ISSN 0543-5846
METABK 59(3) 411-414 (2020)
UDC – UDK 678.5:538.22/621-426:62.001.57:621.311.1:620.16=111

FEM MODELING OF MAGNETIC MICROWIRE AND ITS USING FOR STRESS MONITORING INSIDE THE COMPOSITE BEAM

Received – Primljeno: 2019-12-16
Accepted – Prihvaćeno: 2020-02-25
Review Paper – Pregledni rad

The proposed article is devoted to the stress evaluation inside the composite beam using the embedded magnetic microwire sensors. The interlaminar stresses with high values can occur inside the composite structures during the operation. It is essential to monitor the stresses and to increase the lifetime of the composite materials by prediction using the research results from the stress distribution estimation and also during the operation using the embedded magnetic microwire-based sensors. In the article the results of the mechanical stress distribution between the magnetic microwire coating and core and the discussion about the experimental application of the magnetic microwire inside the composite beam are presented.

Key words: composite, magnetic microwire, finite element method (FEM), mesh, stress

INTRODUCTION

The proportion of composite materials in the engineering industry is widespread and is still growing. Composite materials combine many advantageous properties, due to which they are used in the manufacture of modern equipment of various kinds. Despite this fact, they also have several disadvantages. An undesirable feature of composite materials is their inhomogeneity, sudden cracking within the material as a result of the maximum load exceeding. One of the ways how to prevent these unfavorable properties is to monitor the stress of the composite structure by means of applying magnetic micro-wires inside the structure. In order to sense critical stresses, it is possible to built in the magnetic microwire sensors within the composite structure during the manufacturing process. Before the magnetic micro-wires are used to measure the stresses of the structure, it is necessary to know the mechanical properties of the magnetic microwires themselves and of the structure as well.

Investigation of magnetic microwire mechanical properties

Before the strength calculations can be made, it is necessary to know the exact geometry of the magnetic microwire. Magnetic microwires consist of a metal core and a glass coating [1]. The most important information for the stress investigating is the connection between the core and the glass of the magnetic microwire, therefore the glass was removed mechanically from the magnetic microwire. After the glass coating mechanical removal, the core was observed using an electron microscope (Figure 1). Nine photographs from were analyzed and imported into the CAD system [1, 2]. At the beginning, a 3D CAD model of the core without the contact surfaces was created. The contact surfaces were modeled based on the imported photos from the microscope observations (Figure 2).

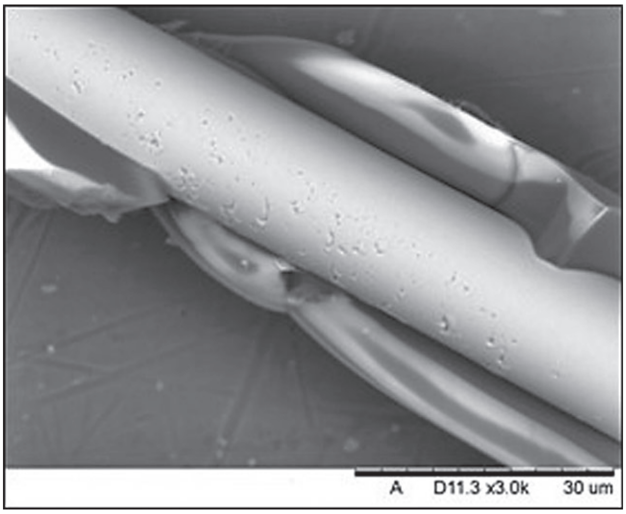

Figure 1 Magnetic microwire under microscope

Based on the 3D model of the magnetic microwire it is possible to perform the finite element model (FEM) analysis and subsequently to investigate the mechanical stress distribution between the core and the glass-coat of the magnetic microwire. The FEM model was created using the hybrid meshing, which means that the finite element mesh consisted of both hexa and tetra element types. The area of the interest is meshed using the hexa type elements and the middle of the core is meshed by the hexa elements. The attention during the meshing

