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Compressive strength and microstructure of Self Compacting Concrete with nylon fiber substitution

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Abstract. Concrete is the most widely used construction material as building material because it has advantages such as easy workability, high compressive strength, and economical in terms of manufacturing and maintenance. However, there are some disadvantages obtained from the use of concrete, such as low tensile strength, easy cracking, and brittleness. Therefore, it is necessary to add fiber to the concrete to increase the ductility and use of SCC concrete to maintain workability after fiber substitution. The variation in the addition of nylon fiber is 0.5% and 1% to the weight of cement with a diameter of 0.35 mm and 0.65 mm, a length of 15 mm, and 20 mm. With the addition of 1% of 0.65 mm diameter and 15 mm length, the compressive strength of SCC concrete increased by 126%. The nylon fiber was also found to be evenly distributed in the concrete mixture and did not experience clumping and the volume weight of the concrete was reduced by 5-7% of the normal concrete. The SEM results show a clear interface between concrete and nylon fiber, and the slippery morphology of nylon fiber causes the bonding with concrete to become weak.

1. Introduction

At present, the development of science and technology is very rapid along with the adjustment of human needs that continue to increase. Development in the field of construction in the modern era shows significant developments, including in the construction of bridges, tunnels, housing, office buildings, hospitals, shopping centers, and so on. The most important part is the quality of concrete. Construction work for conventional concrete which has a large specific gravity and solidification or vibration of concrete is absolute to do. The goal of compaction is to reduce the amount of air trapped in fresh concrete, resulting in homogenous concrete with no voids. However, employing standard methods to obtain high-quality concrete typically entails more effort and cost.

Nylon fiber is a material with polymer fibers that have the properties of fibers, films, and plastics. Nylon is formed by a group associated with a repeat hydrocarbon unit of different lengths in a polymer having a specific gravity of 1.15. The main reason for adding fiber to concrete is to increase the energy absorption capacity of the mixed matrix, which means increasing concrete ductility. The addition of ductility also means the addition of concrete behavior to fatigue and impact. Nylon fibers are fibers produced with the fibers forming elements that are a long chain of synthetic polyamides, where less than 85% of amide bonds bind directly (- CO-NH -) two aliphatic groups. Polymers, namely linear polyamides, are referred to as nylon. There are two primary methods to produce nylon fo fiber applications. In the first method, molecules with an acid group (COOH) react with molecules containing amine groups (NH2), creates the material known as nylon, which is named based on the number of carbon atoms between two acid groups and two amine groups. A compound containing an amine on one side and an acid on the other side polymerized to form a chain with a repeating unit NH-[CH2] n-CO-) x. Since the early 1980s, synthetic micro or macro nylon fibres have been utilised to strengthen concrete shrinkage. In the case of micro, monofilament, and fibrillation forms, monofilament was used in lengths ranging from 13 to 38 mm, with a size of 20 mm being the most widely utilised. Because this fiber is so thin, the amount per weight (the amount of fiber) is in the range of millions per 1 kg of concrete. Concrete added with fiber in a certain volume percentage has more ductile properties compared to non-fiber concrete.

