



STRENGTHENING OF THIN FLEXURAL MEMBERS USING STRIPS EXTRACTED FROM USED TIRES

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ABSTRACT

Present study investigates the ability of using the damaged tires in the field of structural engineering. The proposed reinforcement material in this study represents an innovative approach to reuse strips extracted from used tires to increase the ultimate flexural capacity of thin flexural members, include thin timber beams and corrugated steel plates, satisfying clean environment and economic considerations by consuming the waste materials in the structural field. Results showed that the proposed reinforcement increases the ultimate flexural load value of the thin timber beam specimens in the range of 24.113 % to 30.809 %. Similarly, the ultimate flexural load was increased in the range of 83.95% to 101.7% for the rib type corrugated steel plates specimens. Also, the deflection of the specimens has been reduced as a result of the proposed reinforcement method.

KEYWORDS: Timber Beams, Corrugated steel plates, Used Tires, Flexural Strength, finite element analysis.

1. INTRODUCTION

Increasing the production leads to increase waste materials that causes environmental, public health or aesthetic problems (Bolden J, et al 2013) and (Garrick G 2005). Recycling of waste material is the most appropriate economical solution to reduce the heavy onus on the landfills of the country (Bolden J, et al 2013). One of the most difficult and problematic waste materials is the worn tires of vehicles (Bulei, C, et al., 2018) and (Elnour M. and Laz, H. (2014). The disposal of used vehicles tires in some countries is a problem of increasing significance due to the annually incessant accumulation of more than hundred million tires which are either backfilled, stored or dumped illegally (Garrick G 2005) and (Edil, T, et al., 2004). Backfilling of damaged tires contains disadvantages represented by the big number of occupying spaces, unfavored site vision, host for the growing of mosquito larvae and fire risk (Garrick G 2005). Avoiding the continuous accumulation of used vehicles tires needs to develop novelty methods of recycling and reusing the used tires. Recycling process aims to exploit the advantages available in the raw materials of damaged tires characterized by unique properties such as tensile resistance, sound concealment and high chemical absorption. Adopting Strips of the Used Tires (SUT) 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, T, et al., 2004). Recycling of damaged tires requires, usually, either mechanical or thermal preparation processes to convert them into useful materials. Mechanical process conducted upon the tires represents extracting useful materials to be in the form of chopped small pieces or strips while the thermal process extracts useful materials such as steel wires from the tire's texture thermally (Pilakoutas, K, et al., 2004) and (Nayeem, A, et al., 2019).

Many researchers (Ahn, I, et al., 2015), (Aiello, M and Leuzzi, F, 2010), (Su, H, et al., 2015), (Moustafa, A and Elgawady, M, 2015), (Habib, A, et al., 2020), (Ahmadi, M, et al., 2017), (Youssf, O, et al., 2017) and (Sharaky, I, et. al., 2020) have suggested the use of the graded rubber particles obtained from damaged tires as aggregate in the concrete mix by the partially replacement of the coarse or fine natural aggregate. Other studies (Sengul, O, 2016), (Hu, H, et al 2018), (Simalti, A, and Singh, A, 2021) and (Köroglu, M.A., Ashour, A, 2019) 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 type fibers. Pilakoutas et al (Pilakoutas, K, et al., 2004) suggested the ability to use the extracted steel wires from the texture of used tires as fibers that could be mixed with the fresh concrete to produce fibrous concrete. it was concluded that the extracted fibers behave similarly to the behavior of standard steel

fibers which enhance the concrete ductility. However, they pointed out the need of finding the optimal way to extract steel wire from the tire's texture which reflects the complication of such a technique. [Johnny Bolden et al \(2013\)](#) referred to the successful use of used tires, extracted mechanically as a complete piece or separated, in mixes of concrete and asphalt, soil embankments, unstable soil fill or clay composites. In the present work, simple mechanical process was adopted to extract the strip from the original tire frame to be a useful material used in the structural field saving the clean environment condition.

