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EFFECT OF RICE HUSK ASH AND STEEL FIBERS ON SELF-COMPACTING CONCRETE PROPERTIES

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ABSTRACT: Steel fiber waste is in the form of ductile and tough fibers, making it suitable for increasing the tensile strength and flexural strength of Self-Compacting Concrete (SCC). The use of rice husk ash (RHA) as an additive in SCC concrete is expected to improve the quality of SCC concrete while reducing the use of Portland cement as an adhesive. This study aims to examine the tensile strength and flexural performance of SCC concrete beams with rice husk ash added and steel wire scrap waste. The research was conducted by making a concrete beam specimen to examine the flexural performance, and a concrete cylinder test object to examine the tensile strength and compressive strength of concrete. The specimens were made with 4 variations; the variations used are distinguished based on the percentage of RHA and steel fiber waste. The results showed that the use of RHA in SCC concrete can increase the compressive strength of concrete. It is proven that concrete with RHA added increases compressive strength by 8.45%. The use of steel fiber waste in SCC RHA concrete can increase the tensile strength of concrete by 28.15%, increasing the flexural strength by 9.3%. So, it can be concluded that the addition of RHA and steel fiber waste to the SCC mixture can increase the strength of the SCC.

Keywords: Tensile Strength, Flexural Performance, Self-Compacting Concrete, Rice Husk Ash, Steel Fiber

1. INTRODUCTION

The current development of the construction industry requires infrastructure and buildings with large and complex loads. Usually, concrete structures with large and complex loads require tight reinforcement, making it difficult for concrete compaction [1]. As a result, the concrete becomes hollow and porous, which causes the strength and durability of the concrete to decrease. One way to overcome this is to use self-compacting concrete known as self-compacting concrete (SCC). SCC is a concrete that can flow to fill the formwork and tight reinforcement gaps without segregation and the concrete remains homogeneous [2,3].

The need for concrete in earthquake-prone areas is concrete with high ductility, workability, high strength, ease to flow without compaction, and durability, and the structure must be designed with special details and using ductile materials [4,5]. This is so that when an earthquake occurs, the structure can behave ductility, reducing the loss of life due to the collapse of the structure. One way to increase the ductility of concrete is to add fiber to the concrete mix. The presence of fibers in the concrete mixture can inhibit cracking, increase the ductility of concrete, and can increase the tensile strength of concrete [6]. One type of fiber that can be used is steel wire scrap. Waste pieces of steel wire are in the form of 1-2 mm diameter fibers with an average length of 10 cm and are ductile.

The results of research by T. Suresh Babu [7] who added glass fiber to concrete can increase the compressive strength, flexural strength, modulus of elasticity, and ductility of concrete. Similar studies using steel fibers in concrete slabs can also increase the ductility of concrete and have higher energy dissipation than concrete slabs without steel fibers [8]. The use of steel fibers in concrete by 3% of the weight of cement can increase the compressive strength, flexural strength, and split tensile strength of concrete [9]. The use of steel fibers with an aspect ratio of 45-65 can increase compressive strength, tensile strength, strength to fatigue, and strength to impact [10]. Another similar study is that the use of steel fibers of 1.5% of the volume of concrete can increase the tensile strength and flexural strength of concrete, but the workability of concrete decreases [11].

Besides the addition of fiber to the concrete mixture, the increase in concrete strength can also be produced from the addition of rice husk ash (RHA) to the concrete mixture. The use of RHA as a material for partial replacement of cement in concrete shows that the use of rice husk ash by 15% in place of cement can increase the compressive strength of concrete and the mechanical strength of concrete [12-15]. The use of rice husk ash as an added material to concrete soaked in seawater can increase the tensile strength and MOR of concrete [16]. It is necessary to research the performance of SCC concrete using waste fiber from steel wire pieces and rice husk ash as a partial replacement for cement.

