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EPOXY RESIN MECHANICAL PROPERTIES DETERMINATION IN ASSEMBLY APPLICATIONS BY MEANS OF FEM SIMULATIONS

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Abstract
A wide use of adhesive substances and especially of epoxy resins in metal structures with elevated strength is registered during the last years. Epoxy resins possess enhanced mechanical, chemical and physical properties, i.e. increased shear and compression strength, resistance in solvents, as well as at high temperatures.
In the present paper, two-components of epoxy resin were tested through a developed experimental apparatus, applying tensile stress loads. Rolls and aluminum pipes, as well as further specimens were used. The specimens were cemented under constant temperature and humidity conditions. The experimental results were simulated with the aid of FEM-based procedures. The stress–strain curves of epoxy resins derived from previous works, were considered. The results revealed that the resins fail mainly due to poor adhesion with the cemented surfaces and not owing to cohesion release.

Keywords: *Epoxy resins, mechanical properties, resin, tensile strength, FEM simulation*

1. INTRODUCTION

A significant mechanical property that was studied in the present paper is the behavior illustrated during static tensile loading. This procedure was performed by means of an apparatus, which was able to apply tensile loads on the cemented specimens and record at the same time the tension force versus the displacement of the cemented specimen, up to the ultimate fracture of the resin. The specimens used in the tensile experimental procedures are made of aluminum tubes.
Various epoxy resin failure modes are elucidated through improved FEM simulation models. For every experimental procedure, the corresponding FEM simulation models are created considering the specimen geometry and the mechanical properties of specimen and epoxy resin materials.
A comparison of the experimental results to the analytically determined ones showed that different epoxy resin types exhibit that in all epoxy resin examined cases, fracture is initiated due to bad adhesion of the soldered faces.

2. STATIC TENSILE LOADING OF EPOXY RESINS.

An important property of epoxy resin materials is their strength under static tensile loading. This behaviour is due to adhesion between the epoxy resin and the glued material. The static tensile loading behaviour of epoxy resins is detected using the experimental set-up shown in figure 1. The operation of the experimental apparatus is numerically controlled. Operational parameters and experimental data acquisition are [1].

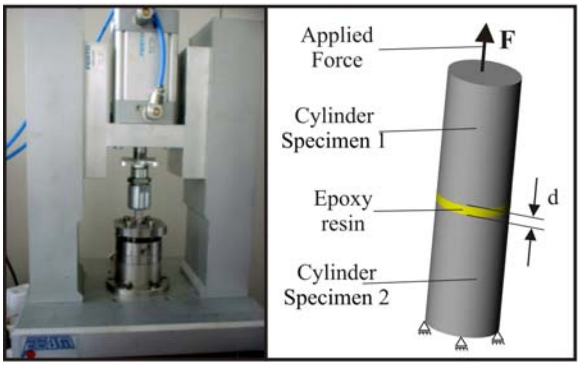

Figure 1: *Experimental set-up for the tensile loading of glued specimens by epoxy resins.*

This apparatus has the capability of measuring the applied force and the occurring elongation of the glued specimens at the same time. The maximum available tensile load is 5500 N. Elongation measurement is achieved with an inductive sensor, with accuracy below 1 μm.

The examined specimens are cylindrical rods of 15 mm diameter glued with various types of epoxy resin materials [2, 3, 4]. Holes were opened through, at both ends of the specimens, in order to hold them onto the tension apparatus. In the right part of figure 1, a typical glued specimen as well as the applied tensile force is shown. The thickness of the epoxy resin between the glued surfaces is from 20 up to 100 μm. The lower part of the specimen is founded to the tester base, while the upper part is mounted to the piston pin of the experimental device and follows its movement.

The applied tensile force versus the relative elongation of the epoxy resins are illustrated in figure 2 for the examined epoxy resin types. The end point of each curve refers to the separation of the glued specimens. It is evident, that the tested epoxy resin (DP 490) withstands a tensile separation force up to 4130 N, before any separation between the rods occurs.

