VIII International Conference on Fracture Mechanics of Concrete and Concrete Structures
FraMCoS-8
J.G.M. Van Mier, G. Ruiz, C. Andrade, R.C. Yu and X.X. Zhang (Eds)

UNIAXIAL FRACTURE ENERGY OF WASTE TYRE RUBBER CONCRETE

ILDIKO MERTA[*] AND ELMAR K. TSCHEGG[*]

[*] University of Technology Vienna, Institute for Building Construction and Technology
Karlsplatz 13/206/4, 1040 Vienna, Austria
e-mail: ildiko.merta@tuwien.ac.at, www. hochbau.tuwien.ac.at

Key words: Uniaxial Fracture Energy, Wedge Splitting Test, Reinforced Concrete, Waste Tyre Rubber

Abstract: This paper reports on an experimental study of the uniaxial fracture energy of concrete reinforced with waste tyre rubber granulates of different size and with waste tyre chips containing steel belt wires. The concrete mixture has been prepared to provide a concrete class of C25/30 according to Eurocode 2 normally used for typical slab-on-ground applications. Three different rubbers granulate: 0.4-0.7 mm, 2-3mm and 3-6mm and tyre chips of a size up to 20mm have been used. The dosage in the concrete matrix was kept 3.2% by volume. Cubic concrete specimens of dimensions 150×150×130 mm, with a 30 mm long and 3 mm wide starter notch cut at the top were uniaxially tested with the wedge splitting test method according to Tschegg. The addition of waste tyre particles was found to improve the post-crack ductility and fracture energy of plane concrete. The most distinctive increase was observed by concretes with waste tyre chips.

1 INTRODUCTION

Addition of steel fibre reinforcement to concrete very effectively enhances the deficiencies of low tensile strength, crack resistance and energy absorption capacity of plane concrete. However, the manufacturing process of steel fibre reinforcement requires an extremely high energy-consuming process. The motivation for this research was to find energy saving alternatives to steel fibres in concrete applications where high crack resistance and increased energy absorption capacity is needed, such as slabs-on-ground, industrial floors, pavements or overlay constructions. In recent years the addition of waste crumb rubber to concrete has been extensively studied. However, the literature generally focuses on using the particles as replacement for coarse or fine aggregate in concrete [1-5]. Research results indicate that with the introduction of rubber particles the toughness, ductility, plastic deformation, and impact resistance of concrete increased significantly.

In this research an experimental study of the uniaxial fracture energy of concrete reinforced with waste tyre rubber granulates of different size and with waste tyre chips containing steel belt wires has been carried out employing the wedge splitting test method according to Tschegg [6, 7].

2 EXPERIMENTAL PROGRAM

2.1 Concrete Specimens

For experimental work concrete specimens of dimensions 150×150×130 mm³ with a 30 mm long and 3 mm wide starter notch cut at the top of the specimen have been employed. The rectangular groove on the upper side of the cube, needed for the load transmission pieces, is achieved by gluing two stone pieces thereon (Fig. 1).

Figure 1: Concrete specimen for the wedge splitting test according to Tschegg [6, 7].

Concrete of a class of C25/30 according to Eurocode 2 standard has been used with a characteristic cylinder compressive strength of 25 N/mm^2. The coarse aggregate in the concrete matrix used was river gravel with maximum particle size of the fine aggregate 8mm and of coarse aggregate 16mm. The water/cement ratio was 0.6. The mix design proportion of the concrete matrix was as follows: water 168 kg/m^3, cement (type CEM II) 280 kg/m^3, coarse aggregate 1026 kg/m^3, fine aggregate 944 kg/m^3 and superplasticizer 18.7 g/m^3.

As fibre reinforcement, waste tyre chips and waste tyre rubber granulates of different size has been used (Fig. 2). These were supplied by one of the major tyre recycling company in Austria (Asamer) and originate from different types of cars and trucks.

Tyre chips (Fig. 2d) are the result of the secondary shredding process and they contain a relatively small quantity of high tensile strength (1500-1900 N/mm^2) steel belt wires and rubber particles of different size. The size of the tyre chips used for the specimens of the MV5 series was up to 20 mm (Table 1).

