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Skid Resistance and Micro-structure of Concrete Containing Waste Plastic Fiber for Rigid Pavement

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Abstract

This research analyzes the skid resistance and micro-structure of concrete by adding waste plastic fiber as an additive agent. There are parameters to be tested in laboratory scale such as ultrasonic pulse velocity (UPV) for chemical content related to concrete quality and skid resistance value (SRV) in the application of rigid pavement. The test is conducted by making concrete specimen in cylinder mold 150 mm × 300 mm. It is mandatory to test the concrete cylinders at the age of 28, then the concrete fragments from the compressive strength test are used for micro-structure testing through scanning electron microscopy (SEM) and UPV in order to check the quality of concrete and natural rocks. In this research, skid numbers from 5 mixing mode concrete pavements were collected using a British Pendulum Tester (BPT). The result shows that by adding waste plastic fiber additive into the concrete mixture in a huge amount (more than 1%) will decrease the concrete quality as it will have more concrete cavity. Based on the chemical test, there was no significant differences in terms of the percentage. However, based on the SRV test, high amount of plastic fiber will increase the level of skid resistance significantly. Based on this research, concrete with the waste plastic fiber as an additive agent can be used in the rigid pavement as it has higher SRV.

***Key Words*:** Fiber, Concrete, Micro-structure, Skid Resistance, Additive Agent

1. Introduction

Indonesia as a developing country, has shown promising economic growth in these past few years. To facilitate this economic growth, there needs to be an improving pattern of Indonesia's infrastructure happening, such as highways, which are needed to mobilise goods and services throughout the country. Adequate highway infrastructure needs a paving structure which is good and reliable. Today, there are two types of pavement layers that are in widely use in Indonesia: flexible pavement and rigid pavement. Flexible pavement generally are made of asphalt mixing, this type has its advantages such as: suitable for medium to high speed roads, can be used for roads with low or high traffic, easy construction and maintenance, can be constructed in stages (adaptable), has constant roughness throughout its service age. The production of flexible pavement relies on the availability of mineral aggregate (stone) the most important ingredient behind the rising cost of pavement structure [1]. While flexible pavements are made from asphalt, rigid pavements are made from reinforced concrete, this type of pavement excels in roads where there are dense traffic and weight is needed to be distributed evenly, high flexural strength, more durable and weather resistant, longer service life and therefore lower life cycle cost, and has a higher skid resistance than flexible pavement. In the pavement construction, safety and comfort are important

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aspects in the quality design of both rigid and flexible pavements. Very often in highway engineering, especially during the pavement design, the question of choosing between two types of pavements – flexible and rigid pavement comes to the fore due to a pavement should always be able to fulfil health and safety regulations for its user in any kind of weather and in a long span of time, during its service years.

The concrete used in the making of rigid pavement, are generally made of cement, fine aggregate, coarse aggregate, water, and sometimes other additives are added so that a better mechanical property of the concrete is obtained. Concrete as a construction material has a high compression strength, but it's weakness is in its tensile strength. Concrete's tensile strength is rather low compared to its compressive strength. This has led to interest in finding suitable replacement material as a substitute for natural stone [1]. In order to improve this property of concrete, sometimes other materials are added such as fibers. These fibers can be made out of : steel, polymers, minerals, and natural fibers [2]. One type of polymer which can be added to concrete are plastic fibers in the form of polyvinyl chloride (PVC). This material can be found in the form of flex banners, which are widely used for advertising goods and services in Indonesia. As advertisements has a limited life span, after they are used they turn into waste for their environments. This research aims to utilise these waste into the mixture of concrete as a product for rigid pavements in highways. Figure 1 shows the waste plastic fiber used in this research.

