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ANALYSIS OF THE ADHESION STRENGTH OF A SHAFT-BUSHING JOINT

Abstract: *One of the methods for finding a solution to the general problem of lightweight structures while maintaining their reliability in racing cars is the use of adhesive-bonded joints. The international student project Formula Student allows engineering students to find the connection between theory and practice in real world conditions, in this case to create adhesive-bonded joints and test their strength, while acquiring new knowledge firsthand in one of the most technological sports in the process. The main results of this study and analysis of the shear strength show that the properly created adhesive-bonded joint between the steel rod and the carbon fiber tubes for the control arms of the sports car is sufficiently robust and reliable, thereby lightening the structure.*
Keywords: *adhesives, adhesive bonding, steel pins, carbon fiber tubes, experimental study and analysis of the shear strength*

1. INTRODUCTION

The assembly of parts by adhesive-bonding is a modern, reliable and high-performance method for obtaining conditionally non-disassembling structures. Particularly attractive is the possibility of connecting different materials and structures - metallic, non-metallic, dense and porous, as well as all sorts of combinations between them. In the creation of many and complex multilayer structures, adhesion bonding methods are widely applied. The main reasons for this are practical or technological inaccessibility to the structural elements or constraints arising from the heterogeneity of the materials from which they are made. Another important advantage of this approach is the residual internal stresses which, compared to other technologies, have the smallest value. The effect of this advantage is expressed in the operational lifetime of the created joint. [1]

Environmental and competitiveness requirements force companies in the automotive industry to look for ways to lighten the construction while preserving its reliability. One way to achieve this is to apply adhesive-bonding. This problem is also of particular importance in racing cars. Studies in this field have been popularized even among students from technical universities, where ideas for design and technological improvement of transport prototypes are encouraged. A current problem in this direction is the additional lightening of the construction of the sports car of the Technical University of Sofia for 2017 following the international Student project "*Student Formula*".

The specific objective of the present study is to determine the strength changes produced by three different types of epoxy adhesive layer compositions between a steel pin and a carbon fiber tube at a shear load depending on the magnitude of the gap and the length of the axial contact between them.

2. EXPERIMENTAL PART

2.1 Materials

2.1.1 Adhesives

Two-component structural epoxy adhesive **3M DP490** [6]

Table 1 – *Technical specification of the adhesive **3M DP490***

Technological time	=	**300 min**
Shear strength	=	**36 MPa**
Peel strength	=	**5 kNm**
Elongation	=	**3 %**

Two-component structural epoxy adhesive **Kanopox 11** [7]

Table 2 - *Technical specification of the adhesive **K11***

Technological time	=	**75 min**
Shear strength	=	**18 MPa**
Peel strength	=	**8 kNm**

Two-component structural epoxy adhesive **ADEKIT H 9952** [8]

Table 3 - *Technical specification of the adhesive **ADEKIT H9952***

Technological time	=	**120 min**
Shear strength	=	**26 MPa**
Peel strength	=	**5 kNm**
Elongation	=	**3 %**

2.1.2 Adherents

Steel inserts

A steel rod with length 1200 mm, having steel specifications (**Table 1**) was cut according a CNC lathe specification (**Fig.1**) and the inserts, or pins, were divided in the following manner:

- **27** pins having **Ø 9.7** mm - 9 pieces 10 mm long, 9 pieces 12.5 mm long, 9 pieces 15 mm long;
- **27** pins having **Ø 9.8** mm - 9 pieces 10 mm long, 9 pieces 12.5 mm long, 9 pieces 15 mm long;
- **27** pins having **Ø 9.9** mm - 9 pieces 10 mm long, 9 pieces 12.5 mm long, 9 pieces 15 mm long;

Table 4 – *Technical specification of the steel at temperature 20°C*

σ_B	380 – 490 MPa
Hardness	HB 10^{-1} = 131 MPa

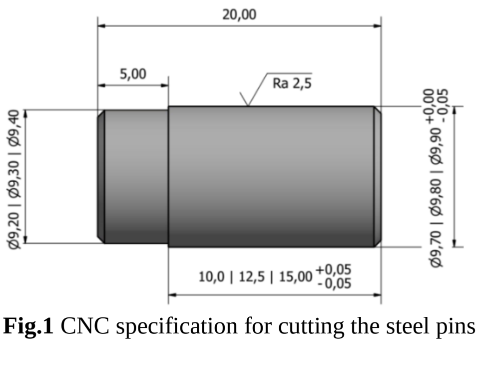

Fig.1 CNC specification for cutting the steel pins

Carbon fiber tubes

The carbon fiber tubes were manufactured by *Easy Composites*, *UK*, having the following technical specifications (**Table 5**):

