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DETERMINATION AND MONITORING OF STRENGHT PROPERTIES OF AIRCRAFT COMPOSITE STRUCTURES BY MAGNETIC MICROWIRES

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Abstract. The submitted paper deals with the application of magnetic microwires as sensors. The aim is to summarize the engineering view of the given issue and to inform about necessary steps for practical application of such a new sensor in the aircraft industry. The paper talks about the formation of composite samples necessary for tensile strength tests, the aim of which is to obtain material properties of composite materials. The obtained material properties of fiberglass samples are processed into graphical and tabular form. Subsequently, the material properties are used in the strength calculations of the prismatic beam, in which magnetic microwires are applied in the experimental part of the work. There are described in the submitted article two application of magnetic microwires as a stress monitoring sensors.
Keywords: composite; magnetic microwire; mesh; beam

1. INTRODUCTION

Due to their advantages, composite materials are widely used in the aviation industry. When applying composite materials, it is necessary to know their behavior, and predict mechanical properties. The aim of the introductory chapters of the article is to provide the reader with information about the possibility of obtaining the properties of composite materials and choosing the most suitable matrix composition from the strength point of view. The output is the material properties, which are applied to the experimental aircraft structure of the prismatic beam in the following chapters of the article. In the conclusion there are summarized possibilities of prediction of experimental investigation of aircraft structures. One of the progressive tools to monitor the mechanical properties of composite structures are magnetic microwires. A number of numerical simulations have to be carried out to observe the internal mechanical stresses for application of magnetic microwires in real construction during flight operation. With numerical computer simulations it will be possible to realistically assess and apply this measurement methodology to aviation practice. Obtaining material properties is a necessary step in strength calculations. In terms of Fem calculations, the main disadvantage of composites is their material, which is orthotropic, each material layer may have other mechanical and material properties. Composite materials have a greater dispersion of properties compared to conventional materials, and statistical analysis is therefore essential in the evaluation of properties.

2. MECHANICAL PROPERTIES OF COMPOSITE MATERIALS

The mechanical properties of the composite are determined experimentally and the determination must be simple and straightforward. It is based on the most widespread uniaxial pull test. In this test, a fiberglass specimen clamped in the jaws of the tearing machine is prepared. The sample is stretched according to the prescribed rules until it tears. The force size and its corresponding elongation, resp. in our case tensile stress and sample elongation [1].

2.1. Production of composite samples

The first step in determining the mechanical properties necessary for strength calculations of aircraft structures and their monitoring is the production of composite samples. Composite samples are made according to ASTM D3039. The length of the samples is 250 [mm], the width is 25 [mm] and the thickness is 2 - 3 [mm]. Composite specimens are adhered with epoxy resin duralumin shims (Fig. 1) for better grip into the pneumatic jaws of the tearing machine. Sample production is done by manual wet lamination [1].

