TENSILE STRESS TRANSFER CHARACTERISTICS OF FESIB MICROWIRE

Miroslav ŠMELKO*, Patrik KAŠPER, Pavol LIPOVSKÝ, Katarína DRAGANOVÁ,
Technical University of Košice, Faculty of Aeronautics, Rampová 7, 041 21 Košice, Slovakia
**Corresponding author.* E-mail: miroslav.smelko@tuke.sk

Summary. The article explains the possibility of tensile stress measurement in composite materials by the use of magnetic microwires. The amount of composite materials in modern airplane constructions is still increasing. It can reach the range from 50% to 100% depending on the type of the airplane. In comparison with metal materials, the composite materials have different behaviour in creation and propagation of dislocations. An embedded microsensor for internal tensile stress measurement can be created during the composite material fabrication by inserting the microwire inside the composite material. The sensor can be placed into the critical part of the construction between material layers, therefore it is possible to sense the stress of each layer. The present state of the art and planned practical goals are described in the paper.

Keywords: microwires; tensile stress; transfer characteristic

1. INTRODUCTION

Magnetic amorphous microwires are the ones of the latest research results of the micro and nano technology in the field of magnetic materials [1], [2]. They are extremely lightweight, flexible, durable, anti-corrosive and suitable for applications especially in sensor technology with broad application range. Bistable magnetic microwires are characterized by rectangular hysteresis loop, which shows bistable behaviour. Magnetization process accomplished by a single Barkhausen jump at the field value called switching field H_{SW}, see Fig 1.

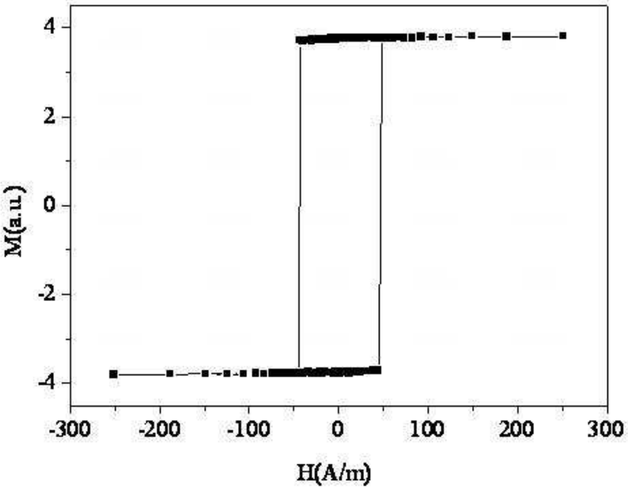

Figure 1 Rectangular histeresis loop of bistable microwire [3]

The switching field carries information about several physical quantities such as external magnetic field, temperature or applied mechanical stress. The magnetic microwires used in these experiments had outside diameter 35 μm, what makes them suitable for built-in sensor applications. The induction method of H_{SW} measurement allows us to monitor processes which occur under the surface of tested material. These advantages make it possible to create contactless built-in sensor for stress measurement applications.

2. MEASUREMENT OF H_{SW}

The switching field was measured by induction method. Excitation coil was fed by triangular shape current, while sensing coil was used to detect the induced voltage peaks. When domain wall runs through the microwire, induced peak occurs in the sensing coil. This method is expressed in Fig. 2.

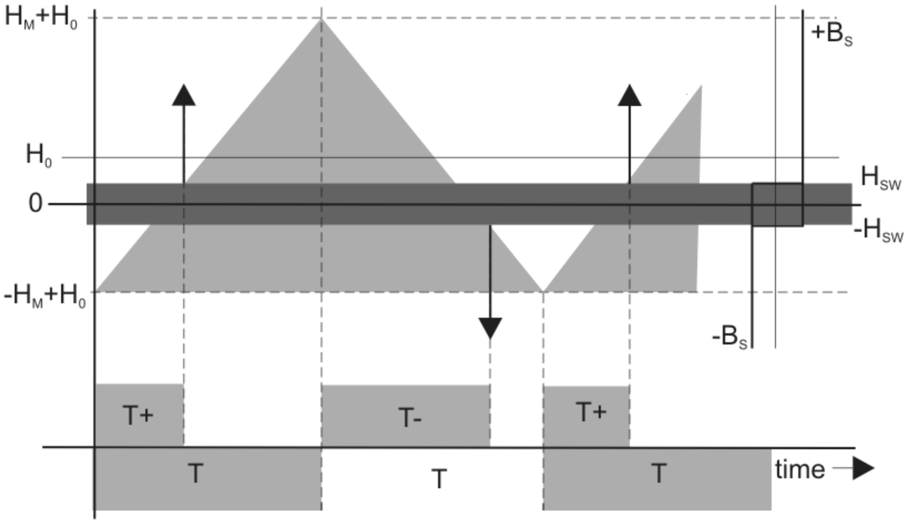

Figure 2 Principle of induction sensing method [4]