2. RESEARCH SIGNIFICANCE

This study discusses the use of steel wire waste as steel fiber in concrete mixtures and the use of RHA as a substitute for cement in concrete. The use of RHA is expected to reduce CO2 emissions caused by cement production, which hurts the environment. The utilization of steel wire waste is also expected to reduce steel wire waste from construction work that is not utilized. Hopefully, this research can be useful for the public, academia, and industry as additional insight and reference in developing science and material research. Besides that, more previous studies have given results on the effect of adding RHA or steel fiber alone. So, with this research it is expected to provide information related to the effect of adding RHA and steel fiber simultaneously.

3. METHOD

The test object to examine the flexural performance of the concrete beam is in the form of a concrete block measuring 100 mm x 100 mm x 1000 mm, while to test the compressive strength and tensile strength, a concrete cylindrical specimen with a diameter of 15 cm and a height of 30 cm is used. SCC concrete specimens were made with a Water Cement Factor of 0.30. The specimens were made with 4 variations, namely without fiber and without RHA, 0% fiber 5% RHA, 0.5% fiber 5% RHA, and 1% fiber 5% RHA. The percentage of fiber is calculated against the overall weight of the concrete, while the RHA weight is calculated based on the weight of the Portland cement used.

The percentage of 5% RHA is based on the results of Amalia's study that the use of RHA of 5% by weight of cement in SCC concrete can increase the workability of concrete and the compressive strength of concrete [17]. The percentage of steel fiber used is based on the results of previous studies that the use of steel fiber up to 1.5% in concrete can increase the tensile strength and the flexural strength of concrete [11].

Testing of the flexural performance of concrete beams, tensile strength, and compressive strength was carried out after the specimens were 28 days old and were treated by covering them with wet burlap sacks. The materials used in this study were Portland Composite Cement (PCC) adhesive, superplasticizer admixture, fine aggregate from natural sand, coarse aggregate from natural crushed stone, steel wire scrap waste, and rice husk ash from red brick burning waste.

In this study, the filling ability of SCC concrete was tested with the slump flow test T50cm tool, while the passing ability property was tested with the L-Box tool.

Rice husk ash used in this study has a fineness rate of 97% passing sieve number 200 (sieve diameter 0.075 mm). The fiber used is in the form of straight-cut braided wire waste, with a diameter of 0.80 mm and a length of ± 50 mm. The ratio of length (L) to diameter (D) or commonly abbreviated as L/D is 62.5. The shape of the fiber is straight and stiff, and the value of the fiber ratio (L/D) is less than 100; it does not cause the fresh concrete to clot.

The aggregate used in this study is the material that meets the requirements for concrete mixtures. Sand meets the requirements for grading zone 2 based on BS 882:1973 and coarse aggregate meets the requirements for a maximum diameter of 10 mm according to ASTM C 33-78. The material properties of aggregate can be seen in Table 1.

Table 1 Material properties of aggregate

Material Properties	Sand	Coarse Aggregate
Specific Gravity	2.57	2.54
Specific Gravity (SSD)	2.59	2.58
Apparent Specific Gravity	2.61	2.65
Loose Fill Weight (kg/m3)	1430.50	1289.66
Solid Fill Weight (kg/m3)	1617.37	1444.19
Water Absorption (%)	0.59	1.69
Water Content (%)	3.86%	2.45%
FM (%)	2.45	6.01
Sieve Analysis	Sand Zone 2(BS)	Max Aggregate Diameter 10 mm
Mud Content (%)	2.8%	0.82%

The chemical compositions of cement and RHA are shown in Table 2.

Table 2 Chemical compositions of cement and RHA

Item	Cement (%)	RHA (%)
SiO2	22.00	90.00
Al2O3	5.00	0.30
Fe2O3	3.00	0.40
MgO	2.00	0.80
SO3	2.00	1.00
Na2O	0.40	0.10
K2O	0.70	3.00

4. RESULT AND DISCUSSION

4.1 Fresh SCC Concrete Properties

The use of waste fiber from steel wire pieces in the SCC concrete mixture causes the fluidity of the SCC concrete to decrease (Fig. 1). This can be seen from the time it takes for the concrete flow to reach a diameter of 50 cm the longer it takes. This condition occurs because the addition of fiber in the mortar makes the flow of concrete obstructed. The higher the percentage of fiber added to the SCC concrete, the lower the filing ability of the concrete [18]. However, the use of waste fiber from steel wire pieces is up to 1%, and the filling ability of the concrete still meets the requirements set by EFNARC, which is 2.00 - 5.00 seconds (Table 3).

