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# Mechanical Properties of Rigid Pavements Incorporating Different Percentage of Steel Fiber

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**ABSTRACT**

Nowadays, rigid pavement construction has widely used in road construction industry. Although rigid pavement is widely used in road construction, it tends to fail within time due to many reasons. Fatigue is the important aspect in the rigid pavement design. Due to applications of the heavy loads fatigue occurs in the pavement in the form of micro cracks. Fatigue concepts which is an important parameter in cement concrete pavement and mainly failure occurs due to fatigue failure. As a result, it is crucial to optimize and improving concrete structures to suit diverse engineering requirements. This paper investigates the effect of steel fiber on the improvement of structural behavior such as compressive, tensile and also flexural stiffness performance of rigid pavements. In this respect, the concrete mix design accordance to Design of Normal Concrete Mix (DOE) method was employed in the preparation of the specimens. A series of concrete laboratory tests have been carried out to evaluate the mechanical properties of the concrete sample incorporating 1, 3 and 5% of steel fiber. As a result, the performance (compressive, tensile and flexural) of modified rigid pavements improved remarkably 15-60% with 5% additive of steel fibre at 7 and 18 days curing time. Based on these studies, the addition of steel fiber reinforcement into the rigid pavements has a significant effect on mechanical properties of concrete mixture.

## 1. Introduction

In Malaysia, highway agencies have been scouring the globe for ways to cut construction costs, improve pavement quality, and reduce expensive yearly maintenance expenses. Engineer and contractor had to deal with significant changes in construction methods over the years. Many problems can occur during construction of rigid pavements such as preparation of under-layers, materials selection, concrete producing, hauling, placing, compacting, finishing, and curing [1-3]. In

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rigid pavement, concrete slabs provide the majority of the bearing capacity [4]. This is due to the stiffness of concrete slabs, which allows the weight to be distributed across a large area, which results in low stress on the layers beneath it. Concrete slabs that are rigid and have low elasticity distribute traffic load to the subgrade where it covers a large area [5]. According to Pandey *et al.,* [6] it has classified the types of rigid pavement failure which is linear cracking and these types of failures split the slab into two or three pieces. This occurs cause by traffic loads at repeated levels, curling due to heat gradient, and moisture loading at repeated levels. If the linear cracking becomes worst, then it is need to restore the pavement by full-depth repair [6,7].

Other than that, the previous researcher highlighted that, the phenomenon of linear cracking is also referred as panel cracking. Linear cracking will have an impact on the pavement's ride quality. Linear cracking allows moisture to migrate through the pavement body, which can lead to erosion of the foundation or subbase, which also may lead to the pavement losing its soil support. The fissures may spall and disintegrate if it is not sealed [8]. In addition, rigid pavement can also have corner breaks, it is caused due to excessive pumping below the pavement, as such there is no more support exist below the pavement to take vehicle load. Subsequently, fatigue is one of the major causes of distress in rigid pavements. The propagation of these cracks causes internal progressive damage within the structure, which ultimately leads to failure of the pavement due to fatigue [9].

The heat of hydration, limited thermal conductivity, shrinkage, and creep are all elements that contribute to pavement fatigue damage. When the ratio of tensile stress in the pavement and modulus of rupture of pavement material reaches 0.45, micro cracks and micro-voids generated due to excess water capillary cavities increasingly extend under the action of repeated loading. Due to this downside, the researchers had tried to find an alternative towards the problem [10,11]. The research found that the additional of steel fiber in concrete rigid pavement can lift the strength of rigid pavement and indirectly affect the flexural strength and tensile strength of the concrete. Even many researchers have brought the evidence that the additional of steel fiber in concrete can improve the ability of concrete, it is still not being used widely [12].

Application of various types and forms of fibers, such as cellulose, mineral, and polymers, in asphalt mixtures has been shown to increase their resistance to permanent deformation and improve their tensile strength [13]. The use of fibers in asphalt mixtures is not a new concept and has been found to enhance their performance compared to control mixtures, although the outcome is also influenced by the fiber content. One approach to incorporating fibers into asphalt mixtures is by adapting the technology of fiber reinforcement in cement concrete, which involves using a variety of natural and synthetic fibers [14]. The primary objective of incorporating fibers into the rigid pavement is to improve their mechanical strength, which in turn can lead to greater strain energy and better fracture characteristics [15].

