WIRELESS STRAIN GAUGE FOR COMPOSITE MATERIALS

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The following article deals with the possibility of creating a wireless sensor by embedding a magnetic microwire in a composite material. Conventional strain gauge measuring methods comprise of measuring surface stress, while measurements inside the material are limited [1]. There is one significant disadvantage of strain gauges - a galvanic connection between the sensor and the sensing device. Magnetic microwires [2, 3, 4] offer the possibility to create a built-in sensor inside the material. Moreover, the sensor itself reacts to several physical quantities [5] and special measuring method allows us to measure these parameters simultaneously. These advantages make this sensor a very perspective and interesting technology application [6].

Keywords: strain gauge, tensile stress, wireless, magnetic microwires

1. Introduction

The amount of composite materials in plane construction of modern airplanes exceeds 50%, in case of big airliners. The amount can reach 100% in small sports airplanes. Composite materials are modern and very perspective for any kind of construction, especially the one of airplanes. There is a one disadvantage of using composite materials, besides many advantages, and it is the absence of a plastic deformation region in their stress-strain curve. Only few signs occur before the material fails, for example sound emission. According to [1], there are two methods to measure off the tensile stress in composite materials, the first one using strain gauges, the other one optic fibres. Strain gauges are suitable for surface measurement only and the fibre-optics method is relatively large in comparison to the composite structure. The embedding of optic fibres can cause structural defects of the composite material.

Magnetic microwires in a role of the tensile stress sensor [6] are suitable for measuring the strain inside the composite material (Fig. 1). Due to their small dimensions and high sensitivity to several physical quantities, magnetic microwires are very perspective to use in the sensor technology. The diameter of a microwire can be manufactured in range from few to several tenths of micrometres. The microwire consists of a ferromagnetic core covered by a glass shell, therefore the microwire itself can be denoted as a composite material. The glass shell, as the remnant of the production, protects the core from the possible environmental influence, e.g. corrosion etc. The glass shell is a contact layer

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between the microwire and the composite material, such as glass fibre, carbon fibre or other.

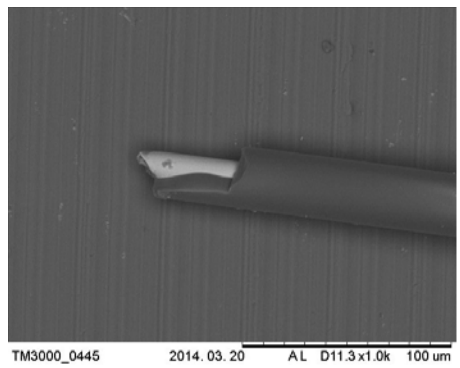

Fig.1 An ending of a microwire sample with 35 μm overall diameter

Microwires with high and positive magnetostriction of the core are characterized by the rectangular shape of the magnetization curve. In special cases, we can observe a bistable behaviour of the microwire magnetization. These microwires are often called bistable microwires, see Fig.2 left.

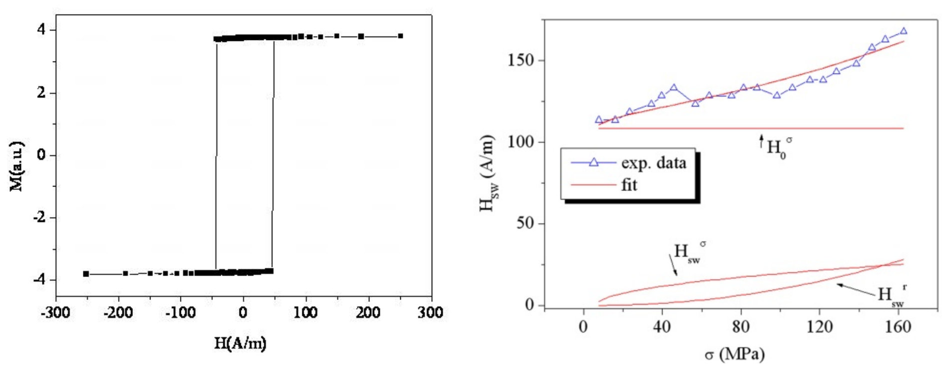

Fig.2 A rectangular hysteresis loop of a bistable microwire on the left and the dependence of the switching field on the tensile stress on the right [7]

The magnetization curve of bistable microwires has only two stable states, which are positive and negative saturation. A switch between these stable states occurs when the value of external field reaches the point called the microwire switching field, H_{SW} (sometimes also signed H_C – the critical field). The closure magnetic domain overcomes potential barrier, runs through the microwire core in a single Barkhausen jump and changes the magnetization of the microwire. The value of this external field is given by the chemical compound of core, the production process parameters and the post-processing.

