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The Effects of the Fineness Level of Rice Husk Ash as a Partial Cement Substitute in Self-Compacting Concrete (SCC)

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ABSTRACT

Rice husk ash (RHA) is recognised as a sustainable mineral additive derived from waste. The substitution of a portion of cement with RHA could improve the mechanical characteristics of concrete, leading to the increased adoption of Self-Compacting Concrete (SCC). The properties of rice husk ash need to satisfy specific criteria to ensure its reactive qualities are fully effective, including the fineness of the husk ash. The quality can be achieved using a filtering technique to obtain the RHA with a certain level of fineness, with division in several zones, 0,1,2,3 and 4. RHA from each zone partially replaces 10% cement in the SCC mixture. To obtain the physical characteristics of SCC, tests were carried out in the fresh phase, which includes slump flow, V-Funnel, and L-box tests. Meanwhile, compressive strength, flexural strength, and modulus of elasticity tests were conducted to obtain the mechanical properties of the mixture. The results of the fresh concrete test showed that all mixtures are qualified as SCCs, and the results of the hardened concrete test suggested that the fineness of RHA enhances its mechanical properties.

1. Introduction

RHA is one of the waste materials from rice burning and is known as one of the supplementary cementitious materials (SCM) that can be used to improve various properties of concrete. RHA is an excellent and pozzolanic material with high reactivity. Pozzolanic properties are essential as they denote the potential to be involved in chemical reactions determining the concrete's strength. This property improves the microstructure properties in the interfacial transition zone (ITZ) between the cement paste and the aggregate in any concrete, thereby improving strength and durability. The capacity for enhancing strength is essential for materials intended for structural purposes [1].

The use of RHA as SCM has been extensively researched in various types of concrete, including self-compacting concrete (SCC). The increasingly widespread use of SCC requires development with SCM materials. RHA serves as an alternative to cement in creating self-compacting concrete (SCC),

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recognised for its impact on SCC's mechanical characteristics [2]. It was found that the cement replacement rate of 5-10% could improve the mechanical properties of SCC. However, the addition of RHA decreases the working capacity of the SCC. Past research has comprehensively assessed how RHA improves SCC's physical and mechanical features [3, 4]. A further study indicated that key factors which influence the reactivity of RHA could have an optimal impact on the compressive strength of concrete when the ratio of RHA material to cement replacement is 10% [5]. Using these additives in concrete mixtures can improve concrete's compressive strength and durability [6-9].

Moreover, RHA's characteristics affect concrete's physical and mechanical properties [10-13]. In some studies, incorporating RHA into concrete has enhanced its compressive strength by 10% to 30% [4,14-17]. An investigation by Bheel *et al.,* [18] on the mechanical behaviour of concrete incorporating RHA and wheat straw ash revealed that replacing Portland cement with these ashes led to diminished drying shrinkage of the samples. This study showed that the development of compressive strength, flexural strength, and split tensile strength increased with the age of preservation.

In contrast to conventional concrete, such SCC concrete offers increased flowability and is self-compacting. Of course, the capacity of this concrete to seamlessly flow and occupy every nook of its formwork is enhanced by utilising a comparatively finer aggregate than that found in traditional concrete [19]. The characteristics of SCC include filling ability, escape ability, and segregation resistance [20-22]. Partial replacement of Portland cement by RHA increases water demand, which can be compensated for using a superplasticiser. In addition, this unfavourable effect is more pronounced for blends of RHA with finer cement [23]. It has been argued before that RHA can be ground to a fineness whereby the porous structure of the particles has collapsed [24,25].

Researchers have also explored using RHA for partial cement replacement [26-29]. The incorporation of RHA as a supplementary cementitious material within the concrete sector has been scrutinised. It has been ascertained that finely milled RHA enhances the strength characteristics of concrete, signifying that utilising RHA in conjunction with cement can yield robust and durable concrete [30]. However, the study revealed that rough RHA is unfavourable for developing concrete strength. In addition, Zain [31] found that the quality and standard fineness depend on the grinding process and duration, combustion period, and chilling duration. These factors are crucial in procuring RHA that meets the requisite fineness and quality standards. In addition to small amounts of carbon, silica content, silica crystallisation, size, and surface area of RHA affect the performance of its pozzolanic activity. Zain *et al.,* [32] and Rodrigues *et al.,* [33] stated that treating the RHA with fine grinding is necessary to ensure the quality of RHA. In other words, the fineness of the RHA material affects the reactivity of RHA as a pozzolan and contributes to the mechanical strength. The study also suggested that the reactivity of RHA depends on the amount of reactive SiO_2, determined by the combustion temperature and ash fineness. In addition, it affects mechanical properties such as strength and durability.

The study by Firdaus *et al.,* [34] revealed that the fine quality of fly ash enhanced the compressive strength of the geopolymer mortar. The study used a filtration technique on fly ash pozzolan material to obtain a certain level of fineness. The results confirmed that finer fly ash results in higher compressive strength. Through an identical procedure, the pozzolanic content of RHA is processed to attain a designated level of fineness, which can bolster the physical and mechanical attributes of SCC. The fineness of RHA significantly enhances the strength of concrete mixtures, as the reactivity of RHA is closely linked to its specific surface or particle factor [35]. Other studies have also concluded that additional cementitious materials, capable of partially replacing cement, necessitate specific pretreatment involving chemical activation, regulated combustion temperatures, and mechanical milling procedures [36-38]. Further research has indicated that the properties of rice husk ash (RHA) are significantly affected by combustion [39]. Factors such as the temperature and duration of combustion and pre-burning treatments influence the material's porosity. These factors predominantly affect the internal pores, increasing RHA's surface area [39]. The distribution of pore size in RHA particles can be divided into macropores (>50 nm), mesopores (2- 50 nm), and micropores (<2nm). It can be concluded that the micropores and mesopores affected the pore volume significantly, thereby influencing the specific surface area of the RHA [40, 41]. Meanwhile, the specific surface area of RHA increases with fineness or degree of grinding [39,42].

Based on these studies, the grinding method emerges as a viable approach to RHA properties with enhanced amorphousness and porosity, thereby ensuring optimal reactivity. This quality is contingent upon precise control of time, temperature, and environmental conditions. Contrary to the previous approach, this study employs a research method that disperses RHA across multiple zones to achieve the desired fineness. Furthermore, the physical and mechanical properties of the SCC with the RHA mixture from the various zones will be determined.

2. Methodology

2.1 Sampling and Sample Preparation

Rice husk ash (RHA), a waste product from the incineration of rice husks, was obtained from PT. Buyung Putra Pangan. This research used the RHA filtering technique based on the fall zone as an RHA substitution in the self-compacting concrete. This filtering was differentiated into 4 zones and used to substitute cement as the main ingredient. This technique aims to analyse the effects of RHA fineness level on the compressive strength, split tensile strength, and modulus of elasticity of the mixed SCC compared to a normal one without RHA.