## 2. Material and Method

This section describes the materials and method used in this study. The raw material was characterized using various methodologies outlined in this section. In order to get the desired result, three (3) replications specimens were prepared with a total of 72 samples were tested. To maintain reliability, the study adhered strictly to guidelines set forth by the American Society for Testing and Materials (ASTM), British Standards (BS), and American Association of State Highway and Transportation Officials (AASHTO).

### 2.1 Material

Steel fiber is the main material used in fabrication of the specimens. Steel fiber Dramix 5D is local Malaysian product which manufactured by Kimmu Trading Sdn Bhd. From the manufacturing properties, the tensile strength of the steel fiber is 2.3 N/mm$^2$ with the tolerances of steel fiber is plus minus 5%. The Young's Modulus is plus minus 210.000 N/mm2 with the wire ductility is 6%. The steel fiber is classified as Fiber Family 5D with the length of 60mm and diameter of 0.900mm. The aspect ratio of this steel fiber is 65. In the other hand, the fiber network for this steel fiber is 3.0 km per m$^3$ for every 15 kg/m3. From this materials properties evaluation, it's also identified that this steel fiber contained 3.132 fibers/kg. According to the CE, the minimum dosage for steel fiber is 15 kg per m$^3$.

### 2.2 Sample Preparation

In the batching process of plain concrete of rigid pavement with additional of steel fiber, there was a several procedures should be taken in order to ensure the samples are properly fabricated. Firstly, the ingredients to produce concrete was provided and complies material properties test. Then, cement, fine aggregates, coarse aggregates and steel fiber with 1%, 3% or 5% as additional fine aggregates is added to the mechanical concrete mixer. After that, the dry mixtures were batch for a few minutes and water was add partially to ensure that the mixing process was perfectly done. Next, the plain concrete with additional of steel fiber was produce and pour into block formwork with desire dimension. Finally, the mixing process is repeat with different percentage of steel fiber as additional of fine aggregates.

The sample preparation procedure to produce plain concrete with additional of steel fiber is started with the mixture is place in the mold with dimension of 150mm × 150mm × 150mm for cube, also pour into formwork with dimension of 100mm × 100mm × 400mm for prism and also in cylinder with dimension of 100mm × 200mm using trowel. Then, the concrete was place in the mold and formwork in three layer of approximately equal volume and been compacted using rod with 25 strokes. The mixtures will be left in the formwork for 24 hours before pull apart and become dry sample. Then the dry sample was weight using digital weight machine to check the weight of concrete. All the sample is left into the curing tank for 28 days before start testing. All specimens were prepared in the desired dimension and materials tabulated in Table 1 and Table 2, repectively.

**Table 1**
Size and Volume of sample used

| Sample | Size (mm) | Volume per one specimen (m$^3$) | Number of specimens |
|---|---|---|---|
| Cube | 150 x 150 x 150 | 0.003 | 24 |
| Prism | 100 x 100 x 400 | 0.004 | 24 |
| Cylinder | 100 x 200 | 0.020 | 24 |

**Table 2**
Sampling identification

| Quantity | Cement (kg) | Water (kg) | Fine aggregate (kg) | Coarse aggregate (kg) |
|---|---|---|---|---|
| Per $m^3$ | 405 | 190 | 775 | 1065 |
| Per trial mix of 0.072 $m^3$ (24 cube specimens) | 29.16 | 13.68 | 55.80 | 76.68 |
| Per trial mix of 0.096 $m^3$ (24 prism specimens) | 38.88 | 18.24 | 74.40 | 102.24 |
| Per trial mix of 0.480 $m^3$ (24 cylinder specimens) | 194.4 | 91.20 | 372.00 | 511.20 |

### *2.3 Experimental Program*

This section describes the mechanical performance of rigid pavement mixture subjected to compressive, tensile, and flexural strength after 7 days and 28 days of curing session.

#### *2.3.1 Compressive strength test*

To assess the behavior or response of a material or structure in concrete to carry the load, a compression test was conducted according to the ASTM C 39 [16] and depicted in Figure 1. Compressive strength of cubes gives the information of the potential strength of the concrete mix. Compressive strength over a period of time also indicates the extend of quality control being exercised at site. It also helps in determining whether correct mix proportions of various materials were used to get the desired strength. In this study, a total of 24 cube samples were tested after 7 days and 28 days of curing.