Researchers around the world are pursuing to develop high-quality concrete using fibers and other mixtures in concrete up to certain proportion. Campoy, et al. [3] states that the tensile strength increases when the fiber percentage reaches 18.13% or more and an increase in the steel fiber will produce the optimum modulus of rupture until it reaches 31,99%. For the macro synthetic, polyester and carbon fibers, a greater performance was obtained, whereas the cellulose and PET fibers were the one with the lowest performance managing to lower the MOR in a range of 9.56 and 18.85% respectively. Furthermore, Karakurt and Arslan [4] states that fibers are reinforced concrete against external effects which can occur during the service life of the rigid pavements and harmful effects. Ali and Mohod [5] explains how polypropylene fibers effect reinforced concrete towards pavements, research shows that there is an increase in tension as big as 20–41% towards Steel Fiber Reinforced Concrete (SFRC) if compared to conventional concrete. Senaratne, et al. [6] shows that the savings per beam, due to recycled aggregate materials, was nearly 2.5 times higher when compared to the cost increase due to the addition of steel fibers in the typical beam design. These results confirm that the additional cost increase of utilising steel fiber could considerably be offset by the quantified sustainable benefits of recycled aggregate in the optimum mixture. On the other hand, Medeiros et al. [7] shows that the load frequency effects the weakening behaviour of plain concrete. The number of cycles to failure at the lowest loading frequency (1/16 Hz) is only at least one order of magnitude lower than at the highest load frequency (4 Hz). However, for concrete reinforced with polypropylene and steel fiber, the number of cycles to failure under low load frequencies gets closer to that under higher load frequencies, namely the same order of magnitude for steel FRC. Such a trend can be attributed to the effectiveness of fibers in bridging cracks, thus preventing the cracks to lengthen during load cycles. Nobili et al. [8] used polypropylene-based fiber reinforced concrete (PFRC) as a pavement material in tunnel construction work at Quadrilatero Marche-Umbria, Italy. A 6-month observation has been carried out on the road pave-

Figure 1. Waste plastic fiber.

ment used for traffic, indicating that the PFRC provides an efficient, safe and inexpensive solution to highway work. Other studies on fibrous concrete as rigid pavements also show good results, with different types of fibers such as polymers [9], polyester fiber and glass fiber [10–12], natural fiber [13,14], steel fiber [15,16], and waste plastic fiber [17].

This research aims to test these concrete mixtures which has the fibers from flex banner waste as an additive agent for rigid pavements in highways. As for the parameters which will be used in testing are: skid resistance, density and integrity tests using ultrasonic pulse velocity, observation of the fibers micro-structure using Scanning Electron Microscopy (SEM) tests.

2. Theory and Formula

2.1 Materials

The materials used in this research are: cement (type I), fine aggregate/sand from Sumedang, coarse aggregate from Cigudeg, water, as well as plastic fiber waste obtained from used flex banners. Table 1 shows physical characteristics of the materials used while Figure 2 shows particle size distribution of fine aggregate and coarse aggregate.

2.2 Skid Resistance Test

An important aspect which needs to be paid attention in a pavement construction is its roughness and skid resistance. Skid resistance is the force obtained between the surface of the road and the wheel, a certain coefficient is needed to avoid losing control of the vehicle especially when braking in a wet road surface. To satisfy a good coefficient in skid resistance, testing is needed to be done using a British Pendulum Tester (BPT). All skid resistance testing done will be based on the principle of a vehicle's tire (rubber) moving at a specified speed creating friction towards the pavement surface.

British Pendulum Tester (BPT) is a test using a dynamic pendulum, used to measures skid resistance when a rubber slider on a 20 in (508 mm) pendulum arm contacts a test surface inside a laboratory or on the field. The yield value of skid resistance testing is stated in the British Pendulum Number (BPN) in accordance to ASTM E303, "*Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester*" [18]. The minimum skid resistance value for a few locations of a pavement can be seen in Table 2.

2.3 Ultrasonic Pulse Velocity (UPV) Test

UPV test purposely to find out the concrete homogeneity, fracture, changes within the concrete in order to

Table 1. Characteristic of materials

Physical properties	Fine aggregate	Coarse aggregate	Waste plastic fiber
Specific gravity (gr/cm^3)	2.52	2.56	-
Density (gr/cm^3)	1.51	1.53	0.80
Clay lump level (%)	2.75	0.68	-
Water absorption (%)	2.47	2.75	-
Finess modulus	2.67	7.09	-

