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ENHANCING THE FLEXURAL LOAD CAPACITY OF THE REINFORCED CONCRETE SIMPLY SUPPORTED SLABS USING DAMAGED TIRES STRIPS (DTS)

Key words: flexural strength, reinforced concrete slabs, damaged tires strips

Introduction

One of the most difficult and problematic waste materials is the used tires of vehicles (Elnour & Laz, 2014; Bulei, Todor, Heput & Kiss, 2018). The disposal of damaged vehicle tires in some countries is a problem of increasing significance due to the annually incessant accumulation of more than a hundred million tires which are treated by either burning, backfilling, storing or dumping illegally (Edil, Park & Kim, 2004; Garrick, 2005). All these procedures are not friendly environment solutions, for instance, the burning process of tires pollutes the air and dumping them wastes valuable land for storing. Also, they exhibit unfavored site vision, host for the growing of mosquito larvae, fire risk, and generated harmful gases, such as carcinogens when stockpiled (Garrick, 2005; Simalti & Singh, 2021). Avoiding the continuous accumulation of damaged vehicle tires needs to develop novelty methods of recycling and reusing the used tires to dispose them safely and economically. The recycling process aims to exploit the advantages that available in the raw materials of the damaged vehicle tires characterized by unique properties such as tensile resistance, sound concealment, and high chemical absorption (Edil et al., 2004).

The objectivity of using the damaged tire strips as an additional reinforcement in the field of construction is to achieve two concepts, a clean environment and economic considerations. A clean environment is achieved by consuming the damaged vehicles tires accumulated in the societies while

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the economic considerations are represented by reducing the consumption of raw materials, increasing the thermal insulation due to the existed rubber material and saving the cost of the recycling process by using damaged tires directly. Recycling of damaged vehicle tires requires, usually, either mechanical or thermal preparation processes to convert them into useful materials. In the mechanical process, the steel cords in the tires are pulled out by a punch-like mechanism in order to be shredded and the remaining steel could be extracted by magnetic separators. The mechanical process produces crumb rubber (rubber granules) and steel cords. The thermal (pyrolysis) recycling process technique, on the other hand, uses a thermochemical method to decompose the tire. This technique produces, in addition to steel, carbon black and oil (Sengul, 2016) which are not ambient friendly productions. Using the damaged vehicle tires in the structural field satisfies sustainability concept and economic considerations if they can be used to replace raw construction materials made from limited resources (Edil et al., 2004).

Various methods for recycling of scrap tires have been suggested since the 1940s (Cao, 2007). Recently, researchers have been interested by the optimal disposal of waste tires (Yildirim, 2007; Celik & Atiş, 2008) which may be recycled using modern technologies such as chipping tires and convalescing steel cords to extract the useful materials within the tire contents (Bdour & Al-Khalayleh, 2010). The extracted useful materials could be used in several aspects within the civil construction field. For instance, graded rubber particles obtained from damaged tires are used as aggregate in the concrete mix by the partially replacement of the coarse or fine natural aggregate (Habib, Yildirim & Eren, 2020; Sharaky, Mohamed, Torres & Emara, 2020). Other studies (Sengul, 2016; Simalti & Singh, 2021) have investigated the ability of using the extracted steel pieces obtained from the recycled tires as steel fibers to produce fibrous concrete instead of the commercial types of fibers. Also, recycled damaged tires in the form of powder material was introduced as a material that could be used to replace part of the cement content in the concrete mix (Li, Ruan & Zeng, 2014; Valente & Sibai, 2019). Another aspects, such as asphaltic concrete (Shu & Huang, 2014) or concrete walls (Cecich, Gonzales, Hoisaeter, Williams & Reddy, 1996) are cases that were investigated to consume the recycled damaged tires. In the structural field, the reinforced concrete one-way slabs (RCOWS) and the reinforced concrete two-way slabs (RCTWS) give the opportunity as suitable structural members to be reinforced with the damaged tires strips (DTS) as an additional reinforcement. The ability of extracting the damaged tires strips (DTS) from the original tire frame directly by using a simple mechanical method used in the present work provides a friendly-environment recycling method rather than methods adopted in literature which are themselves considered as pollution operations (Pilakoutas, Neocleous & Tlemat, 2004).

