THE USE OF FEM TO ASSESSMENT EXPERIMENTAL RESEARCH

Jan Godzimirski, Marek Rośkowicz

Military University of Technology, Institute Technology of Aircraft
tel.: (22) 683 95 75
e-mail: jan.godzimirski@wat.edu.pl

Abstract

The results of experimental investigations and the analyses of numeric adhesive materials and their joints were introduced in the work. Experimental investigations concerned the fatigue life of materials and adhesive joints and their static long-time life, however numeric analyses were aimed at explanation of effects appearing during experimental investigations. It found that the finite element method enables recognition the effects appearing while adhesive bond is loaded (short-term, long-lasting, periodically variable and static), and this way to forecasting their life. The valuable advantage of using FEM in analysis of the short-term strength and fatigue or long-lasting life adhesive bonds there is also an option of shortening or even replacing some time-consuming experimental tests with such kind of analysis.

In investigations, thanks to using of FEM, was successful to explain cause of higher short-term strength and fatigue life of overlap joints made of steel sheet in the comparison with performed of alloy aluminum sheet and the mechanism destruction of roller specimen, performed from adhesive materials, loading on axial compression cyclically in which cracks occurred along the generating line. The cause of the essential difference of the static long-lasting life adhesive bonds (about comparable short-term strength), which the joints were made from epoxy adhesive only and joints made from epoxy plastic reinforcement the glass fabric was also explain.

***Keywords**: adhesive joints, epoxy, strength, fatigue life, static long-lasting life*

1. Introduction

The FEM is used contemporarily both to the calculations of continuous problems in mathematics, how also in engineering practice for analysis stress, strain and deformations fields, electric, magnetic, thermal fields, flow problems and also coupling fields e.g. the temperature stress problems or electro-thermal problems [1, 9]. At present valuable supplement of different investigative methods also makes up thanks to its advantages i.e. analytic and experimental. In case of these last which cost and time consuming, is the serious defect particularly, numeric analyses seem more and more useful.

The labour consumption of experimental methods, both model investigations, how and the investigations of real objects is particularly sensible during the project works, where is search optimum solutions and when the different variants of the construction are subjected the analysis. Identification on this stage of physical processes having of the direct influence on safety and the durability of the construction and the identification of responsible mechanisms for the destruction of the construction seems the fundamental issue. Numeric methods let limit time-consuming and expensive experimental investigations on this stage and to raise the quality of projected constructions. General recommendations connected with the kind of applied solutions and materials also let formulate.

Problems, where the necessity of recognizing the destruct mechanisms and the observation of physical effects exists in the farther draught there are the strength analyses of the construction in which materials and joints adhesives are used. In literature undertaking the problems of temporary strength and the durability of adhesive joints (and this both long time static durability as and fatigue life), the lack is universal prognostic methods relating to this kind of joints, to have can the use in the engineering practice. It exists therefore one need the leaderships of the investigations which purpose is search of processes appearing in adhesive materials and the layer of adhesive joints. Don't take into account these processes can bring the designed joint to destruction and in the consequence to applying bonding as the methods of joining constructors discouragement.

The use of FEM to the assessment of the experimental investigations of materials and adhesive joints is particularly well-founded after take into consideration of the specific features of the adhesive bonding. Constructional adhesive bonding is such kind of the joints in which bonds of elements about very different mechanical proprieties: (the adhesive polymer material – metal elements – the problem conditioned badly physically) and the elements of the joints differ boundary strip oneself geometrical dimensions about the line of the size additionally [3, 4]. One should take into account the nonlinearity of effects in the consequence while making analyses. The joint investigation with utilization of only experimental methods seems too time-consuming and groundless economically. However, the search of solutions on the way of analytic investigations is the difficult question or even impossible. It probable is little construction the credible mathematical model, which will consider the nonlinearities of all effects appearing in constructions with adhesive joints and then finding for this model of the exact analytic solution.