In the structural field, timber beams and corrugated steel plates give the opportunity as suitable structural members to be reinforced with SUT. Timber and corrugated steel plates are materials used for many years for construction purposes such as buildings, bridges and plenty of other structures. It stills to be significant building materials that could be investigated to get better knowledge in their behavior which allow designers to use timber and corrugated steel plates more effectively in more complicated cases ([Harte, A., 2009](#)). Therefore, thin timber beams and corrugated steel plates are adopted as cases of study in the present work.

2. METHODOLOGY

2.1. Adopted specimens and materials

Two groups of specimens were prepared to investigate the proposed strengthening material, the first group contains eight specimens of thin timber beams divided as four specimens free from any reinforcement represent the control specimens identified as (TTC) and four other beams reinforced with SUT identified as (TTR). Each adopted specimen has dimensions of (20×150×1000) mm respectively represent thickness, wide and length of the beam, as shown in [Fig. 1.a](#). The second group represent four specimens of rib type corrugated steel plates divided as two control specimens free from the SUT identifies as (RTC) and two other specimens reinforced with the SUT identifies as (RTR) have dimensions of (1×200×1000) mm respectively represent thickness, width and length as shown in [Fig. 1.b](#).

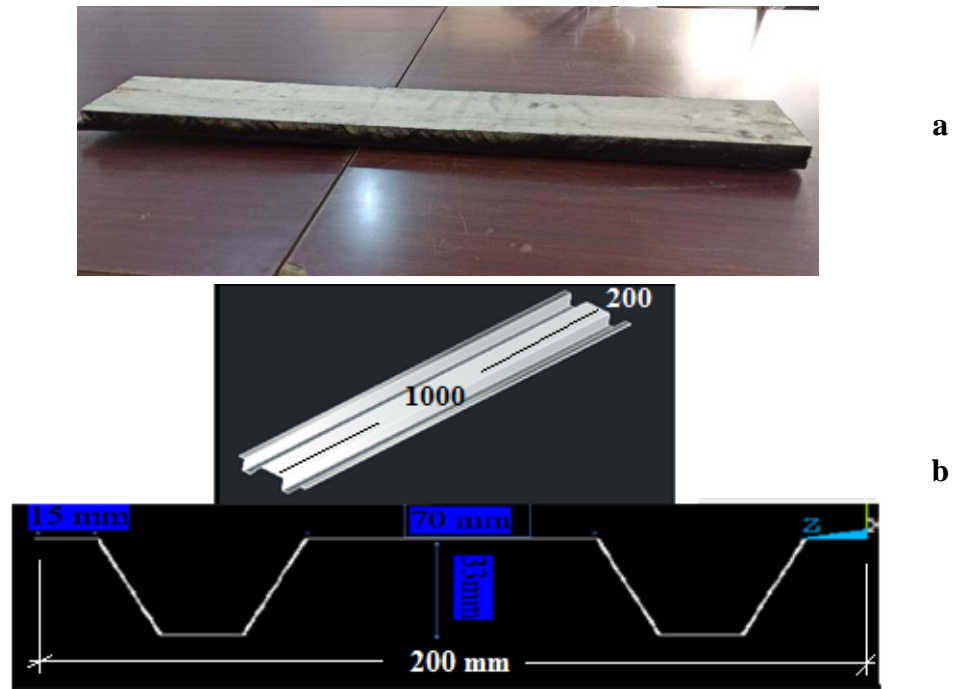


Fig. 1.a. Thin timber specimen, b. Rib type corrugated steel plate.