The flexural strength of the structural members is very significant in the design of any structure. So, the present work investigates the flexural behavior of the reinforced concrete one-way slabs (RCOWS) and the reinforced concrete two-way slabs (RCTWS) in simply supported condition based on experimental tests. For the tested specimens, the study investigates the ability of increasing the flexural strength capacity as well as reducing the central deflection due to the application of DTS as an innovative additional reinforcing material that is not used before for such purpose.

Material and methods

Adopted specimens and reinforcement

The investigation includes testing of two groups of structural members reinforced by the DTS as an additional reinforcement. Group one represents the reinforced concrete one-way slabs (RCOWS) models while group two includes the reinforced concrete two-way slabs (RCTWS) models. Eight adopted specimens were investigated within the first group being with dimensions of 2,000 × 500 × 110 mm respectively represent length, width and thickness of the slab such that the effective span is 1,800 mm for each model, as illustrated in Figure 1.

All specimens of the RCOWS group consist of three Ø8 mm steel bars spaced at 150 mm c/c, in tension zone while Ø8 mm steel bars are used as a secondary reinforcement, for shrinkage and temperature, distributed along the length of the slab spaced at 250 mm c/c. For the RCTWS group, one test specimen reinforced by the DTS as a case study in addition to the control specimen were investigated with dimensions of 1,000 × 1,000 × 100 mm respectively represent length, width and thickness of the slab such that the effective span is 950 mm for each model, as shown in Figure 2. The main reinforcement of the RCTWS group is represented by a square steel mesh of Ø6 mm of bars spaced at 150 mm in two directions for all specimens, as shown in Figure 2.

Adopted categories of the DTS

Based on the adopted RCOWS and RCTWS groups, DTS were prepared according to two categories. The first category, adopted in the RCOWS models, represents DTS with dimensions of 1,960 mm length, 200 mm width and 10 mm thickness while the second category has the dimensions of 960 mm length, 150 mm width and 10 mm thickness used in the case of RCTWS models. As a main component consists the tire frame, the steel-cord construction of the standard tire casing is 4@0.28 mm (the cable is made up of four filaments) placed within ±23° inclination in the tire belt (Edeskär, 2004). It is expected that DTS have the ability to increase the ultimate flexural load capacity due to the existence of steel wire mesh within texture of the tires strip when they are fixed throughout the slab tension zone.

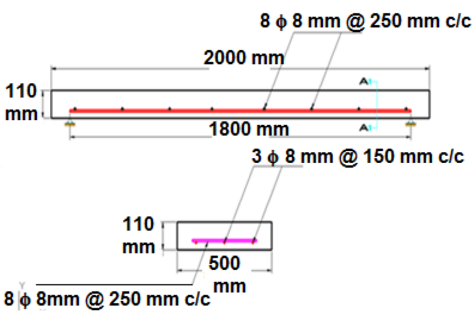

FIGURE 1. Details of the tested RCOWS control model

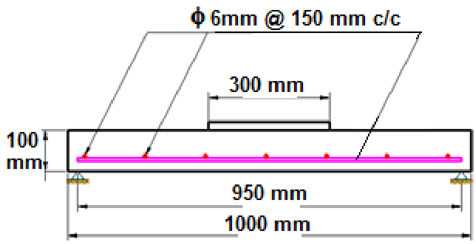

FIGURE 2. Details of tested RCTWS control model

Investigated parameters for the RCOWS and RCTWS models

In the present work, seven parameters have been studied for the RCOWS models representing seven cases of study, compared with one control specimen, while one case study is investigated for the RCTWS group in addition to the control specimen as following:

– Effect of using a single layer of DTS applied in the tension zone at zero elevation from the lower face of RCOWS model, identified as SOLS.
– Similar case study mentioned in the previous point is considered except that the DTS is applied at elevation of 25 mm from the lower face of the slab, identified as SOUS.
– Effect of using double layers of DTS applied such that the first layer being above the second layer (in vertical position) placed at elevation of 25 mm from the lower face of the RCOWS model, identified as SOUDV.
– Similar case study mentioned in the previous point is considered except that the two layers are placed within the same elevation (in horizontal position) at 25 mm from the lower face of the RCOWS model, identified as SOUDH.
– Three cases of study investigate the effect of overlapping distances as 50, 100 and 200 mm with respect to the flexural load capacity for the continuous DTS, in case when they are used for long spans, applied at elevation of 25 mm from the lower face of the RCOWS model, identified as SOUSO3, SOUSO1 and SOUSO2 respectively.
– The unique case study adopted for the RCTWS group is identified as STR which study the effect of using two layers of DTS, each layer contains three strips applied horizontally separated by 150 mm distance. The first layer is applied within the zero elevation (below the main steel reinforcement) in one direction of the RCTWS model while the second layer is placed in the elevation of 25 mm from the lower face (above the steel reinforcement) in the transverse direction with respect to the first layer. In this group, one model represents the control specimen identified as STC without DTS and another model represents the investigated case study reinforced with the DTS explained earlier.

Extracting and fixing process of the DTS

The DTS should be extracted first from the used tire using hand grinding machine to be as a layer that is able to be placed and fixed within the structural members throughout the tension zone, as shown in Figure 3.

FIGURE 3. Extracting the strips from the complete tire (Valente & Sibai, 2019)

Strip's fixing process represents the placing of each tire strip over the structural member, in the adequate position, without any separation between the contacted surfaces as much as possible. DTS have, usually, curvature tendency due to the original state that they were within the tire frame, as shown in Figure 3. Therefore, this behavior should be prevented during the fixing process of the DTS over the structural member by using steel nails. The steel nails are distributed each 100 mm along the slab length, to ensure that the strip is completely placed and fixed over the slab surface.

Experimental program

Ordinary Portland cement was used to produce the concrete mix used in the present work. For all slabs, cast-in situ concrete was used and the designed mix consists of ingredients listed in Table 1 by weight.

Both of the main reinforcement and the DTS fixing processes upon the prepared molds were conducted first before concrete casting, as shown in Figure 4. Six cubes (150 × 150 × 150 mm) were used to perform compressive strength tests using a digital compressive machine with a maximum capacity of 2,000 kN with a loading rate of 0.9 kN·s^{-1} in accordance with the standard BS 8110-1 (British Standards Institution [BSI], 1997). All cubes were tested after 28 days curing and the average compressive strength value of six cubes was calculated producing f_{cu} = 41.3 MPa and f_c = 33 MPa.

All slabs' models were tested, in the structural laboratory, using 2,000 kN capacity hydraulic machine (universal machine) under 5 kN·min^{-1} loading rate, to record the ultimate flexural load. Specimens of the RCOWS group were tested until failure under two-line load, as shown in Figure 5a.

The specimens were simply supported and the supports were placed at 100 mm from the ends of the slab's edges producing 1,800 mm clear span. For the RCTWS specimens, the slabs were neatly positioned on a steel frame that acted as basic supports on four sides, as shown in Figure 5b. The effective span was 950 mm in each direction and all four supports lines were positioned at 25 mm from the slab's edges. For all tests, the central deflections were measured using a dial gauge with a sensitivity of 0.01 mm per division. Crack emergence was carefully monitored, using the crack reader, in the first stage of loading to assign and record the load value corresponding to the first generated crack. This process was continued until the failure stage reaching. As the failure occurs, the load of failure was registered when the load becomes constant with an increase in deformation referring to the complete failure.