In the research of Suhana and Sugriana [1], the fiber used in the concrete mix was nylon. In general, monofilament is better known as nylon string. Monofilament nylon is a single-component product formed from a plastic that is melted into a braid through an iron mould. The strength of nylon monofilament varies depending on the size of the fiber diameter. In Gonzalo's study [2] in general, the increase in concrete strength caused by radiation fibers is 5, 10, 50, and 10 kGy depending on the percentage applied to the fiber and fiber content in the concrete. The fibers are combined with Portland cement, gravel, sand, and water in volumes of 1.5 percent, 2 percent, and 2.5 percent after their tensile strength is determined. The compressive strength of concrete is measured and compared to the findings of similar materials. The maximum compressive strength value is observed for 50 kGy fiber and the fiber volume of 2.0 % strength is 122.2 MPa, compared to 35 MPa for concrete without fiber. In the study of Aries Munandar [3], based on the test results obtained the average value of compressive strength of lightweight concrete gas with nylon fiber addition of 0%, 0.25%, 0.5%, 0.75%, 1% increase of 7.62%, 15.48%, 31.54%, 50.37% respectively, compared to lightweight concrete without fiber. With a fiber content of 1%, the splitting tensile strength raised to 46.04 %, and the modulus of elasticity rose to 63.18 %. SCC (self-compacting concrete) is defined by Tjaronge et al.[4] as concrete that, while still in the form of fresh concrete, can flow through the reinforcement criteria (passability) and fill the entire space in the mould in a solid manner without requiring manual compaction or mechanical vibration (criteria fillability).SCC is a plastic fresh concrete that easily flows because the weight itself fills the entire moulded concrete has properties for self-solidification, without the aid of a vibrator for compaction. A good SCC must remain homogeneous and cohesive, not in harmony, there is no blocking, and no bleeding. According to Okamura and Ouchi [5], one solution to obtain a durable concrete structure that is bound to the ability of construction work is the ability of the concrete itself to solidify, which is able to flow into the mould's nooks and crannies, due to its weight and no need any vibrators, with a composition of a mixture consisting of 50% coarse aggregate and 40% fine aggregate of the concrete volume and the water-cement ratio between 0.25 -0.40. Tjaronge, MW et al. [6] SCC is concrete which has high fluidity properties so that it can flow and fill spaces in the mould without compaction or only requires very little vibration to compact it. This can reduce the compaction time. When casting multi-story structures, the SCC can be lifted and moved through a pump to a higher level when there is a high amount of liquidity. One of the chemicals that affect the ability of SCC to flow is the superplasticizer. SCC has the advantages of being very thin, having a high slump for a long time (slump keeping admixture), not requiring manual compaction, being more homogeneous and stable, the compressive strength of concrete can be made for high / very high quality, being more impervious, having smaller porosity and shrinkage, being more durable, having better and smoother concrete surfaces, having less noise pollution, and requiring less labor. In Erniati's research [7] the SCC concrete microstructure analysis was performed by Scanning Electron Microscope (SEM) which was used to analyze the morphology of the SCC concrete and PCC cement. Also, the effect of seawater uses on SCC is analyzed.

This paper aims to analyze the compressive strength of SCC with the addition of nylon fibers, fiber distribution in concrete, and the microstructure of SCC concrete related to the morphology and interface between nylon fibers and mortar.

2. Experimental Program

2.1. Material

The materials used are Portland Composite Cement, aggregate, nylon monofilament (Figure 1), and superplasticizer. The source of aggregate material in this study is from Bili-Bili with aggregate characteristics that have an SSD density of 2.58 and modulus of fineness of 2.61 for fine aggregates whereas coarse aggregates have SSD density of 2.62 and modulus of smoothness of 6.00. The aggregate testing method refers to the Indonesian National Standard (SNI) and the American Society of Testing Materials (ASTM) [8].

Figure 1. Nylon monofilament and Compression test

2.2. Specimen design

The cylindrical specimens used had a diameter of 100 mm and a height of 200 mm. Nylon fibers with diameters of 0.35 mm and 0.65 mm, lengths of 15 mm and 20 mm, and cement weights of 0.5 % and 1 % were added to SCC specimens to produce various SCC results. All materials (coarse aggregate, cement, fine aggregate and nylon) were mixed under dry conditions for 1 minute, then water containing SP was added and blended continuously for two minutes. This was followed by the manual mixing of the materials for one minute to scrap those trapped at the bottom and side part of the pan. The mixing was continued for two minutes until the concrete was homogeneous, before the fresh concrete was placed in the molds. Slump flow testing is performed using the Abrams cone, testing is carried out to determine the level of workability (ease in work) of the concrete mixture that has been made. The mixture design method used is *The European Federation of Specialist Construction Chemicals and Concrete System* (EFNARC) 2005 [9]. Then the treatment of test specimens is carried out aimed at keeping the surface of fresh concrete always moist until the concrete is considered to be hard enough. This humidity is maintained to ensure the hydration process of cement takes place perfectly. Test specimens are curing in water until they are tested.

2.3. Specimen testing

Testing for compressive strength is conducted at ages 7.14 and 28 days following SNI 1974: 2011 [10]. Then the concrete sample is split into two parts so that it looks inside the concrete. The distribution of the surface in the concrete was observed in the distribution and the amount of fiber in several parts which can be seen in Figure 2. Also tested the modulus of elasticity in concrete aged 28 days. Microstructure analysis was performed with the *Scanning Electron Microscope* (SEM) test, used to analyze the microstructure morphology of nylon fibers as well as the interface between concrete and fiber nylon.