The RHA underwent sieving before being processed according to the fall zone parameter, which determined the fineness of the rice husk ash. The apparatus depicted in Figure 1 demonstrates that the RHA from the container was blown from the container to the pipe. The RHA flew through the pipe and descended into the apertures spaced across four equidistant fall zones. The RHA in the container is called Zone 0, while the RHA, which falls at each distance of 2.5 m, 5 m, and 7.5 m, is called Zone I, Zone 2, and Zone 3, respectively. This study did not use Zone 4, the farthest zone, since very few RHA were flying to the region. The finer portions of the RHA in each zone were used in the mixture of various SCC samples. The method of pre-treating by-product materials prior to their incorporation as an additive in concrete mixtures is presented as a novel approach in the study by Firdaus *et al.,* [34].

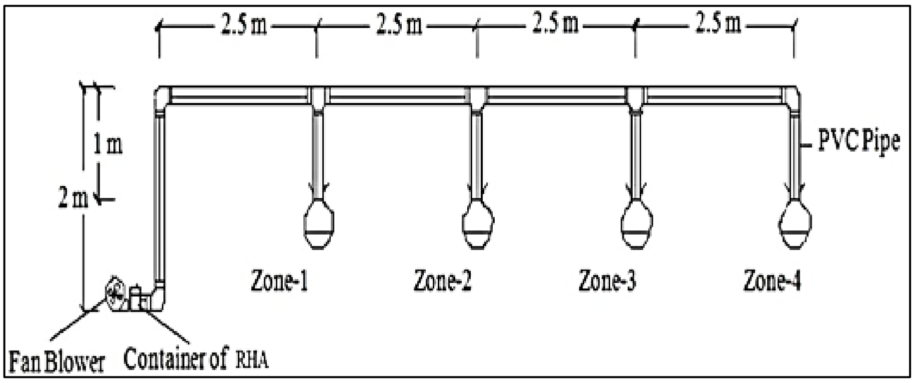


Fig. 1. RHA filtering based on fall zone

Figures 2 to 5 show the XRD patterns of RHA samples prepared under different fineness levels. All samples exhibited abroad band at approximately 2θ=21°- 22°, which is the characteristic peak of amorphous silica. The lowest level of RHA fineness (Zone 0) shows the highest sharp peak at approximately 2θ=20.9°. In contrast, the other zones exhibit a lower sharp peak even at the increased fineness of RHA. A qualitative assessment of the samples' crystalline nature is achievable by assessing the narrow reflections' intensity against the broadband [43,44]. The pronounced broad peak evident across all samples signifies the amorphous characteristic of silica. As the XRD patterns of the finer RHA samples exhibit fewer sharp reflections, there is a reduction in crystalline properties. Consequently, the finer the RHA, the better the amorphous quality of silica becomes. The chemical composition of RHA based on the XRF Test is provided in Table 1.