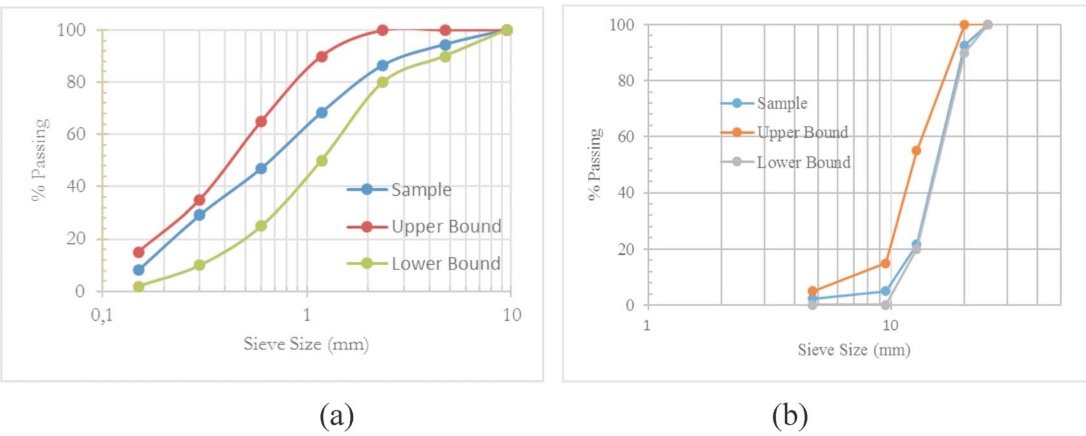

Figure 2. (a) Particle size distribution of fine aggregate, (b) Particle size distribution of coarse aggregate.

Table 2. Minimum value of *skid resistance* (wet condition) [19]

Category	Location type	Minimum skid resistance
A	Difficult sites such as: - (i) Roundabout (ii) Bends with radius less than 150 m on unrestricted roads (iii) Gradients, 1 in 20 or steeper, of lengths > 100 m (iv) Approaches to traffic lights on unrestricted roads	65
B	Motorways, trunk and class 1 roads and heavily trafficked roads in urban areas (carrying more than 2000 vehicles per day)	55
C	All other sites	45

Note: for category A and B where vehicles drives with a high speed (> 95 km/hour) an additional texture depth of minimal 0.65 mm is needed.

determine the concrete quality. Using an analysis of variations in ultrasonic velocity wave propagation, it is possible to verify its computation or detect heterogeneous areas in concrete. The higher the wave speed indicates higher concrete density. In contrast, lower wave speed indicates the low quality of concrete. The transducer used has a frequency of 20–150 kHz. The UPV test refers to IS 13311 (Part 1): 1992 "Non-Destructive Testing of Concrete-Methods of Test" [20]. The wave propagation on the test is calculated based on this theorema:

$$V = L/T \qquad (1)$$

where:
V is the pulse velocity (km/sec)
L is the path length (m)
T is transit time of the pulse (μsec)

Table 3 shows the velocity criterion for concrete quality grading based on IS 13311 criterion.

2.4 Scanning Electron Microscopy Test

Scanning electron microscopy (SEM) is a highly capable examination technique for materials. Specifically, The SEM capable to show images of the surface structure, micro-structure of the material, including chemical composition along with its percentage. Examination and analysis of the surface given by the SEM will be able to tell us data which is given by the surface layer about 20 μm from the surface.

2.5 Analysis of Variance (ANOVA)

ANOVA is a general technique that can be used to test the hypothesis that the means among two or more groups are equal, under the assumption that the sampled populations are normally distributed. There is only one hypothesis used in ANOVA, namely the two-way hypothesis (two tail). This hypothesis is used to find out whether or not differences are found which are not specific and which ones are different. The hypotheses of interest in an ANOVA are as follows:

H_0: $\mu_1 = \mu_2 = \ldots = \mu_n$, There is no difference in the means of factor

H_1: $\mu_1 \neq \mu_2 \neq \ldots \neq \mu_n$, There is a difference in the mean of factor

In this study the ANOVA test was carried out with the help of statistical software namely SPSS.