The results of experimental investigations and the analyses of numeric adhesive materials and their joints were introduced in the work. Experimental investigations concerned the fatigue life of materials and adhesive joints and their static long-time life, however numeric analyses were aimed at explanation of effects appearing during experimental investigations.

2. The fatigue investigations of adhesive materials and their joints

Investigations of fatigue life were subjected adhesive single lap joint specimens load on shear performance from steel St3 (Fig. 1) and similar specimens (about the somewhat different thickness of sheet metals equal 1.96 mm) made from the aluminum alloy PA7T4.

The surfaces of specimens were prepared to bonding the method of sandblasting and then the wash extraction naphtha. Specimens were bonding epoxy adhesive Epidian 57 curing trietylenotetraamina (curing agent Z1) in temperature 60°C during one hour. In the fatigue investigations specimens was applied a load of the zero-pulsate cycle about the maximum value of the load even 2.1 kN. The fatigue investigations were submitted to three specimens of every kind. The average durability of steel specimens average 427 000 cycles, and perform from the alloy of aluminum only 4085 cycles.

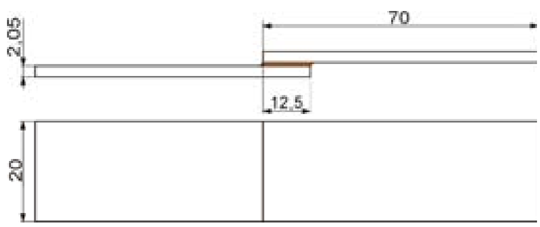

Fig. 1. Shape and the dimensions of the single lap specimen load on shear

The distributions of stresses were assigned in joints of testing specimens under the maximum load of the pulsate cycle in order to explain of this effect the method FEM. The non-linear proprieties of adhesive and the deformation of specimens arising from their fixing in the fixtures of the testing machine were considered in calculations. Joints were modelled one layer of elements adding fins on their ends according to the work [8].

The distributions of stresses along the length of adhesive layer were introduced on Fig. 2– steel specimens and Fig. 3 – the specimens of the aluminum alloy. The distribution of reduced stresses (maximum principal stresses) in adhesive layer of testing specimens were compared on Fig. 4. It was found that considerably higher value of maximum reduced stresses in the joints of specimens performed of the aluminum alloy what was cause of their smaller durability. It also resulted from numeric calculations that larger short-term strength should be characterized of steel specimens in comparison to aluminum alloy specimens. Performed investigations confirmed this thesis, the mean short-term strength of steel specimens amounted 4.24 kN, and duralumin 3.19 kN. In durability research, the maximum load of pulsate cycle of steel specimens was on level 0.5 of their short-term strength, and duralumin on level 0.67.

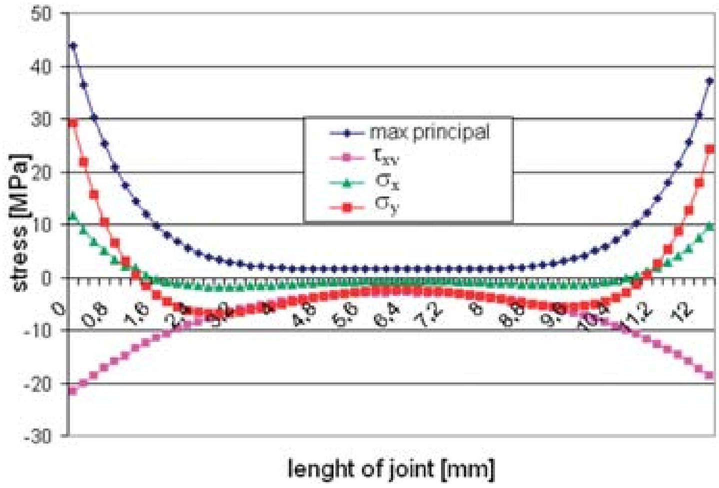

Fig. 2. Distribution of stresses along the length of adhesive layer for the steel specimens