Results and discussion

Experimental test results for the RCOWS group

This group contains eight specimens of one-way slab models identified as SOC, SOLS, SOUS, SOUDH, SOUDV, SOUSO1,

TABLE 1. Components of the concrete mix

Average compressive strength after 28 days [MPa]	Cement content [kg·m^{-3}]	Fine aggregate content [kg·m^{-3}]	Coarse aggregate content [kg·m^{-3}]	Water content [kg·m^{-3}]
33	450	900	800	228

FIGURE 4. Reinforcement and DTS fixing processes and concrete casting for the RCOWS and RCTWS models

a b

FIGURE 5. Locations of supports and point loads for (a) RCOWS models and (b) RCTWS models

SOUSO2 and SOUSO3, which were described earlier. During the test, each model was tested such that the load was gradually subjected until the first crack appears and the first crack load in the sagging zone (at mid span) was recorded. Then, as the applied load was increased, more cracks started to form and propagate in the tension zone until the complete failure which was a flexural failure mode for all of the tested specimens such as SOC and SOUS specimens shown in Figure 6.

For each specimen, the experimentally recorded first crack load and the ultimate load as well as the observed mode of failure are listed in Table 2. In Table 2, the last column represents the percentage of increasing in the ultimate load for each DTS reinforced specimen compared to the control specimen (SOC). It is observed that the ultimate increasing ratio was 80% for the case of SOUDH specimen while the lower increasing ratio was 16% for the case of a b

FIGURE 6. SOC models (a) and SOUS models (b) in the complete failure

SOUSO3 specimen compared to the control specimen. The reason of better performance for the SOUDH specimen compared to SOUDV specimen could be attributed to the location of the two horizontally applied strips that are not interacted with the compression zone of the slab. This case happened in the case of SOUDV specimen which has DTS interacted through the slab compression zone that is not acted to enhance the flexural strength.

Figure 7 shows the load–deflection curves for all specimens investigated in the RCOWS group.

The behavior of all specimens was elastic following the same path until the first crack load. The first crack load was increased by 100% for all of the DTS – reinforced slabs compared to the control (SOC) specimen. In the second stage, the load–deflection curves behaved nonlinearly until the complete failure. In this stage, the failure was in flexural mode and it was noted that all specimens failed without any separation between the DTS and the surrounding concrete due to the efficient mechanism of shear connecters provided by the well distributed steel nails.

In case of overlapping the DTS, it was observed that the overlapping distance of 200 mm behaved better than other cases of 50 and 100 mm overlapping distances which produced an increase in load capacity of 70% relative to the control slab. Also, the use of double DTS layers placed horizontally

TABLE 2. Experimental test results for the RCOWS models

Specimen	DTS reinforcement	First crack load [kN]	Ultimate load [kN]	Increasing ratio [%]
SOC	no DTS reinforcement	5	25	–
SOLS	reinforced with single layer down	10	35	40
SOUS	reinforced with single layer up	10	33	32
SOUDH	reinforced with double layer horizontally	10	45	80
SOUDV	reinforced with double layer vertically	10	37	48
SOUSO1	reinforced with single overlap (100 mm)	10	30	20
SOUSO2	reinforced with single overlap (200 mm)	10	42.5	70
SOUSO3	reinforced with single overlap (50 mm)	10	29	16

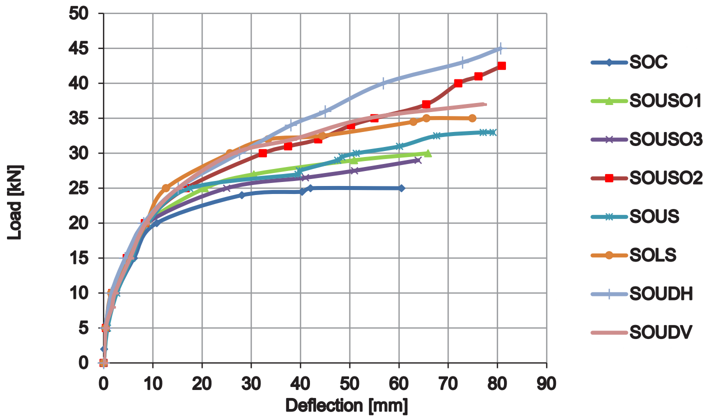

FIGURE 7. Load-deflection curves for the RCOWS group

enhance the ultimate load better than the case when the double strips placed vertically. Furthermore, the use of a single layer of DTS applied in the tension zone at zero elevation from the lower face of the model behaved better than the case when the DTS was applied at elevation of 25 mm from the lower face of the slab specimen. On the other hand, deflection values corresponding to each load value have decreased in the DTS – reinforced specimens compared to the control specimen showing a significant decrease in crack width for the DTS reinforced specimens.

