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STUDYING THE STRUCTURAL BEHAVIOR OF BRICK WALLS STRENGTHENED BY DAMAGED TIRES STRIPS

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ABSTRACT

The present study involves strengthening process applied upon brick walls to increase their ultimate load carrying capacity or improving their ductility behavior by using different types of strengthening materials. These materials include either traditional well-known materials or newly proposed materials. The traditional materials include steel wire mesh (SWM) and carbon fiber-reinforced polymer sheet (CFRPS) while the proposed materials include recycled damaged tire strips (DTS). The purpose of using such abundant and polluted material is to satisfy, respectively, the economic considerations and clean environment in the field of enhancing the structural behavior of brick walls. Eight brick walls models were constructed with dimensions of (1200×1200×240) mm, respectively represent width, height and thickness of each model to be tested by 45° compressive loading. Results exhibited that, the SWM increases the ultimate load carrying capacity for the strengthened models to 51.85% compared to the non-strengthened model when placed on one side of the model. Also, the use of CFRPS placed on one side and on both sides of the strengthened models increases the ultimate load capacity respectively to 18.2% and 385% compared to the non-strengthened model. The DTS material has no ability to increase the ultimate load capacity (-18.2 %) but it successfully converts the brittle behavior of the brick walls to a ductile one. It is recommended to use DTS to increase the ductility for brick walls that are likely be damaged or collapsed to avoid the sudden failure.

KEYWORDS

Brick Walls, Strengthening Materials, Steel Wire Mesh, Carbon Fibers Sheets, Damaged Tires Strips.

1. INTRODUCTION

Strengthening of the masonry walls is an important issue in the field of structural engineering due to their brittle behavior against the static loading or dynamic excitation. This importance is increased in some locations such as Asian countries due to the high repetition of the earthquake phenomenon especially when their societies depend mainly on the brick buildings. The heritage buildings are also of a great importance that should be preserved as they use masonry brick units in their construction. Masonry constructions occupy a wide portion of the world's building and they are considered as the oldest methods used for construction (Motra and Paudel, 2021). In addition to that, there are many historical buildings and cultural legacy in the world built of bricks with the use of various types of the mortar that must be safeguarded for future generations (Celano et al., 2021). Brick buildings are constructed by two main components represented by the bricks and a suitable bonding material, such as cement mortar, where both of those two components have different types and properties. The buildings in this case will be more complex with respect to the structural behavior and their analysis with different types of reinforcement become more difficult (Zampieri et al., 2018). The estimation of nonlinear behavior in unreinforced masonry structures under both vertical and horizontal loading is a challenging task due to the heterogeneous and anisotropic nature of masonry wall components. The structural behavior in the case of masonry building subjected to vertical or horizontal loads involves mainly transferring the loads directly to the foundation due to the brittle nature and low resistance of such buildings compared to other types of structures (Gams, Tomaževič and Kwiecień, 2015). Usually the vertical loads, such as the self-weight or the live loads subjected on the building, cause compressive impacts upon the masonry construction units which are able to resist such types of loading. This case of loading is less severe compared to the case of the horizontal loading, such as earthquakes loading, that causes additional tensile stresses in the structural elements. Recent earthquakes, such as the one that struck in the last time in different parts of the world demonstrated the high seismic vulnerability of masonry structures (Gams, Tomaževič and Berset, 2017). Earthquakes cause ground shaking, which is the most direct and harmful effect on buildings. Seismic waves exert lateral stresses on buildings, which can lead to their swaying. The magnitude of the earthquake, the distance from the epicenter, and the local ground conditions are some of the variables that affect how severe the shaking is and the buildings that are taller or have weaker lateral support are more susceptible(A. Abass and K. Jarallah, 2022).

It has become necessary to search for solutions to be used in the field of strengthening the brittle structural members such as masonry walls (Srinivas and Sasmal, 2016).The tradition solutions in this case are the use of steel wire mesh (SWM) or the carbon fiber- reinforced polymer (CFRP)(Ferretti and Mazzotti, 2021). Additional strengthening materials such as the fiber-reinforced polymer (FRP) has also gained popularity in recent years. The polymeric strengthening materials involve several advantages include the minimal application time, excellent efficiency against horizontal stresses, and lack of added load. On the other hand, the drawbacks are also involved, such as the poor heat resistance when exposed to high temperatures (Can, 2018). CFRP is commonly used with the reinforcement as implemented by (Thamboo et al., 2021). They have tested 36 brick walls that 18 of which were strengthened by CFRP while the remaining were free of reinforcement. The models were investigated under either eccentric or concentric loading. The results showed that the CFRP have increased the compressive resistance by (10 – 20) %. Application of CFRP generally enhanced deformation properties but had little impact on compressive strength (Thamboo et al., 2021).