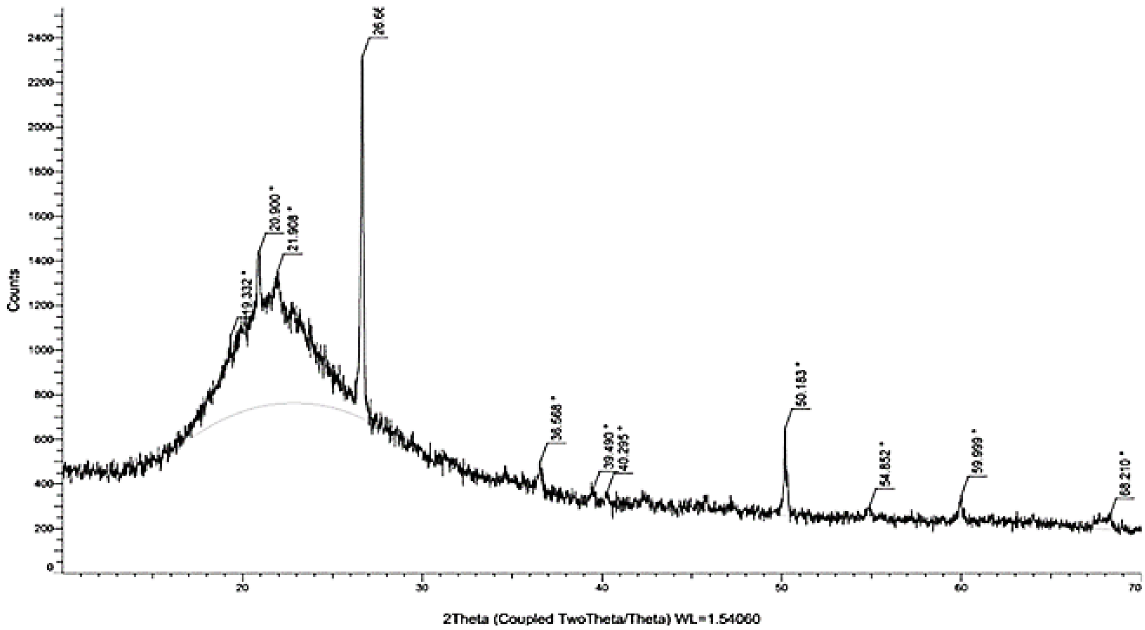


Fig. 2. XRD of RHA with fineness level 0

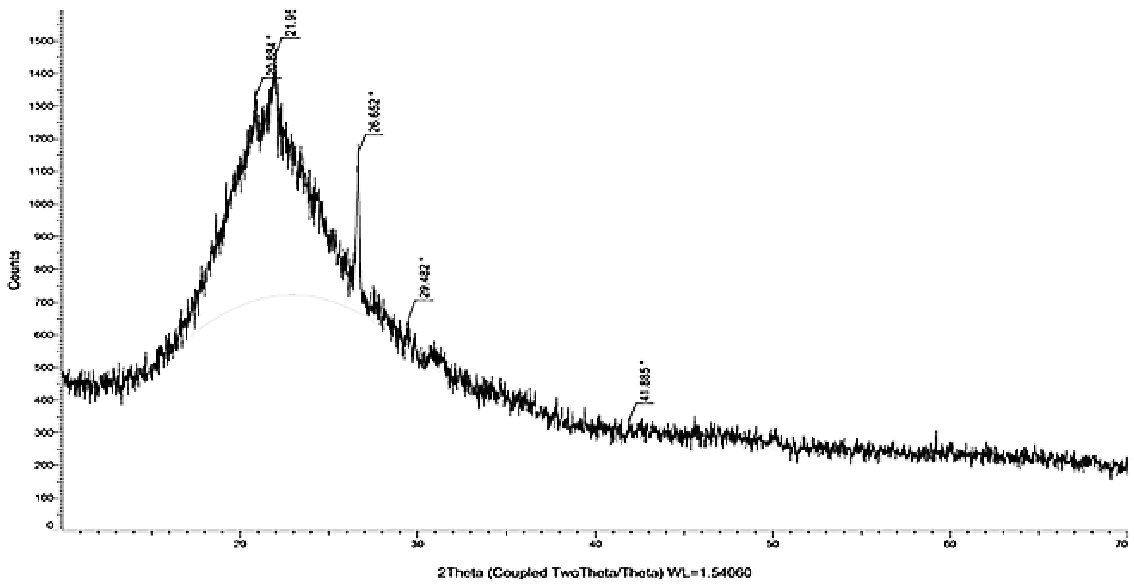


Fig. 3. XRD of RHA with fineness level 1

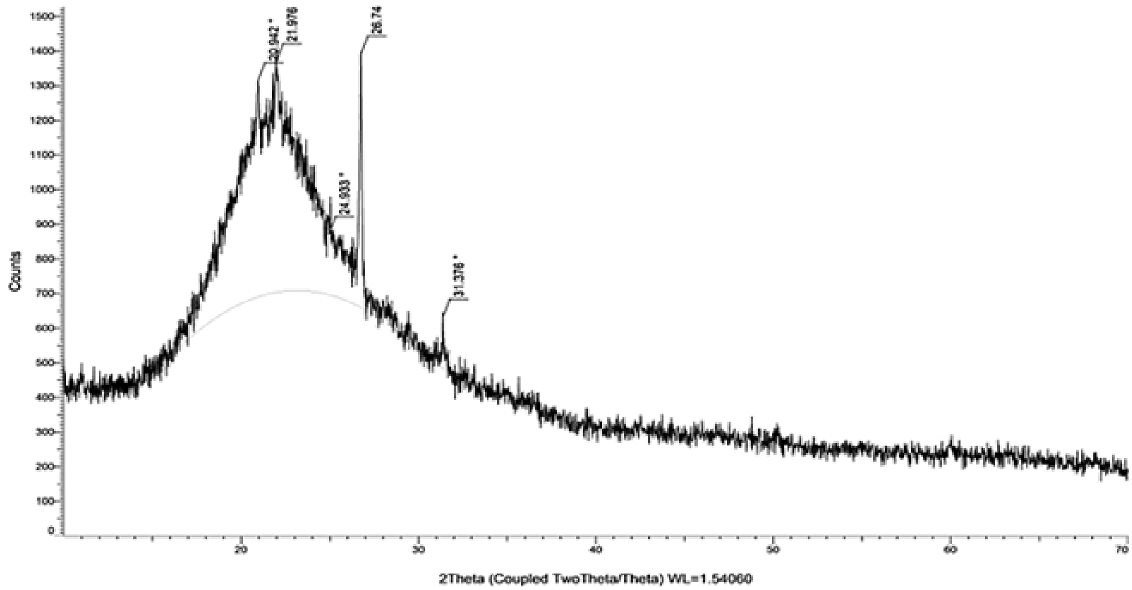


Fig. 4. XRD of RHA with fineness level 2

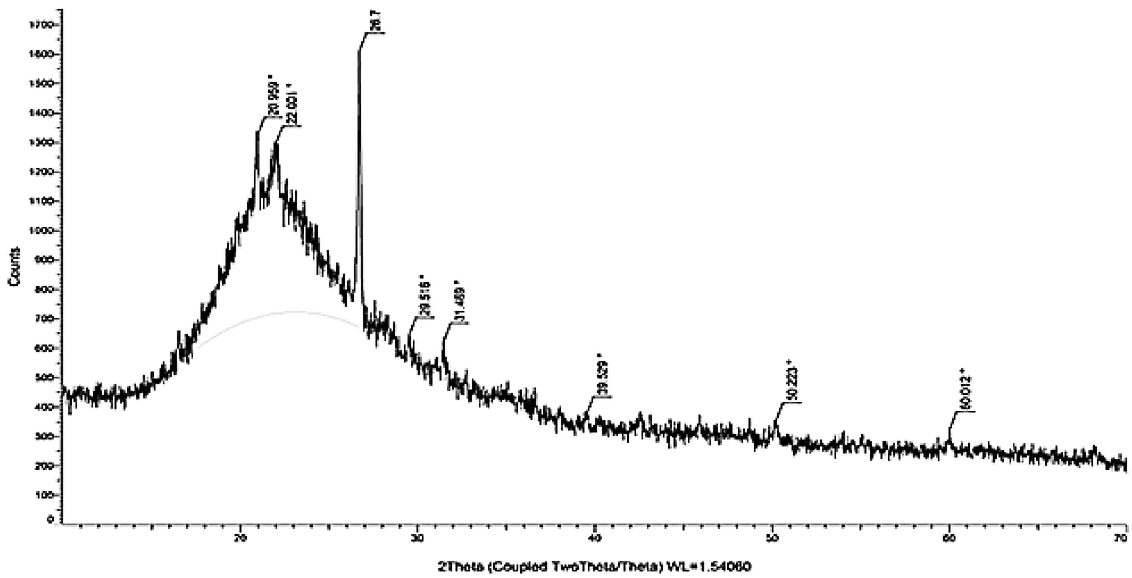


Fig. 5. XRD of RHA with fineness level 3

Table 1
Chemical composition of untreated rice husk ash (RHA)

Element	Composition (%)
SiO_2	93,00
Al_2O_3	0,35
Fe_2O_3	0,23
MnO	0,14
MgO	0,41
CaO	1,31
Na_2O	0,15
K_2O	1,61
SO_3	0,03
LOI	1,90

The superplasticiser used in this study is a type F superplasticiser. This material was used to reduce the water-to-cement ratio of the SCC. The fine aggregate used in this study was sand, obtained from Banyuasin, while the coarse aggregate utilised had a maximum size of 10 mm and was obtained from Bojonegara.

2.2 Mixtures Proportions

The variables in this study comprised four levels of RHA fineness (Z0-Z3), a 10% substitution of RHA for fly ash, and tests conducted at ages 7, 14, 21, and 28 days. All of the variables were assessed based on the parameter of compressive strength. Four self-compacting concrete mixtures were formulated in accordance with the optimal trial mix design. The composition of all samples adhered to the Indonesian Standards (SNI) guidelines. This mixture consists of one normal mortar with 0% RHA and three mixtures of RHA-Z0, RHA-Z1, RHA-Z2, and RHA-Z3 with compositions of 10% fly ash substitution. The mixed proportion of 1 m^3 of self-compaction concrete is shown in Table 2.