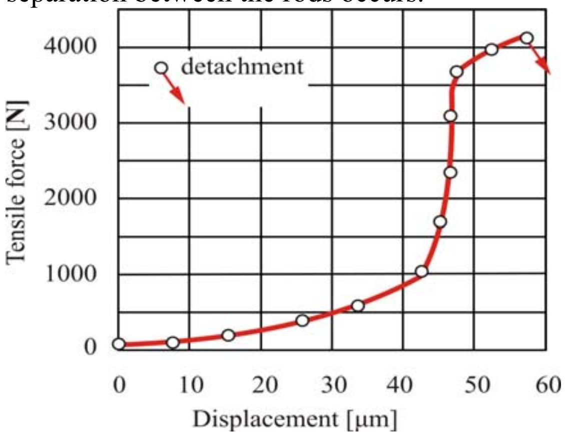

Figure 2: *Experimental results from the tensile tests.*

In that case, the maximum elongation before the epoxy resin failure is 58 μm, as shown at the lower part of figure. Through the deformation increasing, an epoxy resin ductility deterioration occurs, leading to an abrupt fracture, after a steep tensile force growth.

The failure of the epoxy resins and the consequent separation of the glued cylinders can be elucidated through a FEM simulation model of the static tension test. This model is presented in figure 3. A cross-section of the glued cylinders is illustrated in the left part of this figure. The equivalent axisymmetric FEM simulation model is shown at the right part of the figure, where the elements discretization and the axis of symmetry are shown. Mechanical properties and especially the stress-strain curves of the examined epoxy resins and the aluminium tubes, are used as input data in this FEM simulation model.

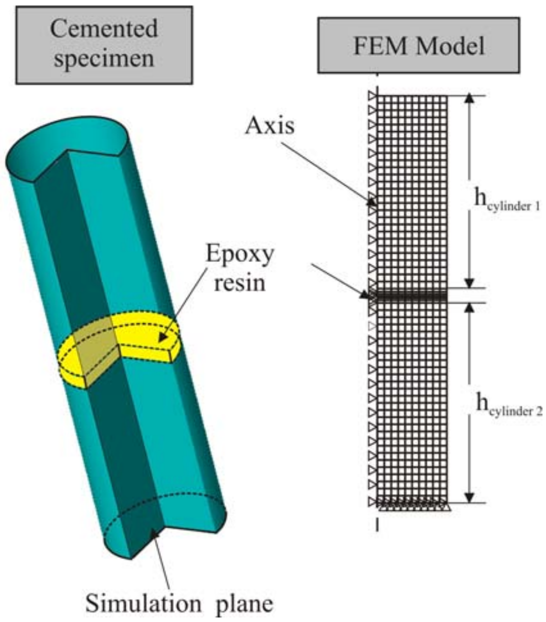

Figure 3: *FEM simulation model of the glued cylinders' tensile test.*

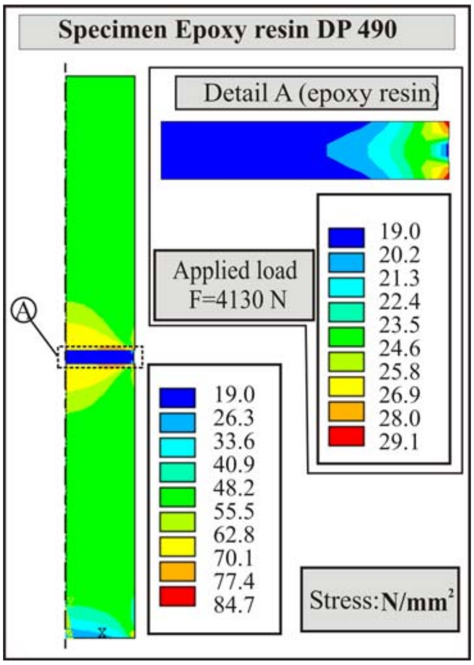

Figure 4: Typical FEM simulation results of the tensile loading for the cylinders bonded with various epoxy resins.

The occurring experimental data described in figure 2 are processed with the FEM simulation model and the failure modes of the epoxy resin are determined which can be either cohesive or adhesive.

