

DETERMINATION OF EPOXY RESINS' MECHANICAL PROPERTIES BY EXPERIMENTAL-COMPUTATIONAL PROCEDURES IN TENSION

K.-D. Bouzakis¹, I. Tsiafis¹, N. Michailidis¹, A. Tsouknidas¹

1. *Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department, Aristoteles University of Thessaloniki, Greece*

ABSTRACT

The use of epoxy resins in metal structures for adhesive reasons is getting wider. 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. Tensile tests were carried out with standard aluminium tension specimens glued with epoxy resins. The thickness of the glue and the acting cross-section area were considered as variables. The specimens were cemented under constant temperature and humidity conditions. The experimental results were simulated with the aid of FEM-based procedures, while the stress-strain curves of the epoxy resins, as obtained by nanoindentations and corresponding FEM-supported algorithm, were taken into account. The obtained results allow the determination of the epoxy resins' strength versus its thickness and the occupying cross-section area.

KEYWORDS: Epoxy resins, Mechanical properties, Tensile strength, FEM simulation.

1. INTRODUCTION

All static tensile strength tests of the glued aluminium specimens were conducted according to DIN 50125 /1/. A special test rig allowed the gluing of the tension specimens at predefined thickness. Furthermore, the effect of the percentile decrease of the glued cross-sectional surface on the overall mechanical strength was monitored /2-5/ in order to further on affiliate this variable to the specimens tensile strength.

A finite element method (FEM) simulation model was developed considering the specimen geometry, the glue thickness and its cross-sectional geometry, as well as the mechanical properties of the specimen and of the epoxy resin.

Comparisons of the experimental results with the FEM-calculated ones revealed the stress distribution of the specimen as well as within the epoxy resins allowing the assessment of the fail mechanisms resulting in the rupture of the glued specimens.

2. EXPERIMENTAL SET-UP

During the tensile tests the loading behaviour of epoxy resins was registered in terms of force and displacement measurements, for a variety of glue thickness and cross-sectional geometry, using the tension-compression device by Zwick, shown in [Figure 1](#). The operation of this device is numerically controlled and several operational parameters and experimental data were controlled by a graphical software package /2/.

This device is able of measuring the applied force and the occurring elongation of the glued specimens at the same time. The maximum available tensile load is 100 kN, while the elongation measurement is achieved with an inductive sensor, having an accuracy of less than 1 μ m.

Proceedings of the 3rd International Conference on Manufacturing Engineering (ICMEN), 1-3 October 2008, Chalkidiki, Greece

Edited by Prof. K.-D. Bouzakis, Director of the Laboratory for Machine Tools and Manufacturing Engineering (EEAM),

Aristoteles University of Thessaloniki and of the Fraunhofer Project Center Coatings in Manufacturing (PCCM),

a joint initiative by Fraunhofer-Gesellschaft and Centre for Research and Technology Hellas, *Published by: EEAM and PCCM*



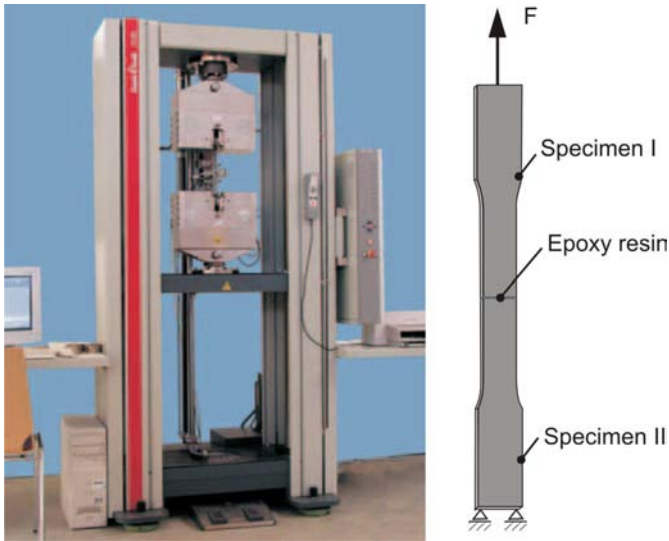


Figure 1: Tensile loading of specimens glued by epoxy resins.