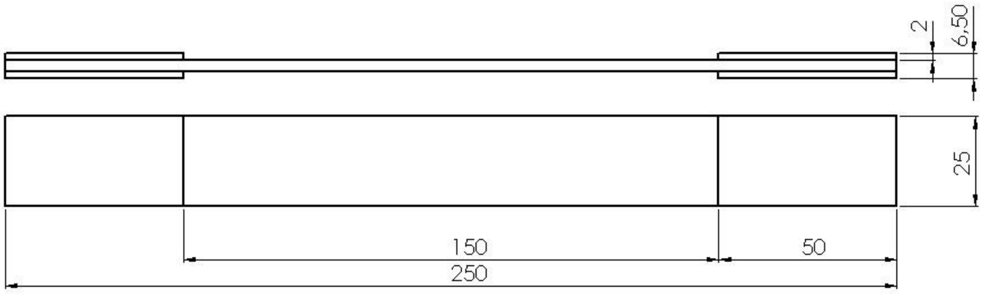

Figure 1 Composite sample sketch

An epoxy resin layer is evenly applied to the polished plate with a roller with hardener. The fiberglass reinforcing fabric is placed at different angles on the resin layer. Again, a layer of the prepared mixture is applied to the fabric by means of a roller so that a further layer of fabric is also partially saturated. The process is repeated for different compositions, resulting in seven sheets of fabric composition graded α = ± 0 °, ± 15 °, ± 30 °, ± 45 °, ± 60 °, ± 75 °, ± 90 °. The fabric surface must be as saturated as possible with epoxy resin. This process is repeated twelve times to form a twelve-layer fiberglass board. Twelve layers provide the desired sample thickness of approximately 2.4 mm. The layers are stacked symmetrically about the longitudinal axis. This process is repeated for all tracks from 0 [°] to 90 [°], creating seven boards with different characteristics. Subsequently, the samples according to Fig. 1. Curing is carried out for 24 hours at 22 ° C. After curing, the duralumin pads are bonded to the samples using epoxy resin and one mat layer from glass fiber. The hardening of the samples results in large interlaminar stresses that need to be removed, therefore the samples are subjected to heat treatment. The samples are warmed up for 6 hours at 60 ° C [1].

Figure 2 Composite sample

2.2. Strength tests of composite samples

Tensile tests are performed on a Zwick Roell Z030 universal test machine with a maximum force of 30 [kN]. The dependence of the tensile stress and the relative strain is called the working diagram resulting from the experimental tests. From the proportional deformation it is possible to calculate the elongation of the test sample and then the Young's modulus, which is once from basic constants in strength calculations.

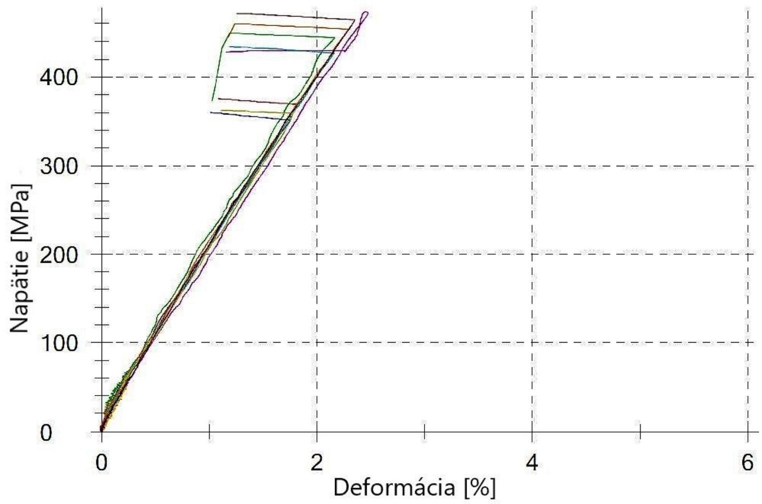

Figure 3 Working diagram

In Fig. 3 we can see the output of the tearing machine. It is a working diagram of the samples tested track α = ± 0 [°]. There are 8 samples torn, but only 5 with higher stress samples are included in the resulting average stress and strain. Three curves, whose stress reaches a limit of about 350 [MPa], cast aluminum ducts so that the samples are not relevant for further assessment.

A sample breach occurs in the measured area and the results can be considered correct. The average fracture point is calculated to 416 [MPa] and the average deformation is 2.2%. The highest strength of all samples is measured with fiberglass samples with fabric composition α = ± 0 [°] (Fig. 3). In the same way, mechanical tests are performed for all prepared samples with tracks α = ± 15 °, ± 30 °, ± 45 °, ± 60 °, ± 75 °, ± 90 ° [1].

2.3. Results of Strength tests of composite samples

The experimental determination of material properties results in the tensile strength, strain and calculated Young's modulus. In Tab. 1 shows the values for each sample type. For tensile tests, the number of 5 samples from each track was selected, which means 35 samples.

Table 1 Results of mechanical tests of composite samples

Sample	Stress [MPa]	Deformation [%]	Young´s modulus [MPa]
α =± 0[°]	416	1,2	34666
α =± 15[°]	352	1,2	29333
α =± 30[°]	230	2,2	10454
α = ±45[°]	104	15	693
α = ±60[°]	238	1,9	12526
α =± 75[°]	280	1,9	14737
α = ±90[°]	380	1,5	25333

3. MODELING OF COMPOSITE BEAM IN ANSYS APDL

The obtained experimental properties of the composite materials can be used in the strength simulation of an aircraft structure beam. The same beam is subjected to experimental measurements using magnetic micro-wires. The aim is to test the possibility of using a new methodology for monitoring aircraft structures to enhance flight safety [1, 2]