The popular strengthening process based on SWM (Shermi and Dubey, 2017), uses both of steel and concrete mortar to produce a high strength capacity covering layer that improves the shear resistance or the diagonal tensile strength of the masonry walls and increase their ductility by improving the deformation capacity (Buyukkaragoz and Kopraman, 2021). Steel wire mesh (SWM) and mortar reinforcement is an economical and effective technique for improving the seismic performance of masonry buildings which is also applicable in both new constructions and retrofits (Shermi and Dubey, 2017). In general, both of the SWM and the polymeric strengthening materials have, usually, high cost and they are not satisfying the sustainability concept as they are consuming the raw materials during the production. Therefore, other proposed available recycled materials are investigated to be used as alternative materials in the strengthening process satisfying the sustainability concept and the economic considerations. In the present study, the investigated recycled material is the damaged tire strips (DTS) which is selected due the abundance of this material in the societies. A significant quantity of damaged tires is produced as a result of civil activity requirements which is considered as plastic material that must be disposed due to its harm effect upon the environment (Hamza, 2021).There is an increasing need to address the issue of tire disposal, and multiple studies have looked into the use of recycled tire components as building materials in various parts of civil engineering. Tires are typically composed of major components: steel, polyester, textile, rayon, nylon, compound of rubber, fillers, plasticizers, and other chemicals (Figueiredo et al., 2017).The tire is a mixture of complex elastomer with the ability to carry high pressure under severe conditions based on components. These components are assembled as layers so that each component participates in resisting the applied pressure along with the participation of other parts (Papakonstantinou and

Tobolski, 2006). In the present study, this material is investigated to be used as a strengthening material for the brick walls to either increase the ultimate load capacity or converting the brittle behavior of the brick wall to a ductile one.

2. STRENGTHENING MATERIALS AND THE ADOPTED SPECIMENS

The present study investigates three types of strengthening materials, two of which are considered as traditional materials while the third is proposed for the investigation. The traditional strengthening materials include 3 mm diameter steel wire mesh (SWM) spaced each 50 mm on both directions and 1.5 mm thickness of carbon fiber- reinforced polymer sheets CFRPS. These materials have relatively high cost and they are not satisfying the sustainability concept when they are used extensively. On the other hand, the proposed material represents the recycled, low cost, damaged tires strips (DTS) applied upon the brick walls to either increase their ultimate load capacity or convert their behavior from the brittleness to the ductility. This material was examined earlier by (Ali, 2021) as a strengthening material to enhance the flexural capacity of the reinforced concrete slabs, (Ali and Alalikhan, 2022) Fig. 1a, , timber beams and ribbed steel plates, Fig.1b, (Alalikhan and Ali, 2022) which exhibited effective behavior in all of these cases.

a

b

Fig. 1. (a) Slab strengthened by DTS (Ali and Alalikhan, 2022) and (b) wooden beam strengthened by DTS (Alalikhan and Ali, 2022)

The DTS is proposed, herein, as a strengthening material to enhance the structural properties of the brick walls for two reasons, the first is due to their availability in all societies and the urgent need to consume such pollutive material satisfying the sustainability concept and economic considerations. The second reason is that the DTS contains steel mesh layers that are expected to provide relative strength to some brittle materials such as the brick wall adopted in the present study or providing more ductility to their structural behavior. Based on literature, the used properties of the DTS are listed in Table 1 (Ali, S. and Alalikhan, A. ,2021).

Table 1. Properties of the used DTS

Dimension of the tire's strip	Rubber's Poisson's ratio	Elastic modulus for the reinforcements within the tire texture (MPa)	Steel-cord construction of the tire casing
Strip with groove has 1200 mm length 150 mm width 10 mm thick	0.4995	2000	4 silks @ 0.28 mm diameter

The DTS have to be extracted from the complete tire frame, as a first stage, before they are used in the strengthening process in the second stage. The DTS could be extracted easily by the hand grinding machine to remove the two surrounding hoops located on both sides of the tire frame leaving just the tire strip, as shown in Fig. 2 (Valente and Sibai, 2019).

Fig. 2. Extracting the strips from the complete tire frame (Valente and Sibai, 2019)

The produced DTS has dimensions of 1200 mm length, 150 mm width and 10 mm thickness forming a strip that could be fixed over a certain brick wall by steel threaded nails have 3mm diameter placed every 200 mm throughout the wall height or width.

