THE ANNALS OF "DUNAREA DE JOS", UNIVERSITY OF GALATI
FASCICLE XIV MECHANICAL ENGINEERING, ISSN 1224-5615
2008

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

Assist. Prof. I. Tsiafis,
Prof. K.-D. Bouzakis, Assist. Prof. N. Michailidis,
Laboratory for Machine Tools and Manufacturing Engineering,
Mechanical Engineering Department, Aristoteles University of Thessaloniki

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 variable. 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

The static tensile strength of glued aluminium specimens according to DIN 50125 was tested [1]. A special test rig was set-up to allow the gluing of the tension specimens at a variable thickness. Furthermore, the effect of the percentile decrease of the glued cross-sectional surface on the overall mechanical strength was monitored [2-5].

A finite element method (FEM) simulation model was built taking into account 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 effect of the occurring mechanical stresses on the rupture of the glued specimens.

2. EXPERIMENTAL SET-UP

The static tensile loading behaviour of epoxy resins with variable thickness and cross-sectional geometry was detected using the tension-compression device by Zwick, shown in figure 1. The operation of this deviece is numerically controlled. Operational parameters and experimental data are fully 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. Elongation measurement is achieved with an inductive sensor, having an accuracy of less than 1 μm. The examined specimens are standard aluminium tension specimens according to DIN 50125 [1], cut and glued together with variable thickness and cross-sectional geometry. A typical glued specimen is presented at the right part of figure 1. The thickness of the epoxy resin between the glued surfaces varies from 0.1 up to 1 mm. 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 cut two parts of the standard tensile specimen are mounted. 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.

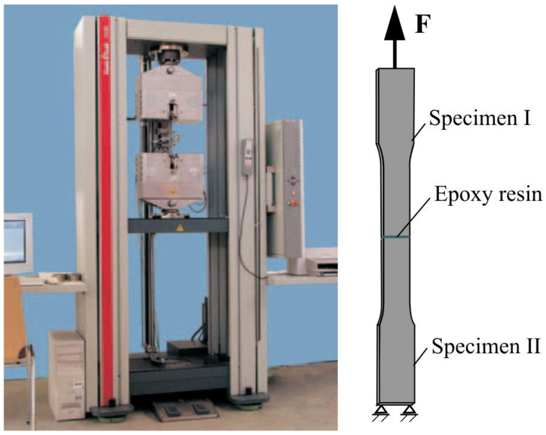


Figure 1: Tensile loading of specimens glued by epoxy resins.

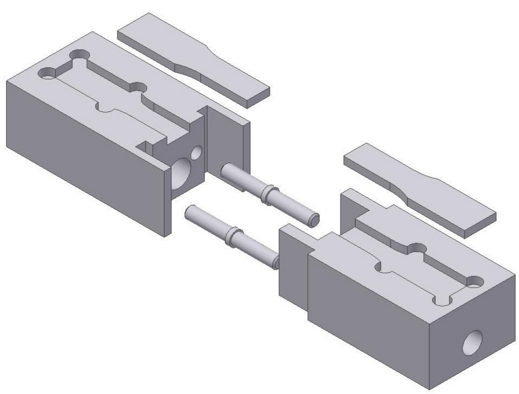
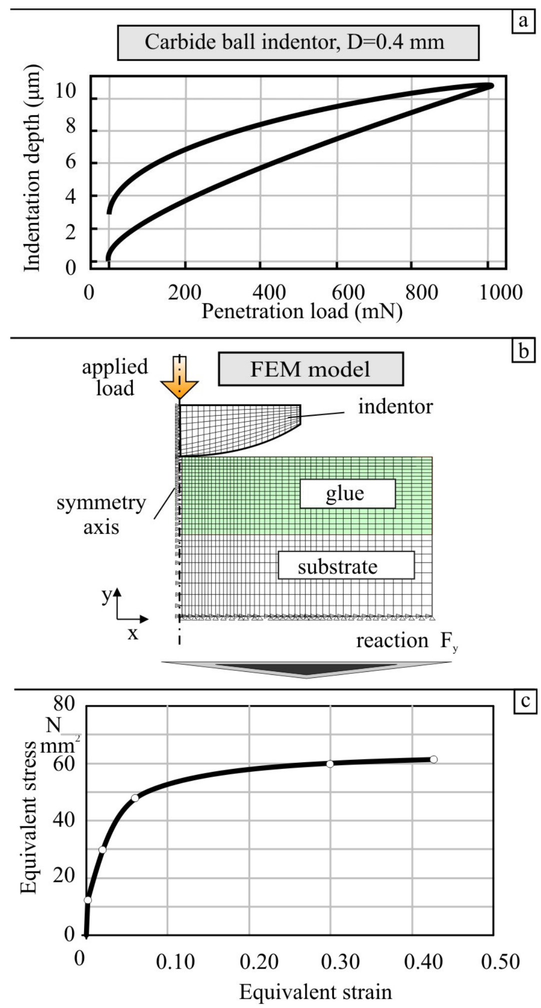


