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APPLICATION OF MAGNETIC MICROWIRES FOR SENSING STRESSES IN STRUCTURES

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The possibility of application of glass-coated microwires for sensing stress in timber structure have been studied. The measurements of the switching field dependence on applied stress have been compared to the classical method of strain measurement – by the digital deformeter Huggenberger and resistance strain gauges. The test results obtained by using microwires proved to be consistent with those for which con-ventional strain gauges were used. However, it was found that the sensing is strongly influenced by the position of the excitation coil.

Keywords: microwire, magnetostriction, timber beam, CFRP strip, strain,

1 INTRODUCTION

Amorphous glass-coated microwires (Fig.1) consist of metallic core (diameter 1-50 μm) and glass-coating (thickness 2-20 μm) [1]. Because of production process consisting of drawing and quenching, the most important mechanical property of microwires is a magnetoelasticity. Having positive magnetostriction, amorphous glass-coated microwires show bistable magnetic behaviour.

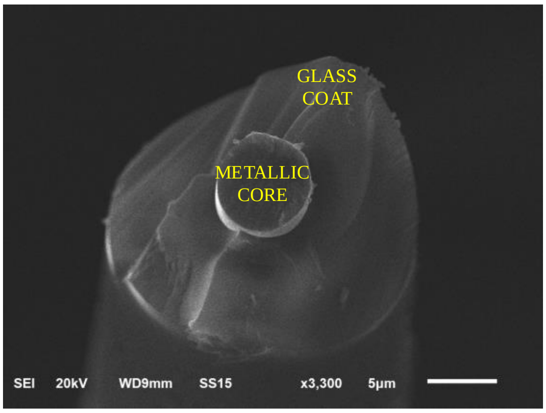

Fig. 1. SEM image of glass-coated amorphous microwire

Bistable magnetic microwires are convenient for measuring strain or temperature fields in the structures. Because of a positive magnetostriction, microwire switching field is strongly affected by external stresses [1]. Microwires can either be glued to the surface of structural members (steel, timber, concrete) or embedded into concrete members without affecting their mechanical properties [2,3]. Moreover, glass-coating provides excellent insulation against aggressive environment for employment of microwires in biological applications.

Magnetic nature of metallic core brings advantage of contactless sensing, due to which they could be excellent components of microwire sensors in wireless networks for health monitoring of structures.

Testing of microwires for sensing the distribution of strains in timber beams under four-point bending is presented in the paper. Six microwires form a network of sensors, which allows sensing of bending of the beams. The test results obtained by using microwires were compared with those obtained by strain gauges and digital deformeter.

2 EXPERIMENTAL INVESTIGATIONS

Experimental measurements were performed in the laboratory conditions using a timber structural element. The beam was of the rectangular cross-section of 250×120 mm (width× depth) and the span of 2000 mm. A carbon-fibre reinforced polymer (CFRP) strip (width of 50 mm, thickness of 1.2 mm, and length of 1000 mm) was bonded on the upper surface of the beam.

The specimen acts as a simply supported beam, which was tested under the four-point bending (Fig.2). Tensile strains occur on the upper surface of beams due to the load forces acting upwards.

Microwires of nominal composition $Fe_{76}Si_9B_{10}P_5$ were used. The diameter of the metallic core was 45 μm, the total diameter 55 μm (including glass coat), and the length 40 mm. Four and two microwires were glued in the longitudinal direction into about a 1.0 mm thick layer of the Sikadur-30 epoxy adhesive (Fig.3) on the surface of the timber beam and the CFRP strip, respectively (Fig.4).

Similarly, four strain gauges (labelled SG1, SG2, SG5, and SG6) were bonded on the upper surface of the timber beam and two ones (SG3 and SG4) on the surface of the CFRP strip (Fig.4). Six and three metal pins were glued on the surface of the beam and the CFRP strip, respectively, for measurement of the elongation by means of a digital deformmeter Huggenberger with a level of precision of 1 μm.