3. Experimental Setup

For experimental program, cylindrical test specimens of size 15 × 30 cm are cast. The specimens is then cured by soaking it in a water bath. The specimens and the curing process is shown in Figure 3 below.

After reach appropriate age, i.e. 28 days, the specimen made then loaded without shock and increase con-

Table 3. Velocity criterion for concrete quality grading (Source: IS 13311 (Part 1): 1992)

No.	Pulse velocity by cross probing (km/sec)	Concrete quality grading
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtful

(a) (b)

Figure 3. (a) Specimens casting process, (b) Curing process of the specimens.

tinuously at a rate approximately 140 kg/cm^2/min until the resistance of the specimen to the increasing load breaks down and no grater load can be sustained. The concrete fragments are then collected for micro-structure observation through testing using the Scanning Electron Microscope (SEM) method. On the other hand, to test its skid resistance, a rectangular sample measuring 30 cm × 30 cm × 6 cm is made. For the research purpose, there are 5 types of concrete mixture made, which are: ordinary concrete mixture without additional waste plastic fiber, along with 4 types of concrete mixture with additional waste plastic fiber. Each of these 4 mixtures has different percentages of fiber in them, 0.25%, 0.5%, 1%, and 2% respectively. As the testing continuously conducted so that specimen need to be marked by code such as WPF0 which is a normal concrete mixture without additional fiber, WPF A, B, C, and D has been coded accordingly. Concrete mixture proportion is designed under the Indonesian National Standard of SNI 03-2834-2002, "The Procedure of Normal Concrete Mixture" [21]. The amount of waste plastic fiber used is 0.25%, 0.50%, 1.00%, and 2.00% for WPF A, B, C and D respectively. Considering the specific gravity is 800 kg/m^3, then for the percentage of 0.25%, the weight of fiber needed is 0.25% × 800 kg/m^3 × 1 m^3 = 2.00 kg. The material mixture required per m^3 for each fiber percentage, including the weight of fiber, water, cement, coarse aggregate (CA) and fine aggregate (FA) as shown in the Table 4.

4. Result Discussions

4.1 Skid Resistance Test

Five runs of BPT over the test sections were conducted for five different type of specimens at Road and Traffic Engineering Laboratory, Institute Technology Bandung (ITB), and the results are tabulated in Table 5.

Table 5 shows the trend of increasing SRV values as the percentage of waste plastic fiber increases in the overall mixture. WPF0 produces the smallest SRV value, which is an average of 62.4, while WPFD has the highest skid resistance value compare to other mixtures, reaching 68.6, up by 9.93% compared to WPF0. It can be concluded that by adding more than 1% of WPF material, the skid resistance value will increase. This is due to the rigid pavement is very dependent on macrotexture and microtexture. With more cavity and porosity, friction in the rigid pavement increases which significantly affected the value of the skid resistance.

Furthermore, all mixtures were conducted in the normal weather conditions which are in room temperatures of around 25–30. Further analysis on SRV revealed that the highest SRV could be obtained by using additional 2% of increment of plastic fiber which was achieved by WPFD as shown in Figure 4.

Based on the results in Table 5, statistical analysis was generated in order to obtain the parameters between average, range, and standard deviation. The analysis results are shown in Table 6 below.

Table 4. Concrete mix design composition per m^3 of concrete

Code	% fiber	Fiber (kg)	Water (kg)	Cement (kg)	CA (kg)	FA (kg)
WPF0	0	0				
WPFA	0.25	2				
WPFB	0.5	4	170.92	432.7	814.62	836.75
WPFC	1.0	8				
WPFD	2.0	16				

Table 5. Skid resistance test results

Mix code	Skid resistance					Average
	1	2	3	4	5	
WPF0	60.0	63.0	62.0	63.0	64.0	62.4
WPFA	65.0	64.0	66.0	67.0	67.0	65.8
WPFB	62.0	64.0	63.0	63.0	62.0	62.8
WPFC	67.0	68.0	68.0	66.0	66.0	67.0
WPFD	67.0	68.0	68.0	70.0	70.0	68.6

