Mechanical Properties of Recycled Steel Tire Fibres in Concrete

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Abstract: Tyre production is increasing every year due to the increase of vehicle sales. The generation and disposal of waste are inherent to life itself and have presented very serious problems to the human community in Malaysia. Recently, some research has been devoted to the use of recycled steel tire fibres (RSF) in concrete. This study is focusing on the use of RSF in concrete mix. The different volume of RSF was used in concrete mix to fabricated and tested. In particular, concrete obtain by adding RSF evidence a satisfactory improvement, mostly in cracking control, compressive strength, flexural strength and also tensile strength. On the other hand, compressive, flexural and tensile strength was positively affected by the addition of RSF. More percentage of volume fractions (Vf) added will give high number of bonding in concrete to delay the crack growth. It gives high result in tensile strength. Moreover, the workability of the concrete reinforced with RSF was significantly affected.

Keywords: Workability; Compressive strength; Flexural Strength; Tensile Strength; Cracking Control

1.0 Introduction

Waste tyres in Malaysia are neither categorized as solid waste or hazardous waste has pose a health hazard since tyre piles are excellent breeding grounds for mosquitoes. Shape and impermeability of tyres helps to hold water for long periods thus provide breeding sites for mosquito’s’. Waste tyres also pose a serious fire hazard since they are easy to ignite. However, once ignited tyres burn are very difficult to extinguish. This is due to the 75% void space present in tyre, which make it difficult to quench the tyres with water or to eliminate the oxygen supply. In addition, a large tyre fire can smoulder for several weeks or even months, sometimes with dramatic effect to the surrounding environment.

Therefore, by using steel fibres extracted from waste tyre in concrete, it would be the best way to make it more economical to manage them and it is environmental friendly besides
enhancing concrete engineering properties. In order to achieve this, a study based on characteristics of reinforced concrete with tyre fibres was done and compared with plain concrete without tyre fibres. By this research, we can gain knowledge on how to enhance concrete engineering properties and at the same time make tyre recycling attractive to be used mostly in engineering fields.

The significant of this study is to investigate the mechanical performance of concrete with steel tyre fibres so that it will improve the concrete performance based on engineering properties. This research will also encourage the tyres factories to think of side business for tyre recycling as the economic benefit is obvious. It will also provide sustainable markets for recycled steel tyre fibres and will encourage material recovery for large amount or tyres.

To achieve this aim, the study carried out based on the following objective[s]:

I. To determine the mechanical properties of recycled steel fibre in concrete.
II. To determine the optimum volume of fibre needed to increase the concrete toughness without failure to the concrete itself
III. To study the effect of fibres length to the mechanical properties of concrete.

Plain concrete is a brittle material, with low tensile strength and strain capacities. The introduction and application of Fibres Reinforced Concrete are purposely to increase the strength and toughness of the concrete because of the micro-cracking and macro-cracking still cannot be slowed down by the use of steel reinforcement inside concrete. Generally, higher strength concrete is more brittle compare to normal strength concrete. However, the composite will become more elastic when the fibres are added into the concrete. When concrete with sufficient amount of fibres content cracks in response to the applied load, the cracks are bridged by fibres which presence to retards the cracks growth. It cannot emphasized too strongly that, at the fibre volumes used in normal commercial application the role of fibres is not to increase strength, though modest strength increases may occur. If what is desired is a strength increase, it is clearly much easier (and much cheaper) to redesign the plain concrete mix, primarily by reducing the water cement ratio.