In this research, there are four types of case study models adopted for the test. Each case study represents a brick wall constructed with dimensions of (1200×1200×240) mm, respectively represent height, width and thickness of each adopted model (ASTM E519-2010) (ASTM E 519-02, 2002) The investigated models were classified based on two groups, the first involves models plastered by the concrete mortar on their both sides while the second stayed without plastering. The first group includes only two models, the first remains without any strengthening material to form the control model identified as (MR.2) while the second model is reinforced by steel wire mesh placed on one side and identified as (WSM.1), as shown in Fig. .3.

Fig. 3. Steel wire mesh (SWM) strengthened model before the plastering

The second group contains six models includes one reference model, identified as (MR.1), without any strengthening material while the other five models are strengthened according to the adopted strengthening materials. The first and the second models are strengthened by CFRPS respectively on one side, identified as (CFRP.1), and on both sides, identified as (CFRP.2), of the model, as shown in Fig. 4a.

a b

Fig. 4. a. CFRPS strengthened model with the upper and lower bracing and b. DTS strengthened model

The third and the fourth models are strengthened by four DTS, Fig. 4b, placed respectively on one side, identified as (DTS.1), and on both sides, identified as (DTS.2), of the model. The fifth model herein is repeated to form the sixth model, identified as (DTS.3), which is reinforced by the DTS on both sides of the model to increase the confidently level of the obtained result based on the proposed strengthening material. Table2 summarizes each case study adopted in the investigation.

Table 2. Properties of each adopted case study

No.	Sample's ID	Properties
1	MR.1	Control model, non-plastered by cement mortar, without strengthening
2	MR.2	Control model, plastered by cement mortar, without strengthening
3	CFRP.1	Non-plastered by cement mortar. Strengthened by CFRPS on one side
4	CFRP.2	Non-plastered by cement mortar. Strengthened by CFRPS on two sides
5	WMS.1	Plastered by cement mortar. Strengthened by one layer of SWM on one side
6	DST.1	Non-plastered by cement mortar. Strengthened by four DTS on one side
7	DST.2	Non-plastered by cement mortar. Strengthened by four DTS on two sides
8	DST.3	Repeating sample for confidence result

It was planned to adopt additional case study strengthened by SWM on both sides of the model but unfortunately this model was collapsed due to an accident before the test.

3. EXPERIMENTAL PROGRAM

The experimental work involves the construction of totally eight brick walls formed by bricks, with (240×115×75) mm dimensions satisfy the Iraqi standards [ISO\ICE 17025:2005 TL009] [M.Q.NO 548 of 1989] [Amendment (1) of 2013 and Amendment (2) of 2015], and ordinary Portland cement mortar as a bonding material. Each model of the brick wall represents a specific case study which either being plastered by the cement mortar or not. The construction process for each model starts by placing the first brick line over two steel channel sections to support the whole model from the bottom edge. Another two steel channel sections applied above the last brick line to support the model from the top edge so that both of the upper and lower edges could be braced together by adequate steel threaded bars from both sides of the model, Fig. 4a. This operation saves the model against collapsing during the transportation or when the model is installed inside the laboratory testing device. All the supporting steel channels are removed later before the test when the model is completely installed inside the testing device, as shown in Fig. 5.

All the models were tested through 45° direction of compressive load, Fig. 5, based on the specifications (ASTM E519-2010(ASTM E 519-02, 2002), in the structural laboratory using the 2000 kN capacity universal hydraulic machine with 5 kN/minute loading rate. Each case study model was erected between two steel bases support the model diagonally from its opposite corners as shown in Fig. 5. During the test, the ultimate load carrying capacity for each model is recorded based on the load – time relationship while the deflection was not able to be measured due to the sudden crash of the model vertically and laterally in the failure stage which prevents the LVDTs to measure the deflections successfully. The modes of failure for the reference, SWM and DTS strengthened models were observed by crack paths follow the opposite diagonal loading direction of the model while the CFRPS strengthened models were covered and may not be able to observe the crack pattern.

a b

Fig. 5. Installed models: a. non-plastered model and b. plastered model by the Portland cement mortar

4. RESULTS AND DISCUSSION

The obtained results are discussed based on two outcomes, the ultimate load carrying capacities and the withstanding period to carry the ultimate load carrying capacity before the complete failure as an indicator for the ductility for each tested case study (Donald R. Askeland, 2010).

4.1. The ultimate load carrying capacity

Based on 45° compressive load test, the ultimate load carrying capacity for each tested model is recorded and listed in Table3.

Table 3. Ultimate load carrying capacity for each tested model

No.	Sample's ID	Ultimate load carrying capacity (kN)	Percentage of increased load carrying capacity (%) with respect to the Control Specimens (MR1 or MR2)	
1	MR.1	33	0	------
2	MR.2	81	145.45	Compared to MR1
3	CFRP.1	39	18.18	Compared to MR1
4	CFRP.2	160	384.84	Compared to MR1
5	WMS.1	123	51.85	Compared to MR2
6	DST.1	24	-27.27	Compared to MR1
7	DST.2	27	-18.18	Compared to MR1
8	DST.3	27	-18.18	Compared to MR1

The bar chart shown in Fig. 6 compares the ultimate load carrying capacity for each tested case study.