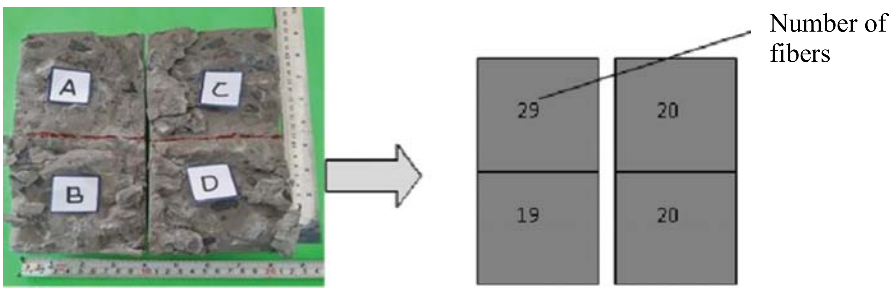


Figure 2. Sketch of the fiber mount calculation on a specimen

3. Result and Discussion

Concrete mixture planning with material weight ratio is carried out to determine the desired concrete strength, according to the methods of the European Federation of National Associations Representing Concrete (EFNARC) for normal concrete compositions, while for concrete with nylon fiber, the addition of nylon fiber is made with a variation of 0.5% and 1% of the weight of cement. The mixture composition shown in Table 1 is as follows.

Table 1. SCC mixture composition

No.	Materials	Normal Concrete	Nylon 0.5%				Nylon 1%			
			D: 0.35 mm		D: 0.65 mm		D: 0.35 mm		D: 0.65 mm	
			L : 15 mm	L : 20 mm	L : 15 mm	L : 20 mm	L : 15 mm	L : 20 mm	L : 15 mm	L : 20 mm
		kg / m^3	kg / m^3	kg / m^3	kg / m^3	kg / m^3	kg / m^3	kg / m^3	kg / m^3	kg / m^3
1	Freshwater	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
2	Cement	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
3	Sand	723.08	720.57	720.57	720.57	720.57	717.48	717.48	717.48	717.48
4	Crushed stone 1-2	907.30	904.15	904.15	904.15	904.15	900.28	900.28	900.28	900.28
5	Nylon	-	2.50	2.50	2.50	2.50	5.00	5.00	5.00	5.00
6	Viscocreate 1.3%	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50

3.1. Slump flow test

The slump flow test has the function to determine the SCC mixing ability, and the results of all variations of the SCC mix meet the slump flow requirements in a range of 550-650 mm.

3.2. Concrete volume weight

The SCC volume weight was carried out on cylindrical concrete aged 28 days. This test aims to determine the percentage change in weight of the SCC with nylon fiber to the normal weight of the SCC.

