Strength of Concrete Containing Synthetic Wire Waste as Fiber Materials

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Abstract. The demand of concrete in construction field is growing as linear with the growing of Malaysia economy. This tendency is expected to continue in the year ahead because of improvement in technology. This study tends to determine the performance of concrete containing synthetic wire waste as fiber materials. In addition, the use of wire waste as fiber materials can reduce the amount of waste dumped into landfills. The increasing amount of wire waste which is uncontrollable may lead to environment issue. Until today there is no researchers have done the studies on performance of concrete containing synthetic wire waste as fiber materials. Therefore, an action is made to overcome the environmental problems by using wire waste as fiber materials in concrete mixture. The amount of wire waste added into concrete mixture are limited to 0%, 0.5%, 1.0%, and 1.5% respectively. Other than that, water cement ratio that used is 0.55. The test that involve in this study is workability, density, compressive strength and tensile strength tests. The compressive strength test carried at the ages of 7 and 28 days and for tensile strength test were carried at ages of 28 days. The result was compared with control mix and the optimum percentage value of using wire waste as fiber materials in concrete was 0.5% for both compressive and tensile strength test. Concrete contains 0.5% of wire waste. These mix shows significant increases about 24.4% and 42.7% increases for compressive and tensile strength respectively, compared to the normal concrete.

1. Introduction
Concrete and synthetic fiber have become more popular and attractive in recent years and frequently used for construction material. This is due to the behaviour of concrete which is low in tensile strength, energy absorption and ductility. The poor tensile behavior of concrete is cause from its low toughness and the presence of defects. Therefore, the concrete toughness needs to be improved and strengthen by add fiber material to increase interlocking tensile in concrete matrix. Therefore, a lot of studies on fiber reinforced concrete have been performed to determined optimum portion and suitable materials of fiber [1-2]. Other study investigates behaviour of pattern, strength and magnitude of fiber to increase the toughness of concrete over plain concrete are commonly observed. Many studies have been extended to investigate in shape, type, diameter and length of fibers [3].

In the 1990s asbestos were used as fiber material in concrete and after the health risks associated with asbestos were discovered, there was a need to find another replacement for the substance in concrete and other building materials. Polyvinyl alcohol (PVA), Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC) and polyesters are commonly used as a fiber material in the market. One of the popular synthetic fiber is PP fiber which is widely used for construction applications such as in ground slab, pavement, shotcrete tunnel linings and blast resistant concrete [4]. The mechanism of
applying synthetic fiber in concrete to improve fracture behaviour and toughness concrete performance. Synthetic fiber in concrete was acted as fiber bridging and interlocking tensile stress during tensile force was applied to the concrete. Fiber bridging tensile is considered the governing factor in improving the mechanical properties of fiber reinforced concrete. This factor is determining by bond component between fiber and concrete surface such as fiber cross section, adhesion, fibrillation and embossed surfaces to improve the fiber-concrete bond. These factors are significantly improving engineering properties of concrete namely in fracture and toughness strength. The enhanced performance of FRC compared to the plain concrete comes from its improved capacity to absorb energy during fracture. This due to the plain concrete fails in a brittle manner at the occurrence of cracking stresses which is at first crack load.

In fact, synthetic fiber was popular in the market to reduce the thermal shrinkage and shrinkage cracking of concrete. Plastic shrinkage will occur if the rate of evaporation at the concrete surface is higher compared to rate of water migration to the surface [5]. This will allow shrinkage forces cracks to appear on the surface. A small amount of fiber is significantly effectively to reduce the plastic shrinkage [5-6]. The goals of this study are to investigate the performance of concrete containing wire waste as fiber materials. A few objectives that use to achieve the goals of the study is to determine the workability, density, compressive strength, and tensile strength of the concrete containing wire waste as fiber materials.

2. Experimental
The wire waste taken from the recycle site has been used to act as fiber materials in a concrete, the wire waste percent used as a fiber material is 0.5%, 1.0%, and 1.5%. The length of wire waste was 40mm diameter with length over diameter ($l/d_f$) is 34.25.