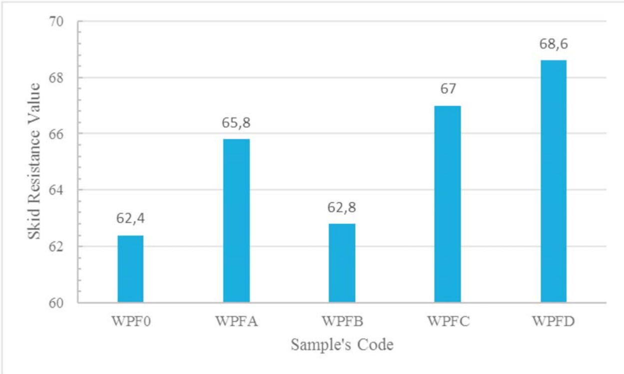

Figure 4. Skid resistance test results.

Skid resistance is affected by micro and macro texture of the road surface. Other parameters that affect the skid resistance are environmental condition, physical characteristics of the material, age of the pavement, and number of traffic. Generally, the skid resistance of rigid pavement is higher than flexible pavements. Table 6 shows the WPFB mixture had the lowest average score of 62.8 and the WPFD mixture had the highest average skid resistance of 68.6. This is due to the WPFB mixture has a smoother texture compared to the other types of pavements, which can cause worn-out vehicle tires to slip or skid. However, a high skid resistance mark will also have consequences on tires as they will wear them out quicker than on flexible pavements.

To study the effect of mixture type, and polishing on the measured macro-structure of each concrete specimen using the skid resistance test method, one-way Analysis of Variance (ANOVA) analysis was performed. An important step analysis using ANOVA is verifying the validity of assumptions used in this analysis. One assumption of ANOVA analysis is that the variances of different groups are equivalent. The hypothesis used in this analysis can be identified as follows:

H_0: The skid resistance value of the mixtures are equal for WPFA, WPFB, WPFC, and WPFD

H_1: The skid resistance value of the mixtures are different for WPFA,WPFB,WPFC, and WPFD

Table 7 shows the results of the ANOVA analysis for the surface roughness on the concrete mixture specimen. The significance of the *F*-test in the ANOVA analysis is less than 0.001 with score of F achieved 23.115 which is smaller than $\alpha = 0.05$. Thus, the hypothesis that the skid resistance value of the mixtures are equal for WPFA, WPFB, WPFC, and WPFD is rejected (null hypothesis (H_0) is rejected). Therefore, mixtures with different percentage of fiber have different skid resistance value for WPFA, WPFB, WPFC, and WPFD.

Table 6. Statistical characteristic of road pavement roughness

	N	Range	Minimum	Maximum	Mean	Std. deviation
WPF0	5	4.00	60.00	64.00	62.40	1.51
WPFA	5	3.00	64.00	67.00	65.80	1.30
WPFB	5	2.00	62.00	64.00	62.80	0.84
WPFC	5	2.00	66.00	68.00	67.00	1.00
WPFD	5	3.00	67.00	70.00	68.60	1.34
Valid N (listwise)	5					

4.2 Chemical and Micro-structure of Concrete

Analysis of the chemical compound in every mixture is done with EDX (Energy Dispersive X-Ray Spectroscopy) corresponding to ASTM E1508-2012 "*Standard Guide for Quantitative Analysis by Energy-Dispersive Spectroscopy*" [22]. This testing was conducted in Laboratorium Sentra Teknologi Polimer – BPPT, Puspitek, Serpong. The result analysis in Table 8 indicate the chemical composition of concrete mixture and waste plastic fiber additive.

Furthermore, testing has been done with SEM (scanning electron microscope), edax and XRD (x-ray diffraction) to see appearance of the micro structure, its constituent elements and the crystal phase. Scanning Electron Microscopy (SEM) test shows concrete micro-structure pattern which ebodies waste plastic fiber additive. This test is shown in Figure 5 to 9. From the figures, it can be seen that WPFD mixtures shows more porosity in the concrete mixture.