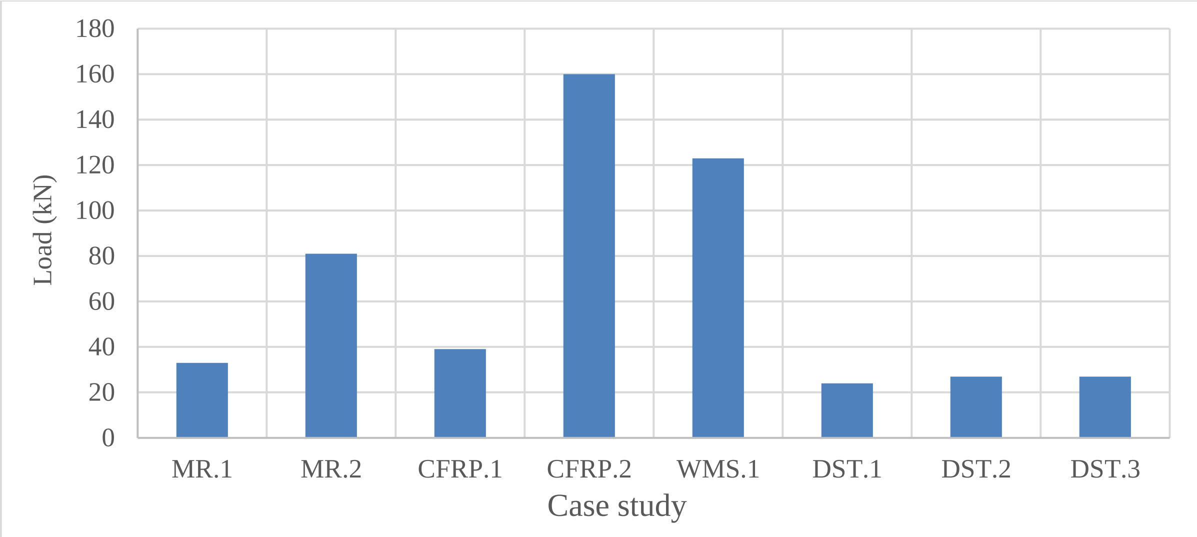

Fig. 6. Ultimate load carrying capacity for each tested model

The first comparison that could be made is between the control specimen of the cement mortar-plastered model (MR.2) and the non-plastered model (MR.1) based on the ultimate load carrying capacity. The plastering with the cement mortar increased the ultimate load carrying capacity by 145.45% compared to the MR.1, as listed in Table 3. Also, from Table3 and Fig. 6, the two-sided CFRPS strengthened case study exhibited the highest value of load carrying capacity (160 kN) among all other models which increased the ultimate load carrying capacity to 384.8% with respect to the control specimen (MR.1). This result was expected due to the high resistance of the CFRP sheet which produced double load carrying capacity compared to the one-sided CFRPS strengthened model (39 kN). The case study strengthened by one-sided SWM produced 123 kN ultimate load carrying capacity, 51.85% increasing ratio with respect to the MR.2, which is higher than the one-sided CFRPS strengthened model. The last comparison here is the models strengthened by DTS which were not able to increase the ultimate load carrying capacity compared to the CFRPS or SWM strengthening materials. It can be seen that, from Table2, there were reductions in the ultimate load carrying capacity values for models strengthened by DTS compared to the control specimen (MR.1) which could be attributed to the role of fixing process that used threaded nails to fix the DTS with the model. The fixing process used hand drilling machine to make holes required for fixing the nails between the DTS and the model. This operation weakens the model specially when it is not plastered with the cement mortar as in the studied cases DTS.1 and DTS.2. However, this behavior was compensated by the role of the DTS in enhancing the ductility of the DTS strengthened model as will be discussed in the next paragraph.

4.2. Withstanding period for the ultimate load carrying capacity

Ductility is the ability of any material to deform permanently without failure before the complete collapse. The ability to withstand ultimate loads within long period without collapse even with large deformations reflects the ductility behavior of the material under loading. On the other side, the sudden collapse which occur within relatively short period reflects the brittle behavior of the loaded material which is undesired for the structural purposes. This observation is recorded for all tested models to compare their behavior during the ultimate loading stage with respect to the period that they need to collapse. Starting with the reference model (MR.1), it is shown from Fig. 7 that the model behaves brittle due to the sudden collapse when the model reached to the ultimate loading stage. Approximately, there is no any time elapsed for the ultimate loading stage shown in Fig. 7 which has a sharp descending to the zero-load value at the end zone of loading history.