The other material used in the present study represents strips of the used tires (SUT) which are used as a strengthening material to investigate its ability to increase the ultimate flexural load value of the adopted thin timber beams and corrugated steel plates. It is expected that SUT have the ability to increase the ultimate flexural load value of the adopted specimens due to the existence of steel wire mesh within the texture of strip when they are fixed throughout the tension zone. The SUT should be extracted first from the used tire to be as a layer that is able to be placed and fixed over the surface of the tested specimen throughout the tension zone. Hence, tire's strip was extracted as a layer with dimensions of $(1000 \times 150 \times 10)$ mm and $(1000 \times 200 \times 10)$ mm represent length, width and thickness respectively. The first-dimension strip type was used to strengthen the timber specimens while the second strip type was used to reinforce the specimens of corrugated steel plates. As a main component consists the tire strip, the steel-cord construction of the adopted tire strip is $4@0.28$ mm (the cable was made up of four filaments) placed within ± 23 -degree inclination in the tire strip (Krmela J, et al., 2021). The density of the rubber material was specified as 1200 kg/m^3 (Materials Specification ASTM D 297) in the FE modeling of the tire.

Strip's fixing process was conducted using steel nails, distributed each 100 mm along the specimen's length. The steel nails were used due to their ability to resist shearing stresses that tend to separate the SUT layer from the specimen subjected to bending. On the other hand, the

epoxy adhesive material was used also to ensure that the strip was completely placed and fixed over the specimen surface, as shown in Fig. 2.

2.2. Experimental work

The experimental work was conducted based on the test conditions represented by using the adopted SUT, timber thin beam and corrugated steel plates tested under the temperature and humidity of the laboratory of faculty of engineering - university of Kufa. SUT should be first prepared by extracting them from the original frame of the tire to be adequately placed over the beam surface. The extracting process was easily conducted using a hand grinder machine in the laboratory, representing a mechanical technique to convert damaged tire to a useful applicable strip. Strips of the damaged tires have, usually, curvature tendency due to the original state that they were within the tire frame. Therefore, this behavior should be prevented during the fixing process of SUT over the beam surface by using short steel nails and epoxy adhesive material with the aid of a temporary steel frame, as shown in Fig. 2. The SUT was symmetrically pressed over the adhesive material by the screws of the steel frame to insure that the adhesive material will eventually distributed throughout the contacted area.



Fig. 2. Steel frame and epoxy for the SUT fixing process.

Both of steel nails and epoxy materials were used as shear connectors to prevent any initial separation between beam surface and SUT during and after the fixing process. Each SUT was fixed over the specimen surface such that the steel wire mesh inside the SUT being in contact with the specimen's surface. After a suitable period for epoxy hardening, all the adopted specimens were tested using IMPACT test machine, 95 kN capacity, by four-point loading for the timber specimens and three-point loading for the corrugated steel plate specimens, Fig. 3 a and b, to check the effect of loading process on the obtained results. The load was applied such that the clear distance between the two supports was 800 mm and 150 mm between the two

points of loading in the timber specimens while the clear distance between the two supports was 940mm in the corrugated steel plate models.



Fig. 3. a. Four-points loading test setup, b. Three-points loading test setup.

The simply supported STU strengthened specimens were tested to investigate maximum flexural load capacity. Dial gauge was installed beneath each of the tested specimen to record the deflection during the test.

3. NUMERICAL SIMULATION BY ANSYS

Adopting of comparative results obtained numerically is an important matter for the sake of results' reliability when they are compared with corresponding values obtained experimentally. Hence, the present study adopted ANSYS ([Release 19.2, Mechanical APDL, 2018](#)) software to compute the ultimate flexural load and deflections of the tested specimens based on the finite element analysis. The adopted specimens were simulated in ANSYS software to conduct the loading process applied gradually upon each adopted specimen so that the loading process is continued increasingly reaching to the rupture strength as shown in [Fig. 4a, b](#).