Figure 4 demonstrates the FEM-determined results of the epoxy resin DP 490. Equivalent stress distributions in the interior of the aluminium cylinders and the epoxy resin are presented. Apparently, the maximum stresses causing the failure of the epoxy resins are observed at the interface between the two materials, the epoxy resin and the cylindrical specimen. A poor adhesion between the two materials is responsible for the early loss of bonding between the glued cylinders, which is verified by the occurring stresses in the epoxy resins, since these stresses are below their stress limits.

3.1 *EXPERIMENTAL PROCEDURE FOR THE TENSILE TESTING OF GLUED BY EPOXY RESINS ALUMINUM TUBES.*

The measurements were performed in the Laboratory of Machine Tools and Manufacturing Engineering "EEDM" of the Aristoteles University of Thessaloniki. The goal of the present experimentation was to determine the tensile strength of various epoxy resins applied on aluminium tubes, representing actual glued assemblies in real conditions.

Special attention was paid in the proper placement of the specimens on the holding table, in order to keep the load parallel, accordingly, to the epoxy resin during the tests, in order to avoid shear loading of the resin.

3. DESCRIPTION OF THE PROPER PREPARATION OF THE SPECIMENS AND THE TEST DEVICE

The examined case was a two aluminium tubes assembly imposed to tensile loading. Steel cylinders were constructed and placed inside the aluminium tubes, as shown in figure 5.

The steel cylinders' length is longer than the tubes by 5 mm and its diameter smaller by 400 μm than the inner diameter of the aluminium specimen, in order to reduce their deformation during the loading stage and not affect the measurements. Threads were constructed in the center of the upper and lower surface of the steel studs, in order to install them on the experimental device.

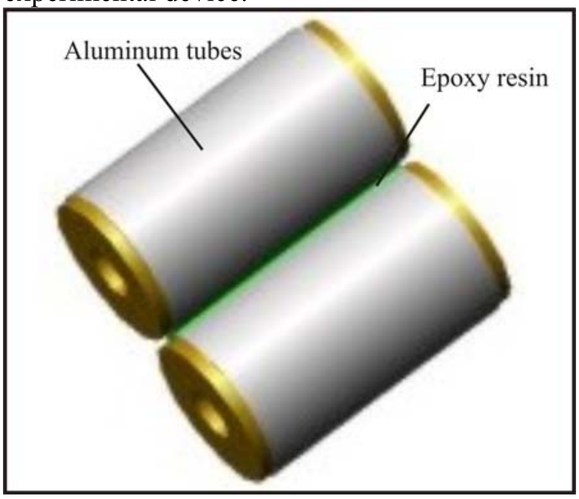

Figure 5: *Glued specimens of the tensile strength test.*

A significant part of the experimental procedure is the proper holding of the assembly on the test apparatus. The upper part of the holding rig consists of a metal Π shape base with holes on its lateral sides in order to fasten with screws the top part of the assembly (see Figure 6). On the metal holding base of the dynamometer, an identical metal Π shape base holds the lower part of the specimen.

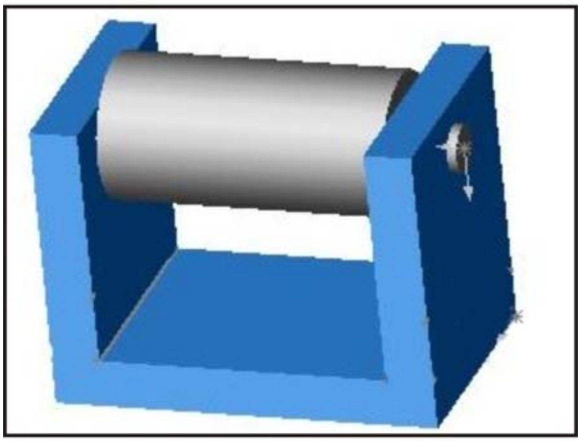

Figure 6: *Holding rig of the tested specimens.*

The experimental set-up for tension tests is based on the one presented in figure 1, taking into account the aforementioned speculations for the suitable seating of the specimens on the holding table. Figure 7 illustrates clearly the herein developed experimental set-up.

