Toughness Test of Waste Tires Steel Fiber Reinforced Concrete

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Abstract. In order to research the application possible of waste tires steel fiber reinforced concrete in road engineering, the effect of waste tires steel fiber and conventional steel fiber on cement concrete using ASTM C1018 were determined. The results show that: the waste tires steel fiber has a significant enhancement effect on the toughness of concrete, and it can be used as green road material as the waste tire powder. With the increase of the steel fiber dose, the loading - deflection curve after initial cracking is fuller, the secondary peak of the load is increasing, and the concrete is getting closer to the ideal elastic - plastic material. The toughness of concrete that reinforced by waste tires steel fiber is lower than that of conventional steel fiber. To achieve the same toughness index, the dosage of waste tires steel fiber required to be about 25%~45% higher than conventional steel fiber.

1. Introduction
With the development of the automobile industry, the recycling of waste tires has received more and more attention. Waste tires are mainly composed of rubber, carbon black and metal, etc., with a high resource recycling value, but inappropriate storage, regeneration, disposal and other processes will cause environmental and safety issues, affecting people's health [1,2]. Therefore, how to rationally and effectively use and disposal of waste tires, to prevent environmental pollution has become a problem people must face.

At present, the old tires are mainly used for refurbishing new tires. Waste tires are mainly used for recycled rubber and the production of rubber powder, while the metal wire part is no better use of channels [3,4]. As the tire wire is mostly cold drawn or tempered steel wire, tensile strength up to 1800MPa, with excellent tensile, bending performance [5]. With the development of steel fiber reinforced concrete [6-9] and the development of tire recycling process, the use of waste tires to produce steel fiber, and then the production of waste tire steel fiber reinforced concrete is possible. In this paper, the toughness properties such as the mid-span deflection when the first crack emerging, the toughness index and the residual strength of waste tire steel fiber reinforced concrete were studied in order to provide reference to recycle waste tire.

2. Raw material and test method

2.1. Raw material
In order to compare the difference between the steel fiber and the conventional steel fiber, the paper uses two kinds of steel fiber raw materials, namely Zhitai waste tire steel fiber and Zhitai conventional milling steel fiber with end hook. The performance of the two fiber’s indicators is shown in Table 1.
Among them, the waste tire steel fiber is mainly obtained by the following process: pull - cut off - shaping.

**Table 1. Parameters of steel fiber**

| Type                      | Tensile strength [MPa] | Bending performance | Equivalent diameter [mm] | Length [mm] | Process     | Shape               |
|---------------------------|------------------------|---------------------|--------------------------|-------------|-------------|---------------------|
| waste tires steel fiber   | 1260                   | qualified           | 1.0                      | 35.34       | cutting     | with indentation    |
| conventional steel fiber  | 990                    | qualified           | 1.0                      | 36.02       | milling     | with end hook       |

P.O 42.5 cement used in this test was produced in Shanxi Weidun. The physical - mechanical performance indicators are shown in Table 2, meet Chinese specification "General Portland cement" GB175-2007 requirements.

**Table 2. Performance indicators of Cement**

| Finess [m²/kg] | Setting time [min] | Compression strength [MPa] | Flexural tensile strength [MPa] | Stability (boiling method) |
|----------------|--------------------|----------------------------|--------------------------------|---------------------------|
|                | initial            | final                      | 3d                            | 28d                       |
| 350            | 180                | 275                        | 35.6                          | 49.8                      | 6.1                      | 8.9                   | qualified             |

The coarse aggregate is made of limestone and has a particle size of 5 mm to 20 mm and the gradation is shown in Table 3.

**Table 3. Coarse aggregate gradation**

| Mesh diameter [mm] | Sieve quality [g] | Sieve percentage [%] | Cumulative sieve percentage [%] |
|--------------------|-------------------|-----------------------|---------------------------------|
| 19.0               | 125.0             | 0.8                   | 0.8                             |
| 16.0               | 930.0             | 6.2                   | 7.0                             |
| 13.2               | 2870.0            | 19.1                  | 26.1                            |
| 9.5                | 5320.0            | 35.5                  | 61.6                            |
| 4.75               | 5360.0            | 35.7                  | 97.3                            |
| 0                  | 400.0             | 2.7                   | 100.0                           |

The source of the fine aggregate is Duling River. Its gradation is shown in Table 4.