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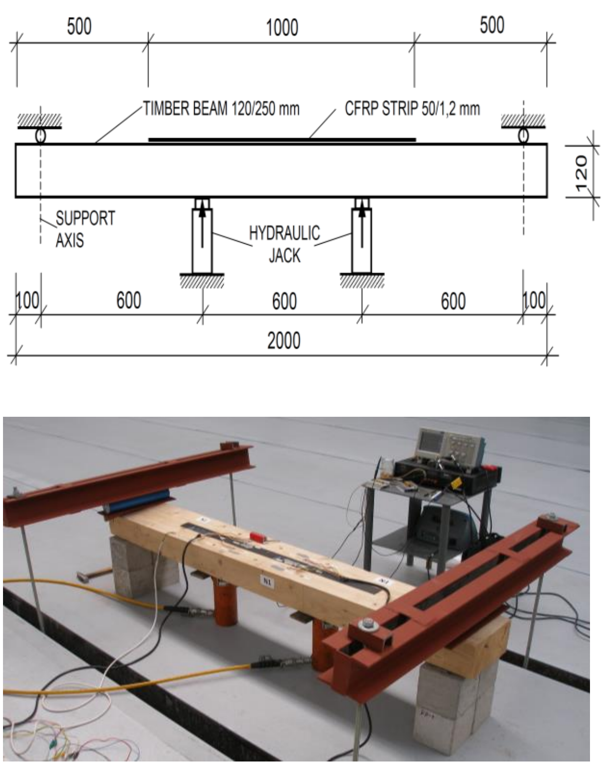

Fig. 2. Test arrangement

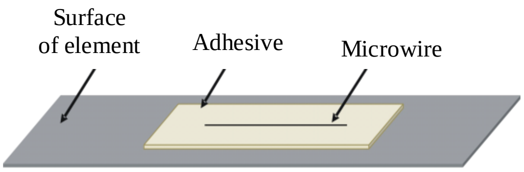

Fig. 3. Fixation of micro-wire on the surface of beam or CFRP strip

The switching field has been measured by induction method using the coil system similar to that described in [3] (Fig. 5). The system uses two flat coils: i) one primary to produce linearly increasing magnetic field having 6 cm in length and ii) one pickup coil to detect the switching field having 3 mm in length. Coils were attached to the surface of the sample. The advantage of the method is that the switching field is proportional to the time at which the switching is recorded.

We have measured the switching field H_{sw} in time base to measure the value of the switching field with higher accuracy (Fig. 6). The change of H_{sw} is proportional to change of t_D. In this case, the measured parameter of the excitation signal U_G, which corresponds to the size of switching field, is value t_D. The resolution of time change measurement t_D is higher in comparison with U_G, which corresponds to the change of the switching field H_{sw}. Finally, the time variation t_D (is proportional to the square root of strain ε according to [2].

$$t_D \propto H_{sw} \propto \sqrt{\varepsilon} \tag{1}$$

The use of this method leads us to the measurement of switching field with increased sensitivity on bending.

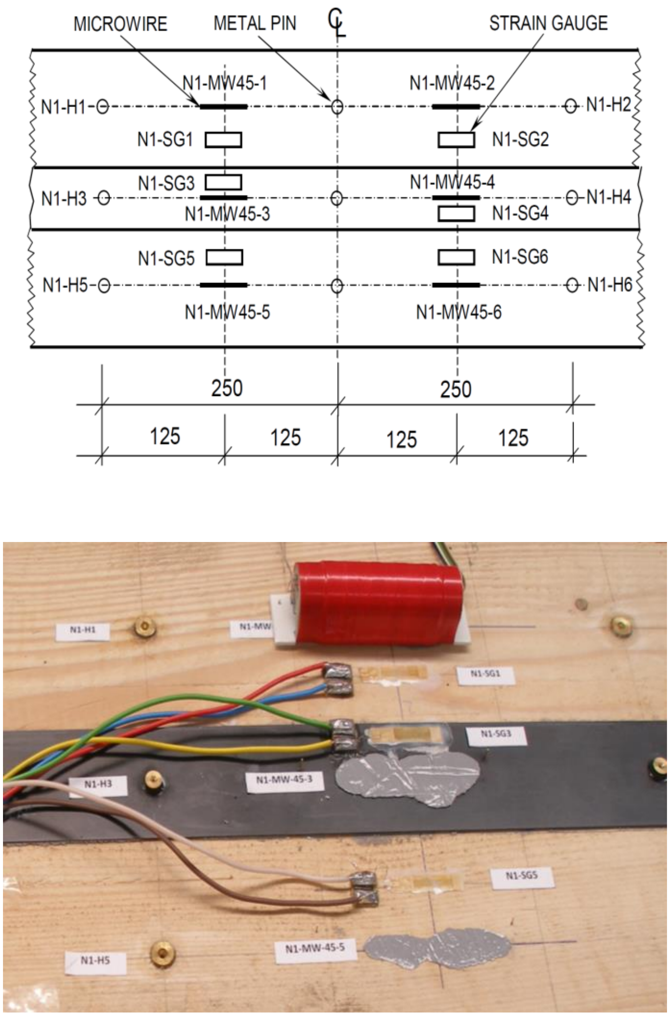

Fig. 4. Positions of microwire sensors, strain gauges, and metal pins

3 RESULTS AND DISCUSSION

Due to the magnetoelastic anisotropy (which is the strongest one in case of positive magnetostriction wire) the switching field is highly sensitive to the stress σ applied on metallic core of the wire. Assuming the nucleation-propagation model [4] for single-domain wall propagation, the switching field H_{sw} is proportional to the square root of the applied tensile stresses