Figure 2: Test rig allowing the gluing of the tension specimens at a variable thickness.

3. EXPERIMENTAL SET-UP

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 mean curve of twenty measurements. This curve is used as input data to FEM modelling in order to determine the 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 deformation occurs into the material by 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 axisymmetric FEM model that was used for the determination of the mechanical properties of the epoxy glue is illustrated in figure 3b. A carbide ball with a diameter of 0.4 mm was applied in the nanoindentation procedure. 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 gives the load F_y, which is the reaction load occurring as the carbide ball penetrates 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 3c.



Epoxy resin	E(N/mm²)	R_E(N/mm²)
DP 490	5500	14.00

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

4. EXPERIMENTAL RESULTS OF THE STATIC TENSILE LOADING

The applied tensile forces versus the relative elongation of the glued specimens with variable thick epoxy resins are illustrated in figure 4. 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. The detail A gives a better overview of the load-displacement diagrams for the glued specimens. Through the deformation increasing, epoxy resin ductility deterioration occurs, leading to an abrupt fracture, after a steep tensile force growth.

The obtained strength properties versus the epoxy resin thickness are demonstrated in figure 5. A glue thickness of 0.1 mm leads to the maximum tensile load needed for the epoxy resin rupture, compared with the rest thickness cases. A continuous decreasing tendency of the glue strength versus its thickness was monitored.

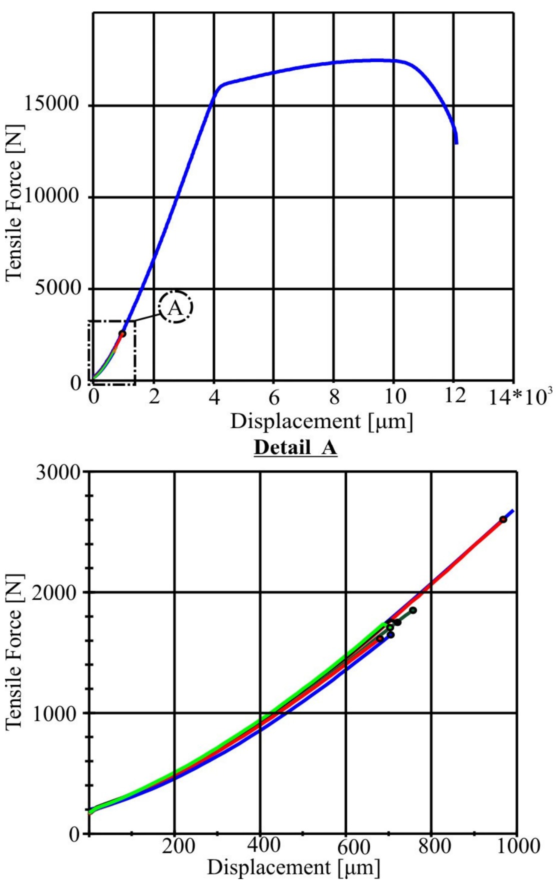


Figure 4: Experimental results of the tensile tests with uncut and glued specimens having various glue thickness.

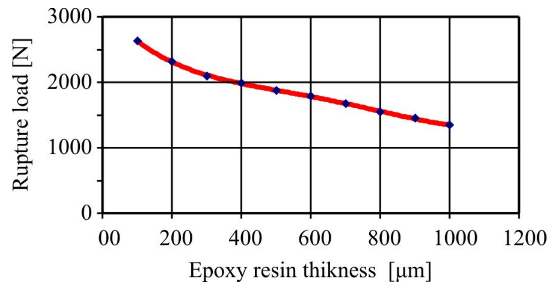


Figure 5: Maximum tensile strength versus the thickness of the epoxy resin.

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 6. The built FEM simulation model is shown at the right part of the figure, where the elements discretization is demonstrated [7]. Mechanical properties and especially the stress-strain curves of the examined epoxy resins and aluminium specimen are used as input data in this FEM simulation model.