### 2.0 Fibre Characterization

Tire fibres from this research were recovered by shredding process of waste tires. The tire fibres used in this research were characterized by different lengths and diameters. Samples about 100 tire fibres extracted randomly and were analyzed. The diameter of each fibre was recorded by a Digital Calliper tool and the length was recorded by using a ruler. The diameter of sample were chosen randomly for 100 samples and recorded. Digital calliper is easy to be used because it can measure the diameter of fibres accurately and display the result on the screen. Due to the small size of diameter of the recycled tire fibre, this is the most suitable machine to be used in measuring the diameter of the samples. The same samples used in measuring the diameter were used in order to measure the length. The length of the tire fibre was referred to the distance between outer ends of the fibres. **Figure 2.1 and 2.2** shows the diameter and length of 100 specimens of fibres use.
3.0 Experimental Design

This study concentrates on the influence of tire fibers on characteristic of concrete reinforced with steel tire fibers. Besides, plain concrete without tire fibers were prepared as control in order to compare with concrete with tire fibers. The observation in this research was concentrated on how well the tire fiber improves the mechanical properties of the concrete by using different volume of fibers: During laboratory works, there are steps that need to be followed in order to prepare the material and testing the specimens. There are:
I. Specific the standard or procedure for the laboratory testing.
II. Prepare materials
III. Design mix of the material
IV. Preparation of tire fibers
V. Preparation of mould (cubes, prism and cylinders)
VI. Instrumentation of the specimens (test for the specimens).

3.1 Mix Design and Material

Mix design is the process conducted to select the most suitable ingredients of concrete and determining their relatively quantities to achieve the desired strength. Raw materials used in this research include cement, fine aggregate (sand), coarse aggregate and tire fibers. Concrete strength used in this study is grade C40. The fibers used for this research were extracted from waste tire. The fibers were cut into various lengths. Since standard steel moulds for cubes, cylinders and prisms specimens has been provided, preparation is only to apply a layer of oil to the surface of the formwork one day before casting. This step is important to make sure it easier to remove the mould after the concrete hardened.

![Figure 3.1: Mould Preparation](image)

Concrete mixing process need to be carried out carefully to ensure the fibers will be distributed uniformly in the concrete mix. Fibers are added in the matrix at the final stage where the entire ingredients (cement, fine aggregate, water and course aggregate) already mixed well. Figure 3.2 shows how the fibers distributed into the mix. In order to avoid the problem in mixing, concrete mixer is used. After 24 hour the concrete are remoulded, all of the specimens need to be cured. Curing process is a procedure use in order to promote hydration of cement that consists of a control of temperature and moisture movement from and into the concrete. Objective of this process is to obtain a good quality of an appropriate mix. All the specimens are soaked in a curing tank as shown in Figure 3.3.
3.2 Specimens Preparation

A total of 6 cubes with 150 x 150 x 150 mm, 3 prisms with 100 x 100 x 500 mm and 3 cylinders with 150 mm diameter and 300 mm height will be cast and prepared for each batch. Six batches of 6 cubes, 3 cylinders and 3 prisms were prepared. One batch was made without recycled tire fibers to be control while the rest of 5 batches were prepared using recycled tire fibers. Every batch of mixture prepared for tests at the age of 7 and 28 days. The percentages of fiber used in this study are 0.2 %, 0.4 %, 0.6 %, 0.8 %, 1.0 %. Percentages are determined by density for each fiber. Table 3.1 gives the proportion for plain concrete and fibers mixes. During the mixing process, RSF were added last to the fresh concrete while the mixer rotates.

Table 3.1: Mix Proportion for plain concrete and RSF mixes

<table>
<thead>
<tr>
<th>Fiber Percentage</th>
<th>0.0% (control)</th>
<th>0.2%</th>
<th>0.4%</th>
<th>0.6%</th>
<th>0.8%</th>
<th>1.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (kg)</td>
<td>27.80</td>
<td>27.80</td>
<td>27.80</td>
<td>27.80</td>
<td>27.80</td>
<td>27.80</td>
</tr>
<tr>
<td>Aggregate (kg)</td>
<td>52.70</td>
<td>52.70</td>
<td>52.70</td>
<td>52.70</td>
<td>52.70</td>
<td>52.70</td>
</tr>
<tr>
<td>Sand (kg)</td>
<td>57.10</td>
<td>57.10</td>
<td>57.10</td>
<td>57.10</td>
<td>57.10</td>
<td>57.10</td>
</tr>
<tr>
<td>Superplastisizer (sp)</td>
<td>0.056</td>
<td>0.056</td>
<td>0.056</td>
<td>0.056</td>
<td>0.056</td>
<td>0.056</td>
</tr>
<tr>
<td>Water Cement Ratio</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>Fiber (kg)</td>
<td>0.00</td>
<td>0.911</td>
<td>1.823</td>
<td>2.735</td>
<td>3.646</td>
<td>4.558</td>
</tr>
</tbody>
</table>