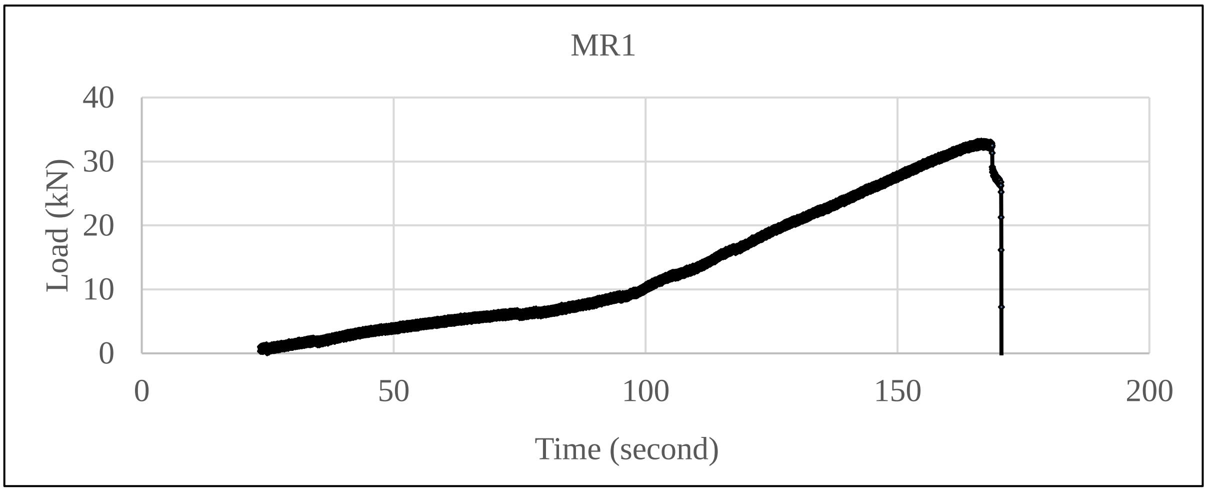

Fig. 7. Load – Time graph for model (MR.1)

This behavior is enhanced for the model (CFRP.1) as shown in Fig. 8 due to the presence of CFRPS strengthening material on one side of the model.

When the loading stage reached to the ultimate load value, Fig. 8, there was a reduction in the load carrying capacity takes a little time after which the model exhibited additional capacity to withstand the applied load and the descending towards the zero-load value happened gradually. This small ductile behavior was increased when using CFRPS on both sides of the model, i.e. CFRP.2, as shown in Fig. 9.

The model offers long period within the ultimate load carrying capacity stage and even when there is a reduction in the ultimate load capacity, there is also an additional load carrying capacity offered by the model which reflects the brittle behavior as shown in Fig. 9. The model strengthened by SWM exhibited also gradual descending towards the complete failure, as shown in Fig. 10.

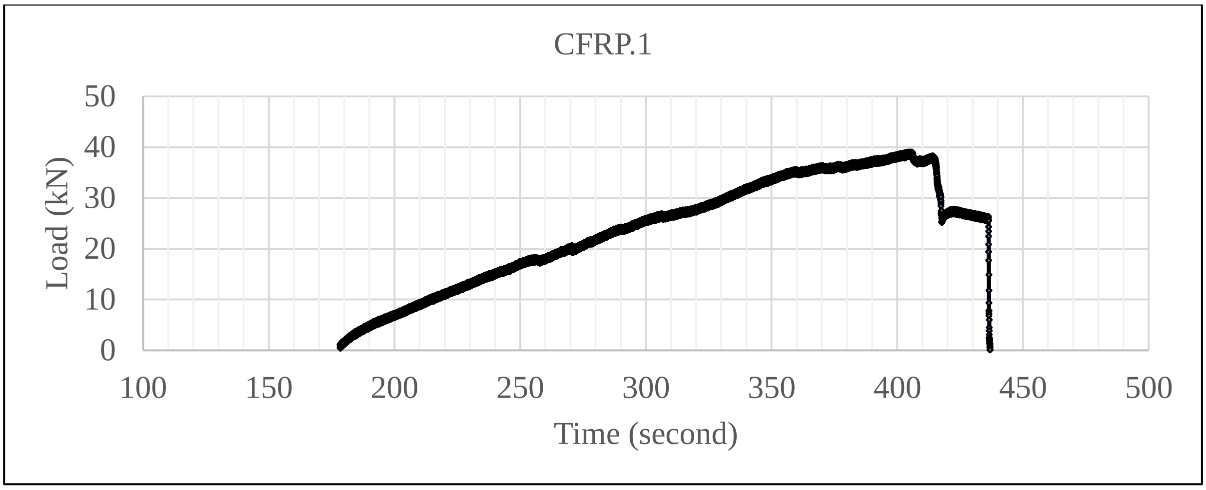

Fig. 8. Load – Time graph for model (CFRP.1)