$$H_{sw} \propto \frac{\sqrt{A\lambda_s\sigma}}{\mu_0 M_s} \tag{2}$$

where A is the exchange stiffness constant, μ_0 is the permeability of vacuum, M_s is the saturation magnetization of the metallic nucleus of the wire, λ_s is saturation magnetostriction and stresses σ varies with the change of applied mechanical load,

$$\sigma = \sigma_i + \sigma_g + \sigma_a \tag{3}$$

where σ_i and σ_g are stresses induced during production process and from different thermal expansion coefficients of glass-coating and metallic core [5, 6].

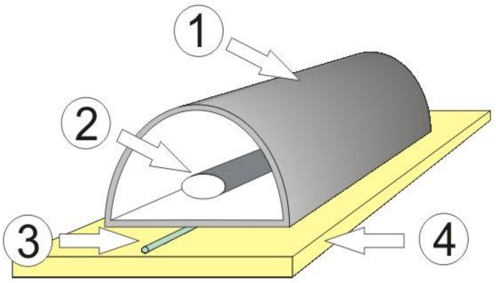

Fig. 5. Schematic design of sensing system. 1- excitation coil, 2- sensing coil, 3- microwire, 4- wooden beam

Stresses from different thermal expansion coefficients do not affect the switching field H_{sw} without change of temperature. In such case, σ_a, which is given by applied mechanical load, is the only variable. By this way the switching field H_{sw} varies due to change of applied mechanical load. According to Hook's law, normal stress σ is given by equation

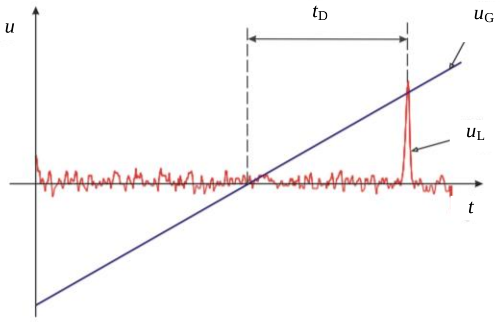

Fig. 6. The switching field is proportional to the time of switching, which is easy to measure

$$\sigma = \varepsilon E \tag{4}$$

where E is the Young modulus and ε is strain of microwires. Applying the triangular shape of excitation magnetic field, the switching field is proportional to the time necessary for switching of domain wall, which is ve-

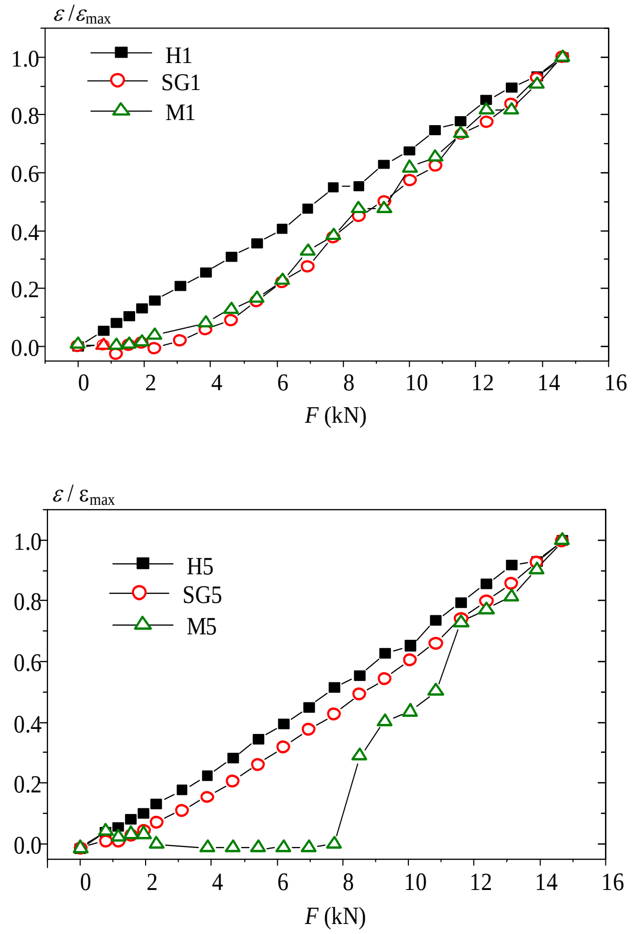

Fig.7. Diagram of $\varepsilon/\varepsilon_{max}$ *vs* load force F obtained by deformeter Huggenberger (black squares), strain gauge (red circles) and microwires sensors (green triangles) for sensors No. 1 and 5 (see fig. 4 for details)