M. Spodniak, K. Semrád, M. Hovanec, P. Korba, T. Musil, Faculty of Aeronautics, Technical University of Kosice, Slovakia (e-mail: miroslav.spodniak@tuke.sk)

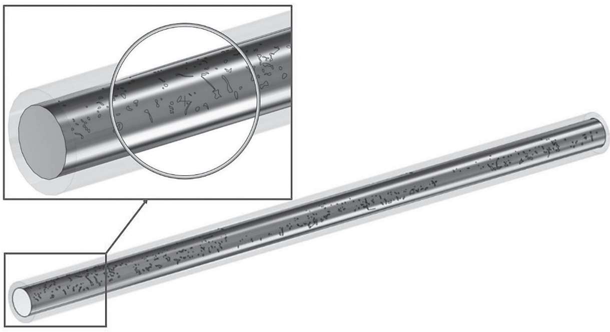

Figure 2 3D model of the magnetic microwire

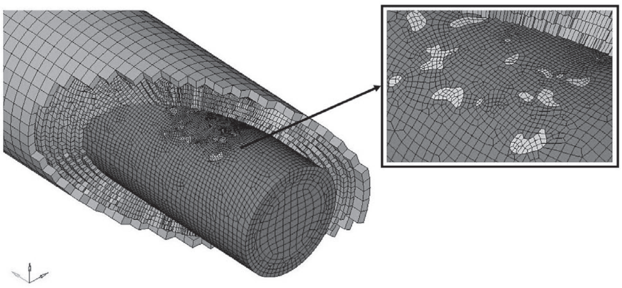

Figure 3 FEM model of the magnetic microwire

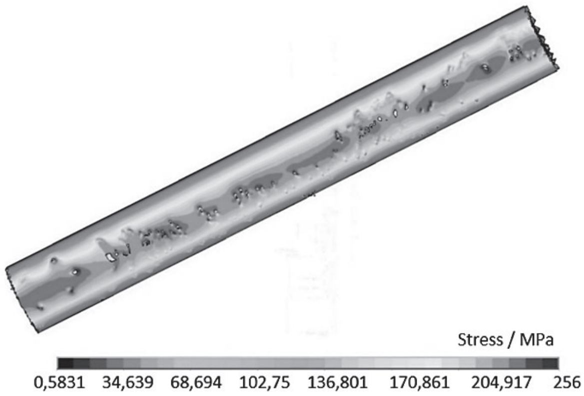

Figure 4 Von Mises stress of magnetic microwire

process has to be payed near the small regions creating the contact between the core and the glass coat of the magnetic microwire. Mesh in such a region needs to be fine enough in order to obtain proper results [3].

Once the core of the magnetic microwire model is meshed the finite element mesh of the coat can be created. The methodology of core and coat meshing is quite similar. First of all, the 2D elements are created on the coat surface of the magnetic microwire such an elements are afterwards mapped into five rows of the 3D hexa elements with the SOLID45 element type. When the glass and the core are meshed it is possible to model the contacts between them. In order to model the contacts, it is necessary to mark every element of the mesh in the contact surface regions between the core and the coat. Consequently, the contacts with the corresponding properties can be modeled. More than 900 small contact surfaces between the glass and the metal core were modeled, which means thousands of the finite elements. It is necessary to mark every single element for the contact modeling, which is a time-demanding process. The final step in the magnetic microwire core and coat meshing is the meshing of a thin composite layer. It will ensure that the boundary conditions can be applied. The resulting FEM model of the microwire with all parts together with the partial section is shown in the Figure 3 [3].

The results of the static contact analysis are presented in the Figure 4, which shows the distribution of the resulting Von Mises stresses on the magnetic microwire core. The figure shows a section of the central part of the microwire without the glass-coating and the composite structure to show the waveform on the core. The maximal Von Misess stress was 256 MPa at the contact joints, which means an extremely high stress concentration around the small area regions connecting the core with the coating [3].