Experimental test results for the RCTWS group

For both specimens adopted in the RCTWS group, identified as STC and STR, the applied load was subjected gradually until the first crack appearing. The cracks continued to appear in the tension face simultaneously with the load increasing until the complete failure of the specimen at ultimate load, as shown in Figure 8.

The test results of this specimen showed an increase in the first cracking load in the sagging zone and failure load of 100% and

a b

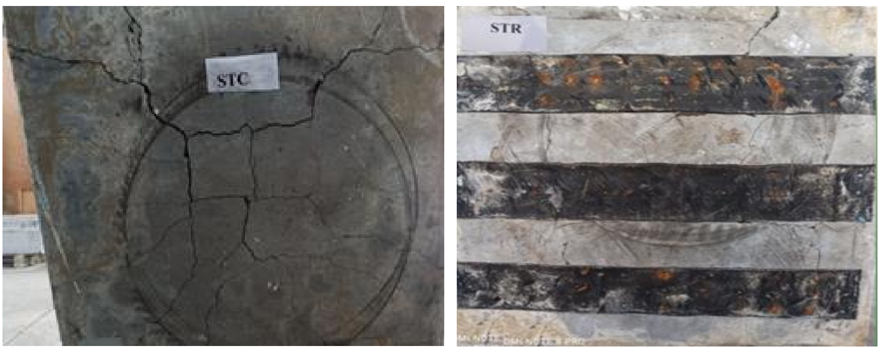

FIGURE 8. Lower face at complete failure of the (a) STC specimen and (b) STR specimen

14.286% respectively compared with the control slab STC, as listed in Table 3.

The ultimate load was increased (Table 3) with the decreasing in the deflection values when using the DTS as an additional reinforcement compared with the control specimen (Fig. 9). The amount of increasing value in ultimate load in this case study is relatively low compared with the RCOWS group cases of study due to the high stiffness of the RCTWS case study. Nevertheless, DTS was able to increase the ultimate load value which reflects the ability of adopting this material as an additional reinforcement in the structural element with relatively high stiffness property.

Statistical comparison

Due to the innovative approach of using DTS as an additional reinforcement in the reinforced concrete slabs proposed in the present study, there is no similar study available in literature to do a comparison with the obtained results. However, a statistical comparison could be implemented with another and similar strengthening material represented by the carbon fiber reinforced polymer (CFRP) that used for the same purpose. Increasing the flexural load values due to the DTS were compared with the corresponding values when using CFRP for one-way slab models obtained by Omar and Rajai (2020) as well as the results of Rami, Jamal and Hasan (2016). On the other hand, results of the increasing in flexural load capacity of the two-way slab models obtained in the present study were compared with results obtained by Dina (2019), and Balamurugan and Viswanathan (2020), as listed in Table 4.

Taking into consideration the highly cost of the CFRP compared with the approximately free cost of the DTS, the use of DTS as a strengthening material provide a good

TABLE 3. Experimental test results for the RCTWS models

Specimen	DTS reinforcement	First crack load [kN]	Ultimate load [kN]	Increasing ratio [%]
STC	no DTS reinforcement	15	112	–
STR	reinforced with DTS strips	30	128	14.286

