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STUDY THE EFFECT OF STEEL WIRES PRE-TENSION ON THE BENDING AND ADHESION PROPERTIES OF BEAD PLY IN RUBBER TIRES

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ABSTRACT

Tires are considered important components of the vehicle by which the vehicle can move on the road. The continuous development in the transportation requires improving tires to suit the modern requirements of the transportation. This work includes studying the effect of using the pre - tension technique to improve the flexural and adhesion properties of bead ply in rubber tires. Pre-tension levels ranging between (0- 1250 MPa) were applied on each single reinforcing wire at room temperature before the vulcanization process. The results showed that the increasing in maximum bending strength, bending stiffness, and maximum shear strength by (26 %) due to pre-tension. The single fiber pull-out test results show that the debond shear strength was increased by (27 %) pre-tension on steel wires.

KEYWORDS: Pre-Tension; Bead Ply; Rubber Tire; Pull-Out Test; Bending Test.

1. INTRODUCTION

The tire is one of the vehicle components which bordering the ground and it consists of many parts. The basic construction of the typical tire is shown in Fig. 1. The bead ply is the internal brink of the tire that embraces the wheel rim and presses against the bead seat. The bead presses the rim to transfer different forces such as steering, traction, acceleration, braking, and directional forces of the wheel to the other tire parts as well as the tread to move the vehicle by the friction forces between the tread and the road and prevents air loss in tubeless tire. Bead failure can be dangerous because it can cause a sudden air pressure drop in the tubeless tire and separation of the tubeless tire from the wheel rim leading to loss of control on the vehicle causing a regrettable accident. This location and function are exposing the tire bead to many forces and stresses so that the bead was reinforced with high strength steel wires that its chemical composition shown in Table 1 (Doradle et al., 2005; Burton, 1954).

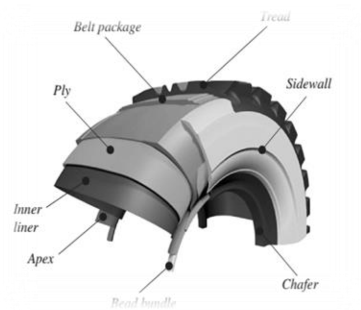

Fig. 1. The basic construction of the typical tire (Adetan et al., 2008).

Table 1. The chemical composition of the bead wires (Mohamed, 2000).

Elements	Percentage (%)
C %	0.72
Mn %	0.6 (0.57-0.66)
Si %	0.2
S %	0.05
P %	0.05
(S+P) %	0.08 combined
Ni %	0.1
Cr %	0.05

The bead can be classified as a composite material where rubber acts as a matrix and steel wires act as a reinforcement which it is called Polymer Matrix Composite (PMC). These wires were coated with copper or bronze to maintain an optimum adhesion to bead rubber. Table 2 shows the general requirements of bead wires. The bead also needs to have very good mechanical properties and it needs to maintain these properties at service conditions including high speeds and high temperature. The bead ply is shown in Fig. 2. (Gent et al., 2006; Kerssker et al., 1969; Frank et al., 1967).

Table 2. The general requirements of bead wires (Mohammed, 2000).

Wire	Units	Mean	Max.	Min.
Dimeter	Mm	0.96	0.98	0.94
Breaking Force	N			1220
Elongation at Break	%			5.0
Weight per unit length	g/m	5.7	6.0	5.4
Plating				
Type	Copper			
Composition	%cu			
Weight	g/kg	0.82	1.18	0.45
Thickness	Micron	0.18	0.26	0.10
Type	Bronze			
Composition	%/Cu/Sn	98/2	99/1	97/3
Weight	g/kg	0.82	1.18	0.45
Thickness	Micron	0.18	0.26	0.10
Adhesion –ASTM	N/50 mm			400
Compound code	4110			

Pre-tension in wires can produce residual stresses in the composite structure when the tension applied on the fibers is removed. The applied tension must not exceed the fibers elastic limit (yield strength) to enable fibers to return to their initial state when the load is removed. The fiber pre-tension has a great influence on the creation of residual stresses and they are greater than those of the other causes. Several methods have been developed to apply pre-tension on the fibers for making this operation more useful. The influence and value of the residual stresses that caused by fiber pre-tension depend on the magnitude of pre-tension on the fibers, properties of composite constituents, and processing history of the composite (Motahhari, 1998).