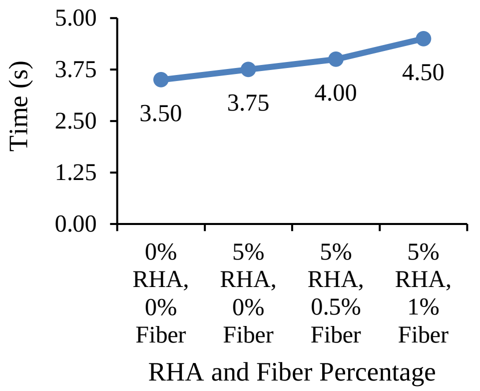

Fig.1 Filling ability concrete SCC RHA fiber waste steel wire with slump flow test T50cm

Table 3 Test results of slump flow test T50 SCC concrete with RHA and waste fiber steel wire

Fiber and RHA Percentage	Time (s)	Requirement (s)
0% RHA, 0% Fiber	3.50	2.00 – 5.00
5% RHA, 0% Fiber	3.75	
5% RHA, 0.5% Fiber	4.00	
5% RHA, 1% Fiber	4.50	

In the Slump Flow T50cm test, the homogeneity of the concrete is also seen. The addition of steel wire fibers to SCC concrete does not cause segregation and bleeding in fresh concrete. The mixture can be mixed evenly and homogeneously. In new concrete without fiber and RHA, the concrete experiences bleeding and segregation. The use of RHA in SCC concrete can improve workability while maintaining the homogeneity of the concrete. The content of silica and the fineness of RHA can help improve performance in fresh concrete conditions. Fig. 2 presents the slump flow test of SCC.

Fig. 2 Slump flow test of SCC

SCC concrete, which has a good passing ability, can pass through tight reinforcement gaps without segregation. The results of the research on SCC concrete using waste fiber from steel wire pieces resulted in lower passing ability and segregation resistance values compared to SCC concrete without waste. This condition can be seen from the h2/h1 value of the L-Box test results that have decreased (Fig. 3). Fig. 4 presents the L-Box test of SCC.

The ability of SCC concrete with steel wire cut fibers to pass through tight reinforcement gaps is lower than that of concrete without fiber. This happens because the pieces of wire impede the flow of concrete, especially if the position of the fibers is transverse, so the flow rate of SCC concrete is hampered. However, all concrete mixes for all variations meet the requirements of concrete as SCC concrete as in the EFNARC provisions which require h2/h1 values of 0.80 – 1.00 (Table 4).

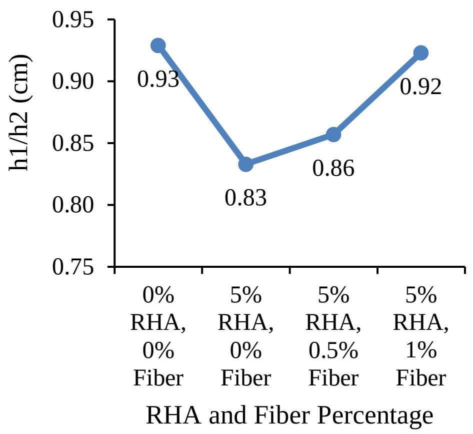

Fig.3 Passing ability concrete SCC RHA fiber waste steel wire with L box

Table 4 Passing Ability Test Results with L Box SCC concrete with RHA and waste fiber steel wire