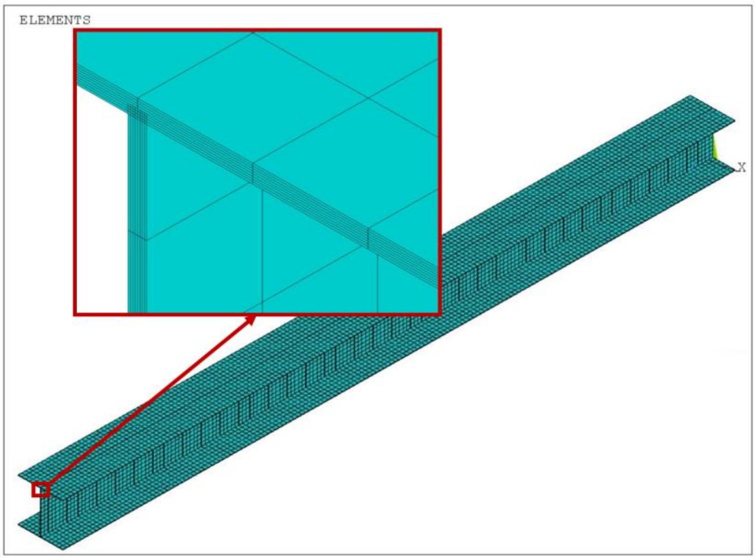

Figure 4 Composite beam modeling

Fig. 5 is showing the number of layers of composite 8. The reason for this number of layers is that the fabric consists of fibers with the angle of the track angle α = 0 [°] and α = 90 [°], as it is a fabric. In order to model the identical model and thus the fabric, the number of layers will be doubled to eight and the thickness of each layer will be divided in half, which means the thickness of one layer is 0.1 [mm]. Two consecutive layers with α = 0 [°] and α = 90 [°] together form a 0.2 [mm] thick fabric, four such fabric pairs form a 0.8 [mm] wall thickness. A beam with a thickness of 0.8 [mm] and four pairs of fabrics corresponds to a real-made beam that will be summarized in the following chapter. After applying the boundary conditions in the form of a loading force at one end and the fixation at the other, a numerical analysis is performed, where the maximum stress is examined, which will be compared with the measured experimental stress [1, 2].

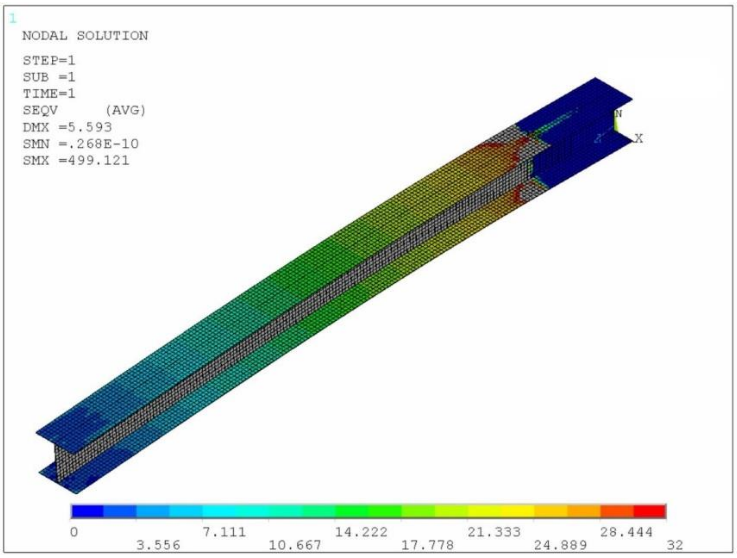

Figure 5 Composite beam results

The resulting reduced stresses can be seen from Fig. 5, where the stress at the local magnetic microwire location is about 28 MPa.

4. EXPERIMENTAL ANALYSIS

As in the numerical simulation in the experiment the beam is at one end fixed and on the other loaded with the same force as in the calculations. To monitor the maximal stress a magnetic microwire sensor is located in upper part of the beam (Fig. 6) [1, 3, 4].

Figure 6 Experimental composite beam

The sensing coil senses the dependence of the H_{SW} switching field and the mechanical stress. According to the resulting graph (Fig. 7), almost perfect copying of the applied load is evident on the beam. One cycle is shown in Fig. 7. The red color shows the mechanical stress calculated in the Matlab program and the blue color indicates the magnetic field of the magnetic field [1, 3, 4].