The tested specimens were all glued in the same way. After the previously mentioned preparation, the specimens were placed on the holding device, and a strain gage was properly connected. Moreover, displacement was applied by means of a pneumatic piston and the tensile force was measured.

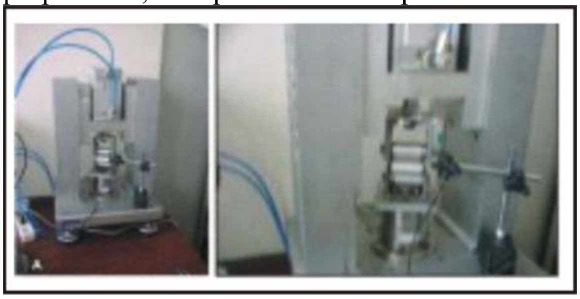

Figure 7: *Tensile tests on the experimental device.*

3.2 *CONDUCTION OF THE TEST PROCEDURE AND RESPECTIVE RESULTS*

Figure 8 presents the experimental results of specimens glued by epoxy resin DP 490 subjected to tension.

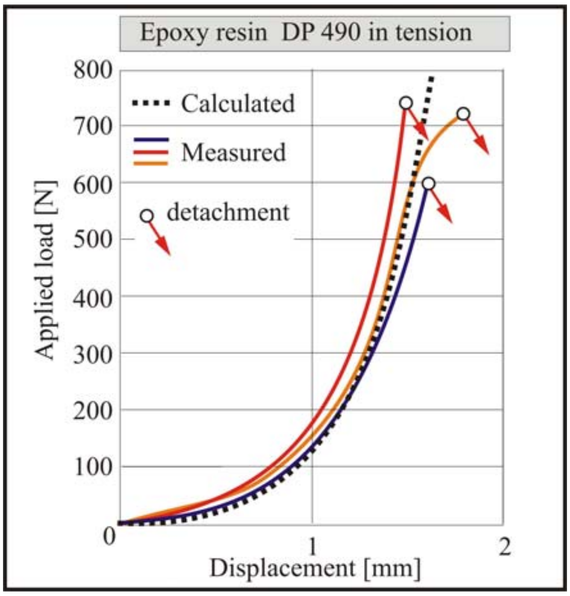

Figure 8: *Theoretical and measured results of the epoxy resins DP 490.*

The range of the force values that lead to fracture of the glued specimen varies between 600 N and 742 N, while the epoxy resin displacement on the specimen before the fracture is in the range 1.48 mm to 1.83 mm. Additionally, the FEM calculated curve is shown in this figure. The good approximation between the theoretical and the measured curves is owed to the appropriate determination of material mechanical properties used in the FEM simulation.

Furthermore, the specimens' behaviour is stronger affected by the adhesive bonds evolved between the glued surfaces, along with the proper application of the loading, to avoid shear effects. The combination of shear and tensile stresses leads to critical reduction of the load, where failure occurs. The dispersion of the experimental results is due to the adhesive bonds developed on these surfaces.

4. SIMULATION MODEL OF TENSILE LOADED GLUED TUBES

In order to determine epoxy resins' failure mechanisms that lead to bonding loss of the glued cylinders, experimentally examined in the previous paragraph, FEM simulation models of the tensile loadings were herein developed.

4.1 *FINITE ELEMENT SIMULATION OF THE TENSION LOADINGS OF GLUED WITH EPOXY RESINS ALUMINUM TUBES*

The problem that is investigated is the join of two tubes for tensile loading, as illustrated in figure 9. In the two tubes system the tubes are joined together along a line. To avoid local overloading of the tubes, the forces were applied on a steel tube placed inside the aluminium tube. In this way, the distribution of the force is uniform on the left tube face, while the boundary conditions imposed on the lower line, prevent the motion at the vertical axis.