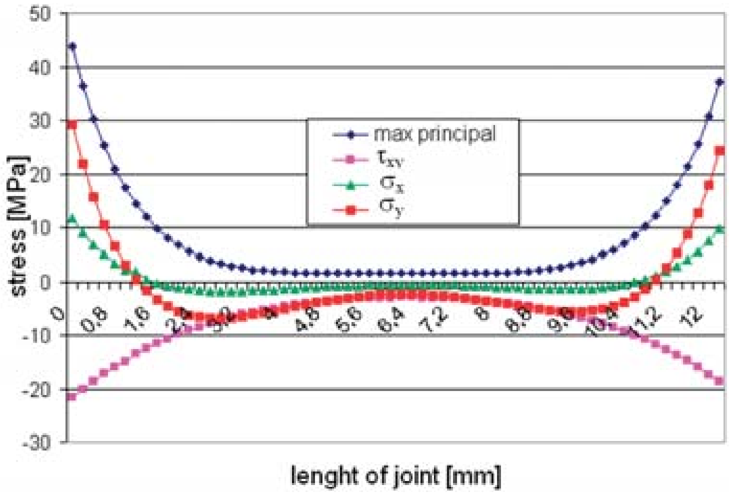

Fig. 3. Distribution of stresses along the length of adhesive layer for the aluminum alloy specimens

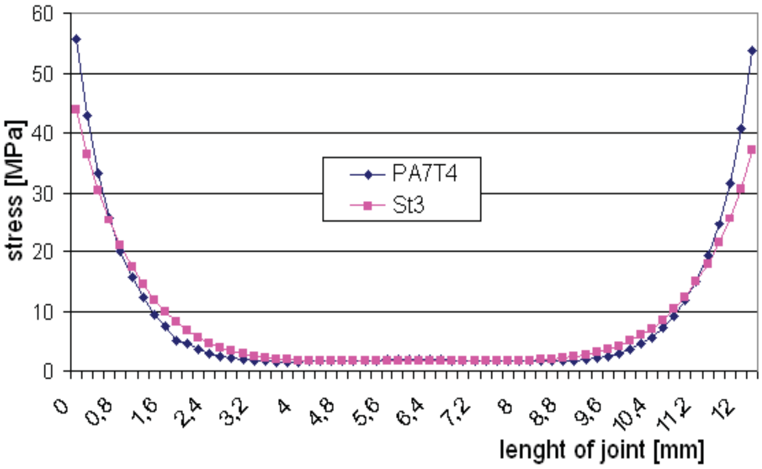

Fig. 4. Comparison of the distributions maximum principal stresses along the length of adhesive layer for the specimens of steel and specimens of the aluminum alloy under loading 2.1 kN

Cast specimens of epoxy adhesive Epidian 57 curing Z1 during 1 h. in the temperature 60°C were also proposed the research of fatigue life. The specimen was loaded compressing cycle in range 0.2-5 kN. It was recorded during the fatigue testing the range of deformations of studied specimens (the double amplitude of deformations) and displacement cross-beam of testing machine (Fig. 5).