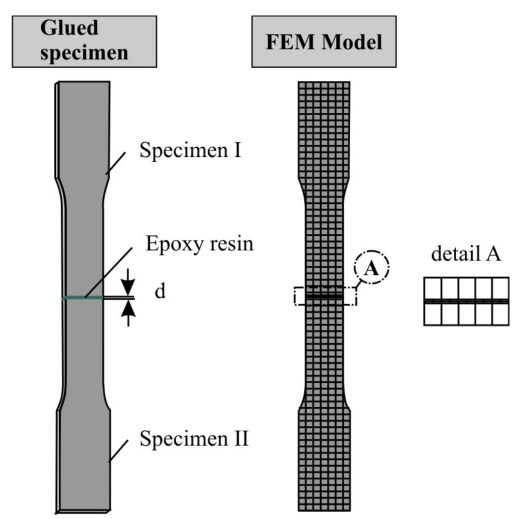


Figure 6: FEM simulation model of the glued tension specimens.

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 7a demonstrates the FEM-determined results of the epoxy resin with a thickness of 0.1 mm and a tensile load of 2730 N. 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 over the yield limits and therefore a rupture occurs. Figure 7b, summarizes the FEM-calculated maximum occurring stresses in the epoxy resin versus its thickness.

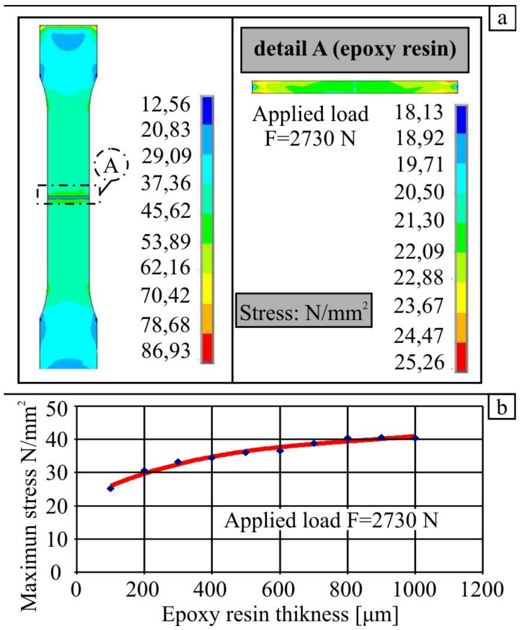


Figure 7: (a) Typical FEM simulation results of the glued tension specimen and (b) occurring maximum stresses in the epoxy resin versus its thickness.

5.2 The effect of the glue cross-sectional geometry

Not only does the glue thickness affects the maximum stresses developed in the epoxy resin between the two parts of the cut specimen, but also the cross-sectional geometry of the glue (see figure 8a) plays a significant role in this. Figure 8b 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 8c. It is evident that the lower the cross-sectional surface, the higher the stresses developed.

6. CONCLUSIONS

In the present paper the determination of the epoxy resin behaviour, considering tensile loading, was explained. This resin was used to glue standard aluminium tension specimens. The experimental results were simulated by means of developed FEM models, and an insight of the occurring stresses within the glue, leading to its failure, 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.

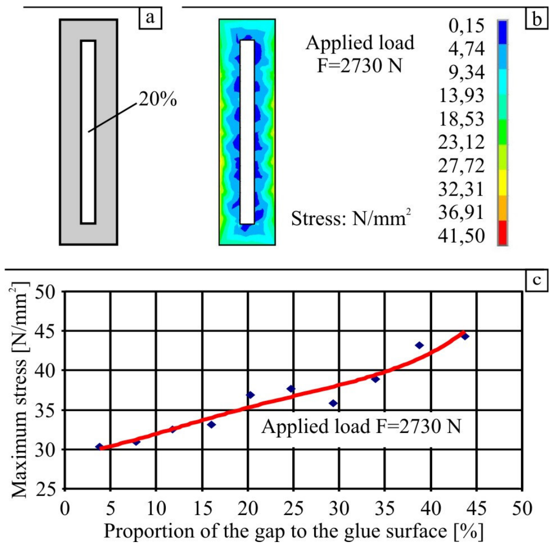


Figure 8: (a) Cross-sectional geometry of the glued surface, (b) occurring stress distributions in the case of a 20% reduced glue surface and (c) maximum stress versus the glue surface percentage.

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.