Fiber and RHA Percentage	h2 (cm)	h1 (cm)	h2/h1	Requirement
0% RHA, 0% Fiber	6.50	7.00	0.93	
5% RHA, 0% Fiber	5.00	6.00	0.83	
5% RHA, 0.5% Fiber	6.00	7.00	0.86	0.80 - 1.00
5% RHA, 1% Fiber	6.00	6.50	0.93	

Fig.4 L-Box test of SCC

4.2 Performance of SCC RHA Beams and Concrete Waste Steel Fiber

4.2.1 Compressive strength of concrete

From Fig. 5, the use of RHA in SCC concrete can increase the compressive strength of concrete. This is proven, in SCC concrete that uses RHA produces a higher compressive strength than SCC concrete without RHA. The use of RHA in SCC concrete makes the concrete more workable, easy to pour, easy to flow, and easy to self-compact to produce denser concrete. The use of RHA in SCC concrete can increase the compressive strength of concrete by 7.04% compared to SCC concrete without RHA.

From Fig. 5 and Table 5, the use of waste fiber from steel wire pieces can also increase the compressive strength of concrete at the age of 28 days. SCC concrete with 0.5% fiber content increased by 8.45%, and SCC concrete with 1% fiber content increased by 7.51%. The greatest increase in compressive strength occurred in concrete with a fiber content of 0.5%. The use of waste fiber from steel wire pieces can produce a concrete compressive strength of 43.60 MPa at a fiber content of 0.5%.

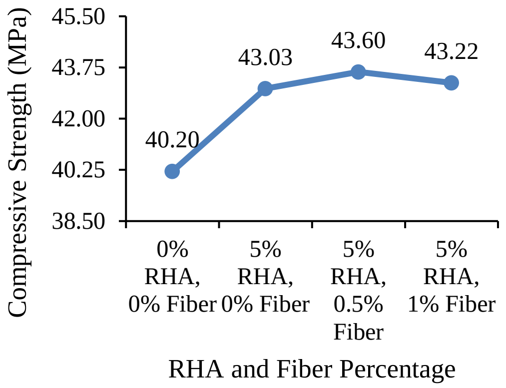

Fig.5 Compressive strength of SCC RHA concrete waste steel fiber

The compressive strength of SCC concrete is closely related to workability, where SCC concrete with a high slump flow value and high filling ability will make SCC concrete easy to flow to fill the voids between reinforcement and easy to self-solidify. In this study, SCC concrete with steel wire cut waste fibers at fiber content up to 0.5% had slump flow values and filling abilities tended to be the same as SCC concrete without fibers. In this study, the steel wire cut fibers used are straight, and ductile, with a fiber ratio of approximately 50. The fiber is straight and smooth and does not impede the flow of concrete so that the concrete can flow, solidify itself, and fill gaps between reinforcement well. Thus, the resulting concrete has a high density, which can be seen from the value of the density of the concrete. Some of these factors cause concrete with fiber content of steel wire pieces to have a higher compressive strength than concrete without fiber.

Table 5 Compressive strength test results of SCC concrete with RHA and waste fiber steel wire

Fiber and RHA Percentage	Compressive Strength (MPa)	% Increase of Compressive Strength
0% RHA, 0% Fiber	40.20	
5% RHA, 0% Fiber	43.03	7.04%
5% RHA, 0.5% Fiber	43.60	8.45%
5% RHA, 1% Fiber	43.22	7.51%

4.2.2 Flexural strength of concrete

The results showed that the use of waste fiber from steel wire pieces in SCC concrete could increase the flexural strength of the concrete beam (Fig. 6). The flexural strength of concrete beams increased by 9.3% in SCC concrete with a fiber content of 0.5%, and SCC concrete with a fiber content of 1% in flexural strength increased by 6.98%. The use of RHA in SCC concrete does not contribute significantly to the increase in flexural strength of concrete beams. This can be seen in the flexural strength of concrete without fiber and RHA and SCC concrete without fiber with an RHA content of 5% has the same flexural strength. Flexural strength is closely related to the tensile strength and compressive strength of concrete. The higher the compressive strength of concrete, the higher the flexural strength and tensile strength.