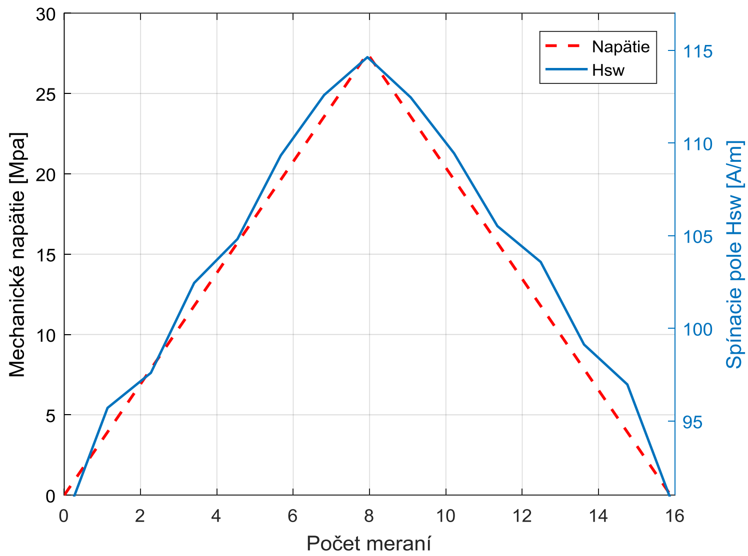

Figure 7 Results of meassurement

5. MAGNETIC MICROWIRE APPLICATION

One possibility to implement magnetic microwire into the aircraft construction is composite wing. For this application FEM analysis of composite wing for ultra-light was carried out. After constraining the model and applying maximal forces the maximal deformation and mechanical stress concentration area was obtained.

From the point of view of the application of magnetic microwires as stress sensors, the results of the overall wing stresses are more important for us. Based on the Von Mises stresses, it will be possible to determine the appropriate location for the application of the microwires and the subsequent measurement of the mechanical stress using these sensors.

Maximal stress is concentrated in the lower part of composite beam. It would be suitable to implement sensor such as magnetic microwire into this area in order to monitor maximal stress inside composite beam between particular composite layers.

The mechanical stress of the wing is evident from Fig. 8. The maximum stress is 865.926 [MPa]. The permissible maximum tensile stresses are 1200 [MPa] and at a pressure of - 800 [MPa].

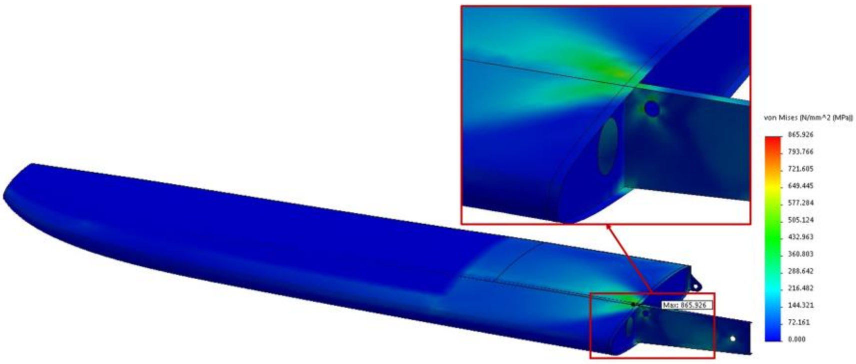

Figure 8 Composite wing maximal stress

Another possibility for magnetic microwire application for aerospace is hinge of a small aircraft. FEM analysis of a hinge was performed as well. FEM analysis is comparing steel and composite material for hinge and possible application of magnetic microwire for stress monitoring. The wing hinge has a maximum compressive force of 1 000 N applied to the connecting hinge eye. The material chosen is steel for the original component and composite for the new component. The wing hinge has a target life of approximately 10 million cycles under a peak to peak loading. The results are in the Figure 4 - 7. The minimum log life is 6,70498 that means $10^{6,70498}$ or 5 069 673 cycles at a point where the Stress von Mises achieves its maximum of 320 MPa. The minimum factor of safety suggests a permissible overload before fatigue life is jeopardized.