The examined specimens are standard aluminium tension specimens according to DIN 50125 /1/, cut and glued together with variable thickness from 0.1 up to 1 mm and cross-sectional geometries. A typical glued specimen is presented at the right part of figure 1. 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.

A special test rig was built to allow the gluing of the tension specimens at a variable thickness. This apparatus is presented in Figure 2 and comprises of two symmetrical parts where the corresponding Al-specimens are mounted. The two pins allow the parallel movement of the two specimen parts and their distance is controlled by a screw with a distance measuring device. When the distance is set, the gluing process takes place.

3. FEM-BASED PROCEDURE TO DETERMINE EPOXY RESIN'S STRESS-STRAIN CURVES

The constitutive law of the investigated epoxy resin was obtained by nanoindentations and a FEM-based algorithm allowing the determination of stress-strain curves. Figure 3a shows the experimental load-displacement indentation diagram, which represents the average of twenty

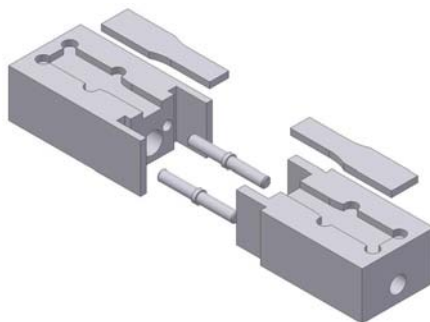


Figure 2: Test rig allowing the gluing of the tension specimens at a variable thickness.

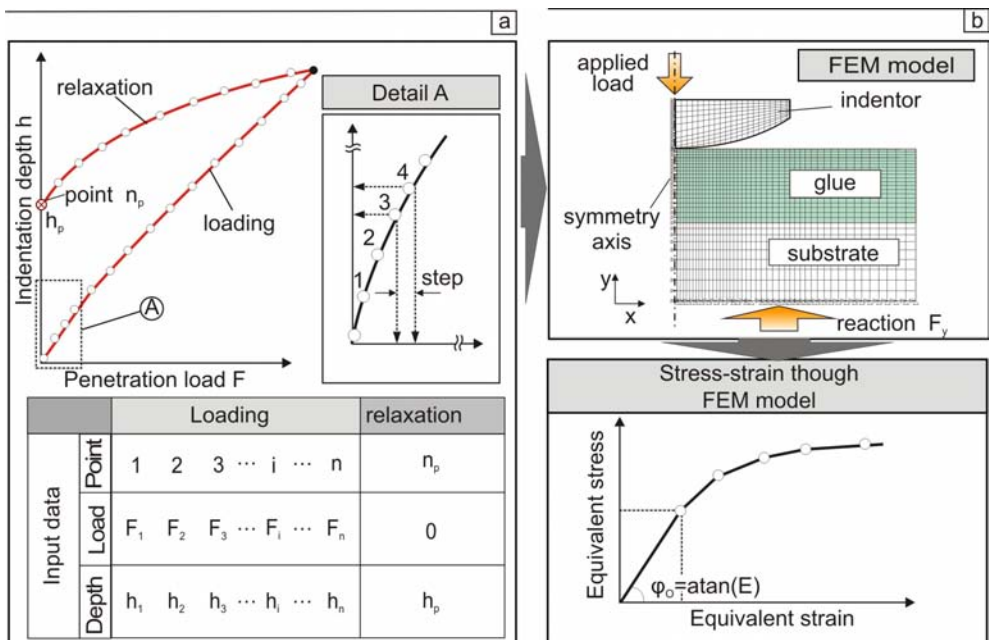


Figure 3: (a) The experimental indentation load-displacement diagram, (b) FEM model and the obtained stress – strain curve.