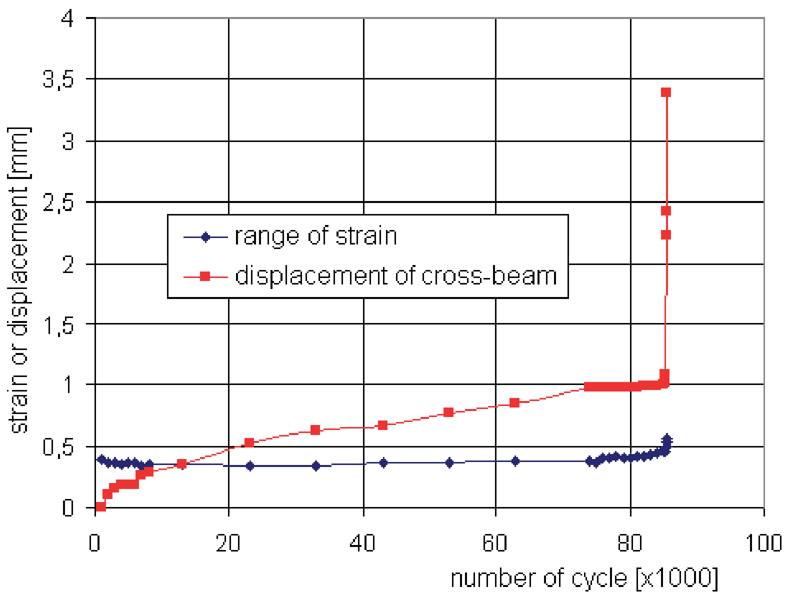

Fig. 5. The change of the strain of the specimen and displacement traverses (the change of the height specimen) during fatigue investigations of adhesive Epidian 57

The small change of the deformations amplitude under the fatigue loading was found and continuous increase of the deformations of the studied specimen, characteristic for the range of the transient creep.

In the result testing of specimen fail which consisted in durable deformation and appear of circumferential cracks (along the generating line) – Fig. 6.

Fig. 6. Character of fatigue failure of test piece perform of Epidian 57 curing Z1 during one hour in the temperature 60°C, put under load the cycle 0.2-5 kN (about the maximum value equal 0.5 short-term compression strength)

Analysis stresses of FEM in roller specimen compressing (Fig. 7) proved that the distribution of stresses in material was in the approximation uniform, and circumferential stresses are practically equal to the zero. In this connection one should suppose that circumferential cracks arising in fatigue loading specimen it was the issue of the change shape of samples in a result of the creep, and the change of the shape caused it arise circumferential stresses.

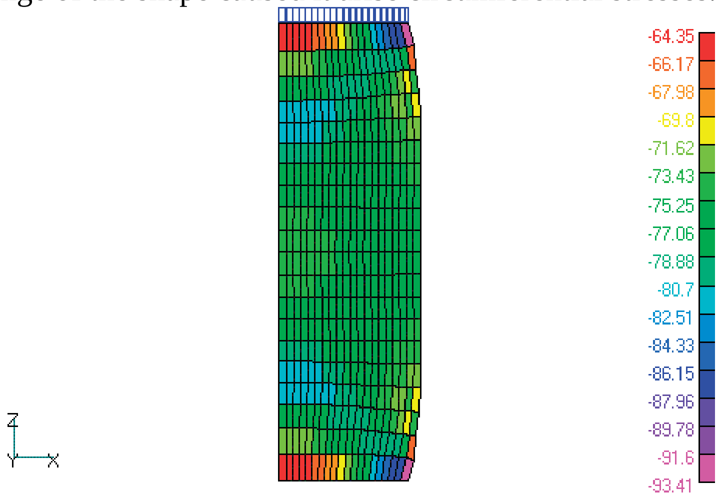

Fig. 7. The distribution of maximum principal stress in the section of the roller specimen loads on the axial-symmetrical compression

The numeric model of the specimen deformed plastically was made for checking this thesis-the shape of the deformation was received on the basis of the measurements of real deformations. Performed calculations proved (Fig. 8) that the deformation caused by creep caused formation of positive circumferential stresses (tension). Their value is six times smaller than the value of maximum negative stresses (compression). It follows that studied plastic decohesion undergoes the under the influence of positive normal stresses.