Table 2
Mix proportions of 1 m^3 SCC

Sample	OPC (kg)	RHA (kg)	FA (kg)	CA (kg)	Water (kg)	Superplasticizer
Normal	591	0	677	875	205	1%
RHA-Z0	531,9	59,1	677	875	205	1%
RHA-Z1	531,9	59,1	677	875	205	1%
RHA-Z2	531,9	59,1	677	875	205	1%
RHA-Z3	531,9	59,1	677	875	205	1%

2.3 Testing of Specimens

The tests carried out in this study include fresh concrete testing and hardened concrete testing. The flowability of fresh concrete of SCC was measured by slump flow test, L-shape box test, and V-funnel test. The hardened concrete testing included compressive strength, split tensile strength, and modulus of elasticity.

2.3.1 Fresh test

The characteristics of SCC are related to its workability. These characteristics are filling ability, passing ability, and viscosity [45]. Fillingability is the ability of fresh concrete to flow and fill formwork spaces. It is also called flowability. Fillingability can be determined by conducting a slump flow test using a slump cone and a flat board about 1m x 1m. The testing equipment can be seen in Figure 6(a).

Passingability is the ability of concrete to flow through tight space structures, such as spaces between reinforcing steel, without segregation or blocking. Passingability testing can be conducted in three ways, namely using L-box (passing ratio), U-box (height difference), and J-ring (in the form of flow value). The L-box tool in this study can be seen in Figure 6(b). Viscosity is the resistance to SCC flow after it starts. The output of this test is flow time. The test that is often used is the V-funnel test. Figure 6(c) shows the V-funnel test tool's image.

(a) (b) (c)

Fig. 6. Flowability and workability test (a) Testing equipment (b) L-box (c) V-funnel

2.3.2 Hardened testing

Compressive strength testing of concrete is conducted using a machine that accommodates a test specimen with a diameter of 30 cm and a depth of 30 cm. This procedure adheres to the ASTM C-39 standards for assessment [46].

$$fc' = \frac{P}{A} \tag{1}$$

where $f'c$ is compressive strength (N/mm^2), P is maximum applied load (N) and A is specimen cross-sectional area (mm^2). A compressive strength device is used to determine the concrete's splitting tensile strength, testing a cylindrical sample with dimensions of 30 cm in both diameter and depth, as per the ASTM 496.96 standards [47].

$$f_T = \frac{2P}{\pi LD} \tag{2}$$

where f_T is splitting tensile strength (N/mm^2), P is maximum applied load (N), L is average specimen length(mm) and D is specimen diameter (mm).

The modulus of elasticity of concrete is the ratio of normal stress to the corresponding strain for compressive stresses below the proportional limit of concrete. The value of the elastic modulus of concrete can be obtained using Eq. (3), which is a standard test method for the modulus of elasticity in compression based on ASTM C-469 Standards [48]. Table 3 shows the hardened results of SCC.

$$E_S = \frac{(S_2 - S_1)}{(\varepsilon_2 - 0.00005)} \tag{3}$$

where:
E_S = Modulus of elasticity (N/mm^2)
S_2 = Stress corresponding to 40% of the ultimate load (N)
S_1 = Stress corresponding to a longitudinal strain of 0.00005
e_2 = Longitudinal strain produced by stress S_2

Table 3
Result of hardened testing of SCC with fineness levels of RHA

Samples	Compression strength (MPa)				Split tensile strength (MPa)	Modulus elasticity (MPa)
	7 days	14 days	21 days	28 days		
	Mean (Mpa) Standard deviation COV (%)				Mean (Mpa) Standard deviation COV (%)	Mean (Mpa) Standard deviation COV (%)
Normal	26.66	35.87	42.59	46.77	4.40	20809
	0.95	0.93	0.95	1.01	0.30	606.70
	3.58	2.58	2.24	2.17	6.82	2.92
RHA-Z0	29.53	37.12	43.46	48.92	4.41	22007
	1.13	0.95	0.53	1.04	0.28	991.51
	3.82	2.56	1.21	2.12	6.36	4.51
RHA-Z1	27.66	38.07	48.44	51.27	4.61	22965
	1.37	1.37	1.14	2.03	0.27	861.18
	4.97	3.59	2.36	3.97	5.83	3.75
RHA-Z2	30.00	43.12	50.67	54.15	5.32	23240.67
	1.80	1.63	1.20	1.05	0.20	961.65
	6.01	3.78	2.37	1.94	3.80	4.14
RHA-Z2	31.81	45.82	51.35	54.56	5.46	23676
	0.96	1.13	1.69	1.48	0.30	1631.39
	3.03	2.46	3.30	2.72	5.42	6.89

3. Results
3.1 Fresh State Properties

Fresh concrete qualified as SCC is tested by slump flow, L-shape box, and V-funnel test. The test results are shown in Table 4. The slump flow value is between 598 and 691 mm. Based on the test results, all mixtures are within the accepted range (600-800, EFNARC [45]). The results of testing fresh concrete with the L-box method are in the range of 0.82-0.91. In alignment with the SCC requirements, EFNARC sets forth that the values for all mixtures examined must be confined within the minimum and maximum boundaries of 0.8 and 1, respectively. The results obtained also revealed that the V-funnel time is in the range of 10-20 seconds. EFNARC [45] mentioned that the recommended flow time is 3-15 seconds. As per the test data, the time recorded on the V-funnel test for all concoctions, except for RHA-Z2 and RHA-Z3, adhered to the acceptable range.

Table 4
Fresh state properties of SCC mixtures with different fineness levels

Type of test	Normal	RHA-Z0	RHA-Z1	RHA-Z2	RHA-Z3	Range EFNARC 2005
Slump flow (mm)	691	682	665	617	598	600-800
L-box (h2/h1)	0.91	0.91	0.86	0.85	0.82	0.8-1
V-funnel (sec)	10	11.5	13	17	20	3-15

The study's results [1,49-51] showed that adding RHA reduced workability. The hydrophilic nature of RHA can influence workability, resulting in diminished productivity. The results show that mixtures using RHA have lower workingability. Rice husk ash absorbs a certain amount of water on the surface due to porous RHA particles with macro size and mesopores in and on the surface, producing a huge specific surface area, thus causing the slump flow to decrease [24,52]. Other researchers also mentioned that the decrease in slump flow was caused by high reactivity due to several RHAs in the mixture [53-56]. The slump flow of the concrete ranged between 598 and 691mm, suggesting that the fineness of the RHA influences its capacity to fill via flow dispersion. Figure 7 illustrates a reduction in slump flow diameter as the fineness level of RHA decreases. The slump flow diminished with the increased fineness of the rice husk ash content, signifying a decrease in the viscosity of the concrete mixture.