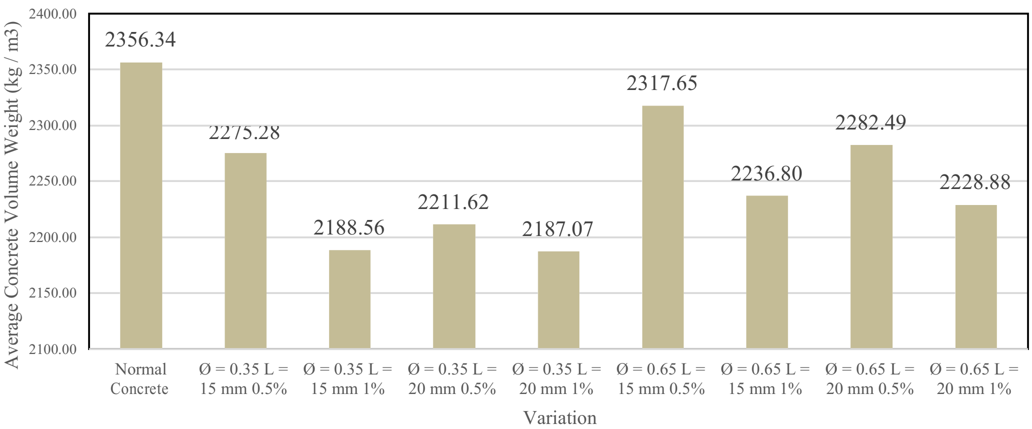
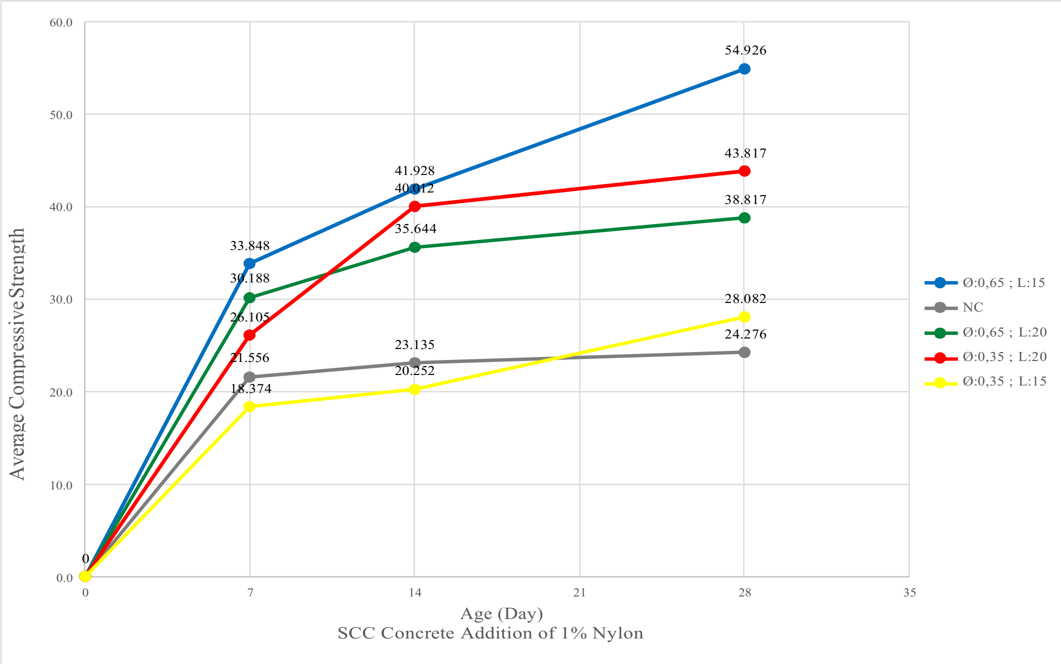


Figure 3. Average volume weight of SCC

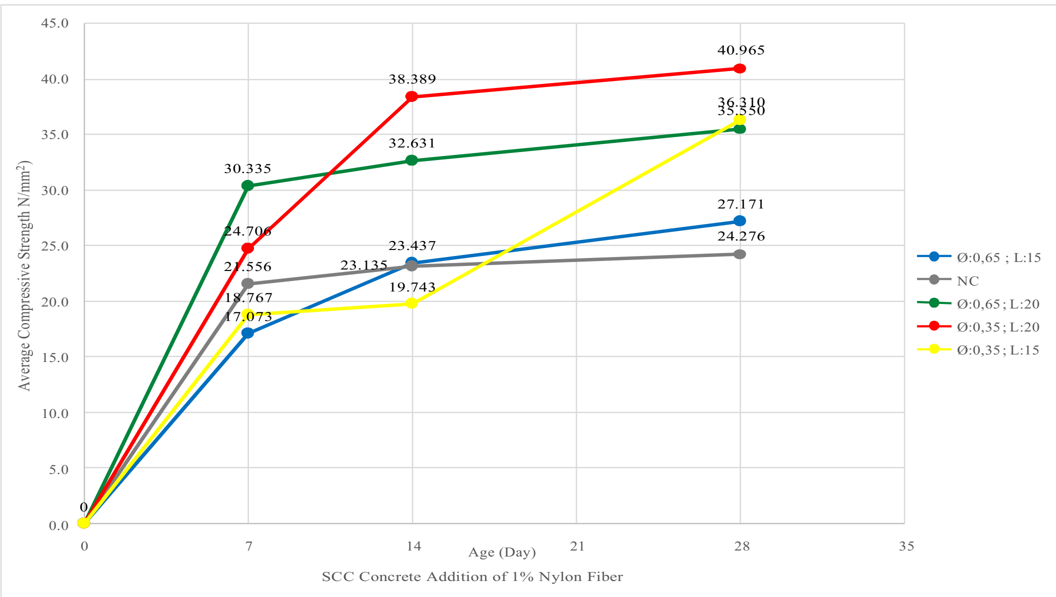
Figure 3 shows the volume weight of SCC fiber concrete, where the greater the percentage of nylon fiber addition to SCC mixture, the volume weight of SCC fiber concrete will be smaller. Then SCC fiber concrete with 0.35 mm nylon fiber diameter has a smaller concrete weight than SCC fiber concrete with 0.65 mm nylon fiber diameter and normal concrete. This shows that the addition of nylon fiber to the SCC affects the value of the unit weight.