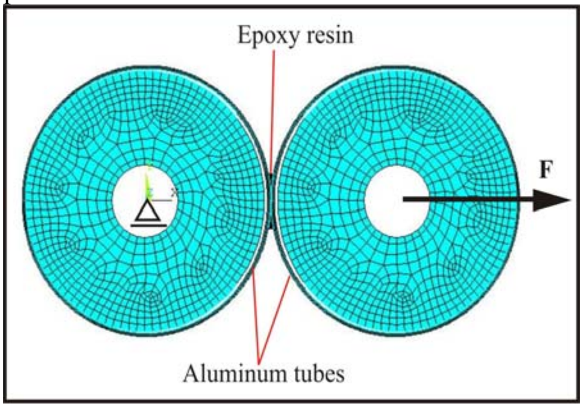

Figure 9: *FEM model of the glued tubes assembly*

In the FEM model, the finite element size of the resin, the aluminium tube and steel cylinder was created different, as shown in figure 10. Contact elements were also used between cylinder and tube interface [5, 6].

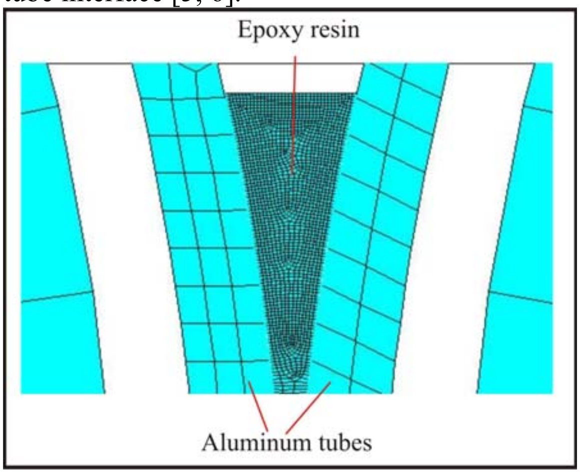

Figure 10: *Detail of the FEM model in the region of the resin and aluminium contact*

4.2 *FEM RESULTS OF THE GLUED SPECIMENS TENSILE TEST*

The abovementioned FEM simulation results are shown in figure 11. The von Mises equivalent stress distribution inside the epoxy resin and the maximum value for the various loads are presented in this figure. These results exhibit that large portion of the resin remains unloaded and they are below fraction limit which is 60 N/mm^2

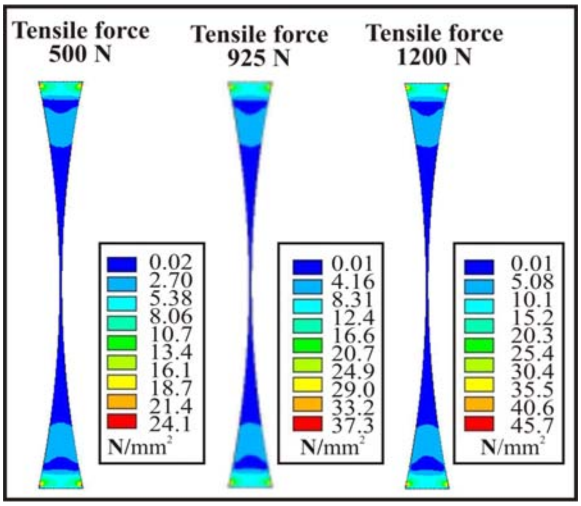

Figure 11: *von Mises equivalent stress distribution under 500, 915 and 1200 N.*

Considering the above, a different developed FEM model was created, by removing the inner not loaded resin region. The results are shown in figure 12. A very small variation of the occurring stresses occurs, in comparison to the previous ones, with the full resin form case.