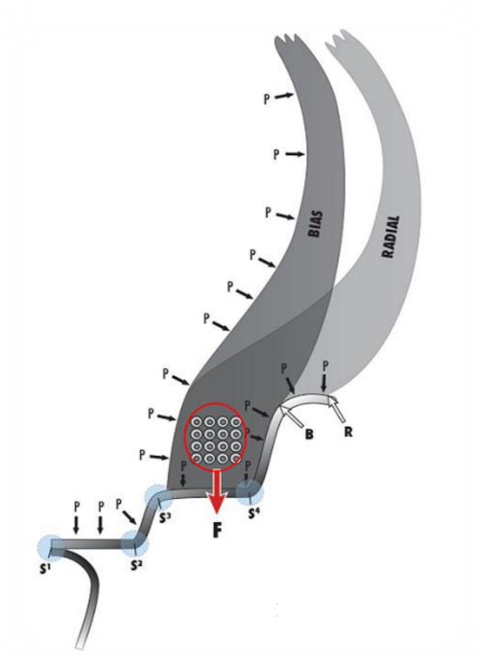

Fig. 2. Bead ply in radial and bias Mounted Tires (WTC, 2017).

2. EXPERIMENTAL WORK

2.1. The rig for applying pre-tension load on bead wires

The rig consists of a steel frame (80*80*120 cm), molds made of low carbon steel, and water container as shown in Fig. 3. This water container can provide the required weight by filling it with a required amount of water. There are two parallel beams at the top of the frame. The distance between these two beams can be controlled by sliding them horizontally in order to suit all the molds. Each mold has a pair of hooks and the mold is perpendicularly fixed by these hooks between the beams. The pre-tension load was applied on the bead wires by three steps:

1-All the wires were fixed from their ends to the mold. Then, the mold was set between the beams of the frame.

2- The other ends of the first wire was connected to the water container after filling it with the required amount of water.

3-The first wire was fixed to the other side of the mold and the load was removed. The last two steps were repeated for all other wires.

Eight values of load were applied on the wires below its yield strength as shown in Table 3.

Fig. 3. The rig for applying pre-tension load on bead wires.

Table 3. The wires pre-stresses and the equivalent loads on wires.

yield strength = 1325 MPa		**wire diameter = 0.96 mm**
Yield force = 958.579 N		**wire area = 0.7234 mm^2**
No.	**Wire pre-stresses (MPa)**	**Load on individual wire (N)**
1	0	0
2	178	129
3	357	258
4	535	387
5	714	516
6	892	645
7	1071	775
8	1250	904

2.2. Rubber Compound Preparation

This compound was prepared at four stages on 2-roll mill. It consists of (13) different material which are mixed together at specified amounts as shown in Table 4.

Table 4. Raw materials of rubber compound IK 4110.

Compound	PPHR
SMR 9720	72.00
SBR 1502	28.00
Whole Tyre Reclaim	70.00
PCTP-50	0.15
Zinc Oxide	5.00
Stearic Acid	4.00
Process Oil	12.00
Phenolic Tack Resin	6.00
N660 Black	140.00
6PPD	0.70
TMQ	0.60
Insol Sul:Oil (80:20)	0.10
MBS	6.27
CPT-100	1.00
Total	345.82

2.3. Preparation of test specimens

The bending test specimens were rectangular in shape with dimensions of (L=110 mm, w=12 mm, and t=3 mm) according to ASTM standards D790-00 as shown in Fig. 4 and Fig. 5. The ratio of thickness to other dimensions was (L=20-30t, w=3-5t, and ls=15-25t). The volume fraction of wires was (8 %) with four wires in each specimen. Standard ASTM D790-00(2004).

The pull-out test specimens were also rectangular in shape with dimensions of (L=200 mm, w=50 mm, and t=12.5 mm) as shown in Fig. 6 and Fig. 7. Each specimen contains five wires embedded inside it. The specimens were prepared according to ASTM standards D1871-98.