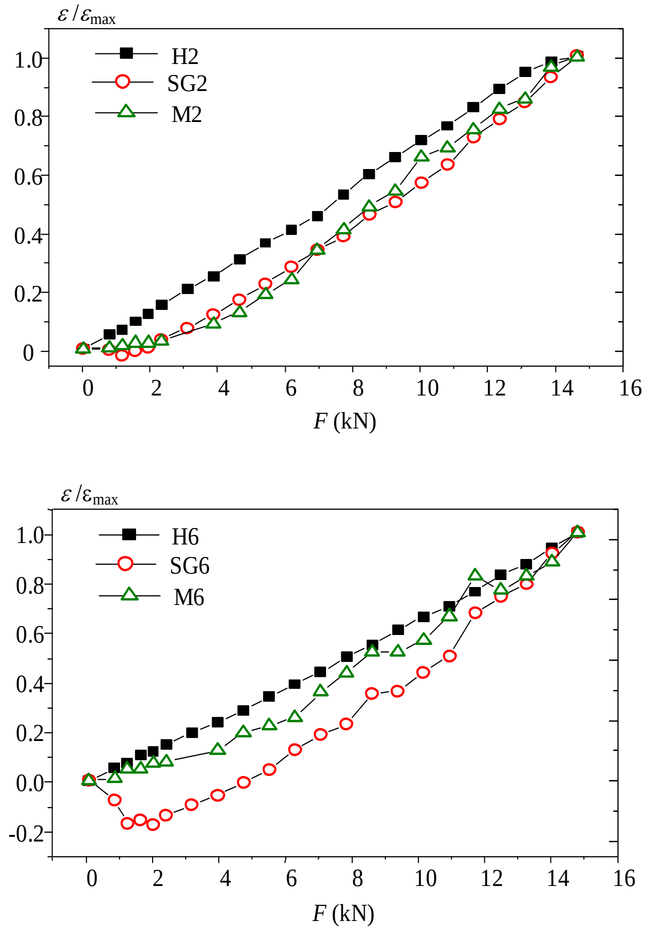

Fig.8. Diagram of $\varepsilon/\varepsilon_{max}$ *vs* load force F obtained by deformeter Huggenberger (black squares), strain gauge (red circles) and microwires sensors (green triangles) for sensors No. 2 and 6 (see fig. 4 for details)

ry easy to measure. Finally, (1) is obtained showing that the switching time is proportional to the square root of strain.

Due to the tensile stress applied on microwires during the test, the switching time (switching field) increases with the applied load. Figures 7 and 8 show the ratios of strain to the maximum strain $\varepsilon/\varepsilon_{\max}$ (called strain rate, where $\varepsilon_{\max}$ is the maximum strain obtained during measurement) measured by the switching time in microwires (green triangles) and compared to those measured by the Huggenberger (black squares) and strain gauges (red circles) for selected positions of the sensor. The strain measured by microwires for positions 1 and 2 fits perfectly to that obtained by strain gauges. Sensor 6 gives the same results as sensors 1 and 2, however, strain gauge show negative elongation at low loads (below 2kN). In contrary, microwire sensor No. 5 gives apparently negative (or constant) elongation at low loads (below 6 and 8 kN, resp.), while the other sensors give monotonous increase of strain. In this case, the discontinuities observed for microwires are result of bad position of sensing coil. Due to a space lack the strain gauge contacts (that were too close to embedded microwires) it was impossible to fit sensing system to the microwires correctly.

One of the advantages of microwires is that the position of the switching field (and switching time) should not be influenced by the distance of the sensing coil (only amplitude of induced maximum will vary with the distance). However, the amplitude of generated excitation magnetic field depends strongly on its distance to the wire. Such a problem can be solved by other design of the excitation coil.

4 CONCLUSIONS

We have studied the possibility of application of glass-coated microwires for sensing stress in timber structure. The measurements of the switching field dependence on applied stress have been compared to the classical method of strain measurement – by the digital deformeter Huggenberger and resistance strain gauges. The test results obtained by using microwires proved to be consistent with those, for which conventional strain gauges were used. Microwires could provide adequate results for strain rates $\varepsilon/\varepsilon_{\max}$ without any previous calibration. However, it was found that the sensing is strongly influenced by the position of the excitation coil, which would be better to be fixed to the surface of the studied beam.

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