3.3. *Compressive strength*

At ages of 3 days, 7 days, and 28 days, compression test was conducted to evaluate the strength of normal SCC with SCC containing nylon fibre using a Universal Testing Machine (UTM) with a 1000 kN capacity. Figure 4 illustrates how the presence of nylon fiber affect the compressive strength result.



(a)



(b)

Figure 4. Average compressive strength of SCC concrete (a) 0.5% nylon fiber; (b) 1% nylon fiber

Figure 4 shows that SCC fiber concrete with the addition of 0.5% and 1% nylon fiber increased in compressive strength from the age of 7 days to 28 days. As the age of the concrete increases, the strength of the concrete also increases, as presented in figure 4.

Figure 5 depicts the highest compressive strength value of SCC fiber concrete with 0.5% nylon fiber addition achieved at 0.35 mm diameter variation with 20 mm fiber length with a compressive strength value of 40.97 MPa. Meanwhile, 0.65 mm diameter variation with 15 mm fiber length produces highest compressive strength value of 54.93 MPa for 1% nylon fiber. Compressive strength of SCC concrete increased by 68.75% with the addition of 0.5% nylon fiber (0.35 mm diameter and 20 mm length) and 126.26% with the addition of 1% nylon fiber (0.65 mm diameter and 15 mm length) at 28 days compared to normal SCC. Overall, SCC fiber concrete with 1% nylon fiber addition has a higher compressive strength than SCC fiber concrete with % nylon fiber addition and normal concrete.

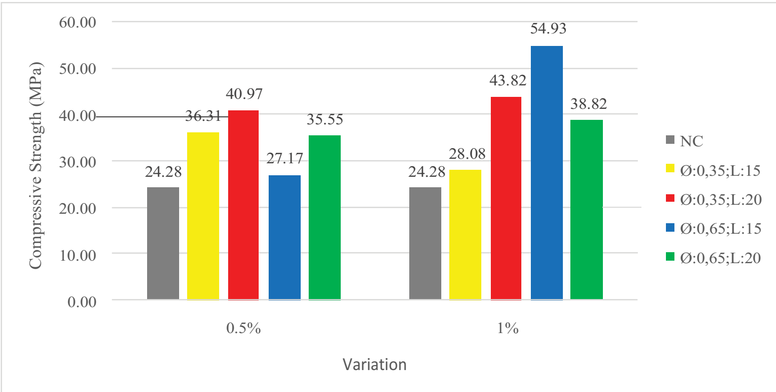


Figure 5. Average compressive strength of SCC at 28 days

3.4. *Modulus of elasticity*

The stress and strain relationship between the SCC concrete using nylon fiber with different variations are shown in Figures 6 and 7. The modulus of elasticity of SCC concrete is presented in Table 2. Form Table 2, it is clear that modulus of elasticity increases with increasing concrete compressive strength value.

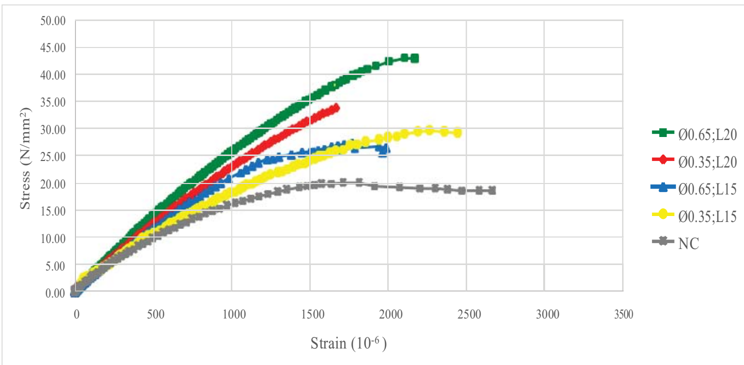


Figure 6. Stress-strain of 28-day-old SCC concrete at the addition of 0.5% nylon fiber