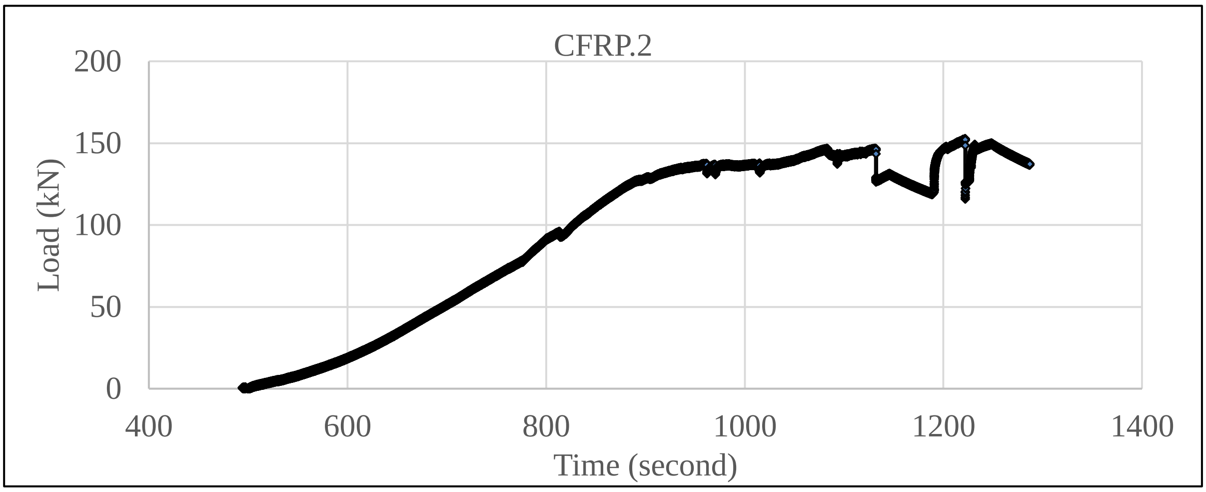

Fig. 9. Load – Time graph for model (CFRP.2)

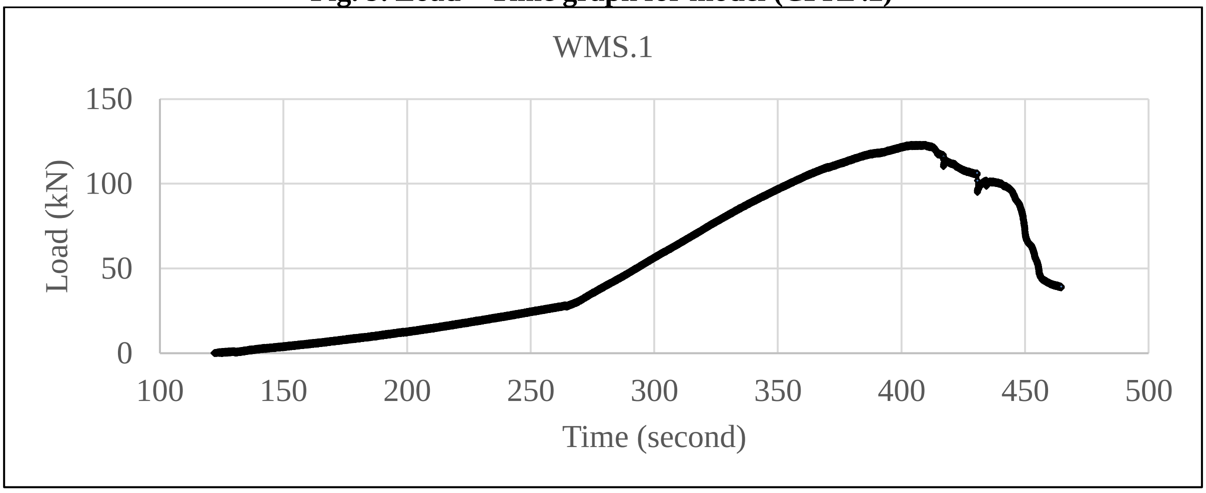

Fig. 10. Load – Time graph for model (WMS.1)

Although it is lower time period takes for the gradual descending in the present case compared to the CFRP.2 model, but it is higher than the case of CFRP.1. It is expected that the period required for the complete failure will be increased for the model WMS.1 if it is reinforced by two sides which was already adopted in the present study but the model was collapsed during the transportation. Nevertheless, the observed elapsed period for the ultimate load capacity zone for model MSWM is longer than the corresponding value observed in model (MR.2) which is the reference model for the same group (both are plastered models), as shown in Fig. 11.