Table 1: Concrete specimens

Specimen	Type of reinforc.	Size range
MV1	--	--
MV2	Rubber granulate (Fig. 2a)	0.4-0.7 mm
MV3	Rubber granulate (Fig. 2b)	2-3 mm
MV4	Rubber granulate (Fig. 2c)	3-6 mm
MV5	Tyre chip (Fig. 2d)	up to 20 mm

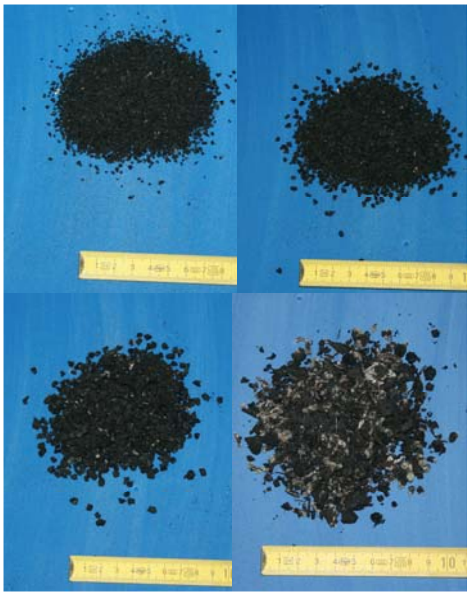

Figure 2: Waste tyre rubber granulates and chips added to the concrete matrix.

The rubber granulates (Fig. 2a, b, and c) are the result of the separation process of rubber and steel wires after the secondary shredding process. Three different granulate size range have been used for the specimens MV2, MV3 and MV4 (Table 1).

The dosage of chips and rubber granulates in the concrete matrix was 3.2% by volume.

2.2 The Wedge Splitting Test Method

In the research the uniaxial fracture toughness of the concrete specimens have been determined with the widely adopted wedge splitting test method (WST), originally developed by Tschegg [6, 7]. It is a very stable fracture mechanics test capable to determine accurately the load displacement diagram of the test specimens beyond the maximum load. The major advantages of the WST are that the specimens are small and compact, the method does not require any sophisticated test equipment; it stores little elastic energy during testing and is well suited for inverse analysis. The WST method was comprehensively investigated by many scientists and it has been proved reliable for fracture testing of ordinary concrete at early age and later for lightweight concrete and for concrete reinforced with steel and synthetic fibres.

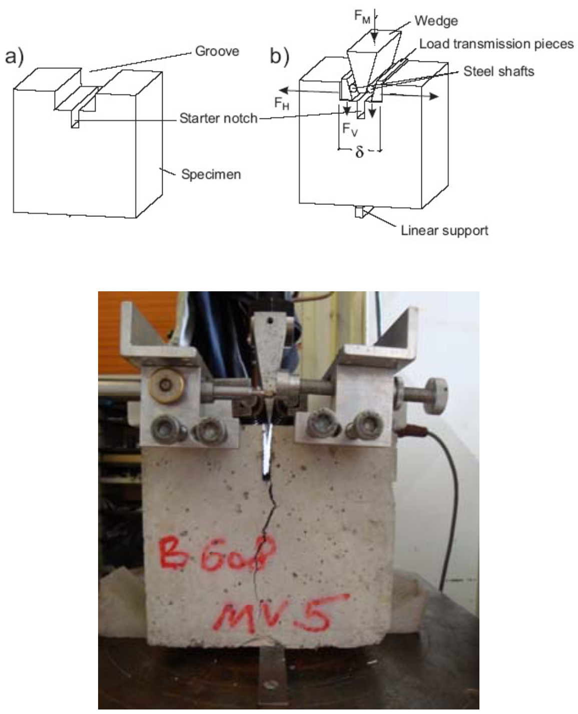

Figure 3: Principle of the wedge splitting test according to Tschegg [6, 7].

