Using Wasted Rubber Material for Reducing Loads and Energy Dispersal in Building Industries: State of the Art

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Abstract. The accumulation of rubber tires poses a great danger to the environment, especially since the number of cars is constantly increasing. Therefore, at the beginning work was done to recycle these tires and use them as an alternative to the natural aggregate used in concrete. It was also used in asphalt used in roads. Packaging for the Shear Connecter used in composite section. As this work gave excellent results in reducing the hardness of the shaker contactor, increasing its durability and resistance, and also preserving it from corrosion by rust. Waste rubber was also used to covering the bolts used to connect the beam with the column in steel structures. Where the presence of rubber gave a high ability to dissipate energy when the steel structure is subjected to a seismic load. It also worked to increase the displacement and increase the durability of the steel structure and also reduce the friction between the bolts and their holes. The presence of rubber around the bolt also delayed the failure time of the steel structure and thus the important aim of the research work has been achieved, which is to maintain the safety of people when the structure is exposed to an earthquake load.

Keywords: - Rubber, Damping, Earthquake, Composite section, connector.

1. Introduction
At the beginning, we get to know rubber, which is made up of a flexible group of molecules, as these molecules are in motion called Brownian, And that this movement takes place continuously at normal temperatures, and when a certain load is placed on these particles and then this load is removed, the particles return to their original shape, and this is the reason why rubber has the ability to be subject to a set of elastic deformations and then returns To be placed after removing the effect. As these particles are highly elastic, which gives the rubber the ability to withstand elastic deformations. Where the properties of the rubber, which is considered one of the category of elastic materials, are determined by a set of basic constants. The first constant is symbolized by the symbol [K], where this factor determines the compressive strength of the elastic material (rubber), and is determined through the equation below:

\[ P = \frac{-\Delta V}{V_o} \] (1)

The second constant is denoted by the symbol [G], which is called Shear-modulus, and is determined through the equation below:

\[ G = \frac{t}{\gamma} \] (2)

The coefficient [E] tensile-modulus and the Poisson ratio [v] are also determined through the equations below:
There are materials that have high stress and low strain, so these materials need to improve their performance by combining two materials, one of which is of high stress and low strain and the other of low strain and high strain, and from this principle the rubber was combined with the steel to increase the stress tolerance and the strain tolerance. Finally, in this paper we will deal with a review of the research in which rubber is used in the packing of the shear connector in composite section, as well as the research in which rubber is used in the coating of bolts in steel structure.

\[
E = \frac{\varepsilon}{\varepsilon} \quad (3)
\]

\[
\nu = \frac{1/2(3K-20)}{3K+G} \quad (4)
\]

Whereas, rubber has a high value for modulus [K], and a low value for modulus [G], where the value of [G] varies between (0.5-5) MPa, the value of Poisson ratio will be approximately 0.499, and [E] equal to three time [G] [1]. These precedent determinants are very important in determining the properties of the rubber used in engineering applications, as due to the increase in the accumulated numbers of waste in general and the waste of car tires in particular, it became necessary to find solutions and methods to recycle these wastes (car tires) and not make them accumulate significantly and lead Therefore, many studies have been conducted on the use of rubber as an alternative to some engineering materials, including coarse and fine natural aggregates, on the condition that the rubber particles have a shape and size similar to the shape and size of the replaced aggregate [2]. One of these experiments is about using rubber as an alternative to aggregates. This experiment uses a cement mortar that contains rubber at ten percent of the weight of the used cement. The source of the used rubber is Car tires, where this rubber has undergone tests, including a tensile and compression test, a hardness test and gave satisfactory results. When examining the models that contain rubber and then comparing them with the models that do not contain rubber in their concrete mixture, it was found that the bending resistance of the models that contain rubber was reduced, but there are useful properties that have been observed from the addition of rubber, as the amount of water that the samples carry by absorbing it during the treatment period, it was reduced by sixteen percent, as was the decrease in weight in the models that contain rubber compared to those that did not contain rubber in their mixture. The rubber also closed the pores somewhat when the surface of the samples was observed in the microscope and compared with those that were it does not contain rubber. In general, the rubber gave good improvements in mortar properties [3]. Another research, among many similar studies on the same path, deals with the use of rubber with the Steel Fibre in Reinforcement Concrete. Where used particles of rubber ranging between (0.178-1.11) mm with Steel-Fibre. A dynamic test was performed for concrete models containing rubber with weights ranging between (5-10-15-20) %, under impact load with (0.2-0.3-0.4-0.5) MPa respectively. The results indicated that using rubber as an alternative to sand resulted in a decrease in the compressive strength with an increase in Dynamic-Compressive-Strength, when the rubber volume increased. Also, the presence of rubber at less than ten percent increased the ability of the models to absorb energy [4]. Rubber is also used in the asphalt used on the road. The rubber gave excellent results for the asphalt mixture containing rubber compared to the mixture that is not rubber [5]. Rubber is also used in research that was recently conducted from 2018 to this year, and this research deals with covering the shear connector with rubber. This used rubber has been tested in terms of compression, tensile and hardness checks. This rubber reduces the shear strength of the connector and gives excellent rigidity to the connector that has become composite from Steel/Rubber to form composite shear connector. The contactor also gives high deformation efficiency when applying repeated loads to the model [6-9]. Also, there is one research and there is no other, in which the rubber is used in wrapping the bolt used in the connection the beam and the column. Also, the used rubber has been tested for compression, tension and hardness. As the rubber in this research has worked on energy dissipation and increased the building's ability to withstand loads [10].
1. Literature review
Many authors documented the use of rubber for different applications in engineering:

2.1 Bozhou Zhuang, Yuqing Liu, Fei-Yang, (2018) [6]
The use of a rubber-coated connector in the connection between steel and concrete in composite sections, as the rubber reduces the hardness and shear force of the connector. The rubber-coated connector is called (RSS) connector and the connector without rubber is called (OHS) connector, as shown in Figure 1. Where in some situations, when using (OHS), the wide applied load and the nonuniform slip may cause the stud shear force close to the Edge of the interface to exceed the permissible maximum value. The deformation-performance for rubber coated connector under cyclic loading was obtained by push out tests and numerical simulation. The results obtained from the examination are shown in Table 1. The Load programme of this review as shown in Figure 2. Also, the type of load in this paper is static load. The Cyclic Upper limit was determined by the approximate Shear-Capacity, which was (125 kN) per stud, before tests. The specimen named (D19_1) was charged with the Monotonous Loaded program (I) to investigate the shear-stiffness of the OHS connector and ultimate-shear ability. The Cyclic Loading program (II) loaded (D19_2) and (D19_3) with constant amplitude and the variable amplitude Loading Program (III). The (EC4) stipulated that, standard push out tests should be performed by Cyclic Loads with an amplitude of 40 per cent of the estimated shear power, and 25 times Cycled. According to (EC4), the Loading Program (II) first carried Cyclic Loads for 15 cycles at 40 per cent of the approximate Capacity (50 kN) and later raised the upper limit for another 15 Cycles to 60 per cent (75 kN). Then, the Cyclic Loads with a constant amplitude at 40 per cent and 60 per cent of the approximate efficiency are intended to test the deformation output of the elastic and elastic-plastic RSS connectors.

Table 1 The test groups [6]

| Specimen | Stud diameter ds/mm | Stud Height hs/mm | Rubber sleeve height hr/mm | Rubber sleeve thickness tr/mm | Loading program |
|----------|---------------------|-------------------|---------------------------|-------------------------------|-----------------|
| D19-1    | 19                  | 150               | -                         | -                             | I               |
| D19-2    | 19                  | 150               | 75                        | 2.5                           | II              |
| D19-3    | 19                  | 150               | 75                        | 2.5                           | III             |

Figure 1. (RSS) connector and (OHS) connector [6].
2.2 Bozhou-Zhuang, Yuqing-Liu, (2019) [7]