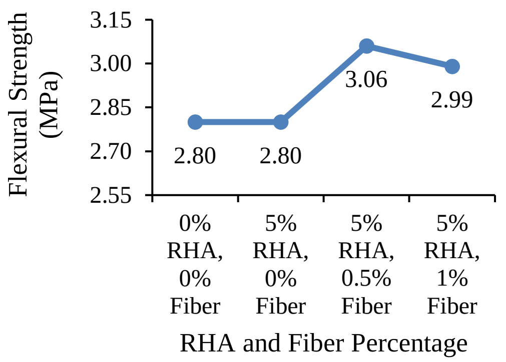

Fig.6 Flexural strength of concrete SCC RHA waste steel fiber

Table 6 Flexural strength test results of SCC concrete with RHA and waste fiber steel wire

Fiber and RHA Percentage	Average Flexural Strength (MPa)	f_r according to SNI (MPa)	f_r according to ACI (MPa)	% Increase in Flexural Strength
0% RHA, 0% Fiber	2.80	3.80	3.93	
5% RHA, 0% Fiber	2.80	3.94	4.07	0.00%
5% RHA, 0.5% Fiber	3.06	3.96	4.09	9.30%
5% RHA, 1% Fiber	2.99	3.94	4.08	6.98%

In the design of reinforced concrete structures, especially to calculate the reinforcement requirements, the flexural strength of concrete is neglected. Tensile areas that occur due to bending moments are completely restrained by reinforcement. Concrete is unable to withstand tension. However, the concrete must meet the flexural tensile strength requirements as stipulated in the provisions of SNI T-12-2004 "Indonesian National Standard: Design of Concrete Structures on Bridges" which is $0.6\sqrt{f_c'}$. Meanwhile, based on ACI 318 Code to calculate the flexural strength is $0.62\sqrt{f_c'}$. The results showed that all SCC concrete specimens did not meet the minimum flexural strength requirements of the SNI provisions and ACI 318 Code (Table 6).

4.2.3 Tensile strength of concrete

Concrete is a type of brittle material, which has high compressive strength, but low tensile strength. The tensile strength of concrete is usually in the range of 10%-15% of its compressive strength. Therefore, in the design of reinforced concrete structures, especially to calculate the need for reinforcement, the tensile strength of this concrete is neglected, and the concrete is considered unable to withstand tension. Concrete only serves to resist compression, while the tensile area is held by reinforcement. However, concrete must have a minimum tensile strength required by standards such as $0.33\sqrt{f_c'}$ based on SNI T-12-2004 and $0.56\sqrt{f_c'}$ based on ACI 318 Code.

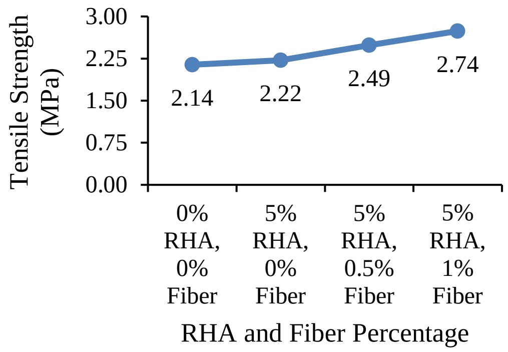

Fig.7 Tensile strength of SCC RHA concrete waste steel fiber

Although not considered, the tensile strength of concrete serves to inhibit cracks due to shrinkage. Concrete with high tensile strength is not easy to crack when shrinkage occurs.

The use of waste fiber from steel wire pieces in SCC concrete causes the tensile strength of concrete to increase. In concrete with 0% fiber content and 5% RHA content, the tensile strength of concrete increased by 3.64%, fiber content was 0.5%, RHA 5% concrete tensile strength increased by 16.56%, and fiber content of 1% RHA 5 % tensile strength of concrete increased by 28.15% (Fig. 7 and Table 7). It is also seen that the use of RHA in SCC concrete can improve the performance of SCC concrete. This is closely related to the workability of concrete, where concrete that uses RHA makes SCC concrete more workable so that the concrete is easy to mix, pour and flow easily to fill the voids in the concrete. This condition makes the concrete hard, which can have implications for the mechanical performance of the concrete.