The high magnetostriction of such microwires is responsible for the reaction to tensile stresses applied on microwires. The width of the magnetization curve, ergo the value of the switching field H_{SW}, is a function of the external tensile stress [7]. As the tensile stress causes a change in the magnetic parameter of the microwire, we can measure the tensile stress by observing the magnetic properties of the microwire. Therefore, the construction of wireless sensor is possible [8].

2. Measuring method

The induction method is often used for measuring the magnetic parameters of magnetic materials. The microwires are excited by an external excitation field of a precise triangular shape. A special excitation coil is used along with a race-track type of a sensing coil. The combination of them allows us to place the measured microwires outside of the excitation coil and create a built-in sensor. Principal scheme of the measurement workstation is presented on Fig. 3.

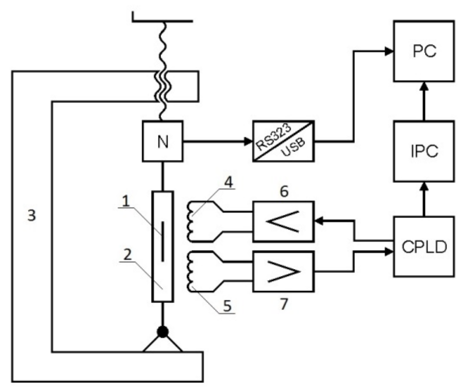

Fig.3 The measurement workstation with the equipment

The measurement workstation consists of a sample *2* with the microwire *1* embedded. The sample is clamped in a clamping device 3, through the reference force gauge *N,* connected to the superior personal computer *PC* via serial interface. The experimental device itself consists of a *CPLD* control device, an industrial computer *IPC*, a power amplifier *6*, an excitation coil *4*, a sensing coil *5* and a preamplifier with a comparator *7*.

The measurement of switching field is performed by precise measuring of time, as it is shown in Fig.4. The magnetic microwire is excited by a triangular shape excitation field with an amplitude H_{MAX}. When the excitation field reaches the value of the switching field of the microwire, the core will change its magnetization. The Barkhausen jump causes a flux density change in the microwire near the circumambience, then the voltage peak is induced to the sensing coil. The time interval between the beginning of the excitation field half period *T* and the voltage peaks is measured by the control device *CPLD*. These intervals are marked as T^+ and T^-. The frequency of the excitation field was set to 500 Hz with the amplitude H_{MAX}=570 A/m. A sampling frequency of the reference force gauge was 1 Hz.

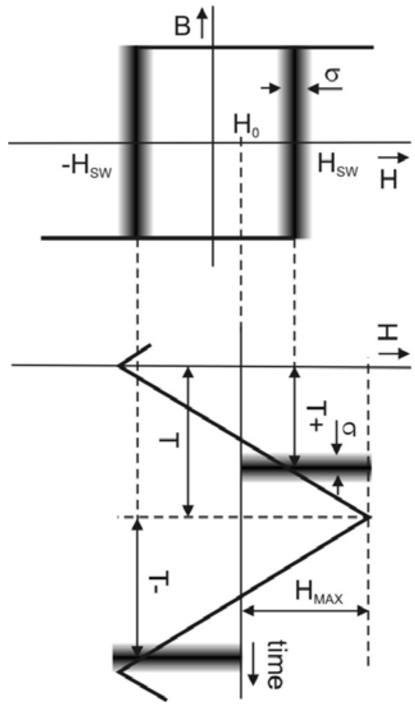

Fig.4 The induction sensing method principle

The external magnetic field H_0 and the microwire switching field H_{SW} can be estimated by simple equations:

$$H_0 = -\frac{H_{MAX}}{T}(T^+ - T^-) \quad (1)$$

$$H_{SW} = H_{MAX}\left(\frac{T^+ + T^-}{T} - 1\right) \quad (2)$$

This method allows us to measure two different physical quantities, the external magnetic field and the tensile stress, by simple measuring of time intervals. Furthermore, the measurement is performed simultaneously and separately.

3. Experiments

A set of composite samples was prepared for the experiment, see Fig. 5. Samples were made of glass-fibre composite material with two layers and a microwire embedded between them. To prevent the samples from the batch deviation, all the samples were made into a single sheet of composite material, consecutively divided into samples. The microwires used, marked as N-38, have a ferrum based chemical compound $Fe_{38.5}Ni_{39}Si_{7.5}B_{15}$, a 35 µm overall diameter and a 20 mm length. The dimensions of samples used were 0.3 x 15 x 280 mm. To improve the clamping of the sample, the endings of each sample was strengthen by additional aluminium layers.