The Ordinary_Headed_Stud (OHS) connector with a diameter of (25 mm) or greater is considered to be the broad (OHS) connector, with higher shear rigidity and ultimate efficiency. Consequently, the necessary number of (OHS) connectors is expected to decrease by using the wide (OHS) connectors within the steel-concrete system that have benefits over smaller ones in construction. Nevertheless, the high rigidity may also cause the Shear Force at the interface edge of the wide (OHS) connector to reach the Design allowable value. The new Rubber-sleeved Stud (RSS) connector was then introduced by covering the rubber sleeve at the shank of the (OHS) connector to minimize the stiffness of connector, allowing the Shear Force in the metal more uniformly distributed concrete interface. Initially, samples containing (OHS) connectors and (RSS) connectors were examined using a push out test. By applying variable cyclic load, the degree of stiffness and deformation behaviour of (RSS) connector and (OHS) connector was obtained. Loading program and Push-Out test tool as shown in Figure 3.

![Figure 3. Loading program and push out test tool [7].](image)

This research contains three samples for examination, the first contains a (OHS) connector with diameter of 25 mm that is not covered with rubber and this model is called (D25-1). The second model also contains a 25mm diameter connector and rubber coated and this model is called (D25-2 & D25-3). The height and diameter of the rubber surrounding the connector is fixed, as the height and diameter of the rubber around the root of the connector is 120mm and 3mm, respectively. First, before applying the download program, you must measure the value of ultimate - capacity of each connector. When measuring it, they found its value equal to 250 KN. The ultimate – capacity, it is used to calculate the upper limit value of the Cyclic Load. The first model (D25-1) is checked under the first loading program to obtain the shear-stiffness and ultimate-capacity of the ordinary Head stud connector. The second model D25-2 was loaded with a value equal to 40% of the ultimate-capacity of the stud, where fifteen cycles were applied. Following this, for another 15 cycles, the cyclic upper limit was raised to 60 per
cent. The third form is loaded with a load equal to ten percent of the ultimate capacity of the stud. Then increase the value of the upper limit to ninety percent of the value the ultimate capacity of the stud. From this loading program, the deformation performance of (RSS) connector and (OHS) connector are known.

2.3 Zhigang Zhang, Xiaoqing Xu (2020) [8]

For field/cast (UHPC) connections, which is a combination of Ordinary Stud and Rubber Sleeve, the Rubber-Sleeved-Stud Shear Connector was adopted using this study. For field-cast UHPC connections, which are a combination of Ordinary Stud and Rubber Sleeve, the Rubber-Sleeved_Stud_Shear Connector was adopted using this study. Also, the type of load in this paper is fatigue load. Static test data showed that the Rubber_Sleeved_Stud shear connector has ample deformation capacity, and its slip rate is 1.5 times that of the regular stud shear connector. Compared to ordinary stud shear connectors, UHPC with high strength and rigidity has a relatively limited effect on improving the shear strength and stiffness of rubber-sleeve stud shear connectors. In this paper, five models are examined below the push-out-test. Two of these models are exposed to Static_Shear_Load and the other three models are exposed to Fatigue Shear-Load. Specimen descriptions are summed up in Table 2.

Table 2. Specimen descriptions [8].

| Specimens  | hr/ mm | tr/ mm | τmin/ MPa | τmax/ MPa | Δt/ MPa | Vmin/ kN | Vmax/ kN | ΔV/ kN | R | f/Hz |
|------------|--------|--------|-----------|-----------|---------|----------|----------|--------|----|------|
| S-0-U      | 25     | -      | -         | -         | -       | -        | -        | -      | -  | -    |
| RS25-0-U   | 25     | 5      | 12        | 62        | 50      | 3.4      | 17.6     | 14.2   | 0.19| 4    |
| RS25-50-U  | 25     | 5      | 12        | 82        | 70      | 3.4      | 23.2     | 19.8   | 0.15| 4    |
| RS25-70-U  | 25     | 5      | 12        | 102       | 90      | 3.4      | 28.9     | 25.5   | 0.12| 4    |
| RS25-90-U  | 25     | 5      | 12        | 102       | 90      | 3.4      | 28.9     | 25.5   | 0.12| 4    |

2.4 Bozhou Zhuang, Yuqing Liu, Dalei Wang 2020 [9]

In this piper, the Rubber_Sleeved_Stud (RSS) connector is used, which consists of an Ordinary_Headed_Stud (OHS) connector coated with a certain percentage of rubber. The rubber used to encapsulate the (OHS) connector reduces the shear force of (OHS) connector. Where a composite bridge made of concrete and steel was used to form a composite structure. The (RSS) connector was used in the contact area between the steel and concrete.