4.0 Result and Discussion

4.1 Slump Test

Results for slump tests are recorded in Table 4.1. It is clearly indicates that the slump of the mixture was reduced when the tire fiber content increased. In other words, we can conclude that, workability of the mixture will decrease by addition of tire fiber in mixture. Slump height for the control specimen which is plain concrete is 55 mm. As we can see from table
above, slump height was decreased because of the addition of fiber into mixture. From 0.2% until 0.6%, the slump height was decreasing. As for 0.8% of fiber volume, slump height was calculated to be 30 mm. This is because of the fiber loss during mixing process due to balling effect; the slump was getting increased than before. The mixture for 1.0% and 0.6% slump was recorded to be the lowest slump height since it only has 10 mm slump height. Therefore, it shows that the presence of tire fiber will stiffen the mixture and lower the workability of the mixture.

![Figure 4.1: Slump Test](image)

4.2 Compressive Strength

The compressive strength of the cubes was tested at the ages of 7 and 28 days. A total of 18 concrete cubes with the dimensions of 150×150×150mm were prepared. They were 3 specimens prepared for each percentage volume fraction of steel fibers (0.0%, 0.2 %, 0.4%, 0.6 %, 0.8 % and 1.0%). The cubes were divided into 6 groups including 6 cubes for each of the mixes with different volume fraction. In order to determine compressive strength for the concrete that is being used in this research, guidelines from ASTM C 109 are used.

![Figure 4.2: Compressive Test on cube](image)
4.3 Flexural Strength

A total of 3 prismatic specimens with the overall dimensions of 150×150×500 mm were prepared for each percentage volume fraction of tire fibers (0.0%, 0.2 %, 0.4%, 0.6 %, 08 %, and 1.0 %). The test was carried out at the age of 28 days. As shown in Table 4.4 below, four-point loading test was conducted to obtain the flexural strength of prisms. The standard used for flexural strength test was ASTM D790.

![Figure 4.3: Flexural Test on prism](image)

4.4 Tensile Strength

The results of tensile strength test were based on cylinders with different volume fraction of tire fiber for 28th days. During tensile strength test, specimens were tested by applying increasing load along the vertical diameter until failure occurs (split). Failure of the specimens occurs along its vertical diameter, due to tension developed in the transverse direction.

![Figure 4.4: Tensile Test on cylinder](image)
4.5 Analysis

Table 4.1: Experimental Results

<table>
<thead>
<tr>
<th>Volume Fiber, Vf (%)</th>
<th>Slump (mm)</th>
<th>Compressive Strength of 7th days (MPa)</th>
<th>Compressive Strength of 28th days (MPa)</th>
<th>Flexural Strength of 28th days (MPa)</th>
<th>Tensile Strength of 28th days (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>55</td>
<td>35.10</td>
<td>45.96</td>
<td>5.355</td>
<td>3.886</td>
</tr>
<tr>
<td>0.2</td>
<td>60</td>
<td>39.41</td>
<td>51.99</td>
<td>5.449</td>
<td>3.392</td>
</tr>
<tr>
<td>0.4</td>
<td>30</td>
<td>47.18</td>
<td>59.17</td>
<td>7.486</td>
<td>3.988</td>
</tr>
<tr>
<td>0.6</td>
<td>10</td>
<td>29.72</td>
<td>34.50</td>
<td>6.243</td>
<td>3.903</td>
</tr>
<tr>
<td>0.8</td>
<td>30</td>
<td>27.66</td>
<td>40.13</td>
<td>6.358</td>
<td>3.503</td>
</tr>
<tr>
<td>1.0</td>
<td>10</td>
<td>27.44</td>
<td>42.26</td>
<td>6.321</td>
<td>4.436</td>
</tr>
</tbody>
</table>