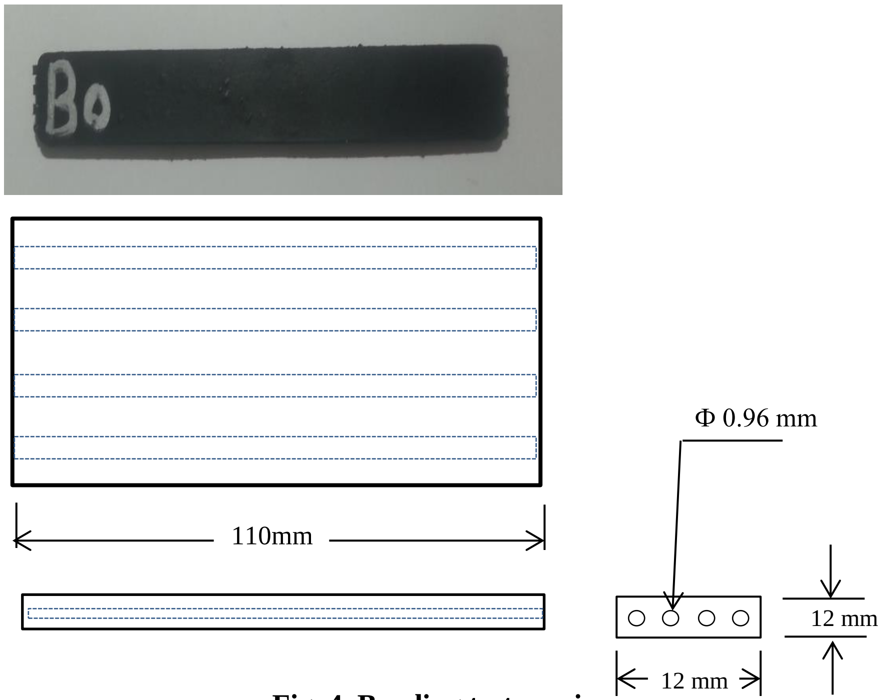

Fig. 4. Bending test specimen.

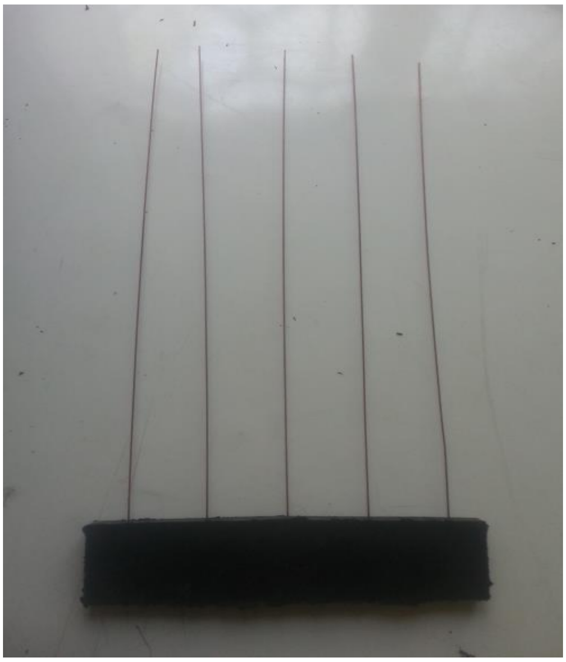

Fig. 6. Pull-out test specimen.

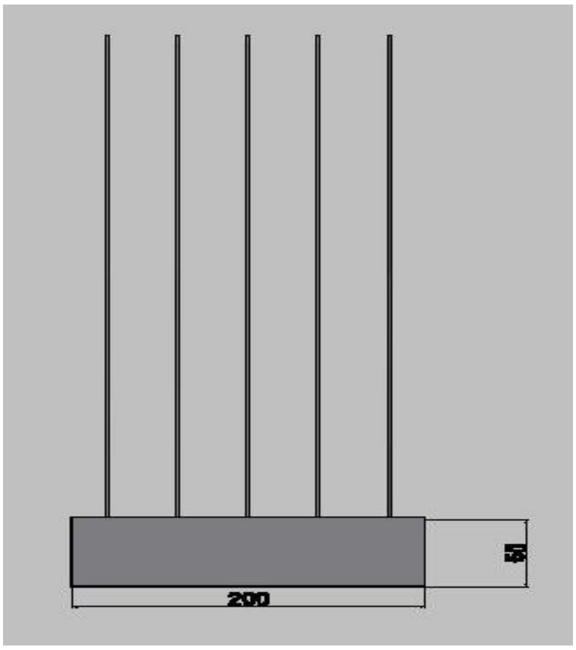

Fig. 7. Pull-out test specimen.