**Fig. 1.** Compression machine

#### *2.3.2 Tensile strength test*

The ability of concrete to resist tensile force or stress is known as its tensile strength. The split cylinder test of concrete method was used to determine the tensile strength of concrete as stated in ASTM C 496 [17]. The Units of Force per Cross-Sectional Area (N/Sq.mm or MPa) are used to measure the tensile strength of concrete The tensile strength of concrete is an important factor to consider throughout the design process. Because it contributes for around 10% of concrete compressive strength, it can have a substantial impact on other structural element strengths in flexure.

### *2.3.3 Flexural strength test*

Flexural strength is one measure of the tensile strength of concrete. It is a measure of unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 4 x 4-inch (100mm x 100mm) concrete beams with a span length at least three times the depth. The flexural test of the concrete beams were carried out in accordance to ASTM C78 standard and specification [18]. A Concrete Compression Testing Machine, with a maximum loading capacity of 1000 KN was employed for the flexural test. During the test, individual beam was placed in the machine (Figure 3), and loaded slowly until failure occurred. A digital caliper was attached to the machine to measure the central deflection of the sample. The failure force and the corresponding deflection were displayed on the screen of the machine and recorded. Flexural strength of the concrete beams was computed using Eq. (1).

Flexural strength, $S = \frac{3WL}{2bd^2}$ (1)

Flexural MR is about 10% to 20% of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials in obtained by laboratory tests for given materials and mix design. The MR determined by third point loading is lower than the MR determined by center point loading, but sometimes by as much as 15%.

## **3. Results and Discussion**

The mechanical performance test was employed in this study to evaluate the stiffness of concrete pavement materials under loading conditions. The specimens were subjected to the test with 7 and 28 days curing, and the modified mixtures were further analysed in the subsequent subsection.

### *3.1 Compressive Strength Analysis*

The compressive strength test for 0% (control specimens), 1%. 3% and 5% concrete with steel fibers has been conducted. According to Figure 2 and Figure 3, the result revealed that the addition of steel fibers in concrete can increases the compressive strength of the concrete. It is also seen that the increases volume of steel fibers can greatly increases the volume of concrete strength. This finding agreed with Behbahani *et al.,* [19] with additional of steel fibers in concrete can considerably increases the compressive strength of concrete from 0% to 15%. From the result obtain on this study, it can be proven that the presence of steel fibers in concrete can benefit the concrete strength. However, according to Ali *et al.,* [20], the compressive behaviour of concrete with addition of steel fiber can be explained by several factors that lead to the strengthening of the binder matrix of the concrete. Firstly, the addition of fibers in the binder matrix improves the concrete's confinement that upgrades the compressive load-bearing capacity by controlling the lateral deformations. Secondly, fibers prevent the cracking of microstructure due to dry shrinkage in the process of strength-gaining [20,21]. Pre-existing microcracks in the binder matrix may proliferate at a faster rate under compressive loads in the case of plain concretes. Furthermore, steel fibers can restrict the propagation of cracks under loading and decreases the stress concentration at the ends of cracks [22].