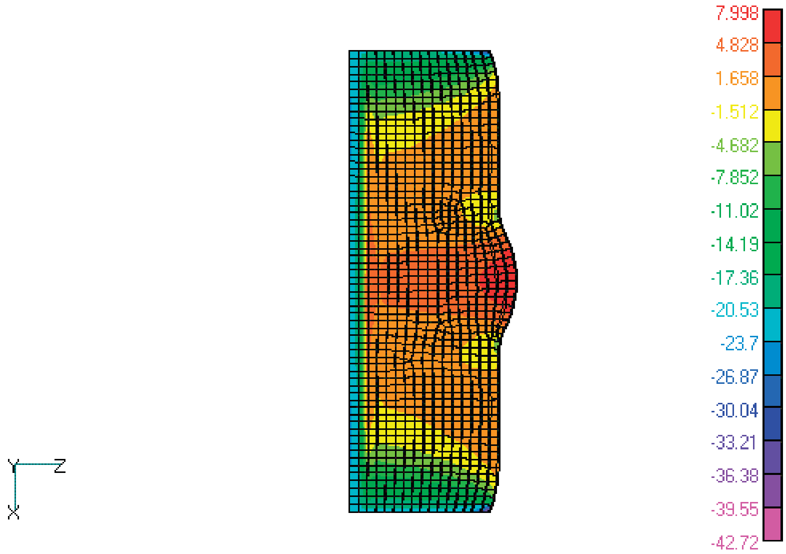

Fig. 8. The distribution of circumferential stresses in the section of roller specimen deformed as a result of the creep

3. The research of static long-lasting life of adhesive joints

Shear loaded adhesive single lap specimens, in accordance with diagram presented on Fig. 1, made of the aluminum alloy PA7T4 were subjected to the investigations of static long-lasting life. Metal sheets in 2 mm thickness were bonded. Surface sheets were prepared to jointing the method of sandblasting and then the washing in extraction naphtha.

Prepared two lots of specimens, in which was used epoxy adhesive Epidian 57 curing trietylenotetramina (TETRA) in the weight relation 10:1. On the needs of investigations adhesive was curing two-stage according to the manufacturer recommendations, i.e. preliminary curing made in the temperature 20°C by 12 hours and then after-bake in the temperature 80°C by 6 hours. Specimens in second lot were submitted the modification, which consisted in the introduction, among joining metal elements, one layer of the glass fabric (GF) additionally impregnated Epidian 57. In this way after curing the joint was formed in the glass-epoxy composite form. The glass fabric of the Belgian firm Syncoglass about basis weight 160 g/m^2 was used in investigations.

The modification of joints did not influence significantly on the change of the short-term strength of adhesive joints. The short-term strength of specimens with modified joints carried out 2.32 ± 0.12 kN and it was comparable with short-term strength of adhesive joints performed from only Epidian 57 about value 2.45 ± 0.15 kN (the fall average strength about approx. 5%).

It was observed however the essential change of static long-lasting life testing lot of specimens. Specimens with modified adhesive joints, under the load even 50 and 60% short term strength (P_n) in the temperature suitably 70°C and 60°C, characterized static life on the level 500 h (investigations were broken after this time). Adhesive bonds whose joints were made from the epoxy adhesive and which were tested in identical conditions (load and temperatures) were marked the durability however on the level only just several hours (cf. Fig. 9 and 10).

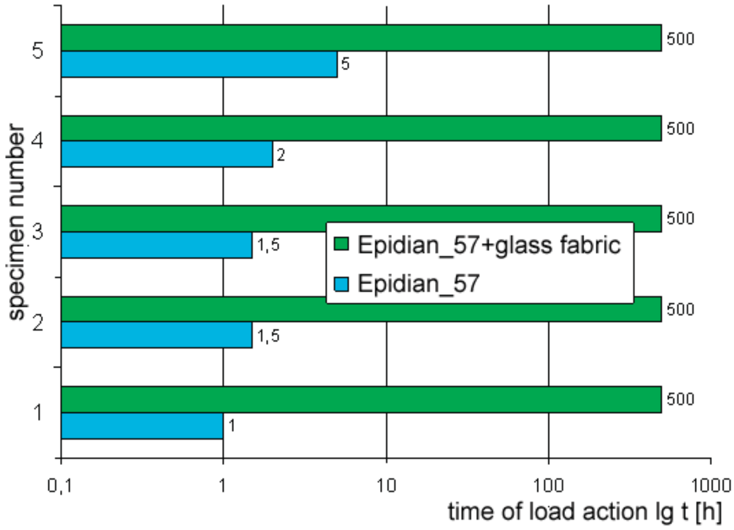

Fig. 9. Comparison of static long-term life adhesive bonds which the joints were made from epoxy adhesive Epidian 57 and Epidian 57 reinforced the glass fabric, testing under the load 0.5P_n in temperature 70°C