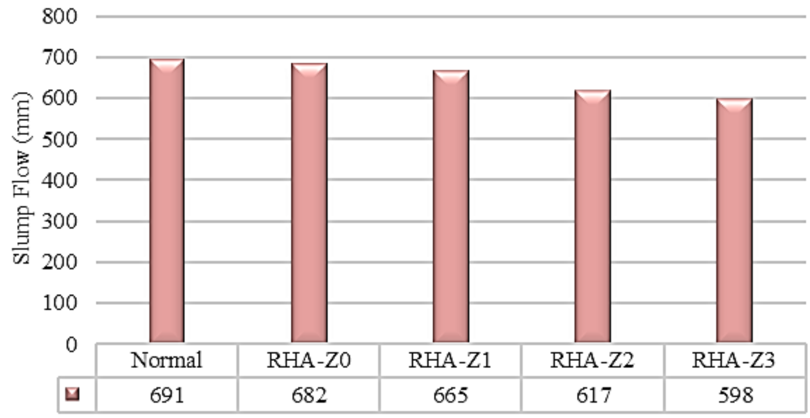


Fig. 7. Slump flow result chart

Based on the EFNARC standard [45], the ratio value for the SCC criteria is 0,8-1,0. Figure 8 illustrates a decrease in the ratio value of the L-shape box test as the fineness of the RHA increases. The L-shape box test of the concrete varied within the range of 0.82 to 0.92, indicating that the RHA's fineness level affects the concrete's passability. Furthermore, the L-shape box ratio value obtained from testing normal concrete was better than that of the concrete mixed with rice husk ash. The effect of the RHA's level of fineness in each zone produces different values. The graph shows that RHA-Z0 has the most optimal ratio values between subtlety zones 1, 2, and 3. The RHA-Z3 had the highest level of fineness with the smallest ratio value (0.82). Therefore, it can be concluded that the fineness level of rice husk ash in the SCC concrete mixture can affect the concrete's ability to pass through gaps in the reinforcement.

The fastest V-funnel test was conducted on concrete with no rice husk ash mixture for 10 seconds. Meanwhile, the longest lasted for 20 seconds with a fineness level of RHA-Z3. The amount of time generated during V-funnel testing affects the ability of fresh concrete SCC to flow into spaces. Figure 9 illustrates the swiftest V-funnel test duration recorded for standard concrete compared to rice husk ash mixtures. In addition, the effect of the fineness of rice husk ash in each zone produced different values. The graph shows that RHA-Z0 had the fastest time among the other zones 1, 2, and 3 for RHA-Z1, RHA-Z2, and RHA-Z3, respectively. The V-funnel test, based on the fineness level of the RHA, shows that increasing the RHA's fineness leads to a proportional increase in the V-funnel time.

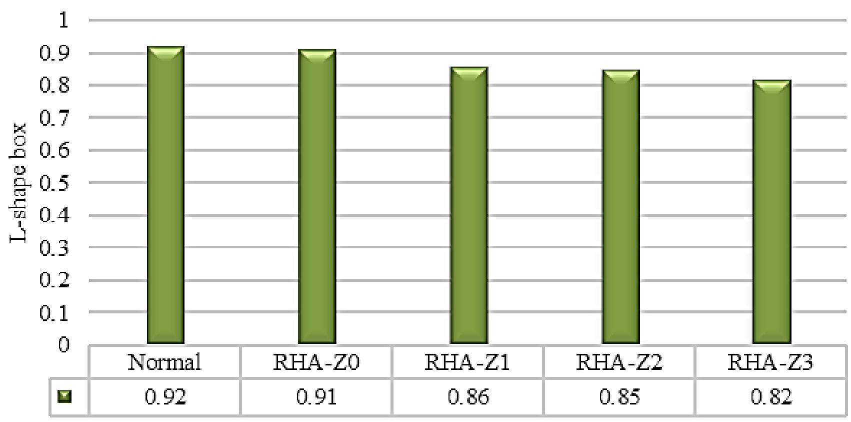


Fig. 8. L-shape box result chart

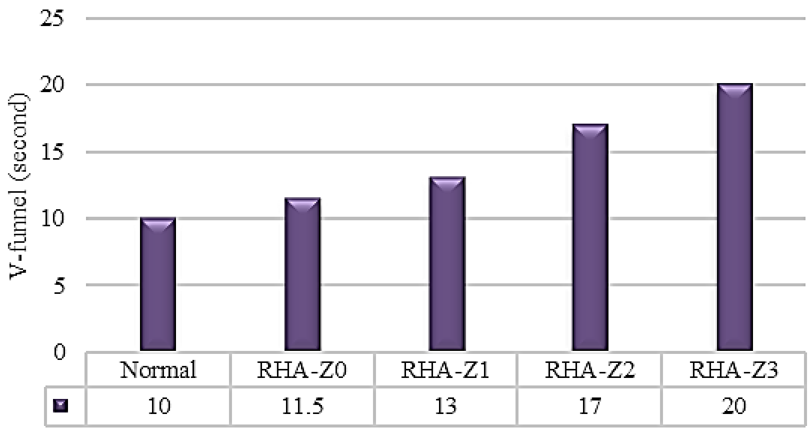


Fig. 9. V-funnel result chart

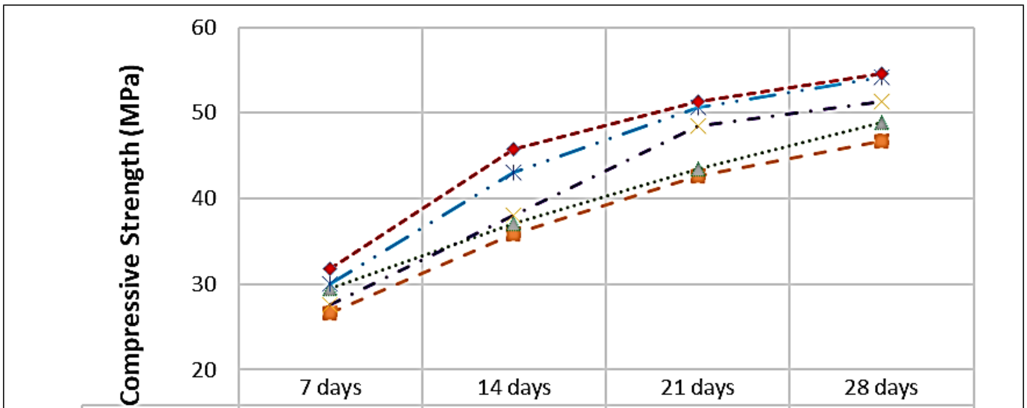
Recent tests on the fresh properties revealed that incorporating rice husk ash (RHA) of varying fineness into self-compacting concrete (SCC) reduced workability. This reduction is likely attributable to the finer RHA particles when compared with cement, which can impede the mixture's flowability. The data revealed growth in RHA content and surface area, coupled with an increase in the binding volume fraction, resulting in an amplified surface area that allows for more water to be absorbed, thus diminishing the amount of free water in the mortar [4,3,14,38]. Such observation proves that the higher surface area of the finer RHA also causes the amount of water to absorb more, so the amount of free water in the mortar also decreases. Utilising the identical superplasticiser, the observed reduction in workability is reflected across all fresh concrete tests, indicating a further diminution of workability. The results of this test reveal that the lowest workability is achieved by SCC mixtures using the farthest RHA, which shows the highest fineness.