The triangle represents excitation current, black arrows represent peaks induced in sensing coil and rectangle represents hysteresis of the microwire. Time axis rectangles represent the time intervals between excitation field and peaks detected by the sensing coil. The measurement of switching field is performed by precise time measuring. Magnetic microwire is excited by triangular shape excitation field with amplitude H_M. At the moment, when excitation field reach the switching field of microwire, the microwire core changes its magnetization. High speed of Barkhausen jump causes high flux density change in near circumambience of the microwire so the voltage peak is induced in the sensing coil. The time interval between beginning of the excitation field half period T and voltage peaks is measured by the CPLD (Complex Programmable Logic Device) control device. These time intervals are marked as T^+ and T^-. Frequency of excitation field was set to 500 Hz with the amplitude H_M=570 A/m.

Switching field can be expressed from the measured time intervals by:

$$H_{SW} = H_M\left(\frac{T^+ + T^-}{T} - 1\right) \tag{1}$$

where H_M is the amplitude of excitation coil, T^+ and T^- are the measured time intervals and T is the half of the period of the excitation field.

For measurement purposes, special electronics had been designed. Controlling, measuring and communication are performed by the CPLD. Analog circuits perform A/D and D/A signal processing, signal amplifying from the sensing coil and for the excitation coil. Functional diagram of the measurement workstation is presented on Fig. 3.

The measurement workstation consist of sample 2 with the microwire 1 embedded. The sample is clamped in clamping device 3 thru reference force gauge N, connected via serial interface to the PC. Experimental device itself consist of the CPLD control device, industrial computer (IPC), power amplifier 6, excitation coil 4, sensing coil 5 and preamplifier with comparator 7. Sampling frequency of the reference force gauge was 1 Hz.

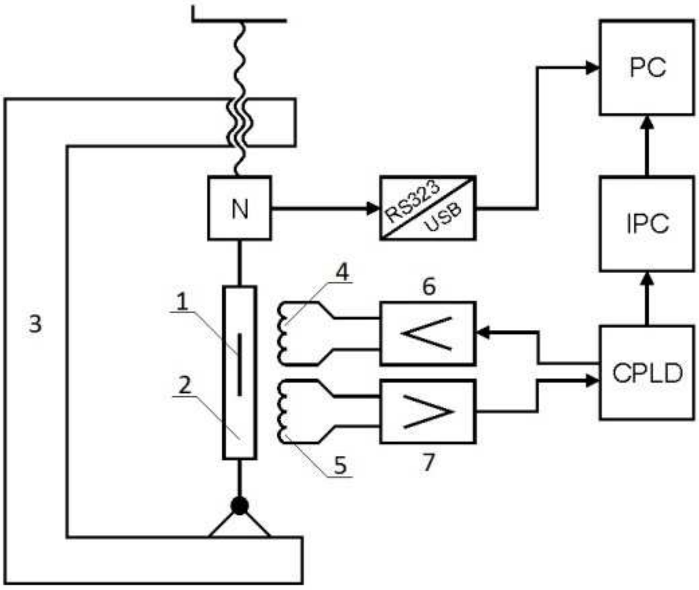

Figure 3 Principal diagram of measurement workstation [5]

Interfacing with peripheral devices is provided by IPC Vortex. Digital excitation signal from the CPLD is formed by integrator to triangular shape excitation signal. The voltage peaks induced in the sensing coil are amplified and transformed to PWM signal by a comparator.

It can be seen from the principal diagram, that the sensed microwire is placed outside of the coil formation. Thanks to special design of the coils, it is possible to embed microwires under the surface in any place of the measured construction.

3. EXPERIMENT

Set of composite samples was prepared for the experiment, see Fig. 4. The samples were made as two layer glass-fibre composite material with microwire embedded between them. To prevent the samples batch deviation, all samples were made as one sheet of the composite material, consecutive divided into single samples. Used microwires are made from iron-based chemical compound $Fe_{77.5}Si_{7.5}B_{15}$, with 30 μm overall diameter and 20 mm length. Dimensions of the samples were 0.2 x 50 x 480 mm. Ends of each sample were strengthened by additional layers to improve sample clamping.