Figure 3 shows the setup of the WST method for uniaxial loading of a cubic specimen. The specimen is provided with a rectangular groove and a starter notch at the top (Figure 3a). The specimen is than positioned on a narrow linear support and the two load transmission pieces and a slender wedge are inserted in the groove. (Figure 3b and c) The load F_M produced by the testing machine is transferred by the load transmission pieces from the wedge into the specimen, which leads to the splitting of the specimen. The friction between the wedge and load transmission pieces (equipped with ball bearings) is negligibly small (<1%). The vertical force F_M, of the testing machine is converted to a large horizontal force F_H and into small vertical force F_V that does not disturb the propagation of the crack. The splitting force F_H breaks the specimen in mode I. The crack mouth opening displacement (CMOD) is determined at the height of the load application line on both sides by electronic displacement transducers. The two electronic displacement transducers are used

Figure 4: Wedge splitting testing machine.

on the one hand to obtain the average of the load displacement and on the other hand serve as crack behaviour detectors. If the crack runs obliquely to the notch, the specimen is eliminated.

The tests were carried out with a mechanical testing machine from Schenck RSA with a load capacity of 100 kN and a rigidity of 8×10^{-3} mm/kN (Fig. 4). The cross-head speed was kept constant with 0.5 mm/min for all tests. This loading rate corresponds roughly to the RILEM recommendation (TC-50 FMC 1985) [8]. The tests were carried out at a temperature of 21°C and a relative humidity of around 50%. The measured data were recorded by means of a state-of-the-art data acquisition system. First the load-displacement curves were determined and then from these the notch tensile strength and the fracture energy (crack resistance) were obtained. The displacement in the load-displacement curve represents the average value of the two displacement transducers.

From the load-CMOD curves the fracture energy absorbed by the specimens during the crack propagation until the separation of the fracture surfaces has been calculated.

3 RESULTS

3.1 Specimen's Notch Tensile Strength

The peak value of the load-displacement curve is defined as the notch tensile strength. The mean value and the standard deviation of the notch tensile strength of the specimens are given in the Figure 5. With addition of rubber granulates to concrete the notch tensile strength of the concrete decreases. For the specimens with low size rubber granulate (specimens MV2 and MV3) the decrease is up to 15% whereas for the specimens with higher size rubber granulate and tyre chips (specimens MV4 and MV5) the decrease is about 10%

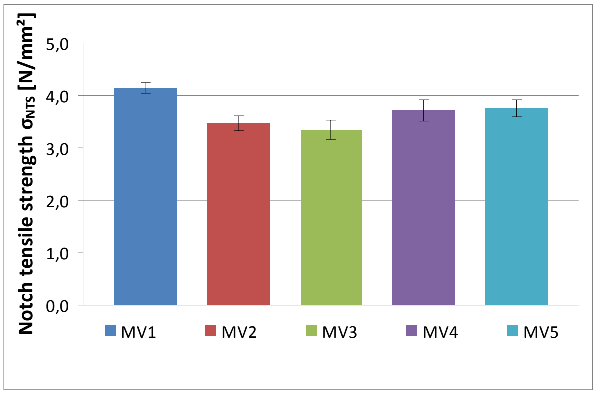

Figure 5: Mean value of the notch tensile strength of the specimens.

3.2 Specimen's Fracture Energy

The fracture energy G_f [N/m] is defined as the post-crack energy absorption ability of the material and it represents the fracture energy that the structure will absorb during failure. It was calculated as the area under the splitting force-displacement curve until the complete separation of the fracture surfaces. The fracture energy for each series of the test specimens is given in Figure 6.

The results shows that the presence of tyre chips (specimens MV5) and rubber granulates of larger size (specimens MV4) enhances the fracture energy of the plane concrete The most distinctive increase in fracture energy of specimens compared to unreinforced concrete specimens was observed by addition of tyre chips, i.e., up to 140% (specimens MV5).