Failure Strength is the level of stress at which the material starts to deform plastically. After failure determination method selection (Distortion Energy - von Mises) and entering the cutoff stress limit for the method (Tensile Yield Stress = 400 MPa) it is possible to plot a Failure Index measure with a fringe plot based on the simulation results. The calculated stresses are compared to the cutoff stresses and the index is plotted. Less than 1 - material has not yielded. In this case the Failure Index is 0,8 max [5].

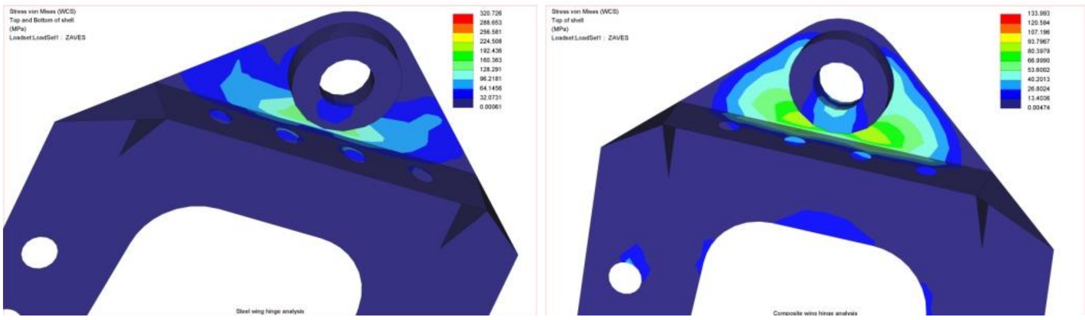

Figure 9. Steel and composite Hinge maximal stress [5]

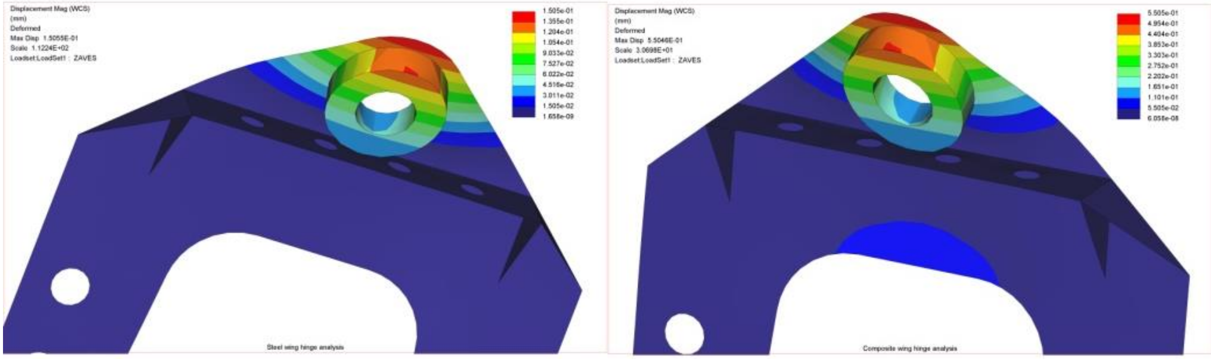

Figure 9 Steel and composite Hinge displacement

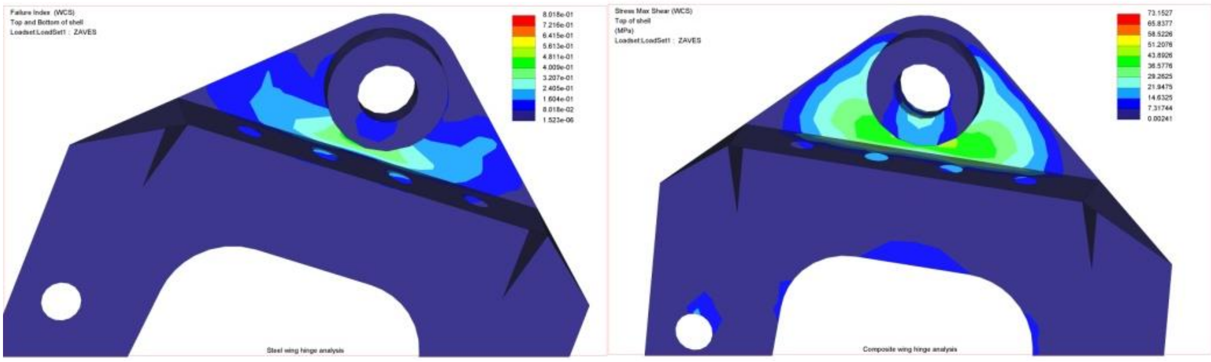

Figure 10 Steel and composite Hinge – Failure Index and Stress max Shear [5]