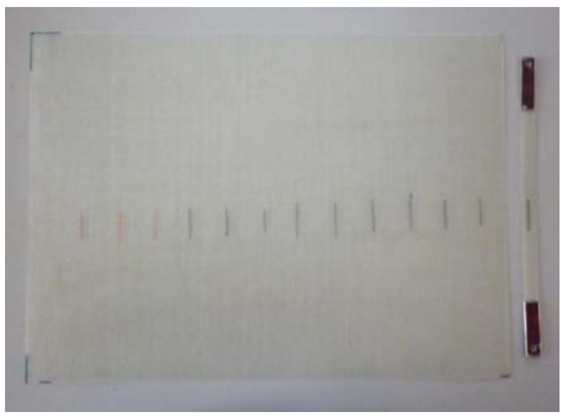

Fig. 5 The glass-fibre composite sheet and a sample with microwire embedded

The sample was exposed to a static load in range from 0 to 36 MPa, which is equivalent to a range from 0 to 200 N. The data measured were taken continuously during the measurement, therefore the changes of load are clearly visible. The sample load was increased after each 15 seconds interval and after reaching the maximum load force, the force was decreased in the same way back to zero. This procedure eventuated into a stair-step load curve, see Fig.6. Each step was performed as a 0,1mm increase or a decrease of the sample elongation. To fix the relative position of the microwire and the coils, the coils were placed on the surface of the sample.

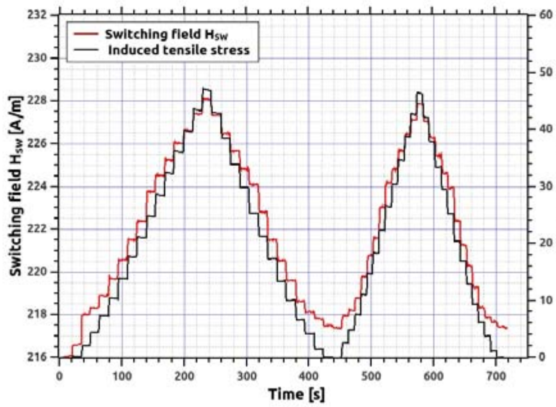

Fig. 6 The stair-step load curve with the response of the microwire

As it is clearly visible, the microwire reacts to the tensile stress load. The microwire response shows linear behaviour and the data measured from the first part of the increasing were used to create the transfer characteristic of such tensile stress sensor, Fig.7.

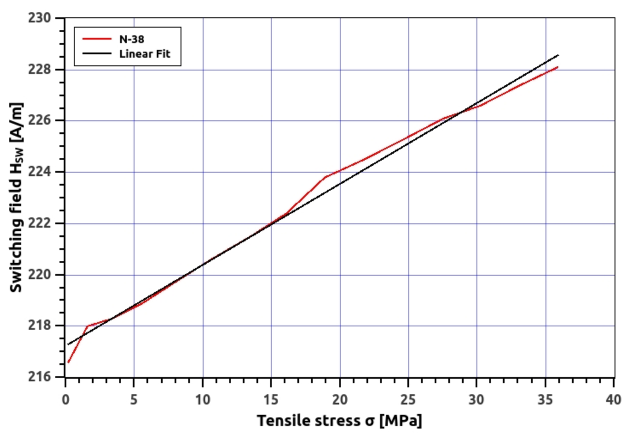

Fig. 7 The switching field dependence on applied tensile stress

This characteristic proves that the behaviour of the prepared build-in sensor is linear. The sensitivity of sensor can be estimated by a linear fit of this data. The slope, therefore the sensitivity of this linear fit curve is 0.316 [A m^{-1} MPa^{-1}].

4. Conclusions

This paper deals with the possibility of creation a contactless tensile stress sensor based on magnetic microwires. The experimental results show that it is possible to collect data from the microwire embedded in the composite material and to determine the internal stresses. This kind of sensor is completely contactless with no need of a power supply and a galvanic connection. The operational life of the sensor is as long as the operational life of the composite material in which the sensor is embedded. The composite material also protects the sensor from the environmental damages. No additional service or maintenance is needed. A big challenge for our future work is to reduce the noise parameters of such sensors, even though this was partially done by improving the method of the post-processing of the microwires.

The small dimensions of sensors do not create any structural defects. The sensing device can be used to measure more microwires embedded in construction. The device can be moved from one sensor to another, because it is placed on the surface of the material. The actual range of device is limited by the energy radiated from the microwire during the switching. The microwires used allow us to measure up to 5 mm under the surface of the material. Along with the linear transfer characteristic, it creates a powerful device for long time structure health monitoring or a material inter-layer behaviour research.

Acknowledgement

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