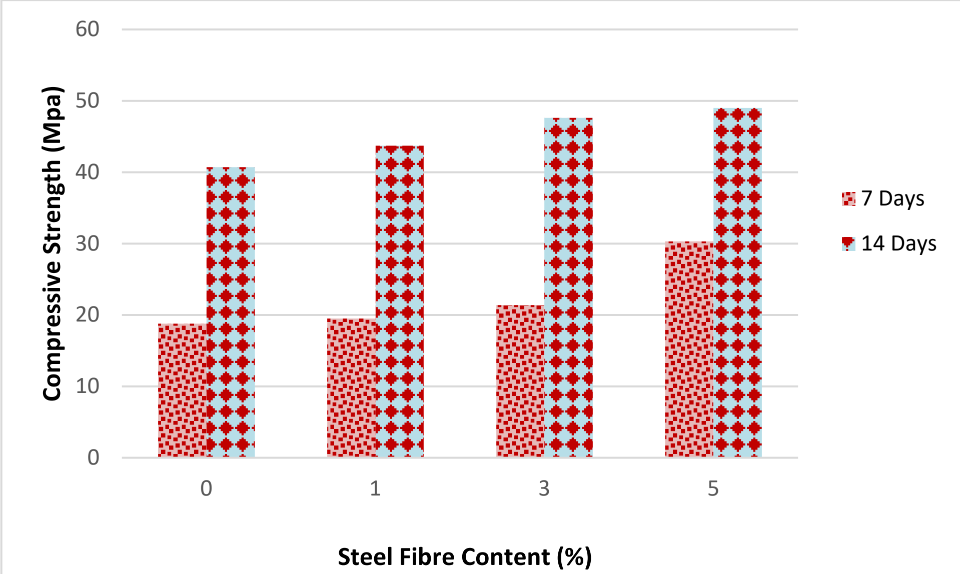


**Fig. 2.** Compressive strength for the specimen of 7 and 14 days curing

### *3.2 Tensile Strength Analysis*

Concrete's tensile strength is its ability to resist cracking or breaking under stress. Despite the fact that concrete is seldom loaded under pure pressure in a structure, measuring the tensile strength is vital to determine the degree of the potential damage. Breaking and cracking occur when tensile forces exceed tensile strength. Concrete tensile strength has a significant influence on the performance of concrete structures, particularly components exposed to high temperatures. Figure 3 shows the strength of normal concrete and concrete containing steel fiber for 7 days and 28 curing session. The comparison of tensile strength test between normal concrete (%) and steel fibes concrete (1%, 3% and 5%) it can be related to the research by Bhati 2019 stated that the traditional concrete has a reasonably high compressive strength compared to ultra-high-performance concrete, but a much lower tensile strength. This means that any concrete construction that may be subjected to tensile stress must be reinforced with high tensile strength materials such as steel beforehand. Because of the importance of tensile strength in regulating possible cracking, there is a growing body of understanding concerning it. From the result gained in this study, the average tensile strength for 28days of curing for all concrete with additional of steel fibers shows a winning result as referring to the (Jabatan Kerja Raya Standard, 2005), concrete tensile strength varies between 300 and 700 psi which is around 2 to 5 MPa. This means, on average, the tensile strength average about 10% of the compressive strength. The addition of steel fiber into concrete mix leads to decrease in slump and workability for the various mix samples. Thus, it improved the resistance to tensile and compression, as evidenced by the UTM test results.