Table 5 – *Technical specification of the carbon fiber tubes* [9]

Internal Diameter	=	**10**	**mm**
Wall Thickness	=	**1,35**	**mm**
External Diameter	=	**12,7**	**mm**
Weight	=	**0,075**	**kg/m**
Density	=	**1,60**	**g/cc**
Young's Modulus @ 0°	=	**90**	**GPa**
Young's Modulus @ 90°	=	**19**	**GPa**

2.2 Techniques

The adhesive application technology used in this experiment is based on commonly accepted rules in the literature ([1]-[4]), which are as follows:

- Mechanical cleaning of the glued surfaces (using type P100 sandpaper);
- After this operation the tolerance of the internal diameter of the tubes becomes $10^{+0,05}_{0}$;
- Degreasing of the glued surfaces (using acetone);
- Application of the adhesive on the glued surfaces (using a brush);
- Assembling and pressing of the glued surfaces (sandwiching simultaneously with rotation);
- Subjecting of the adhesive layer at curing (polymerization) for about 1 week.

The method by which the strength of the adhesive bond between the pin and the carbon tube is determined is known as the "Shaft-bushing Test" [1]

2.3 Test rig

The testing machine that was used in this experiment is the universal American test rig INSTRON 1185 (**Fig.2**):

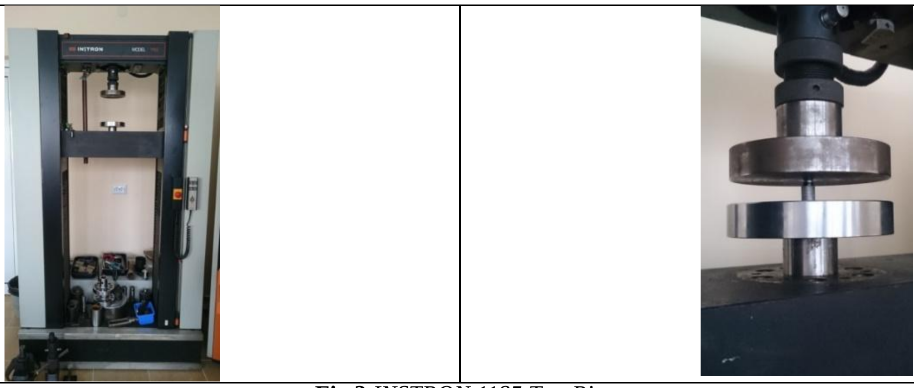

Fig.2 *INSTRON 1185 Test Rig*

2.4 Calculation procedures

Area (S): Given the mixed rupture, it is assumed that the diameter at which the crack develops is the middle of the gap "d_{crack}" (d_{cr}), representing the half-sum form the dimension of the bushing (d) and the pin (Ø):

Ø 9,7 → d_{cr} = (d + Ø) / 2 = (10 + 9,7) / 2 = 9,85 mm
Ø 9,8 → d_{cr} = (d + Ø) / 2 = (10 + 9,8) / 2 = 9,90 mm
Ø 9,9 → d_{cr} = (d + Ø) / 2 = (10 + 9,9) / 2 = 9,95 mm

and therefore

$$S = \pi . d_{cr} . L \qquad (1)$$

for each of the tests.

Force (F): It is found by multiplying the number of squares (from the machine list) by the strength corresponding to one square, i.e. "Number of squares" multiplied by "force per square".