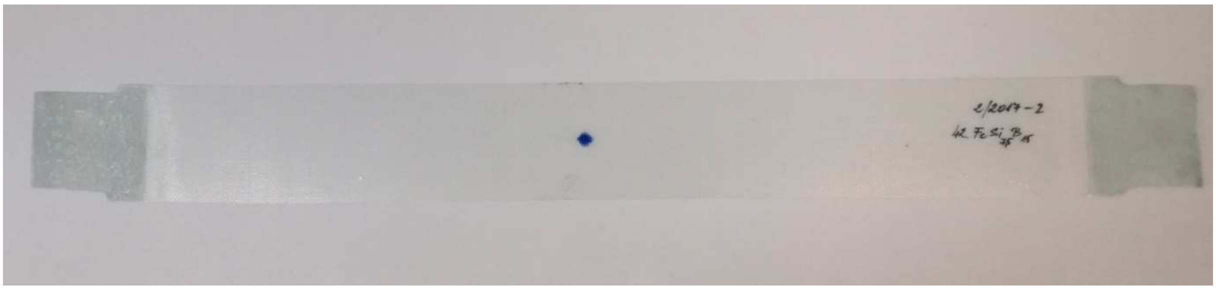

Figure 4 Glass fibre composite sample. Microwire position is marked by dot near the middle of the sample.

Sample was exposed to static loads in range from 0 to 100 MPa, what is equivalent to range from 0 to 1000 N. Measured data were taken continuously during the measurement with 1 kHz sampling rate. The sample load was increased after each 5 seconds until the maximum load force was reached. Then, the force was decreased in the same way back to zero. This procedure eventuates into a stair-step like load curve. Each step was performed as 0,1mm increase, or decrease, of the sample elongation. The 5000 samples of H_{SW} and 5 samples of load force were taken at each step. They were averaged for each step and plotted in the graph to create the tensile stress transfer curve, see Fig. 5.

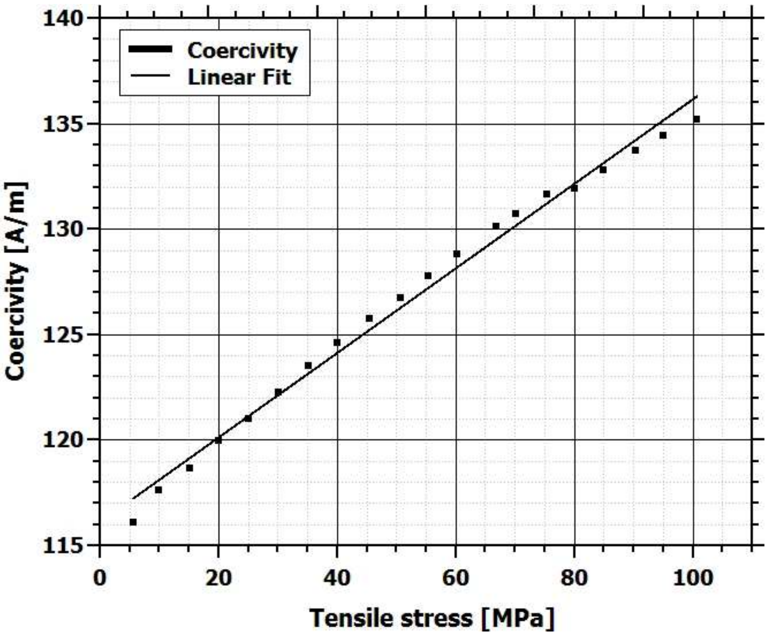

Figure 5 Sensor transfer curve

This characteristic confirms linear behaviour of the prepared build-in sensor. Sensitivity of the sensor can be estimated by linear fit of this data. Slope, thus sensitivity, of this linear fit curve is 0,20037 [A m^{-1} MPa^{-1}].

4. CONCLUSION

This paper is focused to the possibility of creation of contactless tensile stress sensor based on magnetic microwires. Experimental results show that it is possible to collect data from the microwire embedded in the composite material and determine internal stresses. This kind of sensor is completely contactless, with no need of power supply and galvanic connection. Operational life of the sensor is as long as life of the composite material in which the sensor is embedded. Composite material also protects this sensor against damages from its environment. No service or maintenance is needed also. One big challenge for future work is to reduce the noise parameters of such sensors. This was already partially done by improved method of the microwires post-processing.

Small dimensions of the sensor do not create any structural defects. The sensing device can be used to read more sensors embedded in the construction. While it is placed on the surface of material, it can be moved from one to other sensor. Actual range of device is limited by energy radiated by the microwire during switching and with these sensors it is up to 5 mm under the material surface. Together with linear transfer characteristics it creates a powerfull device for long time structure health monitoring or material inter-layer behaviour research.

Acknowledgement

This work has been supported by the grant agencies of the Slovak Republic grants VEGA 1/0201/16, VEGA 1/3074/17 and APVV0266-10.

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