The use of waste steel wire pieces can also increase the tensile strength of concrete. This can be seen from the tensile strength of concrete with the addition of fiber, which is higher than that of concrete without fiber. The greatest increase in tensile strength is in concrete with a fiber content of 1%. The greater the amount of concrete, the higher the tensile strength of the concrete. This means that the use of waste fiber from steel wire pieces in concrete can reduce brittleness and can inhibit premature cracking due to shrinkage in concrete.

Table 7 Split tensile strength test results of SCC concrete with RHA and waste fiber steel wire

Fiber and RHA Percentage	Average Split Tensile Strength (MPa)	f_t according to SNI (MPa)	f_t according to ACI (MPa)	% Increase in Split Tensile Strength
0% RHA, 0% Fiber	2.14	2.09	3.55	
5% RHA, 0% Fiber	2.22	2.16	3.67	3.64%
5% RHA, 0.5% Fiber	2.49	2.18	3.70	16.56%
5% RHA, 1% Fiber	2.74	2.17	3.68	28.15%

Adding fiber to the concrete causes the tensile load that arises to be resisted by the bonding force between the concrete and the fiber, resulting in a transition of tensile stress resistance from the concrete to the fiber. Fiber concrete will fail if the adhesive strength is exceeded and a pullout process occurs. The increase in the tensile strength of the fiber concrete comes from the cumulative resistance of the single fiber concrete bond to the tensile stress.

Based on the results of the compressive strength, flexural strength, and tensile strength tests, it was found that the higher the compressive strength of concrete with the addition of RHA and steel fiber, the higher the flexural strength and tensile strength. This is in line with the empirical relationship between compressive strength and flexural strength as well as tensile strength which is stated in the standard or code.

4.2.4 Density weight concrete

Density of concrete is strongly influenced by the density of the constituent materials. The density of concrete is the ratio between the weight and volume of concrete. The higher the concrete density value, the greater the weight of the structure. Fig. 8 are the results of testing the density of concrete. Fig.8 shows that the concrete with RHA and steel fiber has a higher density than the concrete without RHA and steel fiber. This occurs because concrete with RHA and steel fiber increases in weight with the addition of RHA and steel fiber. Based on the density of concrete, concrete is included in the category of normal concrete.

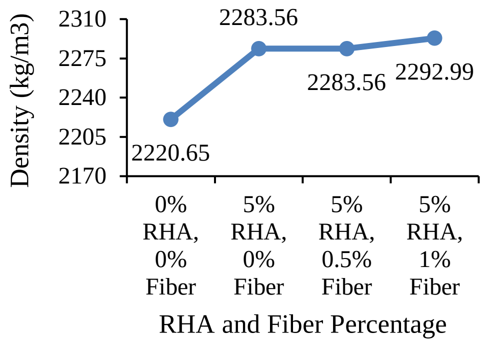

Fig.8 Density of SCC RHA concrete waste steel fiber

4.2.5 Concrete block and cylinder crack pattern

The pattern of the collapse of the beam in the flexural test and the pattern of the collapse of the concrete cylinder in the tensile strength test of the concrete are presented in Fig. 9 to 12. From the figure, the fiber less concrete beam shows a brittle failure, where when the maximum load occurs, the beam immediately collapses and breaks (Fig. 9). The collapse of the concrete cylinder in the split-tensile test also shows the same thing, whereas when the cylinder reaches its maximum load, the test object immediately splits (Fig. 10). Concrete with brittle properties is dangerous when used in structures in earthquake-prone areas, because in the event of a large earthquake the structure can immediately collapse without warning, causing many casualties.