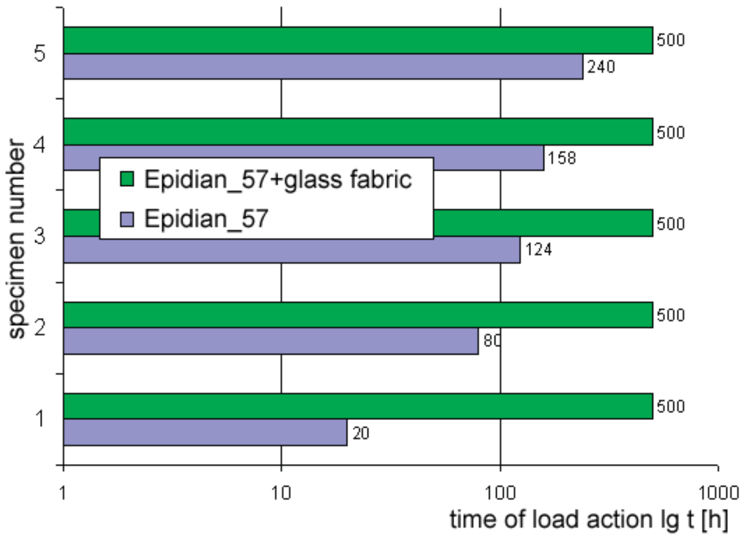

Fig. 10. Comparison of static long-term life adhesive bonds which joints were made from epoxy adhesive Epidian 57 and Epidian 57 reinforced the glass fabric, testing under the load 0.6P_n in the temperature 60°C

On the assumption that the static long-term life of adhesive joints was become dependent on the magnitude of deformations appearing in the adhesive layer of the adhesive bond and that first of all the change of strains (and not the stresses) determine about the static long-term life of the joints. To convinced about rightness the assumption thesis to perform the analysis with make use of FEM. Build the model of the adhesive bond, where bonding elements and joint were modelling the layers of solid elements [2, 7]. In model was considered viscoelasticity proprieties of adhesive joint using the mechanical model Buger's body [5]. Viscoelasticity propriety of the adhesive material was defined determining the values of the creep factors according to the methodology presented in the work [2, 7]. The selected results of the numeric studies of the joint, in the form of the distribution of stresses and strains in the time along the joint, were respectively presented on Fig. 11 and 12.