![Figure 1. Synthetic wire waste without copper inside.](image)

A total of 24 cube specimens were prepared for the workability, density and compressive strength test. All cube specimens were stored in a water tank to cure the specimens for 7 and 28 days. A total of 12 cylinders with a diameter of 100 mm and a height of 150 mm were prepared for the splitting tensile strength test. The moulds were filled to the top with compaction. The concrete in the cylinder moulds are screened to ensure that the top surface is even. Table 1 shows a mix design fiber reinforced concrete for 1 m$^3$.

All the cylinders were stored in a water tank to cure the specimens for 28 days. This study used 0.55 as water cement ratio. Slump test was conducted immediately after the mixing process and slump value was taken to be compared to the control concrete. The cube size used was 100 mm x 100 mm, the compaction was conducted using the tamping rod manually and the concrete sample was curing for 7 and 28 days. Size of 100 mm x 150 mm was used for cylindrical mould. The compaction is conducted manually using tamping rod with 3 layers of compactions. The sample was weight before the concrete...
testing in order to get the density of the concrete as the physical properties. All samples were curing in water curing tank. Sample was tested using ordinary compression machine for the concrete compression cube and also for the tensile test of concrete. The compressive and tensile strength of hardened-state concrete are determined according to EN12390-3:2009 and BS EN 12390-6:2009, respectively. The result of the testing was analysed and graph was plotted to determine the behavior compressive and tensile strength.

| Table 1. Mix Proportion for 1 m³ of concrete. |
|---------------------------------------------|
| Cement (kg/m³) | Coarse Aggregate (kg/m³) | Fine Aggregate (kg/m³) | Water (kg/m³) | Synthetic wire waste proportions (%) | Synthetic wire waste (kg/m³) |
|----------------|--------------------------|------------------------|---------------|--------------------------------------|-----------------------------|
| 345            | 805                      | 980                    | 189.75        | 0                                    | 0                           |
| 345            | 805                      | 980                    | 189.75        | 0.5                                  | 10.65                       |
| 345            | 805                      | 980                    | 189.75        | 1.0                                  | 21.3                        |
| 345            | 805                      | 980                    | 189.75        | 1.5                                  | 31.95                       |

3. Result and discussion
Test was carried out to determine the workability and performance of concrete containing synthetic wire waste as fiber materials. To achieve the objectives, a few tests have been conducted at the Universiti Tun Hussein Onn Malaysia (UTHM) Structure and Material Laboratory such as slump, density, compressive strength and tensile strength tests.

3.1. Slump
Slump test have been used to test the fresh state slump of the concrete to find the suitable workability value for concrete that contain wire waste as fiber materials. Figure 2 shows the slump value for the control and concrete containing wire waste.

![Figure 2. Slump value of concrete containing wire waste as fiber materials.](image)

It shows that slump value for the control concrete is 76 mm. Concrete containing wire waste shows a decrease on slump value compared to control concrete. Concrete contain 0.5% wire waste has a slump value 72 mm decrease 4 mm from the control slump value. Meanwhile concrete containing 1.0% has a
slump value 69 mm decrease 7 mm from the control slump. Concrete containing 1.5% wire waste has a slump value 68 mm which is decrease 8 mm from control slump.

3.2. Density
Table 2 shows that the concrete containing wire waste as fiber have insignificant result compared to the control specimen. The differences between control and concrete wire waste in range of 0.55% to 1.03% for both cube concrete at 7 and 28 days. This trend is similar as steel fiber concrete [7] which is steel fiber in concrete has insignificant effect to concrete density with addition of less than 2% of fiber.

Table 2. Average density of all specimens and percentage different compared to control.

| Type of samples | 7 days (cube) | 28 days (cube) |
|-----------------|---------------|----------------|
|                 | Average Density (kg/m³) | Percentage different compared to control sample (%) | Average Density (kg/m³) | Percentage different compared to control sample (%) |
| 0% (control)    | 2353          | -              | 2302          | -              |
| 0.5%            | 2340          | -0.55          | 2314          | 0.52           |
| 1.0%            | 2351          | 0.47           | 2333          | 0.82           |
| 1.5%            | 2369          | 0.77           | 2309          | -1.03          |

3.3. Compressive strength
The percentage difference of compressive strength for 7 days of 0.5% wire waste was increased up to 17.4% compared to control concrete as shown in Table 3. However, concrete containing 1.0% waste and 1.5% wire waste fiber was decreased down to 0.4% and 1.3% compared to control specimen. The percentage difference of compressive strength for 28 days shows the same pattern. Concrete cubes containing 0.5% of wire waste was increased up to 24.4% compared to control specimen. Concrete cubes containing 1.0% and 1.5% wire waste were decreased with 18.7% and 25.6% respectively.