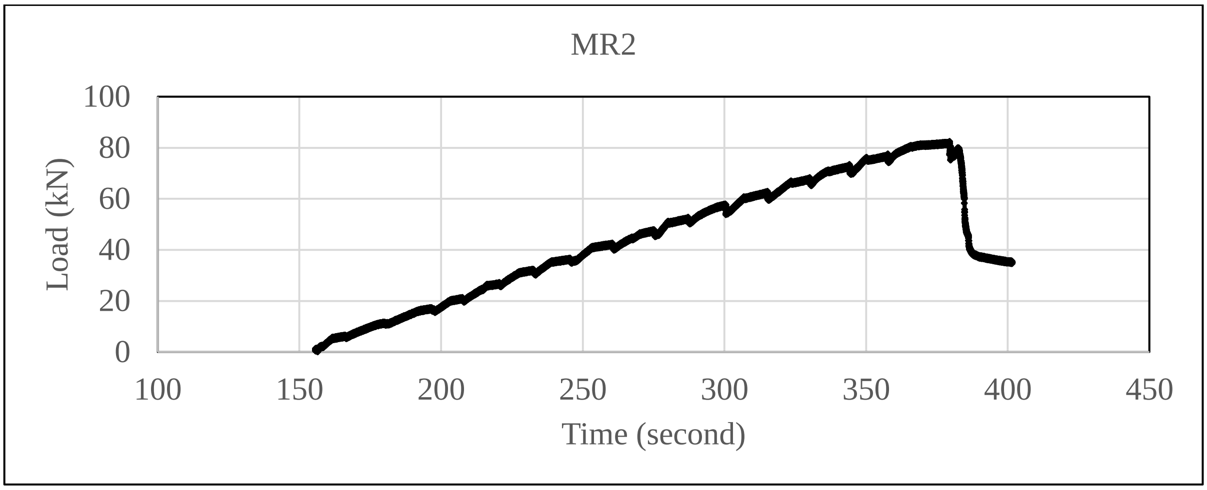

Fig. 11. Load – Time graph for model (MR.2)

It is clear that even when the model is plastered by the cement mortar, it still behaves brittle with sudden drop immediately after passing the ultimate load value and the enhancement in the ductility occurred in the SWM model was due to the SWM strengthening material without important role to the plastering material, as compared by Fig. 10 and 11. The last comparisons are discussed for the models strengthened by the proposed strengthening materials represented by the DTS. It is shown in Fig. 12 that the model strengthened by DTS on one side, DST.1, exhibits additional load carrying capacity after passing the first ultimate load carrying value and the model starts to withstand the increased applied loads exceeding the first ultimate load carrying value recorded earlier.

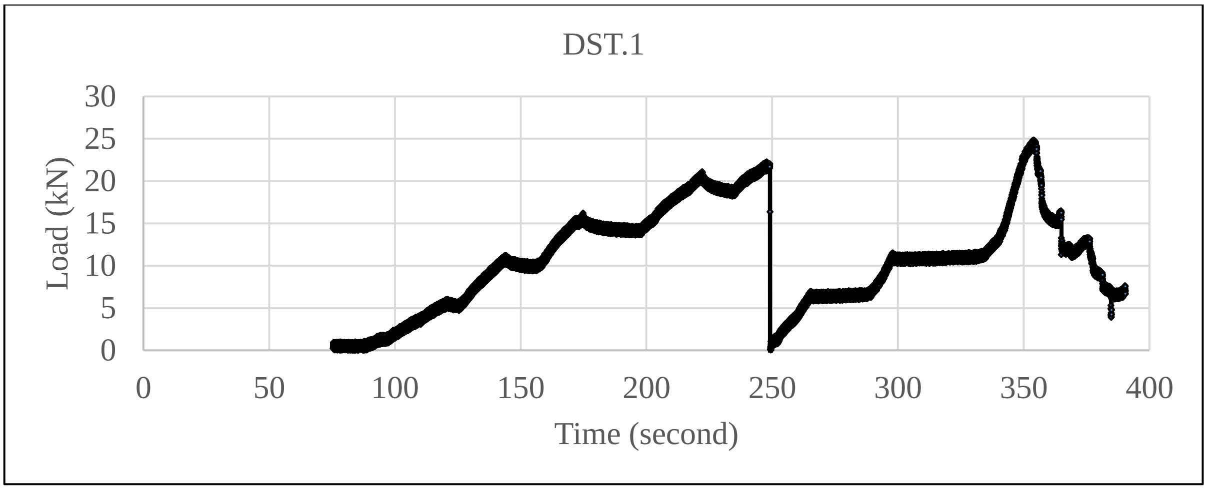

Fig. 12. Load – Time graph for model (DST.1)

The model after failure was crushed is shown in Fig. 13.