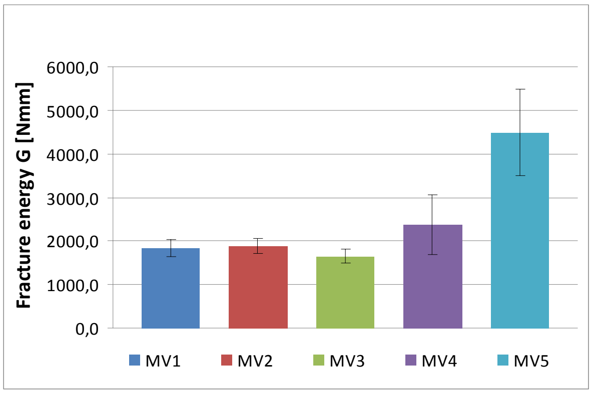

Figure 6: Mean value of the fracture energy of the specimens.

By the MV4 series the addition of rubber granulate to concrete resulted in a 30% enhancement of the fracture energy of the plane concrete. By other two series MV2 and MV3 there was no enhancement observed.

The significant enhancement of the fracture energy of tyre chip reinforced concrete specimens is believed to be the result of the presence of the steel wires with combination of the rubber particles of different size.

In such a way the cracking process during different stages of loading could be affected. Rubber particles of smaller size can bridge the microcracks efficiently, which develop in the first phases of the tensile loading and the particles of larger size and steel wires can be activated as bridging mechanisms at larger cracks.

4 CONCLUSIONS

In this research an experimental study of the uniaxial fracture energy of concrete reinforced with waste tyre rubber granulates of different size and with waste tyre chips containing steel belt wires has been carried out.

It was observed that with addition of rubber granulates and tyre chips to concrete the notch tensile strength of the concrete decreases about 10-15%. With the addition of 3.2% tyre chips by volume to the concrete a 140% increase of the fracture energy compared to plane concrete has been achieved. However further research is needed with higher dosage of chips and rubber granulates in the concrete matrix.

ACKNOWLEDGEMENT

For gratuitous provision of the concrete specimens and waste tyre granulates for the research the authors wish to express their appreciation to the following association and company: VÖZ (Association of the Austrian Cement Industry) and ART Asamer Rubber Technology GmbH.

The authors acknowledge the support of Dr. Michael Jamek, Kilian Heil and Christian Hinterleitner by the experiments.

REFERENCES

[1] Kumaran, G. S., Mushule, N. and Lakshmipathy, M., 2008. A Review on Construction Technologies that Enables Environmental Protection: Rubberized Concrete. *Am. J. of Eng. and Appl. Sc.* **1**, 40-44.

[2] Hernandez-Olivares, F., Barluenga, G., Bollati, M. and Witoszek, B., 2002. Static and dynamic behaviour of recycled tyre rubber-filled concrete. *Cem. and Conc. Res.* **32**, 1587–1596.

[3] Batayneh, M. K., Marie, I. and Asi, I., 2008. Promoting the use of crumb rubber concrete in developing countries. *Waste Management*. **28**(11), 2171-2176.

[4] Aiello, M.A. and Leuzzi, F., 2010. Waste tyre rubberized concrete: Properties at fresh and hardened state. *Waste Management*. **30** (8-9), 1696-1704

[5] Khaloo, A. R., Dehestani, M. and Rahmatabadi, P., 2008. Mechanical properties of concrete containing a high volume of tire–rubber particles. *Waste Management*. **28**(12), 2472-2482.

[6] Tschegg, E. K., 1986. Equipment and appropriate specimen shapes for tests to measure fracture values. Austrian Patent Nr. 390328, Austrian Patent Office, 31.1.1986.

[7] Austrian Norm, ÖNORM B3592, 2011. Determination of the notch tensile strength and specific fracture energy of building materials, building material conections and sandwich materials – *The wedge splitting test method* (Bestimmung der Kerb-Spaltzugfestigkeit und der spezifischen Bruchenergie von Baustoffen, Baustoffverbindungen und Verbundwerkstoffen – *Keilspaltmethode***)**

[8] RILEM TC-50 FMC, 1985. Determination of the Fracture Energy of Mortar and Concrete by Means of Three-point Bend Tests on Notched Beams. *Materials and Structures*, **18**, No. 4, pp. 285.