The concrete properties with different volume fraction of tire fibres are summarised in Table 4.1. From figure above, the highest average compressive strength is at 0.4% which is 47.18 MPa of fibre volume whereas the lowest strength is at 1.0% which is 27.44 MPa. From the results recorded, we can see that, the concrete strength for 7th days were achieved which is more than 2/3 of the design strength of concrete Grade 40. Whereas, for concrete cube compressive strength at 28 days For control cube (0% fibre), the average value of compressive strength was recorded to be 45.96 MPa, followed by 0.2% of tire fibre which is 51.99 MPa and keep increased for 0.4%, 59.17 MPa. However, the result was decreased after 0.4% which is only 34.50 MPa for 0.6%. After that, the result was back to increase for 0.8% and 1.0% which is 40.13 MPa and 42.26 MPa. The highest compressive strength was at 0.4% of tire fibre content whereas the lowest strength was at 0.6% of fibre volume. All of the result recorded was achieved the concrete strength design required except for 0.6%, it only manage to achieve 34.50 MPa whereas the required strength is concrete Grade 40.

The results of compressive strength recorded by Nasir Bedawi (2009) in his research are slightly lower than this research. He was using fibre with specific length which is 20 mm, 40 mm and 60 mm in different batch with different amount of fibre. Compared to the result from this research, it used various lengths of fibre and gives the higher compressive strength result. From here, we can conclude that the length of fibre will affect the result of compressive strength of fibre and with adding different length of fibre in concrete mix will give us higher compressive strength on concrete.

Result of tensile strength of the control cylinder is found to be 3.886 MPa and decrease until 3.392 MPa at 0.2% and increase again at 0.4% which is 3.988 MPa. The result is decrease at 0.6% and 0.8% for 3.903 MPa to 3.503 MPa. However, the strength is increase back at 1.0% for 4.436 MPa. We can see from average values, the highest flexural strength is at 1.0% of fibre content which is 4.436 MPa and the lowest strength is at 0.2% of fibre volume which is
3.392 MPa. From the table above, we can see that, the highest flexural strength is at 0.4% of fibre content and the lowest strength is at 0% (plain concrete). It also shows that, the average value for 0.8% and 1.0% is almost the same which is 6.358 MPa and 6.321 MPa. We can say that, with more than 0.6% of fibre volume added into the mixture did not give any further effect to the flexural strength of concrete. Figure 4.5 shows the relationship between the results recorded.

(a) Relationship between concrete cube compressive strength and $V_f$

(b) Relationship between concrete splitting tensile strength and $V_f$
Figure 4.5: The mechanical properties of RSF with different volume fraction of recycles tire fibre

5.0 Conclusion

Conclusions are made base on the objectives of this study and also from observations done during the entire whole course of this study. This research has shown the performance of steel tire fibre reinforced concrete is much better compare to conventional plain concrete. The conclusions from this research based on the experimental results are:

I. The test result indicated that as the fibre volume of fraction increase the workability tend to decrease significantly. In addition, it can be realize that, the slump test was decrease when the volumes of fibre increase.

II. Steel fibre in concrete can be used to increase the performance of concrete. High percentage of volume fraction (Vf) will give high flexural strength of the concrete. The concrete absorb more energy before fail. The recycled tire steel fibres in concrete will grip the concrete particles when load apply on it until failure.

III. The crack opening width can be controlled by using tire fibre. In concrete that is reinforced with tire fibre, the major effect of the fibre has been noted in the post-cracking case, where the fibre bridge across the cracked matrix. It will bond the concrete together and avoid total failure.

IV. Splitting test and flexural test shows that concrete reinforced with RSF has much greater toughness compared to plain concrete. The cylinder did not split during tensile test because of the presence of RSF as reinforcement. Whereas, prism also did not break into two because of the RSF reinforced in concrete.

V. Due to balling effect during mixing, 0.6%, 0.8% and 1.0% of fibre volume tend to have larger honey comb. Concrete reinforced with 0.4% recycled tire fibre is the most suitable to be use because it give the highest strength of compressive test and flexural strength test.
6.0 Acknowledgement

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References