2.4. Specimens Testing

The bending test was performed according to ASTM D790-00. The strain rate is (2.5 mm/min.). The machine that was used in the test is universal test machine type ED-UTM. The specimens tested with (24 mm) span length and upper grip roll diameter of (12 mm) and two lower grip support rolls with a diameter of (4.8 mm).

The pull-out test was done according to ASTM D 1871-98. The machine that was used is Tensometer (10). The specimen was fixed at the lower grip which it was stationary while the wire was clamped to the upper grip which it was moveable. The pulling force was applied to the wire by the movement of the upper grip upward with a speed of (50 mm/min). The load was applied until the separation of wire from rubber specimen. The result of each single wire was recorded (Standard ASTM D790-00, 2004; Standard ASTM D1871-98, 2004).

2.5. Calculations

1- Bending stress:

The bending stress was calculated from the following equation: Mouritz et al. (1997).

$$\sigma_B = \pm \frac{3*p*l_s}{2*w*t^2} \quad (1)$$

σ_B------- Bending stress (MPa)

p------- Bending load (N)

l_s------- Span length (mm)

The positive sign refers to the bending stress in tension while the negative sign refers to the bending stress in compression. The relation between the pre-stress level and bending stress can be drawn.

2- Shear Stress

The shear stress due to bending in the sample can be calculated from the equation (ASTM D790-00, 2004) [12]:

$$\tau_B = \frac{3*p}{4*w*t} \qquad 2$$

The relation between the pre-stress levels and shear stress due to bending is drawn.

3- Bending Stiffness

The bending stiffness for bending specimens can be calculated from the equation (Ashby, 2005):

$$k_b = \frac{F_{max}}{\delta} \qquad 3$$

k_b------ bead specimen bending stiffness (N/m)

F_{max}-------maximum bending force (N)

δ ------- maximum deflection (m)

The relation between the pre-stress levels and bending stiffness is drawn.

4- Debond shear stress:

This test was used to find the maximum interfacial shear stress at the interface between the wire and the rubber, and this maximum interfacial stress can be calculated according to the equation (Desarmot et al., 1991):

$$\tau_{i_{max}} = \frac{F_d}{\pi*d_w*l_e} \qquad 4$$

$\tau_{i_{max}}$ ------Debond shear stress (MPa)

F_d ------- Debond force (N)

l_e------wire embedded length (mm)

Then the relation between the pre-stress levels and maximum interfacial shear stress (debond shear stress) is drawn.

3. RESULTS AND DISCUSSION

3.1. Maximum Bending Stress and Shear Stress

Fig. 8 shows the relation between the pre-stress and the maximum bending stress produced in the bending specimens. From this figure, the pre-stress increases the maximum bending stress for bead specimens from (63.333 MPa) at zero pre-stress to (80 MPa) at (1250 MPa) pre-stress with the percentage of increase about (26 %).

Fig. 9 shows the relation between the pre-stress and the maximum shear stress due to the bending produced in the bead specimens. From this figure, it can be observed that the pre-stress leads to increase the maximum shear stress for the bead specimens from (3.958 MPa) at zero pre-stress to (5MPa) at (1250 MPa) pre-stress with increasing ratio reaches to (26 %). From these results, it can be noted that the pre-stress levels posses an effect on the composite plate to carry bending and shear stresses. The increase in bending strength occurs due to the pre-stress of bead wires to make the rubber specimen under compression and that make the upper surface more strong and high resist to bending load. The surface that subjected to tensile is also being under compression due to pre-tension compressive residual stress and it requires extra external loads to overcome the compression and start stretching. Fig. 10 shows the effect of compressive residual stresses on the specimen by its constriction after pre-stress removed.