Shear stress (τ): It is found by dividing the force to the area:

$$\tau = \frac{F}{S} \qquad (2)$$

3. RESULTS, ANALYSIS AND DISCUSSION

3.1 Testing of the adhesive-bonded joint with 3M DP490 adhesive

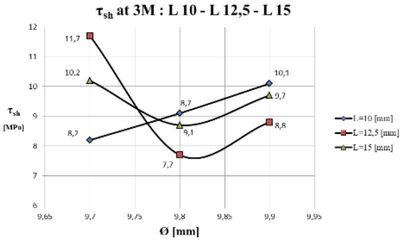

Fig.3 *Shear strength of the adhesive-bonded type "shaft-bushing" joint made with 3M adhesive according to the gap between the elements achieved by a different diameter (Ø) of the pin*

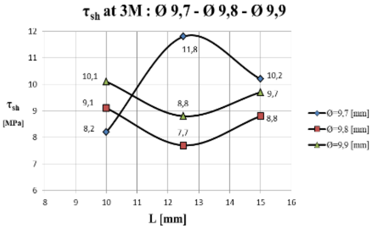

Fig.4 *Shear strength of the adhesive-bonded type "shaft-bushing" joint made with 3M adhesive according to the axial length of the contact (L) between the elements at a fixed value of the diameter Ø = 9,7; 9.8 and 9.9 mm*

Looking at the graphs for 3M adhesive at L=10 - 100N we have very close values for τ_{sh}. Here, with each subsequent larger dimension of L, the average shear stress has increasing values from L=10 to L=12.5, but are then decreasing for L=15. This suggests a good sample of an adhesion-bonded joint and a very good adhesive (**Fig.3**).

For the average contact length - L = 12.5, the highest shear strength value is found.

At 3M L = 12.5 and Ø=9.8 per 100N, similar results are obtained for the average shear stress. From the curve we can say we have good adhesion strength.

From **Fig.4** we find that the highest shear stress is at L=12.5 - 11.80 MPa.

The results of the test of this adhesive indicate that the adhesive technique is correct but the results with using the 3M DP490 glue are slightly weaker than the results of ADEKIT H 9952, shown below, due to the weaker adhesive properties of the adhesive itself.

3.2 Testing of the adhesive-bonded joint with Kanopox K11 adhesive

From the graphical dependencies for K11 (**Fig.5** and **Fig.6**) we can observe the following processes: the first graph shows us with increasing of the size of the pin (Ø), τ_{sh} also grows. From the second, with the increase in the value of L, there is a decrease in the average shear stress.

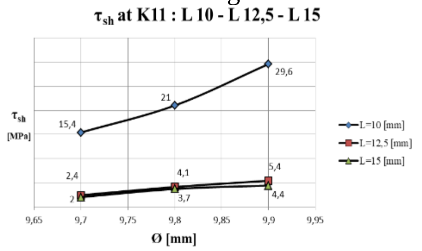

Fig.5 *Shear strength of the adhesive-bonded type "shaft-bushing" joint made with K11 adhesive according to the gap between the elements achieved by a different diameter (Ø) of the pin.*

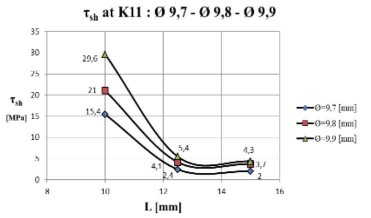

Fig.6 *Shear strength of the adhesive-bonded type "shaft-bushing" joint made with K11 adhesive according to the axial length of the contact (L) between the elements at a fixed value of the diameter Ø = 9,7; 9.8 and 9.9 mm*

The study of the influence of the gap at the mean contact length (L) showed the following results: for L = 12.5 it is 2.4, which is relatively small, given that the force of the machine is set to 200N.

Although the force is reduced from 200N to 50N, there is again an increase in the mean shear stress with each previous Ø = 9.7 - 9.8 - 9.9 and a decrease in the size of L = 10> 12.5> 15.

The study of the influence of the gap at the largest contact length (L) showed the following results: very high shear value - 21 MPa - at L=10, unlike L=12,5 and L=15 where the values are close to each other.

For K11 - L=15 at Ø=9.7 and Ø=9.8 at 50N and Ø=9.9 at 100N increase, similar and increasing values of the mean shear stress are obtained. For the dimension of L, again at any larger size, the average shear stress decreases.

The test results of this adhesive indicate that although the bonding technique is correct, the final results are the lowest compared to those of the other adhesives due to the different properties of the adhesive itself.

3.3 Testing of the adhesive-bonded joint with ADEKIT H 9952 adhesive

The samples bonded with ADEKIT H 9952 are not in their full volume, but they are only single points (**Fig.7**), because at the beginning of the experimental work a quantity of adhesive was promised that was never delivered. These individual points will be compared to those of the previous 3M and K11 studies.