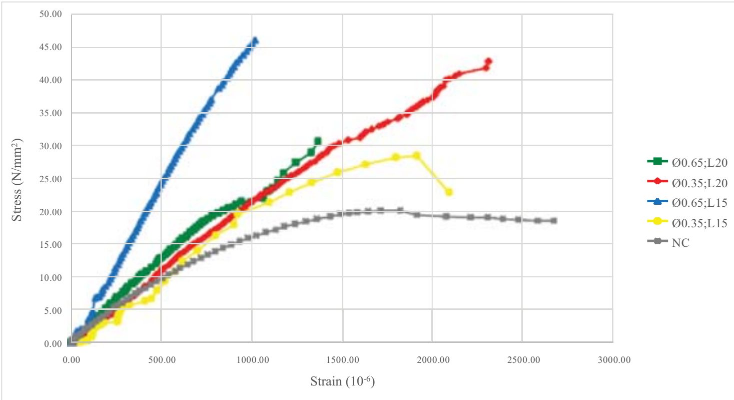


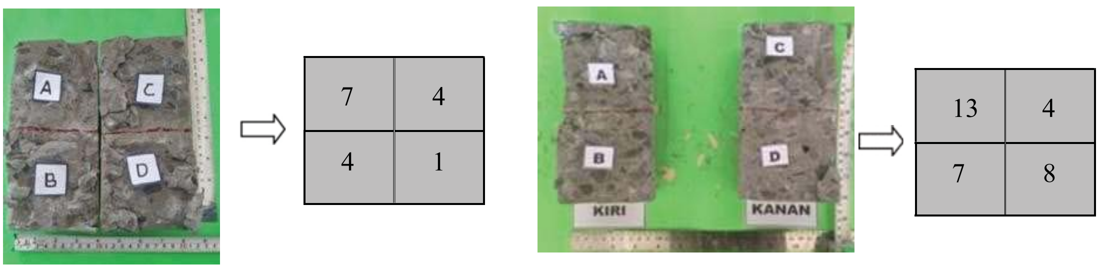
Figure 7. Strain-stress of 28-day-old SCC concrete at the addition of 1% nylon fiber.

Table 2. Modulus of elasticity of SCC

Variation	Elastic Modulus, Ec (MPa)	
	0.5% Nylon Fiber	1% Nylon Fiber
NC	19288.500	19288.500
Ø0.65; L15	23093.835	37665.11
Ø0.65; L20	27189.803	28431.315
Ø0.35; L20	22921.287	22968.397
Ø0.35; L15	21026.448	22229.046

3.5. Fiber distribution

Distribution test results on nylon fiber, show the effect of superplasticizers in improving concrete workability. In this test, each variation of content and type of nylon fiber is taken, each sample is divided into four segments, and the number of segmented nylon fibers is calculated. Observation of the distribution of nylon fibers is done by counting the amount of nylon fiber that is perpendicular to the concrete surface. The specimen is divided into two parts then marked and counted how many nylon fibers in the top half and the bottom half. The distribution of nylon fibers is presented in table 3 and Figure 8 show nylon distribution.



a. Ø=0.65 mm, L=15 mm, 0.5% b. Ø=0.65 mm, L=15 mm, 1%

Figure 8. Nylon distribution testing

Table 3. Distribution of nylon fibers in SCC (%)

Variation	Fiber Count			
	A	B	C	D
Normal Concrete	0	0	0	0
Ø = 0.65 L = 15 mm 0.5 %	43.75	25.00	25.00	6.25
Ø = 0.65 L = 15 mm 1 %	40.63	21.88	12.50	25.00
Ø = 0.65 L = 20 mm 0.5 %	24.00	28.00	36.00	12.00
Ø = 0.65 L = 20 mm 1 %	26.00	34.00	18.00	22.00
Ø = 0.35 L = 20 mm 0.5 %	26.83	24.39	32.52	16.26
Ø = 0.35 L = 20 mm 1 %	22.87	23.94	30.32	22.87
Ø = 0.35 L = 15 mm 0.5 %	36.59	20.73	23.17	19.51
Ø = 0.35 L = 15 mm 1 %	28.07	21.64	24.56	25.73

With the addition of *superplasticizer*, it can improve workability on concrete helping to compact the concrete optimally and not hollow even though there is an addition of 0.5% nylon fiber and 1% of cement weight. This results in the nylon fibers in the SCC concrete being spread evenly, although some variations of the concrete on the top side of the concrete tend to be more fiber. This is caused by the effect of lighter nylon fiber density so that the fiber is lifted above the concrete section. The number of nylon fibers scattered in the SCC concrete increases with the percentage of fiber addition and length.