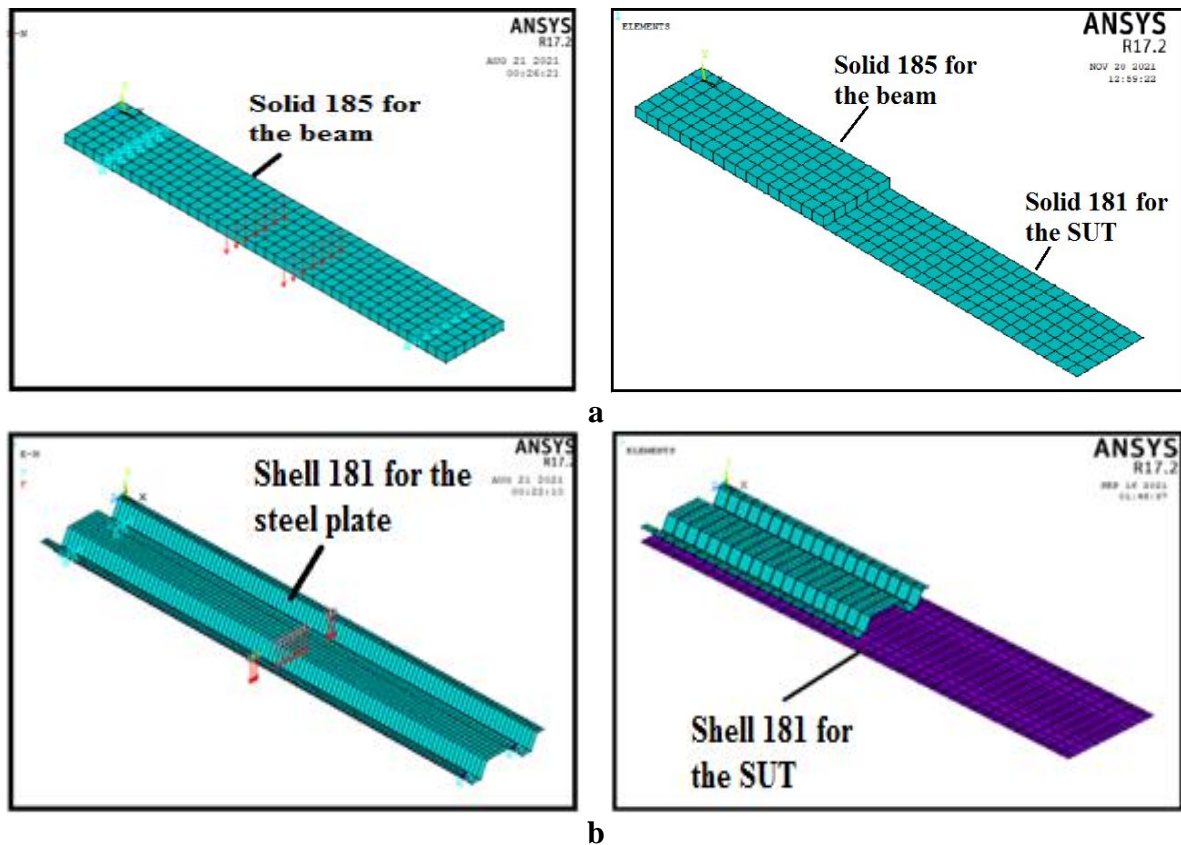


Fig. 4. ANSYS simulation of (a) Timber beams TTC & TTR and (b) Corrugated steel plates RTC & RTR.

In the finite element analysis, SOLID185 element was used to represent thin timber beams, whilst SHELL 181 element was used to represent the corrugated steel plates and the SUT. The properties of the adopted specimens used in the finite element analysis include modulus of elasticity as 16000 MPa and 200000 MPa respectively for the timber beams and the corrugated steel plates which were obtained experimentally.

4. RESULTS AND DISCUSSION

Based on experimental tests conducted upon the first group of specimens (timber specimens), the average values of the ultimate flexural load for each tested specimen were recorded and listed in [Table 1](#). It can be seen that the increase in the ultimate flexural load was 24.113% for the SUT reinforced specimens (TTR) compared with the control specimens (TTC). On the other hand, average values of ultimate flexural load obtained numerically by ANSYS finite element analysis exhibit increasing of 30.809% in the ultimate flexural load for the corresponding specimens. Similar enhancement in the ultimate flexural load capacity was observed with respect to the second tested group of specimens represented by the corrugated steel plate specimens. [Table 1](#) shows an increase in the ultimate flexural load observed in the experimental results reach to 101.7 % for the SUT reinforced specimens (RTR) compared with the control

specimens (RTC). This enhancement was verified by the numerically computed results for the simulated specimens corresponding to the experimentally tested specimens producing an increase in the ultimate flexural load reaches to 83.95 % as listed in [Table 1](#).