measurements. This curve is used as input data to FEM in order to determine the mechanical properties (elasticity modulus, yield strength and stress-strain curve) of the investigated epoxy glue. In order to proceed with the simulation procedure using the finite element method, this curve is digitalized in small steps. The very first region of this curve corresponds to the elastic behaviour of the examined material, where only elastic deformations occur during the indenter penetration. A further penetration of the carbide indenter leads to the elastoplastic flow of the examined material at the contact area beneath the indenter. The used axisymmetric FEM model of the epoxy glue is illustrated in [Figure 3b](#). A carbide ball with a diameter of 0.4 mm was applied for all nanoindentation measurements. The maximum penetration load applied in the investigations was 1000 mN. The penetration depth versus indentation load curve of the investigated material is used as the input data to the FEM model. The solution of this FEM simulation calculates the reaction load F_y , which is a result of the carbide ball penetration into the glue material. The whole stress strain curve of the investigated glues is determined by the continuous FEM simulation of the penetration of the indenter into the material [6-9]. The obtained stress – strain curve is illustrated in [Figure 4](#).

4. EXPERIMENTAL RESULTS OF THE STATIC TENSILE LOADING

The applied tensile forces versus the relative elongation of the glued specimens with variable epoxy resins thicknesses are illustrated in [Figure 5](#). The end point of each curve corresponds to the separation of the glued specimens. It is evident, that the uncut specimen has the overall best tensile performance, compared with the cut and glued specimens. These follow almost the same load-displacement curve with the uncut specimen, but at a certain loading level the glue fails and rupture occurs. Detail A gives a better overview of the load-displacement diagrams for the glued specimens. Through the deformation increasing, the ductility of epoxy resin deterioration, leading to an abrupt fracture, after a steep tensile force growth.

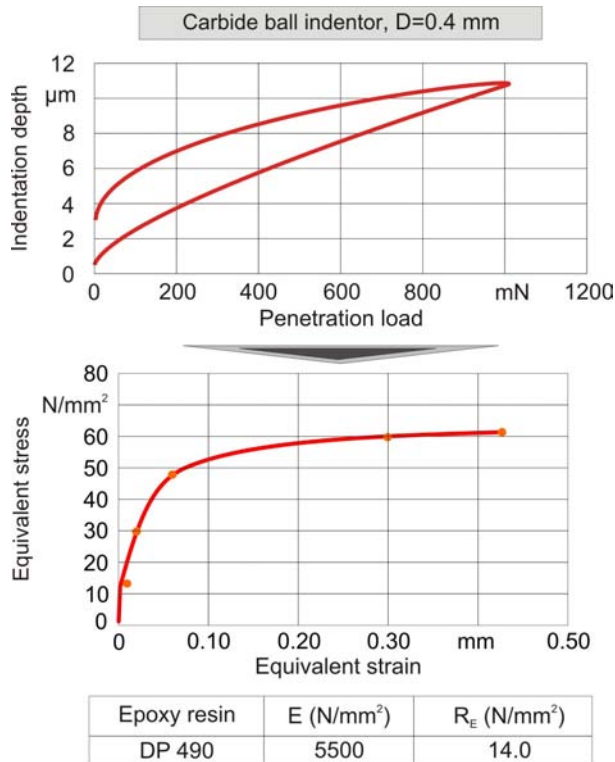


Figure 4: Nanoindentation and stress – strain curve of the epoxy resin.

The obtained strength properties versus the epoxy resin thickness are demonstrated in [Figure 6](#). A glue thickness of 0.1 mm leads to the overall best tensile strength while glue strength versus its thickness shows a continuous decreasing tendency.