Fig. 13. Model of DST.1 after failure

This behavior reflects the ability of the model to take longer time until reaching the complete failure and no sudden collapse happened even when the load carrying capacity reached to the ultimate value which is the ductile behavior desired for the structural purposes. Moreover, the enhancement in the ductility was increased for the model DST.2 due to the two-sided reinforced by the proposed DTS material as shown in Fig. 14.

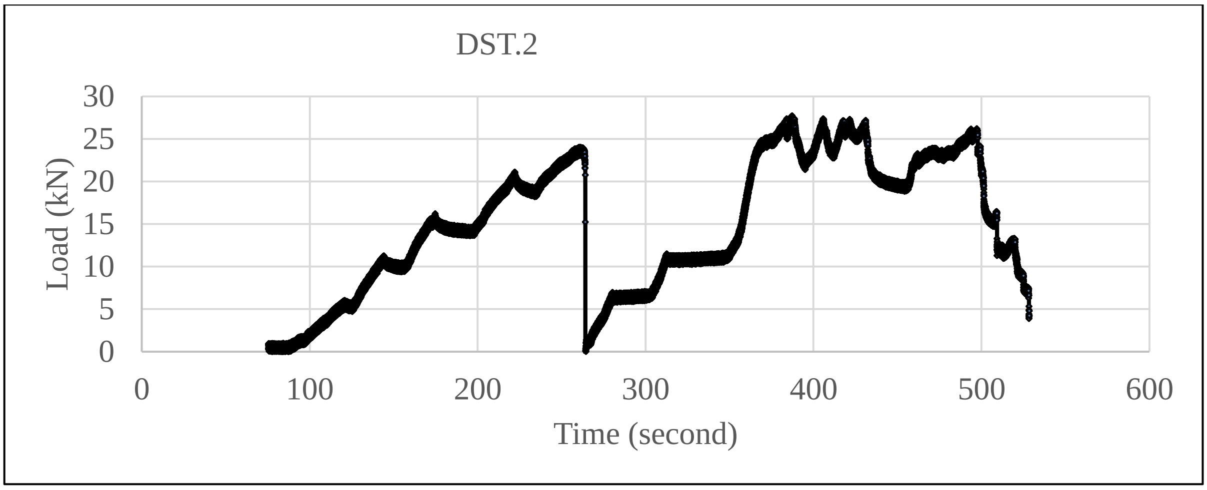

Fig. 14. Load – Time graph for model (DST.2)

Many load-drop-rise locations are observed in Fig. 14 which take long time with gradual lost in the load carrying capacity in the ultimate load carrying zone indicating to the brittle behavior that the proposed material (DTS) succussed to add to the strengthened models.

5. CONCLUSIONS

The present study investigates the ability of using recycled materials represented by damaged tire strips (DTS) in the field of strengthening the brick walls satisfying the clean environment and economic considerations. The study involves testing of eight brick wall models strengthened by steel wire mesh (SWM), carbon fiber-reinforced polymer sheets (CFRPS) and the damaged tire strips (DTS) under 45°compressive loading to increase their ultimate load capacity or enhance their ductility behavior. The study observed the following conclusions:

• The ultimate load carrying capacity was increased for the models plastered by the Portland cement mortar compared to the non-plastered models.

• Both of the strengthening materials of SWM and CFRPS increase the ultimate load carrying capacity for the mortar-plastered brick wall model compared to the plastered reference model.

• The DTS strengthening material was not able to provide additional load carrying capacity for the tested models but it successfully converts the brittle behavior of the models to a ductile one by increasing the period of ultimate load carrying capacity before the complete failure. The ductile behavior is achieved for both cases of one-sided strengthening or on both sides strengthening of the model. This observation encourages to use the proposed DTS in the field of brick walls as a strengthening material due to the availability of such undesired material in the societies satisfying the clean environment and economic considerations.

• The higher enhancing in ductility is produced by the two-sided CFRPS strengthening material (CFRP.2) which increased the period of withstanding the ultimate load carrying capacity before the complete failure.

• It is recommended to use the DTS to increase the ductility for brick walls that are likely be damaged or collapsed to avoid the sudden failure.

For better understanding the behavior of the proposed DTS as a strengthening material, it is advised for future researches to simulate this material numerically using the experimental data for models obtained by this research leading to more aspects in the strengthening's applications.

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