The RHA filtration process that produces RHA types with various zones results in an increased level of fineness. Reference [57,58] suggests that the refined texture of RHA is associated with a higher specific surface area, crucial for pozzolanic activity and leading to increased reactivity, aligning with the factors contributing to the diminished workability of SCC.

The findings indicate that a 10% RHA inclusion yields fresh test outcomes that align closely with the data reported in [45], demonstrating consistency in freshness characteristics like V-funnel flow time, L-box, U-box, and slump flow diameter measurements with the standards set out by EFNARC [45]. Memon *et al.,* [6] observed that the slump flow diameters for all mixtures, except for those containing 10% RHA and 3.5% superplasticiser (595 mm), fell within the EFNARC guidelines [45]. In addition, Safiuddin *et al.,* [59] stated that all mixtures showed good workability according to EFNARC-compliant grades. Therefore, these findings indicate that the particle size of RHA reduces workability, resulting in a decreased slump flow value across all samples. L-box values with smaller ratios and the time it takes to flow with the V-Funnel method are longer.

3.2 Compressive Strength

The SCC's compressive strength results are shown in Figure 10. The results at each variation of 7, 14, 21, and 28 days were analysed to observe the effect of the rice husk ash's fineness on the concrete. Zone fineness levels are Z0, Z1, Z2, and Z3. Therefore, the total variation of the SCC used was 4, including normal concrete with no rice husk ash mixture. The results of the compressive strength test at 7, 14, 21, and 28 days are shown in Figure 10.



	7 days	14 days	21 days	28 days
Normal	26.66	35.87	42.59	46.77
RHA-Z0	29.53	37.12	43.46	48.92
RHA-Z1	27.66	38.07	48.44	51.27
RHA-Z2	30.00	43.12	50.67	54.15
RHA-Z3	31.81	45.82	51.35	54.56

Fig. 10. Compressive strength of SCC

Subsequently, the compressive strength of the SCC incorporating 10% Rice Husk Ash (RHA) by total mixture volume exhibited superior and enhanced performance compared to that of conventional SCC. Figure 10 shows that RHA-Z3 had the highest compressive strength (54.55 MPa) compared to the other fineness zones 0, 1, and 2. Hence, it can be concluded that the fineness level of the rice husk ash in the SCC concrete mixtures can affect the concrete's compressive strength. These results also show the same trend as the research conducted by Firdaus *et al.,* [34]. The outcomes substantiated that the reduced particle size in the cementitious matrix results from the chemical influence of RHA, leading to improved mechanical properties of SCC [38].

Figure 11 illustrates the variation in compressive strength relative to test age for each level of RHA fineness. All variations in the level of RHA fineness show the same tendency to increase. The graph shows that the normal SCC and the RHA-Z3 have the lowest and the highest compressive strength, respectively. Figure 11 compares the average compressive strength of SCC at 28 days of age. The mixture with the highest level of fineness produces the highest SCC compressive strength, 54.56 MPa. Compared to the standard SCC mixture, which registered at 46.77, the enhanced SCC mix exhibited a 16.6% increase in performance. Mixtures with RHA with each level of fineness indicate increased compressive strength. For each category of SCC possessing a greater degree of fineness, the compressive strength for RHA-Z1, RHA-Z2, and RHA-Z3 exhibited increments of 4.6%, 9.6%, 15.8%, and 16.6%, respectively.

The compressive strength demonstrates the impact of enhancing the fineness of RHA, resulting in a marked improvement in the compressive strength of the SCC. Such observation also indicates that the micro-filling capability of RHA is more refined, leading to an escalation in pozzolanic activity. RHA reacts with the cement hydration by-product (calcium hydroxide) and produces additional calcium silicate hydrate (C-S-H). The refinement of RHA leads to a decrease in concrete porosity due to the incorporation of CSH, which enhances the microstructure within the interface transition zone and bolsters the compressive strength of the paste matrix. Using RHA of 10% with a strength of 46.77-54.56 is considered quite effective in producing compressive strength. Several investigations employing RHA substances in place of a portion of the cement have also yielded remarkably similar strengths.

