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# Experimental studies on the behavior of concrete-filled steel tubes incorporating crumb rubber

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ABSTRACT

This study summarizes the results of experimental push-out tests conducted on concrete-filled steel tubes (CFST) incorporating rubberized concrete with the main variables being the recycled rubber replacement ratio, certain sizes of steel tubes having circular and square sections and ages of testing (at 28 days and one year). In addition, 150 mm-cubes were prepared using rubberized concrete mixtures to investigate the impact of shredded rubber contents on the compressive strength of concrete. Four concrete mixtures were designed at a constant water-to-cement ratio of 0.5 and with a cement content of 400 kg/m$^3$. The mixtures were produced by replacing the fine aggregate with crumb-shredded tires at designated replacement levels of zero, 10%, 20% and 30% by total fine aggregate volume. Test results indicated that the use of rubber crumb increased the fresh-state workability and had an adverse influence on the compressive strength of concrete. The details of bond stress and the interface core slip in CFST specimens were estimated and the developed bond mechanisms were explained. The push-out testing of CFST specimens displayed a reduction in the bond strength and the ductility with increasing concrete age.


## 1. Introduction

Recycling of scrap tire is becoming more important with the global expanding of the environmental problem of the accumulation of scrap tire in landfills. 290 million tires are produced yearly in the united states beside an existing 275 million tires are stockpiled [1]. About 5 billion tires is expected to be discarded by the year 2030 due to the increasing number of motor vehicles [2]. This has motivated many researchers to investigate the effect of using the materials extracted out of the recycled tire such as steel fibers and rubber, especially, in the construction materials.

Although research shows that using untreated tire rubber in concrete mixtures can inversely affect the compressive strength, the research shows that it can enhance other properties such as crack propagation, sound and energy absorption, ductility and durability. Furthermore, it can be used to produce lightweight construction materials, which are mainly used for non-structural elements in construction.

Many researchers have put the light on the impact of using rubber as a partial replacement of concrete aggregate on the mechanical properties and durability. Toutanji [3] tested the effect of replacing mineral coarse aggregates with rubber chips with volume percentages of 25%, 50%, 75% and 100% of the coarse aggregate volume. The results showed a reduction in both the slump and compressive strength along with the increment of the volume percentage of rubber chips. Aiello and Leuzzi [4] investigated strength and workability of concrete prepared by using different percentages of volume replacement of both coarse and fine mineral aggregates by similar particle size of coarse and fine rubber. Slump test showed that the workability of concrete mixtures was improved with the increment of rubber replacement. In addition, the loss in compressive strength was more progressive when replacing coarse aggregates with coarse rubber than when replacing fine aggregates with fine rubber. Emiraglue et al. [5] studied the bond strength of rubberized self-compacting concrete (RSCC) and deformed reinforced bars at the ages of 7 and 28 days. A fiber shape rubber was used to replace coarse aggregates by using different volume percentages. It was found that a decrease in slump flow and compressive strength as the rubber content increased. Moreover, a reduction in bond strength was obtained with the increment in rubber content after the 15% replacement of coarse aggregates at both ages.

Concrete-filled steel tubes (CFST) are being used widely in civil engineering projects due to their high strength, high ductility and excellent static and seismic-resistant properties. The steel tube confining the concrete infill enhances its strength and ductility, whilst the concrete core delays the steel tube's local buckling. Thus, the resulting composite sections have relatively high strength and stiffness if compared to ordinary reinforced concrete sections which leading to smaller sections as well as the steel tubes act as formwork for the concrete and they can support significant loads before the final setting of the concrete thereby decreasing the construction time.

Many researchers have used push-out test to evaluate the load that cause slippage between concrete core and steel tube in concrete-filled steel tube (CFST). Early research on the bond strength in CFST was investigated by Virdi and Dowling [6] who tested the bond strength between the concrete infill and the inner surface of the CFST tested at 7, 14, 21 and 28 days. The results revealed a slight reduction in the bond

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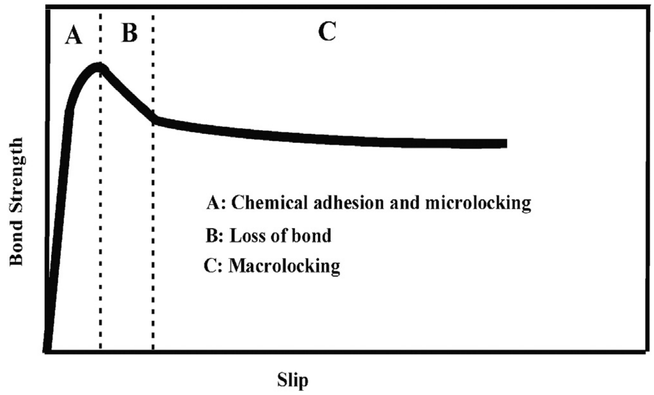


**Fig. 1.** Idealized bond strength-slip curve of push-out test specimens.

strength as the concrete compressive strength increased. Roeder et al. [7] studied the effects of shrinkage, tube dimensions, pressure of wet concrete and internal surface irregularity of the tube on the interfacial bond strength. They conducted a series of push-out tests on CFST specimens with lengths between 758 and 1927 mm, and d/t ratios between 20 and 110 trying to simulate those used in the field. The results revealed that the irregularities in the steel tubes with large d/t did not play a major role in bond strength. Hunaiti [8] conducted push-out tests to investigate the composite action of concrete infill type, the steel tube shape and the concrete infill age on the bond strength between the outer surface of concrete infill and the inner surface of steel tube in CFST. The results showed more improvement of the bond strength in the circular sections than that of the square sections at both ages of 45 and 90 days. A reduction in bond strength with age for both shapes of specimens was recorded. Other investigations studied the effect of cyclic push-out force [9], cyclic shear force [10] use of expansive cement [11] and concrete compaction [12] on the bond strength.