Figure 4. The Steel anchor box configuration [9].
In this paper, the work was done to verify the shear strength of the models that contain a (RSS) connector through a full test of the model and an analysis of this model using the finite element software. Prototype research was carried out using an auto-equilibrated system, that shown in Figure 5.

![Figure 5. Finite element analysis of the model [9].](image)

Thirty-two prestressed bars were placed between the connecter which were fixed to the front of the steel section. In this work, there are two loading steps. The first step includes the prestressed transverse, vertical and longitudinal bars were tensioned to the predicted magnitudes. Then the first step follows, Jacks is extended to achieve the second step cable force charging. In the second step In order to obtain the reliability of the entire loading system, the cable is preloaded with a load whose value is equal to 0.4p and then this load is unloaded. After this loading is completed, the primary loading is performed. The primary loading process includes an increase in the amount of loading between each stage of the loading. Where this increase in the load between one stage and another is 0.1p and this increase in the load continues until the amount of loading reaches 0.6. And where the period in which the model is loaded at each increment is 10 minutes. Then the cable load is increased to 0.05p and this amount is stopped the increase when the cable load reaches 1p. Finally, the load is increased to 1.7p in order to make an assessment of the performance of the structure under the increase in the design cable loading. The response of the origin during the loading process was recorded from beginning to end. The curve of loading are shown in the Figure 6.

![Figure 6. The curve of loading [9].](image)
2. 5 Suhaib.J.Ali, Amer M.Ibrahim, Sarmad Shafeeq (2020) [10]

The aim of this review was to build steel frame connections using the Composite Steel bolts Rubber to link beams to column joints of steel structures instead of traditional Steel-bolts. The Portal-Frames for steel planes were tested under quasi static horizontal Cyclic Load. The research project also includes testing of various Composite steel bolt Rubber diameters that are used to link the beam to columns. The rubberized connections deal with high structural standards through the absorption of damping process by reducing the effect of the stresses resulting from the earthquakes. The tests are investigated to have a more influential effect of the inclined-cyclic load than horizontal-cyclic load. The models examined are made up of a beam (IPE160) with depth equal to 1000mm, and column (HW125x 125) with depth equal to 1500mm. The base is welded to columns where one of the column bases has fixed support and the second base has pinned support. Also, the connection between the beam and column by using shear tab connection, the shear tab connection welded with steel column and connected with beam by two bolts, as shown in the Figure 7 and 8.

**Figure 7.** Model Dimensions [10].
The steel bolt with diameter equal to 7mm. The steel bolt is coated with variable diameters of rubber where these diameters are equal to 0.5\(d_{\text{bolt}}\), 1\(d_{\text{bolt}}\), 1.5\(d_{\text{bolt}}\), and the type of holes are variable between the four type: Standard hole (STD), Oversize hole (OVS), Short-slotted hole (SSL), and long-slotted hole (LSL) that shown in the Figure 9.

In this paper, tests were made for the used rubber. These tests include testing of compression, tension and hardness, as they were carried out in the University of Technology Laboratory in Baghdad. As the results of the tests obtained for each test are shown below:

| Force(N) | Length Change ΔL mm | Compression stress MPa | Strain \(\varepsilon = \Delta L/L\) | Young’s Modulus MPa |
|----------|----------------------|------------------------|----------------------------------|---------------------|
| 0        | 0                    | 0                      | 0                                | 0                   |
| 500      | 1.24                 | 20                     | 0.124                            | 161.4               |
| 700      | 3.94                 | 28                     | 0.396                            | 70.7                |
| 900      | 8.72                 | 36                     | 0.872                            | 41.28               |

The test of compression to rubber is made according to [ASTM] properties based on the Standard-test-Method [D695 – 15 2008].
The tensile test was done based on Standard-Test method for properties of the tensile of plastics [D638-14 2015]. Where the elongation was equal to 1204.1% and tensile was equal to the 15.09 Mpa. The hardness test was done based on Standard-Test-Method for the rubber property-durometer hardness [D2240 – 15 2017]. Where five of the readings obtained from the research were selected, then the rate was taken for them and approved as the hardness of the rubber used as its value is equal to 85.6 shore.