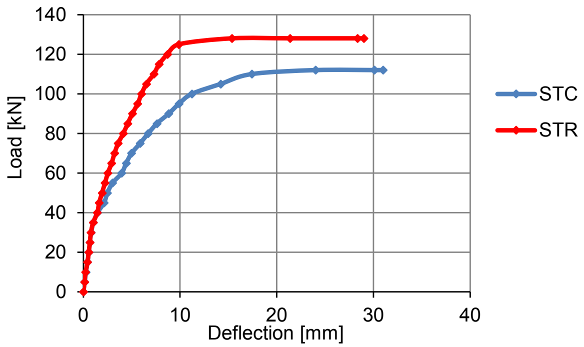

FIGURE 9. Load-deflection curves for the RCTWS group

TABLE 4. Incresing in the flexural load due to the DTS compared with the CFRP

Type of the slabs		Increasing ratios in the flexural load capacity [%]		
One-way slabs	reference	results of the present work using DTS	results of Omar and Rajai (2020) using CFRP	results of Rami et al. (2016) using CFRP
	min. ratio	16.00	41.80	69.00
	max. ratio	80.00	163.00	95.80
Two-way slabs	reference	results of the present work using DTS	results of Balamurugan and Viswanathan (2020) using CFRP	Results of Dina (2019) using CFRP
	min. ratio	–	19.45	72.00
	max. ratio	14.29	97.37	131.90

economically and friendly-environment option to enhance the flexural load capacity of the reinforced concrete slabs, as shown in Table 4.

Conclusions

In the present study, strips extracted from damaged vehicles tires were investigated experimentally as an innovative additional reinforcing material used for the reinforced concrete one-way slabs (RCOWS) and the reinforced concrete two-way slabs (RCTWS) models in addition to the main steel reinforcement to achieve the clean environment and economic considerations. The most significant observations obtained by this research could be stated as following:

- Damaged tires strips (DTS) behaved effectively as an additional reinforcing material for the reinforced concrete one-way slab (RCOWS) specimens that could increase the ultimate flexural load capacity within the range of 16–80%, depending on the case study. On the other hand, ultimate flexural load was increased for the reinforced concrete two-way slab (RCTWS) models of 14.286% for the DTS – reinforced specimen compared to the control specimen. The DTS could be used within the reinforced concrete slabs with no separation between the DTS and the surrounding concrete due to the sufficient shear strength provided by the well distributed steel nails.
- In case of overlapping the DTS, present study recommends that the overlapping distance better to be at least 200 mm that increases load capacity by about 70% relative to control slab and the use of double DTS layers placed horizontally enhances the ultimate load better than the case when the double strips placed vertically. Also, the using of a single layer of DTS applied in the tension zone at zero elevation from the lower face of the model behaves better than the case when the DTS is applied at elevation of 25 mm from the lower face of the slab specimen.
- Using of the DTS in the reinforced concrete one-way and two-way slabs models increases the first crack load by 100% compared to the control specimens. On the other hand, deflection values corresponding to each load value have decreased in the DTS reinforced specimens compared to the control specimen showing a significant decrease in the crack width values for the DTS – reinforced specimens.

– Compared with the high cost of the CFRP, the use of DTS as a strengthening material provide a good economically and friendly-environment solution to enhance the flexural load capacity of the reinforced concrete one-way and two-way slabs.

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Summary

Enhancing the flexural load capacity of the reinforced concrete simply supported slabs using damaged tires strips (DTS). Damaged tires or ended-life tires represent a difficult problem due to their ability to sustain for a long time which are not able to be dissolved easily. Present study focuses on the ability of using the damaged tires strips (DTS) in the field of structural engineering as an innovative reinforcing material used additionally with the main reinforcement. The adopted technique in the present work represents a clean solution to reuse and recycle DTS to increase the ultimate flexural capacity of the reinforced concrete one-way and two-way slabs used in structural systems satisfying clean environment and economic considerations. The tests were conducted upon eight specimens of reinforced concrete one-way slabs (RCOWS) and two specimens of reinforced concrete two-way slabs (RCTWS) reinforced by the DTS as an additional reinforcement. Experimentally obtained results exhibited enhancement for the ultimate flexural load capacity of the RCOWS and RCTWS models reinforced by the DTS in the range of 16–80 and 14.28% respectively, compared to the original reference specimens.