Table 3. Average compressive strength of concrete cube with wire waste as fiber material.

| Type of samples | 7 days | 28 days |
|-----------------|--------|---------|
|                 | Average compressive strength (MPa) | Percentage different compared to control sample (%) | Average compressive strength (MPa) | Percentage different compared to control sample (%) |
| Control         | 22.4   | -       | 33.2   | -       |
| Wire waste 0.5% | 26.3   | 17.4    | 41.3   | 24.4    |
| Wire waste 1.0% | 22.3   | -0.4    | 27     | -18.7   |
| Wire waste 1.5% | 22.1   | -1.3    | 24.7   | -25.6   |

Based on the result compressive strength at ages of 7 and 28 days, the usage of wire waste as fiber materials in concrete was found to have significant impact on the strength of concrete. The result shows that concrete cubes that containing 0.5% of wire waste has highest strength, 26.3 MPa compared to control specimen which is, 22.4 MPa. Thus, compressive strength of concrete containing wire waste showed an increase in the concrete strength when 0.5% of wire waste were added. However, the strength decreased when the percentage of wire waste were increase up to 1.0% and 1.5%. The compressive strength at 28 days for concrete containing wire waste, 1.0% and 1.5% were decreased at 18% and 25%, respectively compared to control specimen.
It was clear that concrete specimen with 0.5% of wire waste has given better results compared to control specimen. The right amount of wire waste has filled the void in concrete thus makes the cube more solid which helped concrete strengthening [8, 9]. While the decreasing of strength started occurs at 1.0% of wire waste. The decreasing in strength happen due to larger doses of fiber that lead to improper distribution resulting in balling of fibres and air pockets which adversely affect the compressive strength of concrete [10, 11]. The overall finding shows that the concrete that contain right amount of wire waste can increase the compressive strength of the concrete.

3.4. Tensile strength
The tensile strength was conducted to determine the strength of concrete containing wire waste fiber at the age of 28 days. It is clearly showing that the tensile strength of concrete containing 0.5% of wire waste is higher compared to control specimen. The result of concrete containing 0.5% wire waste shows the highest tensile strength with strength 3.74 MPa. Figure 3 shows an increasing of tensile strength with additional of 0.5% wire waste but the value started to decrease when 1.0% and 1.5% of wire waste were added. The differences of tensile strength at age 28 days was compared to the control specimen with 0.5% of wire waste was with increasing of 42.7%. However, the 1.0% wire waste and 1.5% wire waste of tensile strength were decreased for 1.9% and 16.0% compared to control specimen. In other study, the inclusion of 0.6kg/m³ nylon and polypropylene fibers in concrete resulted in increase of up to 17.1% and 9.7% in the tensile strength, respectively, compared to the control concrete [12, 13]. This pattern of increasing strength was similar pattern of this present study.

**Figure 3.** Tensile strength of concrete at the age 28 days.

4. Conclusion
Based on the compression and tensile results, it can be concluded that the most suitable proportion for wire waste fiber in concrete was 0.5% wire waste. These mix shows significant increases about 24.4% and 42.7% increases for compressive and tensile strength respectively, compared to the control concrete. The highest difference percentage of tensile strength of concrete containing 0.5% of wire waste with the differences 42.7 % compared to the normal concrete. Meanwhile, the smallest difference percentage and the nearest value to the normal concrete was concrete containing 1.0% of wire waste replacement with the differences about -1.9%. In fact, additional of wire waste exceed 0.5% is found to be not effective which can be seen from the reduction in performance of 1.0% and 1.5% of wire waste. It shows that concrete containing right percentage of wire waste shows a good performance for both compressive and tensile strength.
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