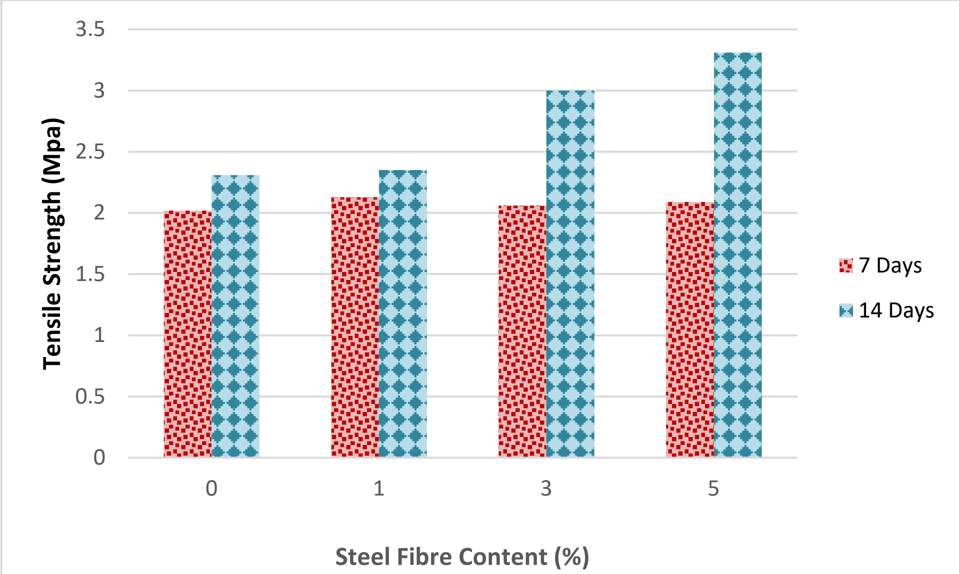


**Fig. 3.** Tensile strength for the specimen of 7 and 14 days curing

### *3.3 Flexural Strength Analysis*

Figure 4 shows that adding steel fiber to rigid pavement can boost its flexural strength. The longer the curing period, the higher the maximal flexural strength that concrete with steel fibers can reach. The sample containing 0% steel fiber and curing for seven days had the lowest maximum flexural strength of 1.38 MPa. Meanwhile, the sample containing 5% steel fibre and curing for 28 days has the highest maximum flexural strength of 3.41 MPa. This result can relate to a study by Latifa *et al.,* in 2013, they stated that the flexibility the inclusion of fiber improves flexibility and toughness. The utility of fibre, which enhanced concrete ductility, was demonstrated in several ways on flexural strength and flexural toughness test. The increase in flexural strength of concrete reinforced with steel fibres is due to the fact that increasing the fibre content in the concrete significantly assists in efficiently managing the development, propagation, and spreading of fractures. As a result, flexural strength improved. Curing for a longer period of time can increase the flexural strength of rigid pavement. It has been demonstrated when 5% steel fibre is compared between 7 and 28 days. At 7 days, the highest flexural strength of 5% steel fibre is 3.06 MPa, whereas at 28 days, the maximum flexural strength of 5% steel fibre is 3.40 MPa. The difference in maximum flexural strength between 7 and 28 days for 5% steel fibre is 11.11%.

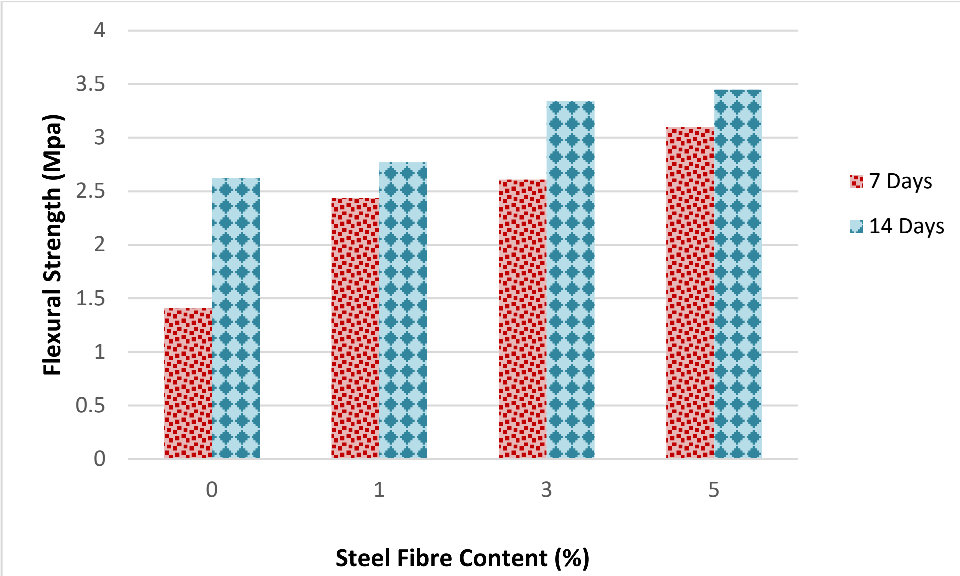


**Fig. 4.** Flexural strength for the specimen of 7 and 14 days curing

## 4. Conclusions

This paper reports the results of a laboratory study conducted at the Advanced Highway Laboratory, UTHM, to evaluate the mechanical performance of rigid pavement mixture incorporating of steel fiber. Overall, this study highlights the potential of using a steel fiber in improving the stiffness performance characteristics of rigid pavement structure. The following findings were observed:

i. In compare between normal concrete and concrete with addition of steel fibers, test result shown that the addition of steel fibers in concrete resulting to significant increment in compressive strength compared to conventional concrete which is in the range of 16.94% to 37.90%. The compressive strength result shown a positive impact on steel fibers addition into rigid pavement mixture.
ii. Tensile strength result in this study shown an improvement between 3.35% to 29.17% which allocate the using of steel fibers in concrete will help to increase the tension that concrete can hold and reduce first crack.
iii. The maximum flexural strength at 28 days with 5% steel fibre in rigid pavement is 3.40 MPa, which is 32.3% greater than the ordinary rigid pavement with 2.57MPa. Steel fiber as an additional material has been shown to boost the flexural strength of rigid pavement due to its characteristics.

Based on the findings, it was concluded that an optimal fiber content of 5% steel Fibers is appropriate for the materials tested. However, further research is needed to validate the optimal fiber content with other performance tests.

The findings indicate that the addition of steel a fibers can improve the resistance to rutting and increase the stiffness modulus, which could ultimately lead to better rigid pavement durability. Nonetheless, further research is necessary to fully understand the effects of different dosages of fiber content and to validate the findings with other performance tests.

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