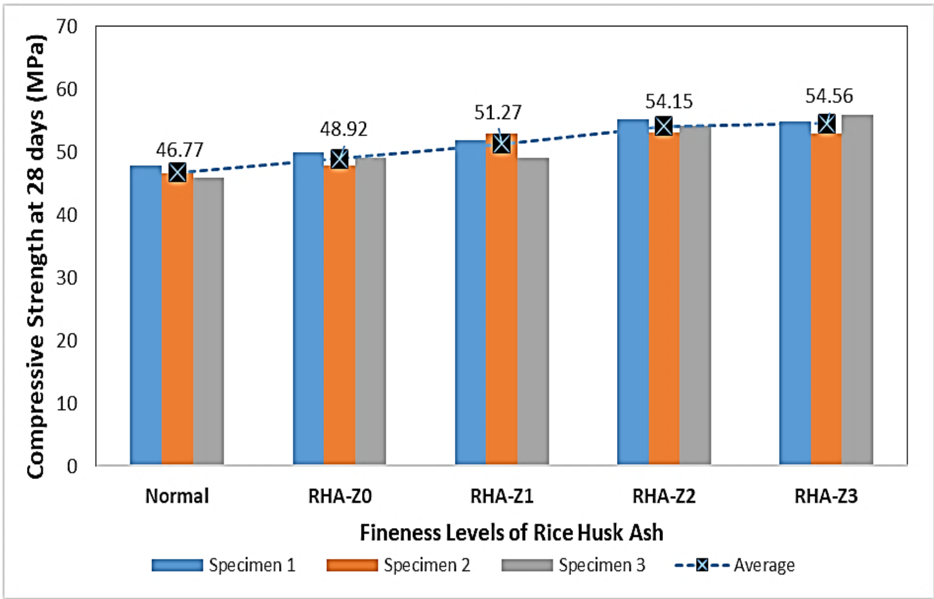


Fig. 11. Compressive strength of SCC at 28 days

Chopra *et al.,* [53] observed that the compressive strength of RHA-based SCCs (0%, 10%, 15%, and 20%) with a consistent water-to-binder ratio of 0.41 ranged from 36.7 to 41.2 MPa at 28 days, increasing to 39.6–46.4 MPa at 56 days. Rahman *et al.,* [60] investigated the compressive strength of SCC mixtures containing RHA (0%, 20%, 30%, and 40%) at 3, 7, and 28 days. As RHA content rises, there is a decline in compressive strength at both 3 and 28 days; however, at 7 days, an enhancement in compressive strength is observed with RHA percentages up to a 20% substitution before it diminishes. Safiuddin *et al.,* [61] demonstrated that incorporating RHA can enhance compressive strength for up to 56 days. At 28 days, the compressive strength is between 42.7 and 94.1 MPa. Maximum compressive strength is observed for an RHA content of 30% with a water-to-binder ratio of 0.35. Juma *et al.,* [62] noted that incorporating a blend of RHA (0-10%) and sugarcane bagasse ash, separately or in combination, can enhance compressive strength by as much as 77.2% over 28 days.

3.3 Split Tensile Strength

The split tensile strength test was conducted after 28 days on the normal concrete and the SCC concrete with varying levels of rice husk ash fineness at each zone. The results of the SCC split tensile strength test are shown in Figure 12. The normal SCC's split tensile strength obtained was lower than that of the SCC with rice husk ash. Based on the graph, the optimal split tensile strength was found at RHA-Z3, 5.46 MPa. Meanwhile, RHA-Z0 produced the lowest tensile strength of 4.41 MPa. Thus, the fineness level of the rice husk ash affected the split tensile strength of the SCC.

Split tensile strength is one of the mechanical characteristics of concrete that is essential for the design of concrete structural elements. One way to determine concrete's tensile strength is to use split tensile strength, tested at 28 days. The results of the split tensile strength test performed on normal SCC test specimens and SCCs with RHA mixtures with a degree of fineness are shown in Figure 12. The split tensile strength increases with the increasing fineness level of RHA. The maximum split tensile strength was achieved with RHA-Z3, which possessed the greatest fineness. SCCs with zones 0, 1, 2, and 3 caused split tensile strength to increase by 0.3%, 4.82%, 20.9%, and 24.1%, respectively, compared to normal SCCs. Highly reactive and linked to compressive strength, RHA particles interact with calcium hydroxide, which enhances the formation of CSH, thereby creating a tighter microstructure in SCCs. The finer the RHA particles, the greater their reactivity in SCCs, thus becoming the primary factor for the initial strength enhancement observed in SCC mixtures. The finer the RHA utilised, the greater the enhancement in tensile strength was demonstrated.

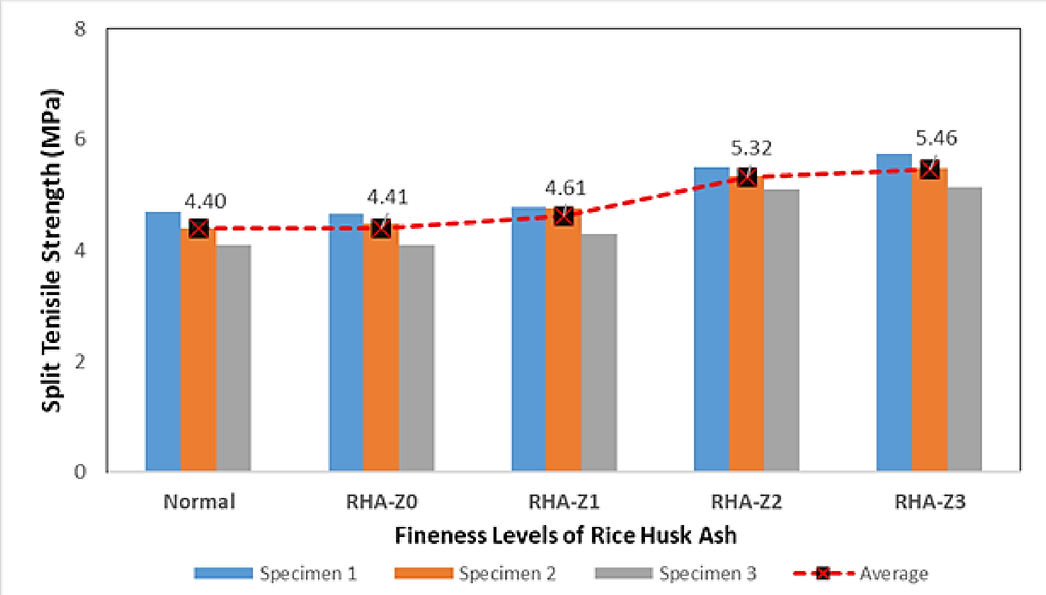


Fig. 12. Split tensile strength result of SCC

Chopra *et al.,* [53] reported that the split tensile strength of SCC incorporating 10% RHA at 7, 28, and 56 days ranged between 2.5-3.7 MPa, representing an enhancement of approximately 25%-37% when compared to a mixture devoid of RHA, which exhibited a tensile strength of about 2-2.8 MPa. Rahman *et al.,* [60] investigated the tensile strength of SCC separations that incorporated different RHA replacement rates of 0%, 20%, 30%, and 40%. The results showed that integrating 20% rice husk ash (RHA) achieved a comparable strength value to a specimen with 0% RHA, while an increase in the tensile strength of the RHA mixture led to a reduction in overall strength. Khadiry *et al.,* [63] reported that after a curing period of 28 days, the compressive strength of Self-Compacting Concretes (SCCs) with Rice Husk Ash (RHA) exceeded that of SCCs with shell lime powder by 0.8%.

3.4 Modulus Elasticity

The modulus of elasticity test for SCC was conducted after 28 days. This test determined the concrete's resistance level to elastic deformation when subjected to force. The results of the SCC modulus of elasticity test are shown in Figure 13. The modulus of elasticity value is obtained based on testing and Eq. (3) as specified in ASTM C469. S1 is the voltage corresponding to the longitudinal strain of e_1, S2 is the voltage corresponding to 40% of the ultimate load, e_1 is equal to 50 millionths, and e_2 is the longitudinal strain produced by the voltage S2. The modulus of elasticity of all the specimens is shown in Figure 13. The modulus of elasticity increases with the RHA fineness level. The highest modulus of elasticity was obtained for RHA-Z3, the specimen with the highest level of fineness. The modulus of elasticity in SCCs for zones 0, 1, 2, and 3 is observed to rise by 5.8%, 10.4%, 11.7%, and 13.8%, respectively, when compared with standard SCC.