Table 1. Ultimate flexural load capacities obtained experimentally and numerically for the two groups of specimens (timber and corrugated steel plates).

Specimen	Ultimate load (kN)		
	Experimental results (Average)	Numerical results (Average)	Numerical/Experimental
TTC	5.640	5.518	0.978
TTR	7.000	7.218	1.031
Increasing in strength(%)	24.113	30.809	----
RTC	2.040	2.100	1.029
RTR	4.115	3.863	0.939
Increasing in strength(%)	101.7	83.95	----

Both experimental and numerical ultimate flexural load average values, for the two tested groups, were compared based on the bar chart shown in [Fig. 5 a](#) for the group of timber specimens and [Fig. 5 b](#) for the group of corrugated steel plate specimens.

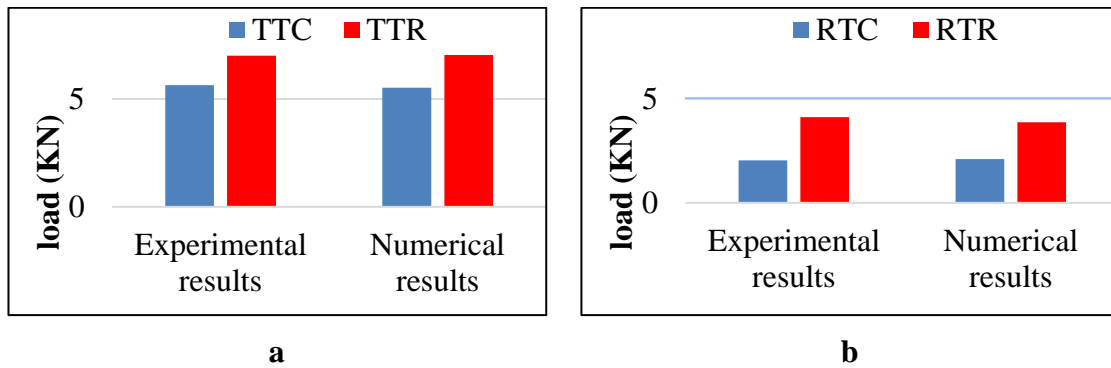


Fig. 5. Ultimate flexural load obtained experimentally and numerically for a. timber specimens and b. corrugated steel plates.

[Figs. 5 a & b](#) show the enhancement in ultimate flexural load due to the presence of SUT as a reinforcing material. The load - deflection curves exhibited that there is a compatible result between the experimental values and the corresponding values obtained numerically from ANSYS as shown in [Fig. 6 a & b](#) for the timber specimens and [Fig. 6 c & d](#) for the corrugated steel plate specimens.