2. Researchers’ results
After the practical and theoretical examinations conducted by the researchers, the following results were obtained:

3-1 Bozhou Zhuang, Yuqing Liu, Fei Yang, (2018) [6]
The load-slip curve is plotted for each specimen in Fig.10. Based on these curves, we found that the corresponding slips of (RSS) connectors are considerably larger than those of (OHS) connectors and the initial stiffness of the (RSS) connectors may be found to be less than that of the (OHS) connectors. With both 50 kN and 75 kN load bearings, (D19-3) slips much less than (D19-2), making (D19-3) more stable than (D19-2).

Figure 10. Curves to load-slip [6].
Concrete side fault mode and steel side flange, as shown in Figures (11-12). When using rubber around the connector to form Rubber Sleeved Stud (RSS) connector used in steel-concrete interface design, when shedding loads the damage area in the concrete is lower in use condition (RSS) connector and also concrete becomes out crash it does not crack This means that the rubber is able to reduction the damage area in the concrete in the Ultimate State limit.

Figure 11. Concrete-side modes of failure(Bozhou Zhuang, Yuqing Liu, Fei Yang, 2018).
They also concluded that the Rubber-Sleeved Stud connector is important to reduce peak tensile stress to concrete, this reduces cracks in the concrete. The degree of stiffness loss has increased with load ranges increasing. A new style connector is capable of maintaining the degree of stiffness deterioration in the serviceability state at a certain amount.

3-2 Bozhou Zhuang, Yuqing Liu, (2019) [7]

Figure 13 and 14 illustrate the failure profile of a large Rubber Sleeved Stud connector and Ordinary_Headed_Stud connector.

Figure 12. Modes failing on the steel flange side [6].

Figure 13. The failure profile of a large Ordinary Headed Stud connector [7].
By observing the model that contains the (OHS) connector, we notice that the concrete is crashed due to refraction in the shank of the (OHS) connector. Due to the large space between the root of the rubber-coated connector and the concrete, the model allowed for great deformation without failure occurring. Fig.15 shows that the concrete block was cut into strips after the push-out check to demonstrate the fault form along the RSS connector.

From the figure above, the area surrounding the (RSS) connector can be divided into two parts, the first consisting of steel-concrete and the second section consisting of rubber-concrete. It is important to mention, that only the root of the connector is in direct contact with the concrete. In the first section, which consists of concrete and steel, we note that there is a large correlation between the root of the connector that is non-rubber coated and the concrete, which leads to the absence of plastic deformation. The second section of the contactor root, which was coated with rubber, exhibited bending shearing deformation. It is important to mention that the rubber-coated connector is subject to compression without breaking, and this leads to a crash in the concrete and not a crack. It was also noted through this research that it is valuable for shear-stiffness of the (RSS) connector, reduced by 41.5% from (OHS) connector.
3-3 Zhigang Zhang ,Xiaoqing Xu (2020) [8]

The load slip curved of this paper as shown in Figure 16. The Eurocode 4 is mentioned that, the Slip-Capacities of the (S-0-U) and (RS25-0-U) Samples are (4.6 mm) and (6.9 mm), respectively. While the Shear Strength of the specimen RS25-0-U is lower than that of the specimen S-0-U, the slip efficiency is 1.5 times that of the specimen S-0-U. Also, when using the Rubber Sleeved Stud (RSS) connector in Field-cast ultra-high performance concrete (UHPC) connections, the behaviour of the (UHPC) becomes plastic in composite sections. The strain gages at the stud roots showed that a small proportion of the fatigue life of rubber sleeved stud shear connectors is consumed by the crack initiation cycle, which is about 5 per cent.

![Figure 16. The load slip curved [8].](image)

3-4 Suhaib.J.Ali,Amer M.Ibrahim,Sarmad Shafeeq(2020) [10]

In this study, four models were tested under Horizontal - Cyclic – Loading. These models Measurement at the Ultimate and Yield Points.