EXPERIMENTS

Application of magnetic microwire inside the composite beam

Before investigation of the mechanical stress of a composite beam by means of magnetic microwires, it is necessary to know the values that should be expected during the measurement and thus it is necessary to predict the magnitude of the beam deformation and the mechanical stress [4]. The composite beam is dimensioned and manufactured according to the Figure 5. The model of the I-beam for the FEM analysis is identical with the tested glass composite part. It is a simple I-beam single side constrained. The second side is loaded by the applied force created by the loading weights added to the end point of the I-beam. Dimensions of the I-beam are 62 x 62 x 960 mm. The beam is constrained at 180 mm and the microwire is placed 710 mm from the free end. The I-beam is loaded in the range from 0 to 14 (kg), which mean the maximal load force F = 137,29 N. The tensile stress σ in the I-beam at the distance l = 710 mm from the free end can calculated as:

$$\sigma = \frac{M_y(x)}{J_y} Z_T$$

where $M_y(x)$ is the bending moment, J_y is the polar moment of inertia and Z_T is the center of gravity [5].

The $M_y(x)$ can be expressed as:

$$M_y(x) = Fl$$

and we can describe the maximal tensile stress σ_{MAX} at the defined point as:

$$\sigma_{MAX} = \frac{M_y(x)}{J_y} Z_T$$

where F is the load force, l is the distance, where the tensile stress is analyzed. Now we can estimate the maximal tensile stress at the defined load as:

$$\sigma_{MAX} = 27 \text{ (MPa)}$$

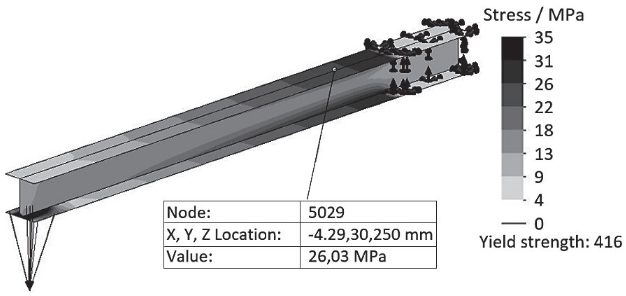

Figure 5 Maximal stress estimation in the area of measurement

The FEM analysis of the composite beam is performed in order to estimate the maximal stress in the area of the magnetic microwire application. In the software the composite layers are modeled with the specific properties. The model is identical to the beam, which is used for the experimental measurement. The mechanical stress results in the area of interest are presented in the Figure 5 [4, 5].

The maximal node stress in the area of the magnetic microwire placement is 26,03 MPa. According to the estimated stress value it will be possible to describe the stress dependency on the switching field during the experimental analysis of the composite beam with the built-in magnetic microwire [4].

For the purposes of the experimental measurement, the composite beam with a constant cross-section was made into which a sensor based on the magnetic microwire was placed. The composite beam is rigidly bounded at one end and to the other end the force in terms of weight from 2 to 14 kg was applied. The load was applied repeatedly from 2 kg to 14 kg and back to 2 kg for 63 times during the experiment. The switching field of magnetic microwire placed in the composite beam was sensed using the sensing coil. The magnetic microwire was placed 25 cm from the beam root and on the upper flange of the beam. The composite beam is shown in the Figure 6.