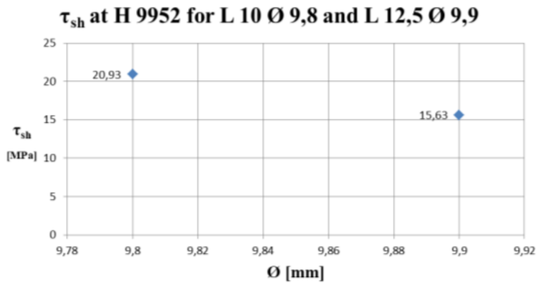

Fig.7 *Shear strength of the adhesive-bonded type "shaft-bushing" joint made with H 9952 adhesive according to the gap between the elements achieved by a different diameter (Ø) of the pin.*

From the last graphical dependence on the three adhesives at Ø=9.9, at ADEKIT H 9952 (L=12.5) we have a high average value, unlike the other two adhesives that have good performance properties.

From the mean shear stresses shown in the three types of adhesive (**Fig.8** and **Fig.9**) it is easy to determine which adhesive is best suited for the intended purpose. Adhesive 3M has the best performance, followed by K11 with decreasing t_{sr} indexes at increasing L. For adhesive ADEKIT H 9952 we have only one shear value (L=10 and Ø=9.8) which presents a very high shear stress.

3.4 Comparison between the three adhesives

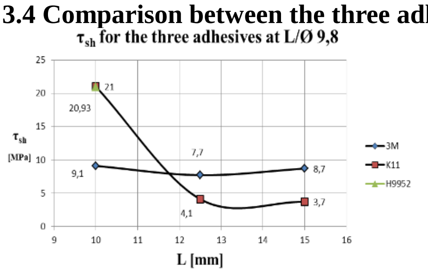

Fig.8 *Shear strength of adhesive joint types made with the three types of adhesive depending on the axial length of the contact (L) between the elements at a fixed diameter value Ø = 9.8mm*

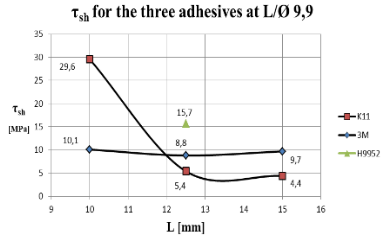

Fig.9 *Shear strength of adhesive joint types made with the three types of adhesive depending on the axial length of the contact (L) between the elements at a fixed diameter value Ø = 9.8mm*

As a conclusion of the conducted experiments and the analysis of the obtained results we can say that apart from the own characteristics of the used adhesives, a decisive role for the successful creation of an adhesive layer of necessary length and with real shear strength is the technology for applying of the adhesive – if it is incorrect, the results will not be real, because the shear strength will be times lower than that given by the manufacturing company due to the insufficient length of the adhesive layer being formed, which in turn can have a lot a greater influence on whether the adhesive in question can be used in similar applications, such as gluing metal with non-metallic.

The results of this experiment were successfully applied in the design and construction of the control arms of the sports car of the TU-Sofia for the 2017 following the "Formula Student" project.

4. Conclusions

The new and original concepts in the present work are as follows:

- A new technology for creating adhesive-bonded joints is proposed and implemented, which consists in the fact that non-metallic components are being used.
- The used method is modern, with high reliability indicators of the final product and predetermines a high-performance way of obtaining conditionally non-disassembling structures.
- The effect of the advantages of the proposed new technology is confirmed in practice, which is expressed in the increased operational durability of the created joints, in the case of considerable lightening of the structures while preserving its strength properties.
- The experiment for testing of the shear strength of three adhesives was systematically planned and conducted in a laboratory;
- The results of the experimental tests are compared and also the results of the comparative analysis are confirmation of the selection of the best among the analyzed adhesives by the average shear stress criterion;
- Two-dimensional results from laboratory tests and experiments have been illustrated, allowing direct comparison of the three adhesives;
- The "Shaft-bushing Test" method used with the INSTRON 1185 universal test rig, has been used and applied in practical experiments to help the resulting numerical results easily and precisely undergo the systematized above-mentioned calculation procedures for the determination of the magnitudes, characterizing the properties of the tested elements;
- The technology used for applying the adhesive for conducting the experiments is known in the literature;
- The results of the conducted experiments were applied in the engineering practice for the purpose of further lightening the design of the sports car of the Technical University of Sofia for 2017 following the international Student Project "*Formula Student*".

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