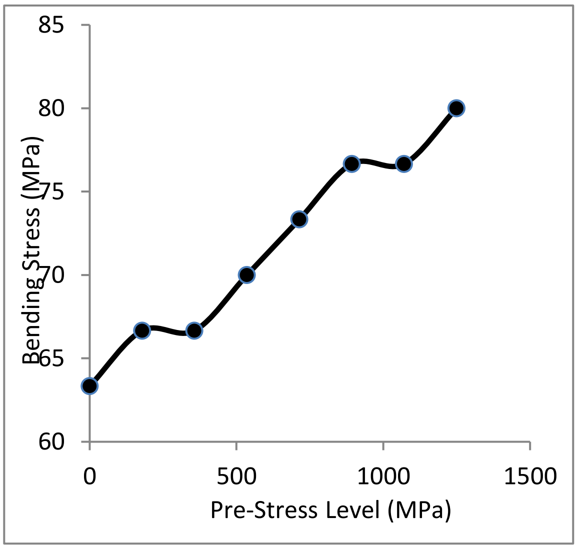

Fig. 8. The relation between the pre-stress level and the maximum bending stress.

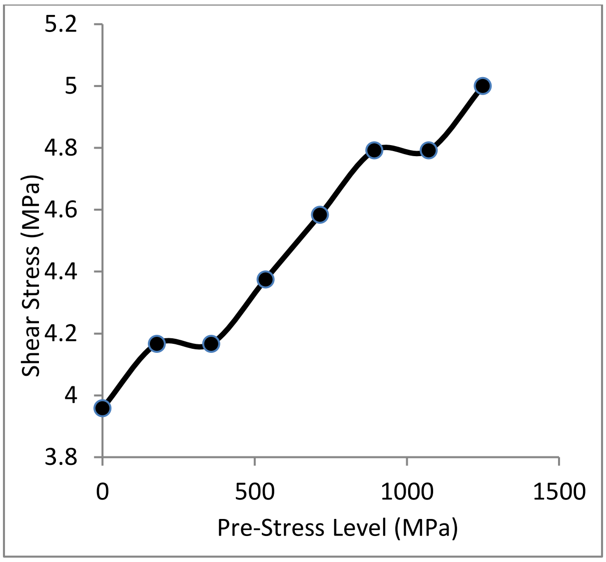

Fig. 9. The relation between the pre-stress level and the maximum shear stress

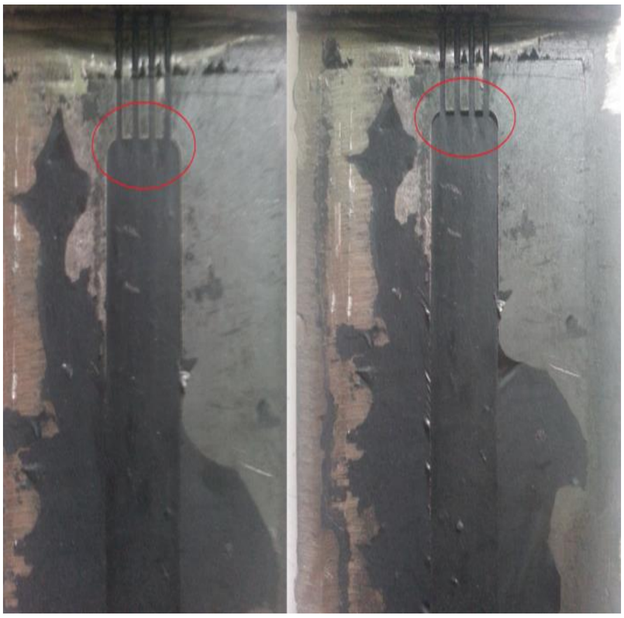

Fig. 10. The specimen constriction after pre-stress removed.

3.2. Bending stiffness

Fig. 11 shows the relation between the pre-stress levels and bending stiffness of bead specimens (load to displacement ratio). This figure shows that the stiffness of composite increases when the pre-stress levels are increased. The increasing in stiffness is found to be from (31.666 KN/m) at zero pre-stress to reach about (40 KN/m) at (1250 MPa) pre-stress, with percentage increase about (26 %). The increase in stiffness means that the specimen needs an extra load to deform or the deformation decreases at constant load. The increase in stiffness is due to the compression force in specimen created by wire pre-tension as well as the residual stress at the interface created also by wire pre-tension.