**Table 4. Fine aggregate gradation**

| Mesh diameter [mm] | Sieve quality [g] | Sieve percentage [%] | Cumulative sieve percentage [%] |
|--------------------|-------------------|-----------------------|---------------------------------|
| 4.75               | 9.0               | 1.8                   | 1.8                             |
| 2.36               | 47.0              | 9.3                   | 11.1                            |
| 1.18               | 57.0              | 11.3                  | 22.5                            |
| 0.6                | 141.0             | 28.0                  | 50.5                            |
| 0.3                | 151.0             | 30.0                  | 80.5                            |
| 0.15               | 57.0              | 11.3                  | 91.7                            |
| 0                  | 41.0              | 8.2                   | 100.0                           |

Water used in this test is Taiyuan municipal tap water.
2.2. **Test method.**

In order to characterize the toughness properties of waste tires steel fiber reinforced concrete, C40 base concrete was used to prepare conventional steel fiber reinforced concrete and waste tires steel fiber reinforced concrete with different volume rate. Then, the mid-span deflection when the first crack emerging, the toughness index and the residual strength were compared.

Concrete mix design reference to Chinese specification "highway cement concrete pavement construction technical rules" JTG / T F30-2015. The mix of C40 concrete is shown in Table 5. Among them, the amount of water-reducing agent is meet the requirement of 30 ~ 55mm slump.

| Strength grade | Water[kg] | Cement[kg] | Sand[kg] | Stone[kg] | Water reducing agent [kg] |
|----------------|-----------|------------|----------|-----------|--------------------------|
| C40            | 195       | 460        | 783      | 998       | 5.8                      |

The Steel fiber volume rate is shown in Table 6. In order to facilitate the comparison, the concrete mixed with a volume rate of 0.5 conventional steel fiber recorded as P-05, and the concrete mixed with a volume rate of 3.6 waste tire steel fiber recorded as F-36.

| Type                      | Volume rate[%] |
|---------------------------|----------------|
| conventional steel fiber  | 0.5 1.0 1.5 2.0 2.5 |
| waste tires steel fiber    | 1.2 1.8 2.4 3.0 3.6 |

The test of toughness of steel fiber reinforced concrete is carried out according to ASTM C1018 toughness index method. The method uses ideal plastic body as the reference datum of material toughness. First, the specimen with size 350 × 100 × 100mm is prepared. After 28 days, the toughness test is carried out using three-point bending loading method. C1018 proposed the toughness test method for the first cracks, and evaluated the toughness of the steel fiber reinforced concrete with three indexes: the mid-span deflection $\delta$ when the first crack emerging, the toughness index $I$ and the residual strength $R$.

The toughness index is determined by the deformation of the concrete when the first crack emerging and its corresponding fracture energy. There are three toughness indicators: $I_5$, $I_{10}$ and $I_{30}$ (or $I_{20}$). The calculation method is shown in Figure 1. For the residual strength index, the method introduces three coefficients: $R_{5,10}$, $R_{10,20}$ and $R_{10,30}$.

ASTM C1018 toughness index method has the following advantages: toughness indicators have no dimension, easy to comparison for the steel fiber reinforced concrete of different performance and size.

![Figure 1. ASTM C1081 Toughness index method](image-url)
3. Test results and analysis

3.1. Load - deflection curve
The load-deflection curves of waste tire steel fiber and conventional steel fiber reinforced concrete are shown in Figure 2 and Figure 3, respectively.

![Figure 2. Load-deflection curve of waste tire steel fiber reinforced concrete](image)

![Figure 3. Load-deflection curve of conventional steel fiber reinforced concrete](image)

When the concrete trabeculae specimen (F-00, P-00) is cracking, the crack is rapidly expanding from the bottom to the top, which is brittle damage. After the steel fiber is doped, the load of the initial crack of the concrete trabecula will increase greatly, and then reach the cracking load and break. After the break, it can still rely on the bonding of the steel fiber and the concrete to bear the larger load. So, the ductility and toughness of fiber reinforced concrete is increased.