3.6. Microstructure of SCC with nylon fiber

From the results of the SEM test, the morphology of nylon fibers and the SCC concrete microstructure with the addition of nylon fibers can be determined. Figure 9 shows the morphology of nylon fibers where the nylon surface is slippery, which cause the bonding between nylon and mortar is weak. Even thought, cement paste can still adhere well.

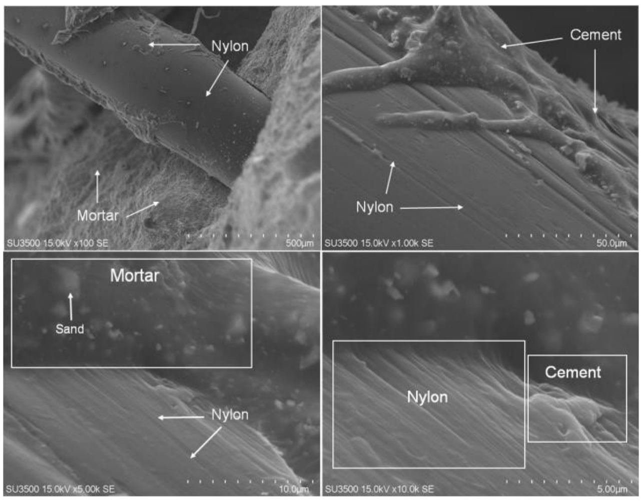


Figure 9. Morphology of nylon fibers and their bonding to cement paste

In figure 10, it is clear that there is a cavity between the nylon fiber and the mortar because the surface of the nylon fiber is slippery so that the mortar cannot blend with the nylon. Or in other words the bonding between nylon fibers and concrete is weak. SEM observations show good concrete density.

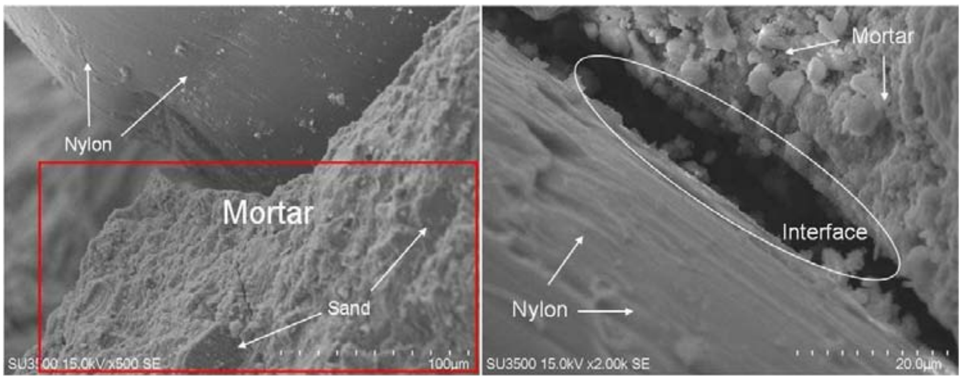


Figure 10. The interface between mortar and nylon fiber

4. Conclusion

In general, SCC concrete has an increase in compressive strength value along with an increase in age, percentage, diameter, and length of nylon fiber. The optimum compressive strength value is obtained at the addition of 1% fiber, 0.65mm diameter, and 15 mm fiber length with a compressive strength value of 54.93 MPa at 28 days. The distribution of nylon fibers in SCC is spread evenly without segregation, although in some variations there is a tendency for more fibers on the upper side. This is because of the specific gravity of the lightweight nylon fiber so that the fiber tends to the upper side of the concrete. The SEM test results clearly show that the surface of the nylon fiber is slippery, hence the bonding between the nylon fiber and concrete is weak, and the presence of interfaces in the two materials.

5. Acknowladgement

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