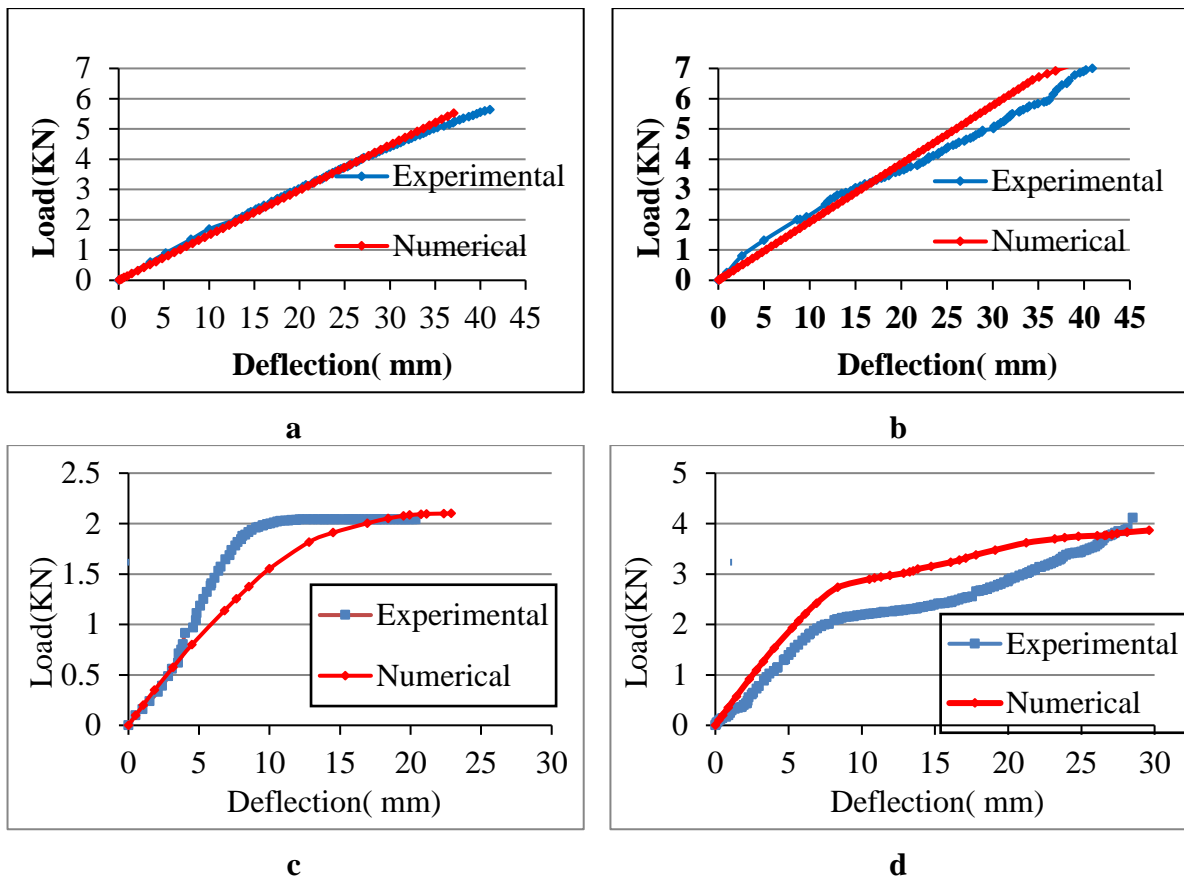


Fig. 6. Load - deflection curves for the experimental and numerical results of a. TTC, b. TTR, c. RTC and d. RTR.

It can be seen that the relationship is completely linear and compatible in the case of load deflection relation shown in Fig. 6 a and 6 b that represent the timber specimens. On the other hand, the relationship started linearly in the case of corrugated steel plates then it was changed non-linearly with some incompatible curves in the middle zone. This could be attributed to some difference existed in the boundary conditions of the tested specimens in the experimental test compared with the numerical simulation. Based on each value of the applied load, the reduction in midspan deflection point could be noticed in Fig. 7 d for the deflection results obtained experimentally for the specimens reinforced with SUT compared with the control specimens.