The pattern of beam failure with steel wire scrap waste fibers shows a more ductile behavior. This can be seen from the failure pattern of the concrete beam, where when the concrete beam gets its maximum load, the beam does not immediately collapse or break, but retains its rigidity (Fig. 11). It is also shown by the crack pattern on the concrete cylinder in the split tensile strength test, where at maximum load the concrete cylinder cracks, but does not immediately split and collapse suddenly (Fig. 12).

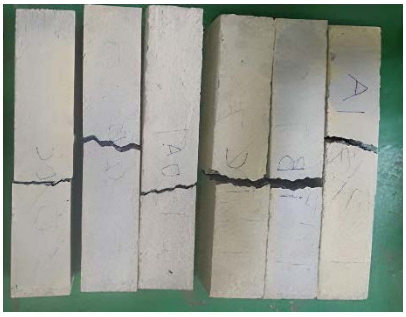

Fig.9 SCC RHA concrete beam crack pattern without fiber

Fig.10 SCC RHA concrete cylinder crack pattern without fiber

From the pattern of concrete cracks with the use of waste fibers from steel wire pieces, the use of fibers can increase the ductility of concrete [19]. Concrete with these properties is needed in structures in earthquake-prone areas. The use of ductile materials in areas with high earthquake risk will make the structure behave ductile when a large earthquake occurs so that the structure does not collapse immediately, and casualties can be minimized.

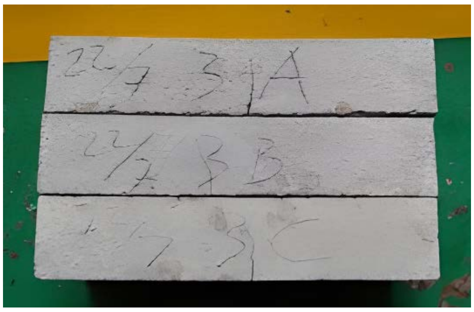

Fig.11 SCC RHA concrete beam crack pattern waste steel wire cut fiber

The addition of fiber to the concrete will make the concrete experience an increase in structural properties which are influenced by the orientation of fiber dispersion, adhesion to crack grooves, and irregular length of embedded fibers. The presence of fibers in the concrete prevents the concrete from breaking instantly. The use of fiber in the concrete mix causes the energy absorption mechanism to be carried out in stages starting from matrix cracking, bonding at the fiber/matrix surface, the action of the fibers binding around them, and the pulling process, pull-out, and fiber failure. This mechanism makes the fiber concrete still able to accept the load even though it has experienced the first crack which is described by the load-deflection curve. This load-deflection curve shows the amount of energy required by the concrete to reach a certain value of deflection.

Fig.12 SCC RHA concrete cylinder crack pattern waste fiber steel wire cut

5. CONCLUSION

It was found that SCC concrete without RHA and fiber and SCC concrete with RHA 5% replaced cement and waste fiber from steel wire pieces which resulted in the value of filling ability and passing ability of SCC concrete that met the requirements of SCC concrete according to EFNARC standards. The use of RHA by 5% of the weight of cement can increase the compressive strength and tensile strength of concrete. The flexural strength of concrete beams increased by 9.30% in SCC RHA concrete with a fiber content of 0.5%, and SCC concrete with a fiber content of 1% in flexural strength increased by 6.98%. The use of waste fiber from steel wire pieces in SCC concrete can increase the tensile strength of concrete. In concrete with fiber content 1% and RHA 5 % tensile strength of concrete increased by 28.15%. The use of waste fiber from steel wire pieces can increase the compressive strength of concrete. SCC concrete with 0.5% fiber content increased by 8.45%, and SCC concrete with 1% fiber content increased by 7.51%. The pattern of collapse of concrete beams and cylinders without steel scrap waste fibers shows brittle behavior or collapse. The use of steel wire cut waste fibers in concrete can change the brittle nature of concrete to become more ductile. Suggestions for further studies related to the bending and shear behavior of reinforced concrete beams with the addition of RHA and steel fiber.

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