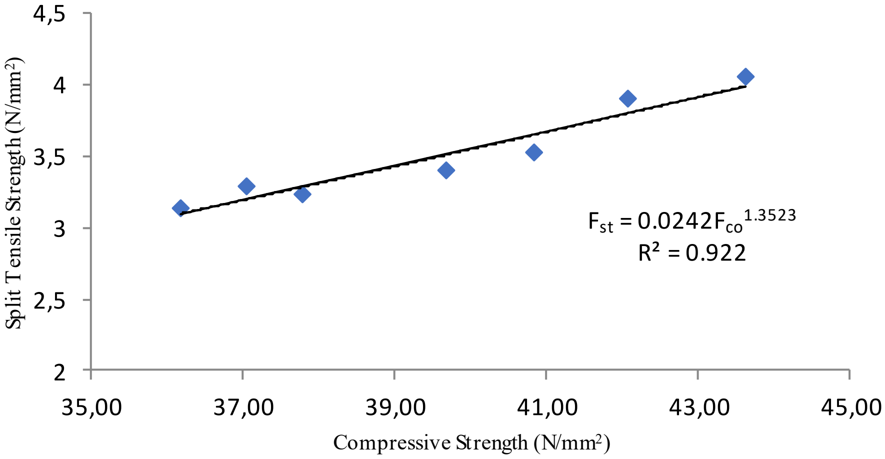

Fig. 4. Relationship between split tensile strength and compressive strength.

The ratio of STS to CS is an important material property in predicting the failure envelope of concrete without performing triaxial compression tests and it has been reported by [54] that for an increasing compressive strength this ratio decreases because the split tensile strength occurs at a much slower rate. In Figure 5, the result from this study shows that as the age of curing increased, the average ratio of STS to CS decreased but the presence of WSF improved the STS considerably thereby increasing the ratio and was most significant at 0.4% addition of WSF.

$$Fst = 0.0242\ Fco^{1.3523} \tag{2}$$

where F_{st} is the 56 day split tensile strength and F_{co} is the 56-day compressive strength of the hardened concrete.

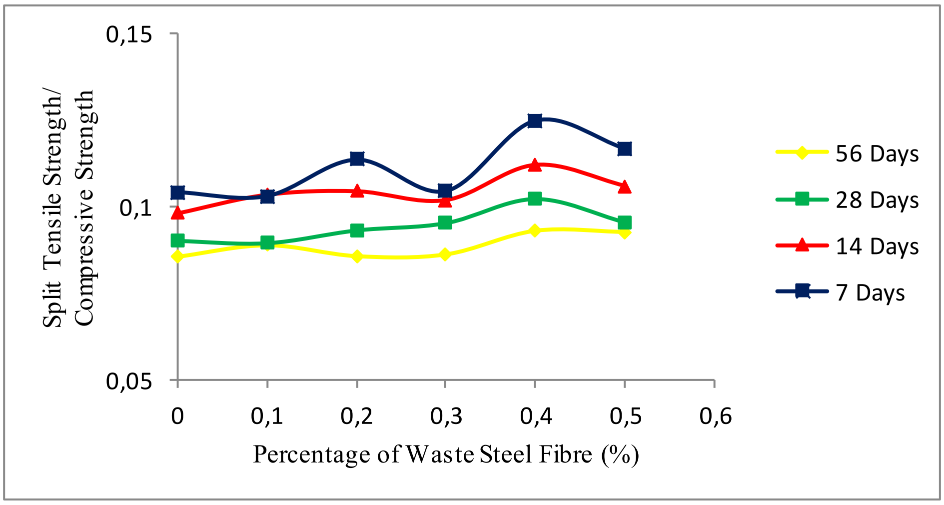

Fig. 5. Effect of WSF on the ratio of split tensile strength-compressive strength across the ages of curing.

4. CONCLUSIONS

Based on the results of experimental studies, the following conclusions were arrived at:

1. The Slump flow, V-funnel and L-box tests carried out showed acceptable values as per the requirements of fresh state properties of SCC. Also, the addition of waste steel fibres did not affect the workability of the fresh concrete samples during casting. In general, SCC modified with 15 % of RHA as a partial replacement for cement was favourably normal when compared with the control samples;
2. The effect of adding WSF was more noticeable in the modified SCC's tensile strength, which improved by 30 % after 56 days of curing, while the compressive strength only improved by 20 %. Thus it may be convenient to conclude that 0.4 % of WSF will be most ideal in SCC modified with 15 % of RHA;
3. The findings from this study have shown that the incorporation of WSF in SCC with RHA has provided an alternative means of utilizing waste steel fibres in a more sustainable approach and reducing some environmental challenges often faced during its disposal.

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