With the increase of the volume rate of steel fiber, the maximum cross-center deflection of the two kinds of concrete trabecular specimen is improved after cracking. Even if the crack finally runs through the whole section, the trabecula can bear a certain load, and this phenomenon is more obvious when it mixed more steel fiber. For the load - deflection curve, the curve is fuller after the initial cracking and the secondary peak of the load is getting higher.
3.2. Effect of steel fiber volume rate and type on flexural toughness of concrete

On the basis of the load-deflection curve, the flexural toughness index and the residual strength coefficient of conventional steel fiber and waste tire steel fiber reinforced concrete are calculated according to the aforesaid method, as shown in Table 7.

### Table 7. Flexural toughness of steel fiber reinforced concrete

| Type               | No.   | Flexural toughness index | Residual strength coefficient |
|--------------------|-------|--------------------------|------------------------------|
|                    |       | $I_5$ $I_{10}$ $I_{20}$ $I_{30}$ | $R_{5,10}$ $R_{10,20}$ $R_{10,30}$ |
| Conventional steel fiber | P-05  | 2.38 3.21 5.14 8.46      | 16.6 19.3 26.3 |
|                    | P-10  | 2.81 3.99 7.55 14.77     | 23.6 35.6 53.9 |
|                    | P-15  | 3.44 4.06 9.87 15.82     | 12.4 58.1 58.8 |
|                    | P-20  | 4.56 6.48 10.80 19.15    | 38.4 43.2 63.4 |
|                    | P-25  | 5.48 9.96 14.59 26.45    | 89.6 46.3 82.5 |
|                    | F-12  | 2.55 3.57 5.33 7.16      | 20.4 17.6 18.0 |
|                    | F-18  | 3.14 5.33 7.14 10.05     | 43.8 18.1 23.6 |
| Waste tire steel fiber | F-24  | 3.87 6.03 9.87 14.71     | 43.2 38.4 43.4 |
|                    | F-30  | 4.26 6.09 10.69 18.74    | 36.6 46.0 63.3 |
|                    | F-36  | 4.75 8.57 14.88 23.75    | 76.4 63.1 75.9 |

With the increase of the volume rate of steel fiber, the flexural toughness index of the two kinds of steel fiber reinforced concrete is increasing, and the growth rate of $I_{30}$ is greater than $I_{20}$. The growth rate of $I_{20}$ is greater than $I_{10}$, and $I_5$ is minimum. That is: with the increase in fiber volume rate, the concrete is getting closer to the ideal elastoplastic material. At the same time, at the end half of the loading process, the higher the dosage of steel fiber volume, the higher toughness of concrete. The residual strength coefficient $R_{10,30}$ were significantly greater than $R_{10,20}$ can also reflect this view.

It is not difficult to find that by comparison of the two kinds of steel fiber when the volume rate is similar, the toughness index of conventional steel fiber reinforced concrete is higher about 30% to 40% than the waste tire steel fiber. Which may be related to waste tire steel fiber processing technology, shape characteristics and other factors. So, to achieve the same toughness, the volume rate of waste tire steel fiber should higher about 25% to 45% than conventional steel fiber.

4. Conclusion

In order to research the application possible of waste tires steel fiber reinforced concrete in road engineering, the effect of waste tires steel fiber and conventional steel fiber on cement concrete were determined using ASTM C1018. The results show as follow:

The waste tires steel fiber has a significant enhancement effect on the toughness of concrete, and it can be used as green road material as the waste tire powder. With the increase of the steel fiber dose, the loading-deflection curve after initial cracking is fuller, the secondary peak of the load is increasing, and the concrete is getting closer to the ideal elastic-plastic material. The toughness of concrete that reinforced by waste tires steel fiber is lower than that of conventional steel fiber. To achieve the same toughness index, the dose of waste tires steel fiber required to be about 25%~45% higher than conventional steel fiber.

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