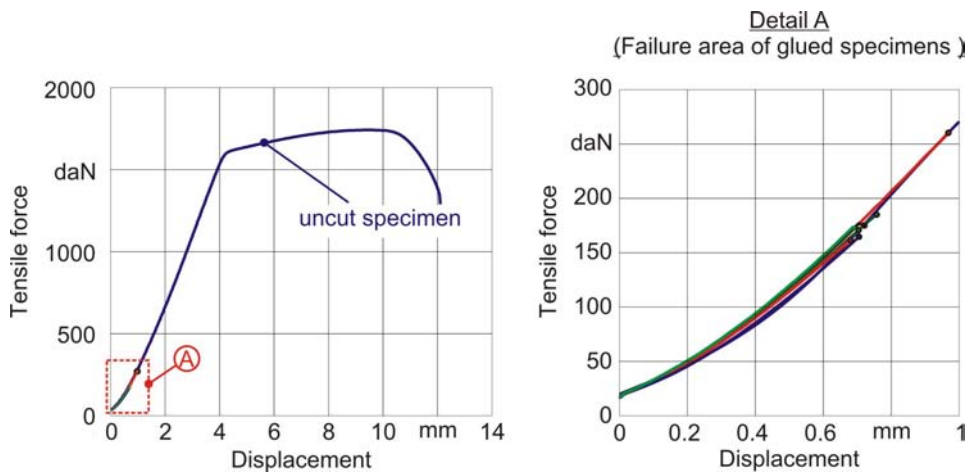


Figure 5: Experimental results of the tensile tests with uncut and glued specimens having various glue thickness.

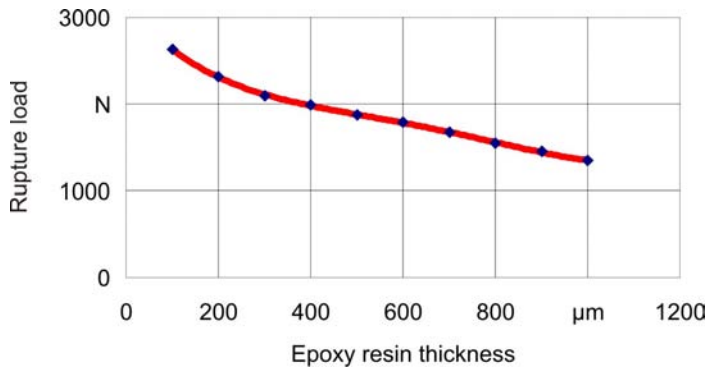


Figure 6: Maximum tensile strength versus the thickness of the epoxy resin.

5. FEM SIMULATION RESULTS OF THE STATIC TENSILE LOADING

5.1. The effect of the glue thickness

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

A cross-section of the glued specimens is illustrated in the left part of [Figure 7](#), while the developed FEM simulation model is shown in the right part of the figure, where the elements meshing are demonstrated [7]. Mechanical properties and especially the stress-strain curves of the examined epoxy resins and aluminum specimen are used as input data in this FEM simulation model.

The occurring experimental data described in figure 4 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 8a](#) demonstrates the FEM-determined results of the epoxy resin with a thickness of 0.1 mm and a tensile load of 2730 N.

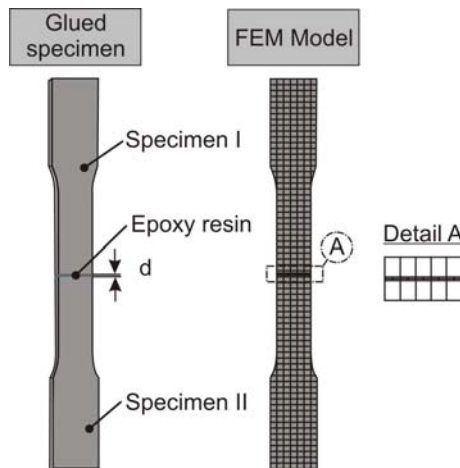


Figure 7: FEM simulation model of the glued tension specimens.

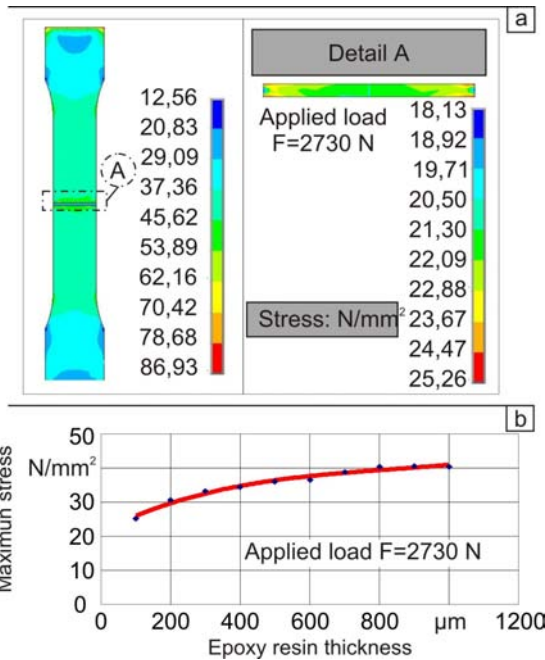


Figure 8: (a) Typical FEM simulation results of the glued tension specimen and (b) occurring maximum stresses in the epoxy resin versus its thickness.