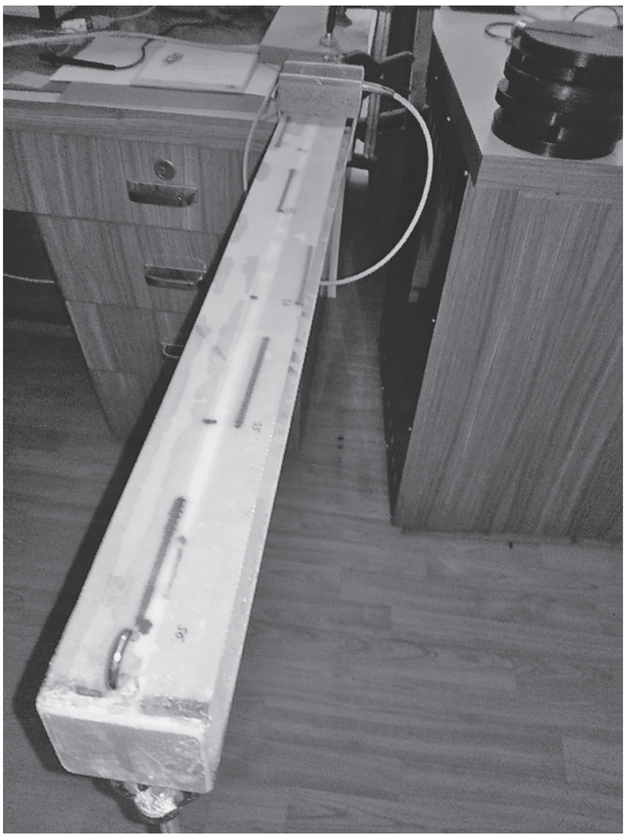

Figure 6 Prepared beam for the experimental testing

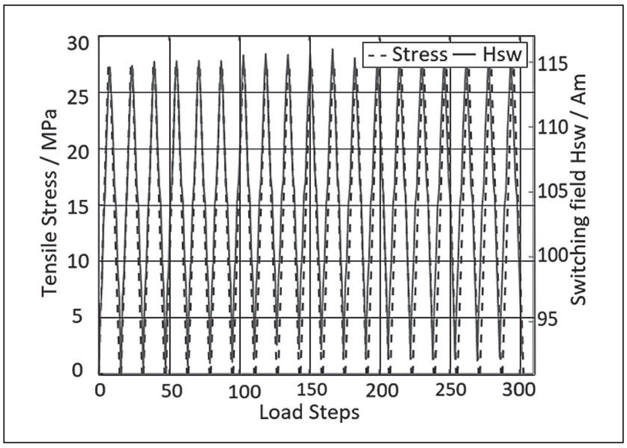

Figure 7 Experimental tests results – switching field and deformation

The results of the experimental stress measurement inside the composite beam are presented in the Figure 7. The plot is showing a dependency of the applied tensile stresses and of the switching field of magnetic microwire on the load step [4, 5].

CONCLUSION

According to the presented results it is possible to determine the dependency between the mechanical stress and the switching field inside the composite beam. Although the dependency is obvious there are some cases when the obtained results are completely different. The switching field of the magnetic microwire can be influenced by several factors. The most adverse effect appears to be at the maximum load of 14 kg, where the bottom flange began to ripple and created an ever-increasing distance between the sensing coil and the microwire, which adversely affects the measurement and therefore the results were not correct. The top flange that was stretched had not ripple and the coil was firmly attached to it, so the results are of high quality, as can also be seen from the experimental results. Regarding the microwire manufacturing and dividing process, the measurement can be also affected by the cracking of the magnetic microwire glass, which leads to the change of the internal forces and thus to the increased measurement errors.

Acknowledgements

This work was supported by the APVV-18-0248, VEGA 1/0429/18, KEGA 052TUKE 4/2018 and the VA

No. 019/2019/1.1.3/OPVaI/DP with the ITMS code 313011T557 projects.

REFERENCES

[1] Šmelko, M., Praslička, D., Draganová, K., Lipovský, P., Kán, V., Bajús, J., Wireless strain gauge for composite materials, UPB Scientific Buletin: Series D, (2016) 1, 59-66

[2] Praslička, D., Šmelko, M., Lipovský, P., Kán, V., Flachbart, N., Offset of switching field in amorphous Fe-based microwires, Magnetic Measurement, (2015), 33-36

[3] Šmelko, M., Spodniak, M., Semrád, K., Tulipán, P., Lipovský, P., Moucha, V., Aeronautical Composite Construction Monitoring by magnetic Microwires, New Trends in Aviation Development 2018 – Danvers USA, (2018), 128-131

[4] Praslička, D., Šmelko, M., Lipovský, P., Kán, V., Flachbart, N., Possibilities of measuring stress and health monitoring in materials using contact-less sensor based on magnetic microwires, IEE Transactions on Magnetics, (2013) 1, 128-131

[5] Roylance, D., Stresses in beams, Department of Materials Science and Enineering MIT, (2000), 1-18

Note: The English Language translation was done by Katarína Draganová, PhD., ING-PAED IGIP, Technical University of Kosice, Slovakia