Table 7. ANOVA test result

Surface roughness	Sum of squares	*df*	Mean square	*F*	Sig.
Between groups	90.150	3	30.050	23.115	.000
Within groups	20.800	16	1.300		
Total	110.950	19			

Table 8. Chemical composition of concrete mixture and waste plastic fiber additive

Element	Composition (% of mass)				
	WPF0	WPFA	WPFB	WPFC	WPFD
C	8.14 ± 0.08	10.82 ± 0.49	10.90 ± 0.55	11.13 ± 0.85	10.64 ± 0.35
O	48.07 ± 0.12	51.14 ± 0.77	51.01 ± 0.30	51.80 ± 0.31	49.67 ± 0.25
Mg	ND	0.30 ± 0.02	0.31 ± 0.03	0.35 ± 0.30	0.31 ± 0.04
Al	0.45 ± 0.05	0.71 ± 0.14	0.32 ± 0.03	0.54 ± 0.10	1.15 ± 0.29
Si	0.90 ± 0.09	1.10 ± 0.07	0.50 ± 0.10	1.07 ± 0.43	1.81 ± 0.46
Ca	42.45 ± 0.05	35.91 ± 0.49	36.96 ± 0.56	35.11 ± 1.13	36.42 ± 0.93

From Figure 5–9 shows that for normal concrete (WPF0) and WPFA has more pores but with a smaller diameter. For WPFB (0.50%), and WPFC (1.00%) has slightly and medium pores but with a larger diameter. For mixture of 2.00% (WPFD) shows more porosity and cavity.

4.3 Ultrasonic Pulse Velocity Test

Table 9 shows the wave velocity which was calculated through the equation (1).

From the results of the UPV test it can be seen that the velocity value in the specimen has a tendency to decrease along with the increasing volume of waste plastic fiber in the overall mixture. WPF0 as a normal concrete mixture shows the highest velocity wave of 3.91 km/sec. On the other hand, WPFD mixture shows that the quality of the concrete is below the value of the other three mate-

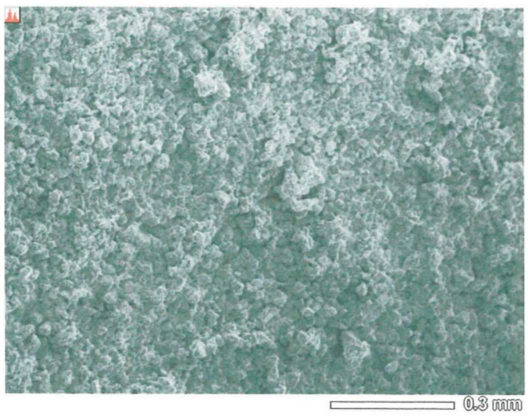

Figure 5. SEM result of WPF0.

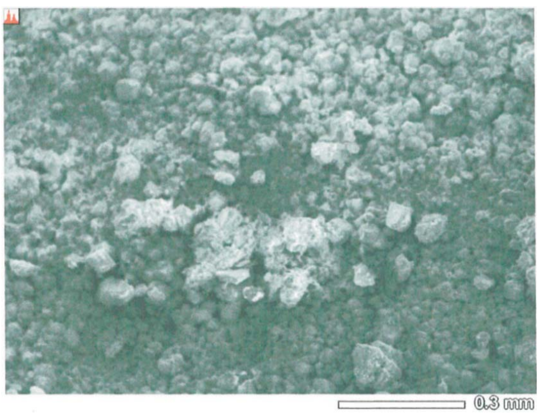

Figure 6. SEM result of WPFA.

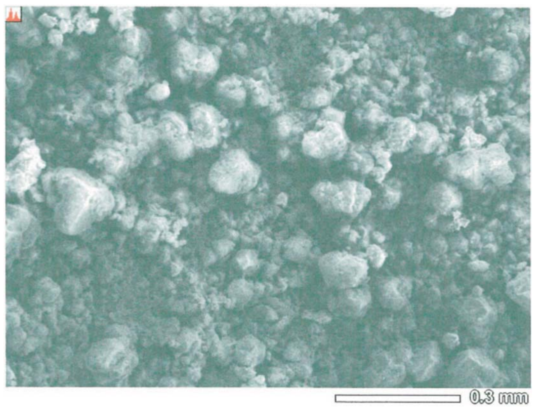

Figure 7. SEM result of WPFB.