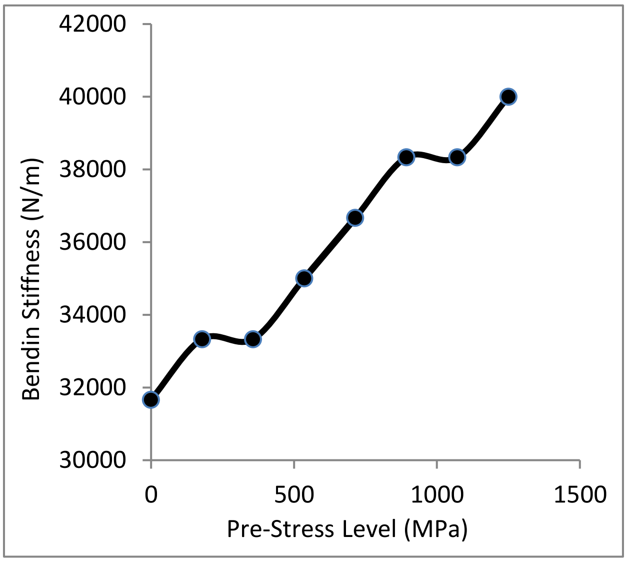

Fig. 11. The relation between the pre-stress levels and bending stiffness.

3.3. Debond shear stress

Fig. 12 shows the results between the pre-stress level and debond shear stress. This relation shows that the pre-tension increases the debond shear stress at the interface between the wires and matrix from (3.410 MPa) at zero pre-stress level to (4.337 MPa) at (1250 MPa) pre-stress level with increasing percentage (27 %). This means that pre-stress level will increase the external load required to pull the wire outside the composite making the composite more strong as shown in Fig. 13. The pre-stress level makes the wire-matrix interface under compression that required a greater force to be applied to overcome the compression force created by pre-tension and to overcome the adhesion between the wire and rubber.

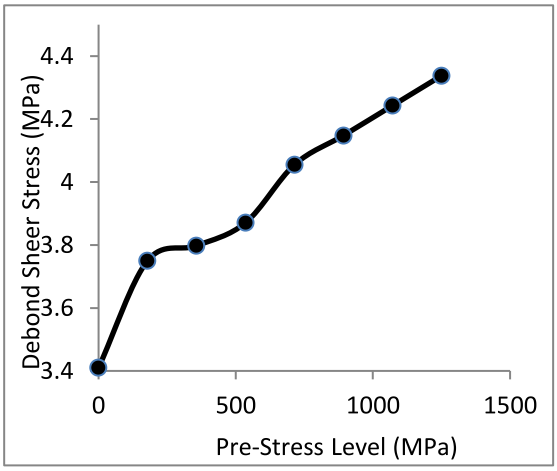

Fig. 12. The relation between the pre-stress level and the debond shear stress.

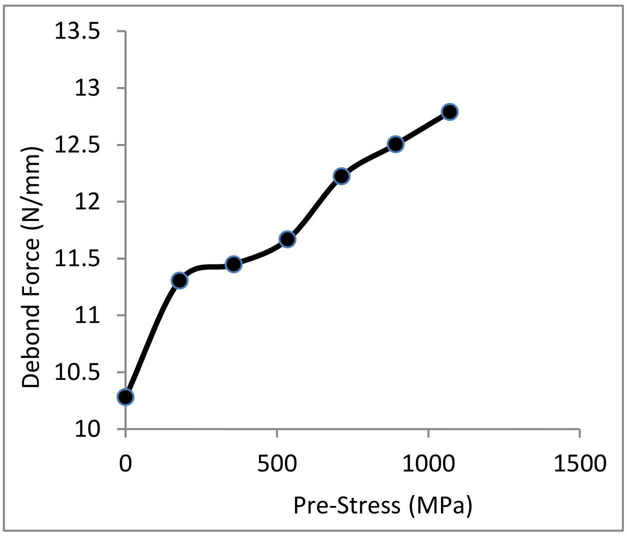

Fig. 13. The relation between the pre-stress level and the debonding force.

4. CONCLUSION

- The pre-stressing of (1250MPa) on steel wires increases the bending strength of bead specimens by (26 %) as the pre-stressing makes the sample under compression after removing the load. This gives more strength to sample that needs a larger stress to be applied to make the sample bend.
- Shear strength increased by (26 %) as the pre-stressing make the sample under compression. Also, the bending stiffness for bead specimens increased by (26 %) with pre-stressing of (1250MPa).
- The pre-stressing of steel wires increases the de-bond shear stress of the bead specimens by (27 %) at pre-stressing of (1250MPa). This occurs due to the residual stress of pre-stressing that make the bonding area have more strength and need more shear stress to de-bond the wire from rubber

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