Construction and Building Materials 113 (2016) 544–552

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Pullout capacity of ladder-type metal reinforcements in tire shred-sand mixtures

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HIGHLIGHTS

- Experimental investigation of pullout capacity of ladder-type metal reinforecments backfilled in tire shred-sand mixtures.
- Higher pullout capacity of reinforcement embedded in the tire shred-sand mixtures than in sand alone by about 26–92% for the normal stresses considered in this study.
- Preliminary guidelines on the pullout capacity of ladder-type reinforcement backfilled with different tire-shred sand mixtures.

ARTICLE INFO

Article history:
Received 6 August 2015
Received in revised form 10 February 2016
Accepted 23 February 2016
Available online 24 March 2016

Keywords:
Tire shreds
Lightweight backfill
Reinforcement
Pullout capacity
MSE walls

ABSTRACT

Tire shreds have gained wide acceptance as an engineered fill in the last two decades. Ladder-type metal reinforcement can be used to reinforce MSE walls with tire shred-sand mixtures as a backfill material. This paper reports the results of laboratory pullout testing performed on ladder-type metal reinforcement embedded in tire shred-sand mixtures. The ladder-type metal reinforcement consists of two parallel longitudinal steel bars welded to a series of cross bars forming rectangular apertures. Mixtures of Ottawa sand with 50–100 mm size tire shreds were prepared at different mixing ratios (0%, 20%, 25%, and 35% by weight of tire shreds). Pullout tests were performed under three normal stresses – 40 kPa, 65 kPa, and 90 kPa. The test results show that the ladder-type metal reinforcement provides higher pullout resistance in tire shred-sand mixtures than in sand alone. Compared to metal-strip reinforcement, ladder-type metal reinforcement provides higher pullout capacity due to the passive resistance that results from the interlocking of tire shreds within the grids of the ladder-type reinforcement. The pullout resistance increased with increasing tire shred content up to 35% (by weight of tire shreds), beyond which segregation of the mixtures was observed.

1. Introduction

About 233 million scrap tires were generated in the U.S. in 2013, while an additional 75 million scrap tires remained in stockpiles [30]. In addition, there has been a steady rise in scrap tire production in the U.S. and in other parts of the world [28,25].

In the tire shredding process, two methods are commonly used to reduce the size of whole tires: (a) cryogenic processing and (b) mechanical grinding [8]. The mechanical grinding process, which is much cheaper than the cryogenic process, reduces scrap tires to different sizes. ASTM D 6270 [6] defines tire shreds as pieces of scrap tires with sizes between 50 mm and 305 mm. Reduction of whole scrap tires to ground or particulate rubber size (0.425 mm to 2 mm) requires many cycles through the shredder unit. Hence, it is more economical to use large-size tire shreds in civil engineering applications. Large-volume utilization of tire shreds as a fill material can help reduce the amount of scrap tires stockpiled every year. The advantages of using tire shreds as a fill material include availability and low cost [24,29], light weight [27], good stiffness and shear strength [8,23,40,7,38,19,26,10,36], high hydraulic conductivity [35], and ease of placement and compaction in the field [16,32]. Resistance to utilization of tire shreds in civil engineering projects is often attributed to unavailability of tire shreds near construction sites and lack of design standards and detailed construction guidelines [21]. However, extensive

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http://dx.doi.org/10.1016/j.conbuildmat.2016.02.160
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List of notations

G_{TS}	is the specific gravity of tire shreds
G_S	is the specific gravity of Ottawa sand
P_{ult}	is the pullout capacity obtained from the pullout test
F^*	is the pullout resistance factor
α	is the scale effect correction factor for nonlinear stress reduction over the embedded length
σ_v'	is the vertical effective stress at depth of reinforcement-soil interface
L_e	is the embedment length of the reinforcement
B	is the width of the reinforcement
C	is the effective unit perimeter of the reinforcement

studies conducted by many researchers in the last two decades have led to better understanding of the behavior of this engineered material.

Tire shred-sand mixtures have gained wide acceptance in the last twenty years, leading to their utilization in construction of geotechnical structures. One such application is the use of tire shred-soil mixtures as a backfill material for mechanically stabilized earth (MSE) walls. Tire shred-soil mixtures can be reinforced with extensible (geotextiles or geogrids) or inextensible (metal strips or metal grids) components.

An important design consideration for such reinforcements embedded in tire shred-soil mixtures is their pullout resistance. Pullout resistance is mobilized through the interaction between the mixture and the reinforcement, as the pullout force is applied on the reinforcement. According to Federal Highway Administration (FHWA) guidelines [12], the pullout resistance of reinforcement can be calculated as:

$$P_{ult} = F^* \alpha \sigma'_v L_e B C \quad (1)$$

where P_{ult} is the pullout resistance of the reinforcement, F^* is the pullout resistance factor, α is the scale effect correction factor for nonlinear stress reduction over the embedded length, σ_v' is the vertical effective stress at the depth of the reinforcement-soil interface, L_e is the embedment length of the reinforcement, B is the width of the reinforcement and C is the effective unit perimeter of the reinforcement. $L_e \times C$ is the total surface area per unit width of the reinforcement in the zone of resistance beyond the slip surface. Berg et al. [12] prescribes values of $\alpha = 1.0$ (for metallic reinforcement) and $C = 2.0$ (for strips and grid reinforcement).