From the table above, the yield point of the FR2 (The frame with 50% rubber) increase by 50%, FR3 (The frame with 100% rubber) the yield point increase to 100% and FR4 (The frame with 150% rubber) the yield point increase to 100%, that compared with FR1 (The frame with 0% rubber). Also, the effect of using steel bolts - rubber where applying rubber to the steel bolt as much as one and a half times in diameter allows the steel frames Re-Distribution - Moments and then delays the frame failure entirely. Also, from the Table 4 we are noting that, the drift of the steel portal frame increases with the increase in the ratio of the rubber. The displacement of the frame increase when increase the ratio of the rubber that coating the steel bolt in the steel portal frame. As shown in the fig14, the number of cycles of the steel – portal frames as shown in the Figure 19.
The protocol for loading ATC-24 is used in this study, and according to this protocol, the models are loaded using two hydraulic jack contacts with the machine used to test. These hydraulic jack applied horizontal -cyclic load-quasi- static load on the steel portal frame. When the load is applied on the FR2(The frame with 50% rubber), the number of cycles are 16 cycles and when applied the load on the FR3(The frame with 100% rubber) , the number of cyclic also 16 cycles, While when see the figure of cycles to the FR 4 (The frame with 150% rubber) We observe that the number of cycles are 40 cycles. When compared the number of cycles to the FR4 with the FR1 (The frame with 0% rubber), we look that, the bolts Fracture and reached in 10 cycles at failure.

3-5 Bozhou Zhuang, Yuqing Liu, Dalei Wang (2020) [9]
By observing the results obtained from the practical and theoretical programs, many advantages were reached that encourage the use of the composite conductor, which consists of the natural rubber coated connector. By observing the results obtained from the theoretical program that includes analysing the model in the finite element method, it was found that the shear strength of the rubber coated conductor was twenty percent less compared to the non-rubberized conductor. This is explained by the fact that the main reason for this decrease in shear strength, That the high shear strength of the natural conductor is transferred part of it to the rubber, and therefore we note that the shear force has decreased in the case of using rubber to coat the connector compared to not using it. It was also observed through the study of the results, that in the case of using rubber to encapsulate the conductor, the distribution of the shear force on the interface becomes more organized, and we also note that the damage that occurs at the interface that contains concrete has decreased compared to the case in which the conductor is used without rubber coating. This conclusion is illustrated more understandably in the curve shown in the Figure 20.
It was also noted in the practical test that when using rubber-coated connectors in the composite model, these connectors give a higher degree of deformation without failure compared to the use of non-rubber coated connectors. Whereas, when using the rubber-coated connector and placing the load whose value is 1.7p, the strain value is (716), which is equivalent 313.8 percent to the normal connector. Finally, when using rubber around the connector, note that it allows for a heavier horizontal and vertical sliding compared to not using rubber around the connector, that shown in the Figure 21.

3. Conclusion
The conclusions of this investigation are as follows.

- When using rubber around the shank of the connector, height has an impact on stiffness, the lower the height, the more it will reduce, also, the thickness of the rubber has an effect on shear stiffness, whereas the thickness of the rubber, less stiffness of shear.
- Rubber has an important improvement in ductility to shear connectors in UHPC, also, the high rubber of (RSS) connector in a (UHPC) has an effect on the shear - strength of the stud - shear connector, which decreases as the height of rubber increases, also, for rubber coated connector under cyclic load, observed accumulation and better deformation recovery.
- When using the rubber around the steel bolts, the corrosion between the holes of the plate and the bolts is decreased, this leads to preserving the steel-frame joints when exposed to the wind and dynamic effects.
• When using a rubber coated bolt in steel joint structures decreases the strain and increases resistance of the steel frame due to rubber damping and absorption.
• The using a rubber coated bolt in steel portal frame joints reduces by more than 1/3 of the cost relative to the overall cost of manufacturing a framed steel-bracing system.
• Finally, in horizontal and inclined frame systems - frames with steel bolts - rubber joints provide the highest degree of energy dissipation also, Rubber enhances steel frame behaviour and performance in two action systems, horizontal and inclined, including resistance, cycle number, drift, strain reduction, ductility index, and damping ratio.

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