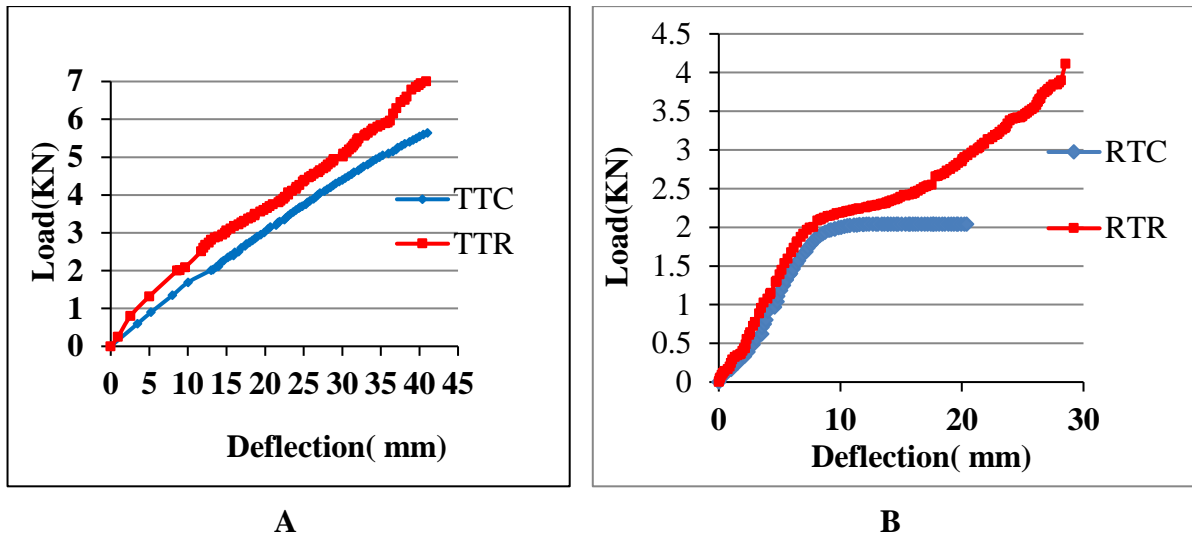


Fig. 7. The reduction in the deflection based on each applied load for the SUT reinforced specimens compared with the control specimens for a. Timber specimens and b. Corrugated steel plates.

For the timber specimens, the reduction in the midspan deflection average values for the results obtained experimentally was 9.04 % while for the corresponding values obtained numerically was 22.67 % for the TTR compared to the TTC specimens. For the corrugated steel plate specimens, the midspan deflection values of the RTR specimens reduced by 39.495% compared to the control RTC specimens tested experimentally while the reduction was 51.129% for the corresponding results obtained numerically.

The reduction in deflection shown in Fig. 7 is due to the increasing in stiffness provided to each specimen reinforced with SUT compared to the reference specimens. Based on the experimental results, no separation was observed between the strip and the surrounding concrete after complete failure which indicates that the steel nails were able to act as shear connectors and resist the shearing stresses in the tested specimens.

5. CONCLUSIONS

The present study has investigated the ability of using the strips of the used tires SUT as a reinforcement material used for the thin flexural members represented by the thin timber beams and the rib type corrugated steel plates.

Based on the test conditions applied upon the tested specimens, the SUT behaves perfectly in the tension zone of the investigated specimens that subjected to bending due to the existence of steel wire mesh within the strip's texture. Results showed that the SUT have increased the ultimate flexural load value of the thin timber beam specimens in the range of 24.113 % to 30.809 % based respectively on results obtained experimentally and numerically by ANSYS

software compared to specimens without reinforcement. Similarly, the ultimate flexural load was increased in the range of 83.95% to 101.7% respectively based on the results obtained numerically and experimentally for the rib type corrugated steel plates specimens. Both of three- or four- points loading tests were conducted respectively upon the timber and steel groups of specimens producing increase in the ultimate flexural load for the SUT reinforced specimens. In addition to the strength improvement, SUT acts to reduce deflection of the midspan timber specimens in the range of 9.04% to 22.67% based respectively on results obtained experimentally and numerically by ANSYS software compared to specimens without reinforcement while the reduction in the deflection was in the range of 39.495% to 51.129% respectively based on the results obtained experimentally and numerically for the rib type corrugated steel plates specimens. This behavior could be attributed to the increase in the stiffness of the reinforced specimens provided by the steel wire mesh existed in the SUT strengthening material.

It is, therefore, the optimal solution to convert SUT to a useful material that satisfies sustainability by saving raw materials and clean environment condition when using in the structural field. On the other hand, extracting SUT by a mechanical process using a grinding machine provides an easy, cheap and clean environment method to prepare SUT to be adequate for the structural purposes. Satisfying economic considerations, SUT provides free reinforcement that could be adopted instead of relatively high expensive materials used for the same purpose.

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