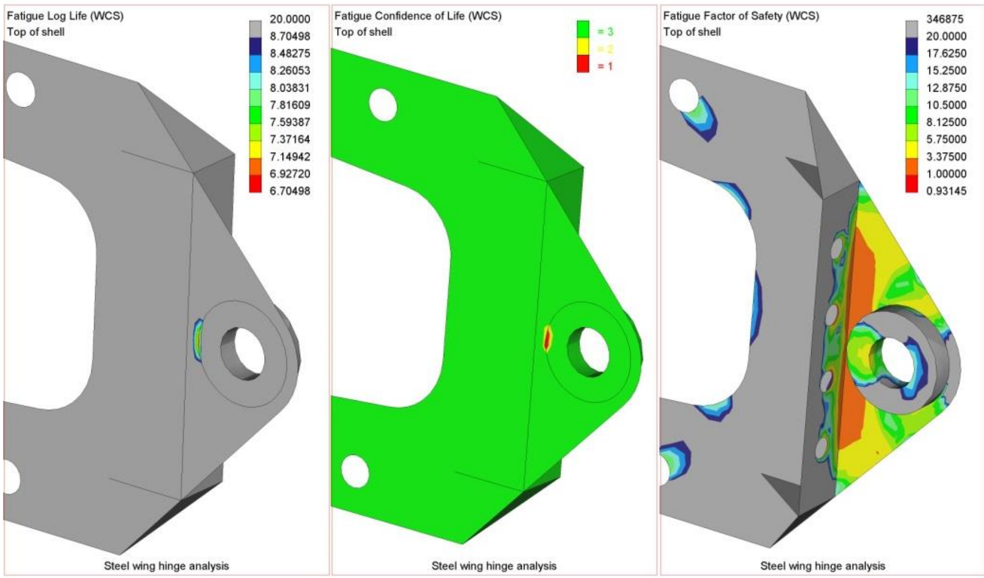

Figure 11 Steel and composite Hinge Long Life, Confidence of Life and Factor of Safety [5]

The BLF (Buckling Load Factor) is the magnification factor by which the loads applied in a previously specified static analysis would have to be multiplied to produce the critical buckling load (BLF ≥ 1 means that model has not buckled). BLF = 54 [5].

According to the results of composite wing hinge analysis that involves the static stress, displacement and buckling analysis shown in Figure 4 - 6 it can be seen that BLF = 13, Max. Stress von Mises = 134 MPa < Ultimate Tensile Strength (600 MPa) and Ultimate Compressive Strength

(570 MPa). Stress Max. Shear = 73 MPa < Ultimate In-plane Shear Strength (90 MPa). The total mass of the new composite wing hinge is 0,04 kg < total mass of the original steel wing hinge (0,13 kg) [5].

6. CONCLUSION

The presented paper summarizes the study of the dependence of mechanical stress, mechanical properties and sensing the stress of composite structures by means of magnetic micro-wires. The aim of the article is to inform the reader about the research in the area of the possibility of monitoring modern aircraft composite structures and the necessary steps in the application of new sensors based on magnetic micro-wires.

In the introductory chapter is described the issue of obtaining the material properties of composite materials, whose output is numerical values determined for strength calculations. The obtained material properties are used in strength calculations, the results of which are summarized in the second chapter. The purpose of strength calculations of composite beam is predicting the stress of a simple aircraft structure. The resulting stress can then be compared to the experimental measurement using magnetic microwires. The output dependence of the mechanical stress and the switching field of the magnetic microwire can later be verified on the basis of the FEM calculation of the composite beam.

The next chapter shows the dependence of mechanical stress and switching a magnetic microwire array that is used as a sensor to monitor structural strength. Based on the results, it can be stated that the sensor is a suitable tool for increasing the safety of aircraft structures. This is a relatively new and very promising monitoring area, as it allows non-contact monitoring of the structure inside the material, without affecting the structure of the composite material. The last chapter discusses the possibilities of application of magnetic microwires in the aircraft industry.

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