Equivalent stress distributions in the interior of the aluminium 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 (between the epoxy resin and the aluminium specimen). These stresses are overcome the yield limit and therefore rupture occurs. Figure 8b, summarizes the FEM-calculated maximum occurring stresses in the epoxy resin versus its thickness.

5.2. The effect of the glue cross-sectional geometry

Another parameter having great impact on the maximum stresses developed in the epoxy resin between the two parts of the cut specimen, is the cross-sectional geometry of the glue (see figure 9a). Figure 9b shows the stress distribution occurring within a 20% reduced glue surface, which leads to the development of the same stress limits at lower displacements. This would lead to a premature glue failure. An overview of the maximum developed stresses in the glue for the same displacement but at various percentile decreases of the cross-sectional surfaces is presented in figure 9c. It is evident that the lower the cross-sectional surface area, the higher the stresses developed is.

6. CONCLUSIONS

In the present paper the failure mechanisms of the epoxy resin, considering tensile loading, were explained. The resin was used to glue standard aluminum tension specimens together. The experimental results were simulated by means of developed FEM models, and an insight of the occurring stresses within the glue, leading to its rupture, was obtained. The effects of the glue thickness as well as of its cross-sectional geometry on the epoxy resin's tensile strength was elucidated.

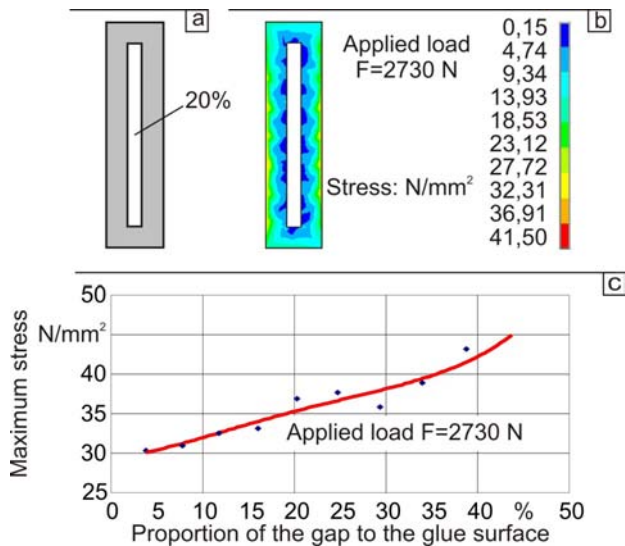


Figure 9: (a) Cross-sectional geometry of the glued surface, (b) occurring stress distributions in the case of a 20% reduced glue surface and (c) maximum stress versus the glue surface percentage.

7. REFERENCES

1. DIN 50125: Testing of metallic materials - Tensile test pieces, DIN Germany, 2004.
2. 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.
3. 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.
4. 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.
5. I. Tsiafis, K.-D. Bouzakis, N. Michailidis, A. Asimakopoulos, A. Koplos, Experimental-Computational Determination of Epoxy Resin Mechanical Properties, used in Assembly Applications, *The Annals Of "Dunarea De Jos" University Of Galati Fascicle XIV Mechanical Engineering*, ISSN1224-5615, pp.26-32, 2005 .
6. 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.
7. ANSYS 10, on line help Manual.
8. I. Tsiafis, K.-D. Bouzakis, N. Michailidis, A. Lontos, I. Anastopoulos, 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.
9. I. Tsiafis, K.-D. Bouzakis, N. Michailidis, A. Lontos, I. Anastopoulos, Mechanical Properties Determination of Various Epoxy Resin by Means of nanoindentations, *Journal of the Balkan Tribological Association*, Vol 10, No 1, pp. 73 - 80, 2004.