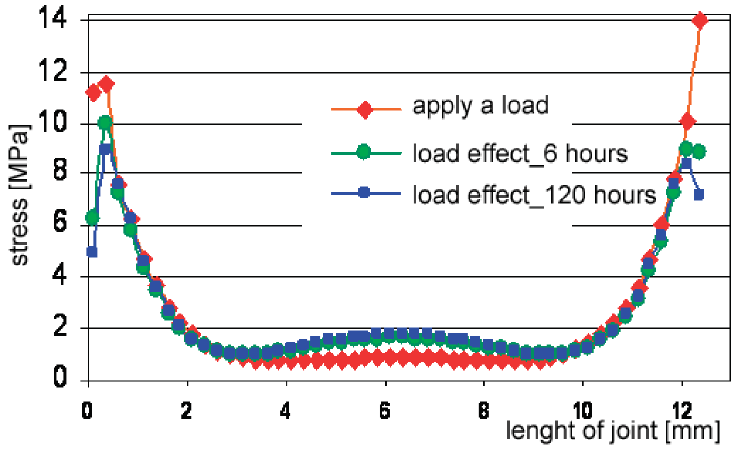

Fig. 11. Change of maximum principal stresses with time along adhesive layer

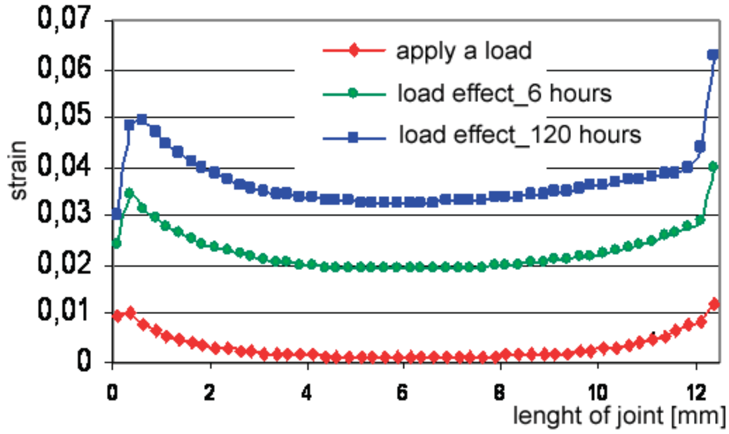

Fig. 12. Change of maximum principal strains with time along adhesive layer

Strains and strains were presented in the moment of applying a load and after 6 and 120 hours. The effect of the little change of stresses was observed (at the end of adhesive layer occurred decrease of stresses) at simultaneous increasing of the principal and particularly non-dilatational strains. The intensive increase of strains was also observed in the initial period load of adhesive bond.

Additional numeric studies were performed to comparison the value of strains occurring in joints made from only epoxy adhesive and joints strengthened the glass fabric. It was defined, on the basis of experimental research, propriety material joints for Epidian 57 [7] and epoxy-glass composite [6]. The quantitatively changes of strains were compared in two models of the bond, in moment of applying load (Fig. 13) and after the simulated time 120 h (Fig. 14).

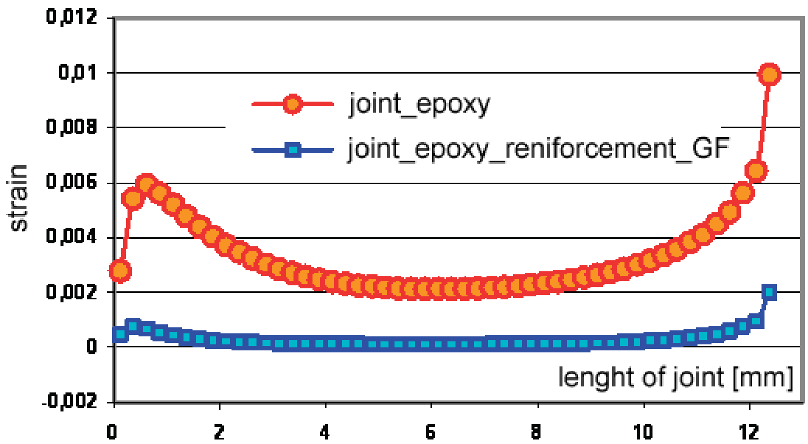

Fig. 13. Distribution of maximum principal strains along joint for different models of adhesive bond in the moment of applying the load