Full-scale field and laboratory studies have been performed to understand the interaction of geogrids with tire shred-sand mixtures [33,13,14,9,37,31,11]. These studies indicate that the pullout capacities of geogrids in tire shred-sand mixtures are similar or higher than that of geogrids embedded in sand alone. Youwai et al. [39] studied the pullout behavior of hexagonal wire reinforcement and suggested that the required embedment length in the resisting zone is similar for sand and tire shred-sand mixtures. Balunaini and Prezzi [9] performed laboratory pullout tests on ribbed-metal-strip reinforcement, showing that the pullout capacity of ribbed-metal strips in tire shred-sand mixtures lies between the capacities obtained in sand alone (upper boundary) and tire shreds alone (lower boundary). Also, the pullout capacities of ribbed-metal-strips decreased with increasing tire shred content of the mixtures [9].

Ladder-type steel reinforcement, because of their geometry, has a potential for increased pullout capacity due to the additional passive resistance when tire shreds get interlocked within the grid-like structure of the ladder. The main sources of pullout resistance for the ladder-type metal reinforcement are: (1) shear resistance developed due to friction at the mixture-reinforcement interface (along the longitudinal and transverse bars) through the embedded length of the ladder [see Fig. 1(a)], and (2) passive resistance generated by the sand particles and tire shreds wedged against the transverse bars of the ladder [see Fig. 1(b)]. The sources of pullout resistance are the same for both ladder-type metal reinforcement and geogrid reinforcement while the pullout resistance is due mainly to interface shear resistance for metal strips.

The objective of this paper is to investigate the pullout capacity of ladder-type steel reinforcement embedded in tire shred-sand mixtures by performing a series of pullout tests. The size of the voids within the tire shred matrix increases with increases in the tire shred sizes. As the size of tire shreds increases, segregation of sand becomes predominant in mixtures of tire shreds and sand with large tire shred content. Hence, considering the balance between the economics of the tire shredding process and the potential segregation of sand, tire shreds with sizes between 50 and 100 mm were used in the present study. Samples were prepared in a pullout box at mixing ratios of 0%, 20%, 25%, and 35% by weight of tire shreds. At each mixing ratio, pullout tests were performed at three normal stresses – 40, 65 and 90 kPa. Pullout resistance factors F^* were calculated from the pullout test results for ladder-type metal reinforcement. A few tests were performed on ladder-type reinforcement embedded in tire chip-sand mixtures (25% and 35% by weight of tire chips) to study the effect of size of tire shred on the pullout resistance of the reinforcement. In addition, the pullout capacity and resistance factor values from ladder-type metal reinforcement were compared with those obtained from ribbed-metal-strip reinforcement provided in Balunaini and Prezzi [9].

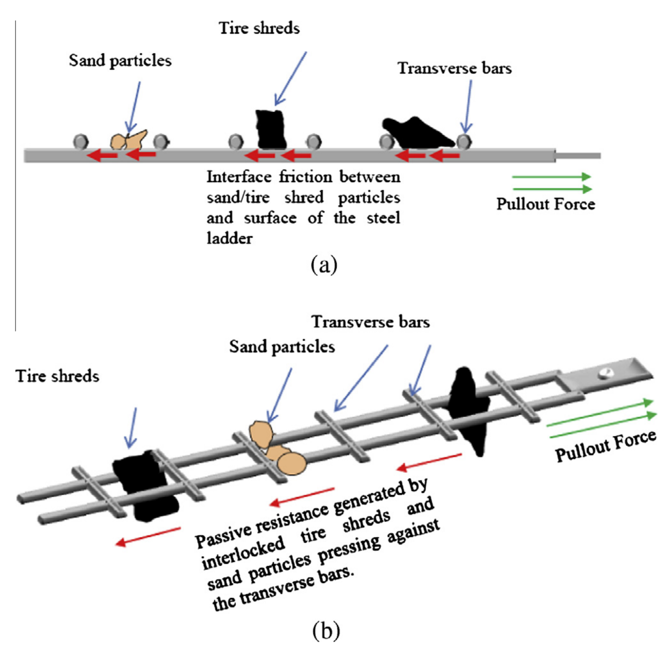

Fig. 1. Mechanism of development of pullout resistance for ladder-type metal reinforcement (a) interface friction, and (b) passive resistance from the interlocking of particles within the reinforcement grid – not to scale (after D. Mohan [15]).