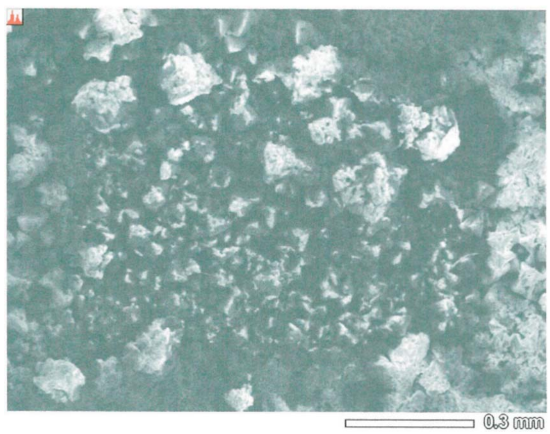

Figure 8. SEM result of WPFC.

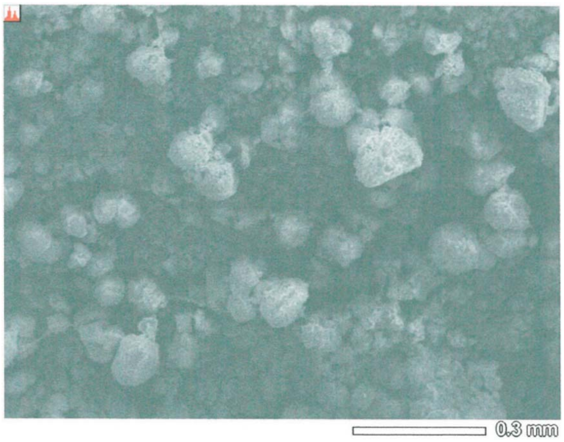

Figure 9. SEM result of WPFD.

rials that have been tested, which is 3.20 km/sec or decreases by 18.16% compared to WPF0. From the wave velocity results obtained for WPFD, the quality of the WPFD concrete is at the medium level. This is relevant in SEM test which shows the micro-structure of WPF mix D had cavity in the concrete.

4.4 Summary of Test Result

Table 10 shows the index summary for three different testing for 4 concrete mixture with WPF. From the result, it can be seen that the WPFD (2%) has the highest skid resistance value and the lowest velocity due to more porosity and cavity as seen in SEM results.

5. Conclusions

Based on the test results, we have concluded several points:

1. SEM result shows that the decreasing Calsium level (Ca) within the mixture in relation to the rise of added fiber. Meanwhile, within the mix of high level of fiber (2%), it shows the cavity in the micro-structure of concrete.
2. Skid resistance test shows the value above 65 except in WPFB. This indicates that the higher fiber within the mixture, the higher skid resistance value on the concrete surface. However, in the application, skid resistance is limited so it will not cause the wheel to burn out.
3. UPV test result shows that concrete which contains 2% of fiber (WPFD) indicates low level quality compare to other three mixtures. This result is relevant to SEM that shows the potency of having cavity within the concrete mixture.

Table 9. Ultrasonic pulse velocity test results

Sample	No.	Length L (m)	Transit time T (μs)	Velocity (km/sec)	Average velocity (km/sec)	Concrete quality
WPF0	1	0.063	16.0	3.93	3.91	Good
	2	0.063	16.2	3.89		
WPFA	1	0.063	15.7	4.01	3.87	Good
	2	0.063	16.9	3.73		
WPF B	1	0.063	16.2	3.89	3.89	Good
	2	0.063	16.2	3.89		
WPF C	1	0.063	16.5	3.82	3.81	Good
	2	0.063	16.6	3.80		
WPF D	1	0.063	19.7	3.20	3.20	Medium
	2	0.063	19.7	3.20		

Table 10. Summary of test result

Mix code	SRV	Avg. velocity (km/sec)	SEM
WPF0	62.4	3.91	Normal: less pores with small diameter
WPFA	65.8	3.87	Slightly pores with small diameter
WPFB	62.8	3.89	More pores with medium diameter
WPFC	67	3.81	Medium pores with large diameter
WPFD	68.6	3.2	More porosity and cavity with large diameter

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