This study's results show an identical trend based on research conducted using the RHA in SCC. Zareei *et al.,* [28] achieved an enhanced modulus of elasticity by utilising RHA materials. An increase in the modulus of elasticity occurs up to a percentage of 20% RHA. An increase in the higher RHA reduces the modulus of elasticity in the SCC specimen. In addition, the elastic modulus of normal vibrating concrete is 9-17% higher than that of SCC specimens.

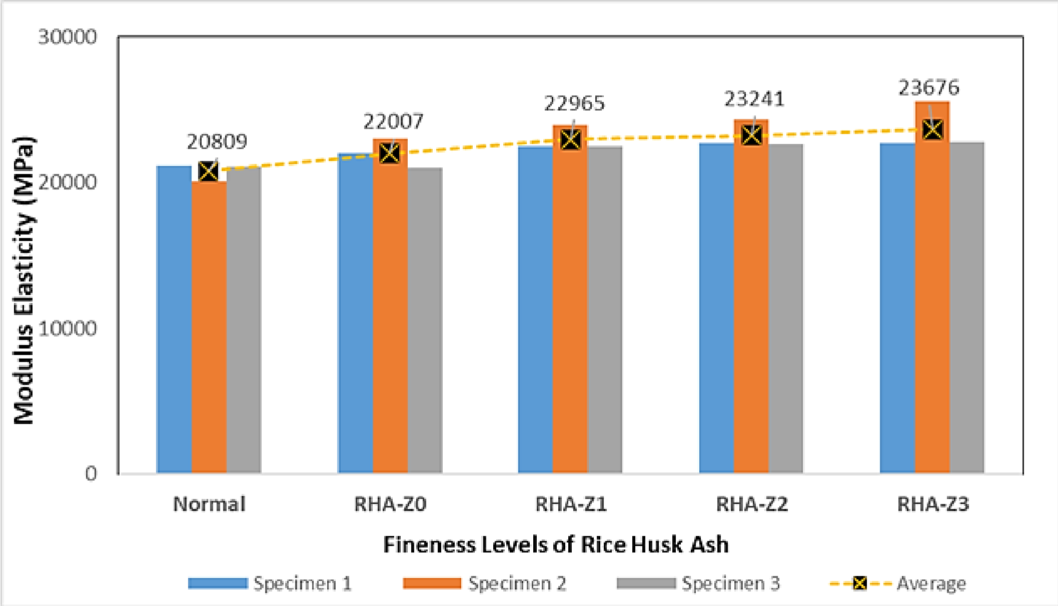


Fig. 13. Modulus of elasticity result of SCC

3.5 Normalised Strength and Modulus Elasticity

The normalised compressive, split tensile strength and modulus elasticity were calculated by dividing the value by the normal of each strength and modulus elasticity. Table 5 and Figure 14 illustrate that both the strength of the concrete and its modulus of elasticity are enhanced as the fineness levels of RHA (Z1-Z3) increase. The fineness of RHA demonstrates a marked increase in split tensile strength, which is significantly more pronounced when compared to the improvements observed in compressive strength and modulus of elasticity. The results show that the SCC with RHA from the higher fineness zone gives better strength and modulus elasticity.

Table 5
Normalised strength and modulus of elasticity

Code	Compressive strength	Split tensile strength	Modulus of elasticity
Normal	1	1	1
RHA-Z0	1.05	1.00	1.06
RHA-Z1	1.10	1.05	1.10
RHA-Z2	1.16	1.21	1.12
RHA-Z3	1.17	1.24	1.14

Based on Figure 14, the modulus of elasticity increases with the same trend as the SCC compressive strength. This value indicates a linear function between the compressive strength and the modulus of elasticity of SCC. Meanwhile, the ratio of split tensile strength significantly increases at the higher fineness level of RHA.

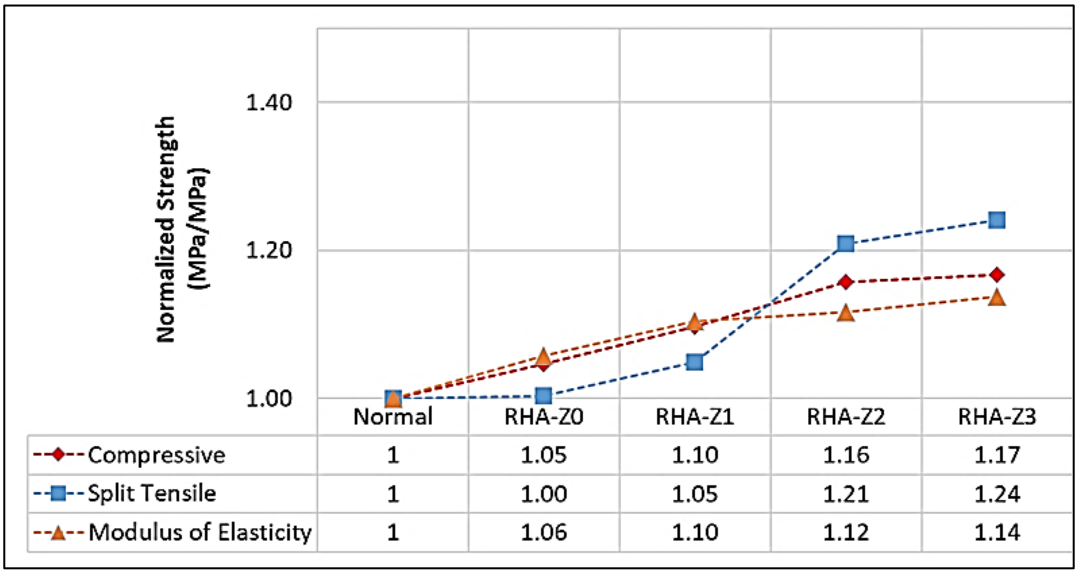


Fig. 14. Normalised strength of SCC

4. Conclusions

Based on this study, the following conclusions could be drawn:

i. The fineness of the RHA increasingly affects the flowability and workability of the SCC mixture.
ii. The finer the rice husk ash used, the stronger the compressive strength produced by the SCC.
iii. The highest compressive strength, at 54,556 MPa, was recorded in the RHA-Z3 zone, whereas the minimum, at 48,921 MPa, was observed in the RHA-Z0 area.
iv. The split tensile strength and compressive strength were proportional. The maximum (5,46 MPa) and minimum (4,40 MPa) split tensile strengths were measured at RHA-Z3 and RHA-Z0, respectively.
v. The modulus of elasticity value, achieved using the finest rice husk ash on RHA-Z3, was optimal at 23,676 MPa.

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