The main parameters considered in the forgoing findings affecting the bond strength are the lubrication [13], interface roughness [7,14, 15,16–19], compaction [17,12], cross-section geometry [7,21,15,22,18, 20], shrinkage [7,21,15,17,18,11] and concrete age [17,9,20].

Based on findings of the mechanism of bond strength, two distinct components contributing to the bond strength were identified excluding the chemical adhesion, namely microlocking and macrolocking. Microlocking is the key between the concrete and the roughness of the steel surface while macrolocking is the resistance to moving of the concrete core along the tube concrete interface due to the manufacturing tolerances associated with the internal tube sizes [17]. Fig. 1 shows the response of CFST subjected to push-out forces where the three stages of bond strength are appeared in terms of an idealized bond strength-slip curve. The chemical adhesion and microlocking of the bond making the linear part of the curve and contribute to the attainment of the maximum bond stress have to be broken for slippage to occur, whereupon macrolocking is activated and determines the residual bond stress [17,20].

Using concrete mixtures in hollow section steel tubes can increase bearing strength, fire resistance, and buckling resistance for the CFST columns. Incorporating rubber in the concrete mixtures of CFST can be a good method of recycling rubber extracted from disposed scrap tires, because the effect of rubber in strength reduction can be overcome. Furthermore, using rubber as a partial replacement for mineral aggregates in concrete mixtures will help to reduce the weight of the structure. Therefore, the cross section dimensions for columns and other structural elements can be reduced.

Bond between concrete and steel in CFST is an important criterion to insure whether the two materials are acting as composite or individual materials. This study aims at investigating some factors that might affect the bond strength in rubberized CFST such as size and percentage of mineral aggregates replaced by rubber, the geometric shape of the steel tube sections, and concrete infill age or the duration of the specimens exposed to weathering.

## 2. Materials and experimental work

### 2.1. Materials

Pozolanic Portland Cement CEM II/A-P 42.5N conforming to the European standards EN 197–1:200 and natural crushed fine and coarse limestone aggregates were used in preparing different concrete mixes. Coarse aggregate at a maximum aggregate size of 25 mm and specific gravity of 2.45 (ASTM C127) was used along with fine aggregates having a fineness modulus of 2.8 and specific gravity of 2.45 (ASTM C128). Fig. 2 shows the sieve analysis diagram of fine and coarse aggregates determined according to ASTM C136.

A mechanical shredded scrap tires provided from a tire-recycling company was used in this study. No any type of treatment or water washing was done on the rubber. The rubber used was fine shredded rubber (crumb) with a size range of 0.6 to 2.36 mm and fineness modulus of 2.35. Sieve analysis curve according to ASTM C136 standard for a sample of about 5 kg was conducted and shown in Fig. 3. The chemical composition and physical properties of the crumb rubber used in this study were provided by the recycling company and listed in Table 1.

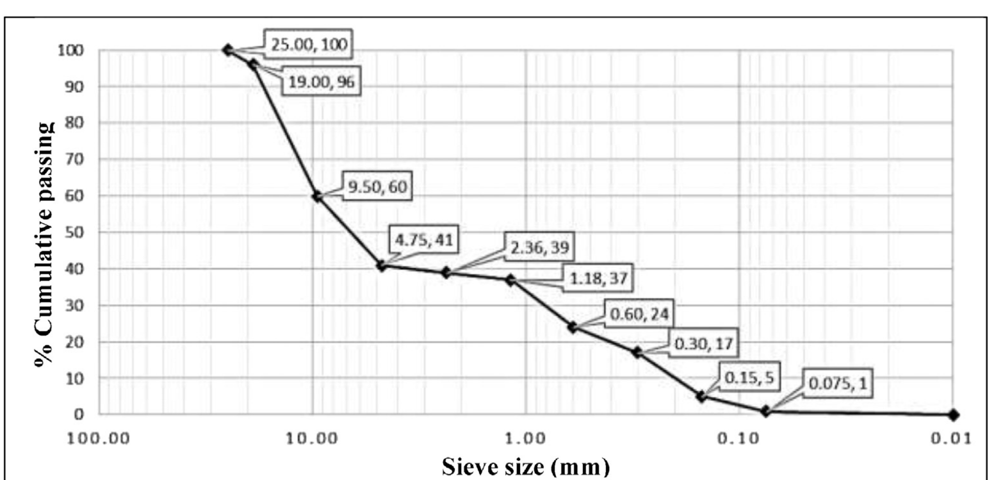


**Fig. 2.** Aggregate gradation.