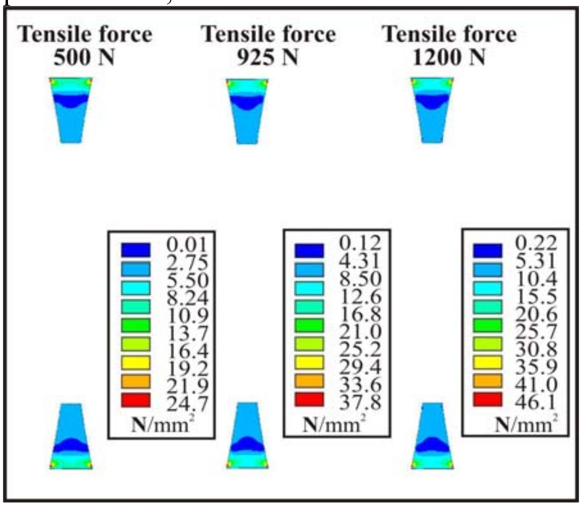

Figure 12: *von Mises equivalent stress distribution under 500, 915 and 1200 N, and removed resin region of 4 mm.*

Figure 13 exhibits the maximum occurring equivalent stresses for various removed resin region cases. It can be observed for removed region widths of 1 up to 4 mm that the maximum equivalent stress remains constant.

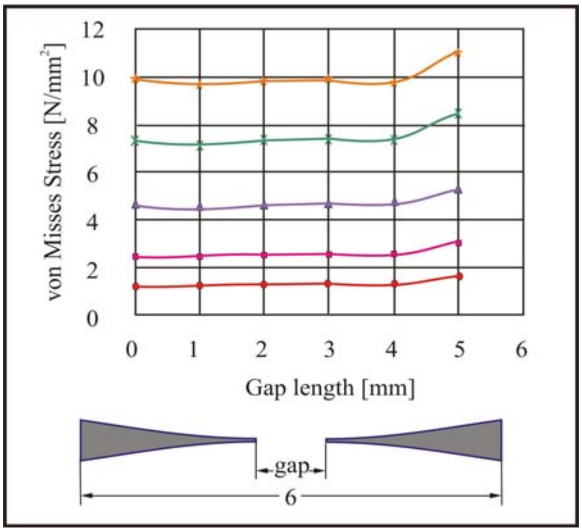

Figure 13: *The maximum developed von Mises equivalent stress for removed resin region 0 up to 5 mm at various loads*

5. CONCLUSIONS

In the present paper the determination of the epoxy resin behavior, considering tensile loading, was explained. This resin was used to glue aluminum cylindrical specimens.
The experimental results were simulated by means of developed FEM models, concerning the stress – strain curves of the involved materials. The results illustrate that the epoxy resin failure occurs due to bad adhesion of cemented surfaces and not by exceeding the ultimate stress limit.

6. REFERENCES

[1] K.-D. Bouzakis, A. Lontos, Creep behaviour determination of monolayer plasma sprayed coatings under dynamic of static loads. Surface & Coatings Technology, 174-175, 2003, 1053-1058.

[2] K.-D. Bouzakis, N. Michailidis, G. Erkens, Thin hard coatings stress-strain curves determination through a FEM supported evaluation of nanoindentation test results, Surface and Coatings Technology, 142-144 (2001) 102-109.

[3] K.–D. Bouzakis, N. Michailidis, S. Hadjiyiannis, G. Skordaris, G. Erkens, A continuous FEM simulation of the nanoindentation to determine actual indenter tip geometries, elastic-plastic material deformation laws and universal hardness, Zeitschrift fuer Metallkunde, 93 (2002) 862-869.

[4] K.–D. Bouzakis, N. Michailidis, S. Hadjiyiannis, G. Skordaris, G. Erkens, The effect of specimen roughness and indenter tip geometry on the determination accuracy of thin hard coatings stress-strain laws by nanoindentation, Journal of Materials Characterisation, 49 (2003) 149-156.

[5] ANSYS 8.1, Online help manual.

[6] Tsiafis, I., Bouzakis, K.-D., Michailidis,N., Lontos, A., Anastopoulos, I.: “Experimental – Analytical Procedures to Determine the Performance of Epoxy Resin under Various Mechanical Loading” Journal of the Balkan Tribological Association, Vol 10, No 1, pp. 60 - 72, 2004.

[7] Tsiafis, I., Bouzakis, K.-D., Michailidis,N., Lontos, A., Anastopoulos, I.: “Mechanical Properties Determination of Various Epoxy Resin by Means of nano-indentations” Journal of the Balkan Tribological Association, Vol 10, No 1, pp. 73 - 8