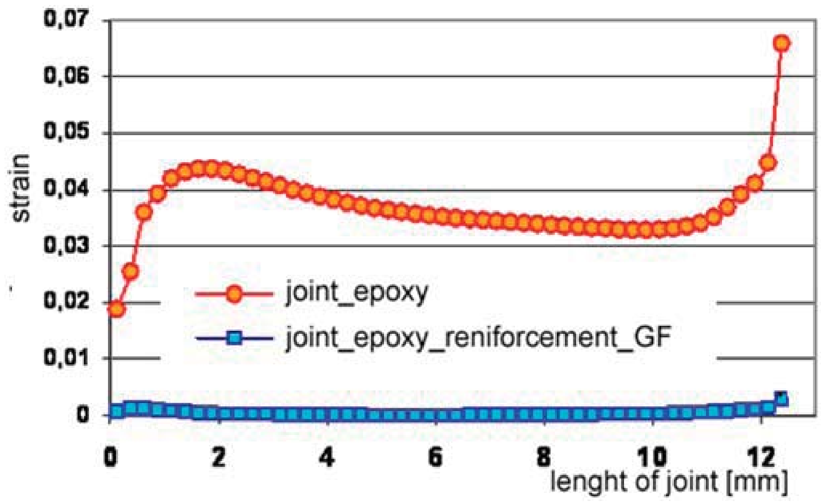

Fig. 14. Distribution of maximum principal strains along joint for different models of adhesive bond after 120 hours

It was found, that the joints in the form epoxy-glass composites are subject to a lesser extent strains in the time. It this connection was proved that glass fabric reinforcement of the joint based on the epoxy material limited the increase of strains, and therefore static long-term life so the prepared joint increased.

4. Conclusions

The finite element method enables recognition the effects appearing while adhesive bond is loaded (short-term, long-lasting, periodically variable and static), and this way to forecasting their life. There is a possibility of proposing the methods and constructional solutions that in order to increasing short-term strength and life (both fatigue and static long-lasting), thanks using this kind of testing.

The valuable advantage of using FEM in analysis of the short-term strength and fatigue or long-lasting life adhesive bonds there is also an option of shortening or even replacing some time-consuming experimental tests with such kind of analysis.

In investigations, thanks to using of FEM, was successful to explain:

- cause of higher short-term strength and fatigue life of overlap joints made of steel sheet in the comparison with performed of alloy aluminum sheet,
- the mechanism destruction of roller specimen, performed from adhesive materials, loading on axial compression cyclically in which cracks occurred along the generating line. In this way the

necessity of taking into consideration while projecting constructional adhesive joints, provided for to long-lasting transmit of changing loads, the creep effect occurring in the material of the joint was confirmed,
- the cause of the essential difference of the static long-lasting life adhesive bonds (about comparable short-term strength), which the joints were made from epoxy adhesive only and joints made from epoxy plastic reinforcement the glass fabric. The necessity of accepting, to the valuation of the effort stage of the adhesive layer in the static long-lasting life analysis of this kind joints, the maximum strains hypothesis was confirmed in this way.

References

[1] Bijak-Żochowski, M., *Mechanika materiałów i konstrukcji*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2006.
[2] Godzimirski, J., Rośkowicz, M., *Numeryczne badania pełzania spoin klejowych*, Biuletyn WAT, No. 2, pp. 109-119, Warszawa 2003.
[3] Godzimirski, J., Tkaczuk, S., *Ocena przydatności metod numerycznych do obliczania wytrzymałości doraźnej połączeń klejowych*, Biuletyn WAT, No. 9, Warszawa 1998.
[4] Kuczmaszewski, J., *Podstawy konstrukcyjne i technologiczne oceny wytrzymałości adhezyjnych połączeń klejowych*, Wydawnictwa Uczelniane Politechniki Lubelskiej, Lublin 1995.
[5] Łączyński, B., *Mechanika tworzyw wielkocząsteczkowych*, WPW, Warszawa 1977.
[6] Ochelski, S., *Metody doświadczalne mechaniki kompozytów konstrukcyjnych*, WNT, Warszawa 2003.
[7] Rośkowicz, M., *Analiza wytrzymałości długotrwałej połączeń klejowych*, Rozprawa doktorska WAT, Warszawa 2004.
[8] Tkaczuk, S., *Prognozowanie wytrzymałości doraźnej połączeń klejowych*, Rozprawa doktorska WAT, Warszawa 2006.
[9] Śródka, W., *Trzy lekcje metody elementów skończonych*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2006.

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