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APPLICATION OF A MAGNETORHEOLOGICAL ELASTOMER IN AN AVIATION STRUCTURE

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Abstract

Magnetorheological elastomers have properties that can be altered by magnetic field. Many materials were invented more than 30 years ago, but their development and improvement over the past three decades has led to new, more varied uses of these adaptable materials.

The main goal of the paper is to present and investigate the application of a magnetorheological elastomer in an aviation structure. The potential advantage of this solution is a possibility to adjust the shape of the wing during the flight by altering the magnetic field strength, which in turn causes deflection of a magnetorheological elastomer.

For the purpose of the investigations, an E214 aerofoil has been selected. The original, carbon composite model set a reference value of both lift and drag coefficient for an E214 profile. A thin layer of magnetorheological elastomer was placed on the upper side of the reversed wing.

In order to fully understand the effect of such structural change on an aerial profile, the new research stand was designed and manufactured for the purpose of this research in the Institute of Aviation. Experiments were conducted due to evaluate the influence of magnetorheological elastomer on the overall performance. Results of investigations were presented and discussed.

Keywords: *magnetorheological elastomer, aviation structure, experiments, test stand*

1. Introduction

Constantly increasing requirements towards modern devices and machines, especially air and automotive constructions, it is becoming more difficult to produce using classical materials. The industry is still in need of new materials which will enable more advanced construction of (various) means of transport. At the end of 20th century and in 21st century, as the new computing technologies are developed all the time, there is an increasing requirement for new materials that could respond to the progress made in IT technologies and that are giving opportunities to invent more effective solutions. Thanks to so called smart materials [6] that can reversibly and almost instantaneously change its properties under some conditions there are possibilities to create devises that fulfils theirs functions better, more efficient, and with lower energy costs. Smart materials are unique, as their properties can be changed by external stimuli. Thanks to their specific characteristics, these materials create the ability to build systems with adaptive properties, which was impossible to achieve with conventional materials. Implementation of smart materials can increase efficiency and reliability of some systems, even allow designing systems, which were never implemented in older generations of cars or aircrafts [6].

An example of such a smart material is a magnetorheological elastomer (MRE). It is a composition of small magnetic particles dispersed in the soft elastomer mould. MRE has been made with soft silicone, polyurethane or rubber matrix with good magnetic efficiency [6, 8]. Upon application of a magnetic field, carbonyl iron particles align with the direction of the field. However, because of the solid state matrix, particles are trapped in polymer chains, which cause the whole material deformation. Under the field, MREs also change their stiffness [4], electrical conductivity [2] and damping capability [9]. Because of these properties, MREs have several applications such as active scaffolds for drug delivery [10], smart vibration absorbers [3] and sensors.

As new technologies are being developed, magnetorheological elastomers have found new applications over the years. For example, Thyssen Krupp AG Company has developed a steering wheel column with an adaptive system of energy absorption in case of a crash in which magnetorheological elastomer is applied in one of the elements [5]. This solution differs from the previous one, which has a metal element responsible for energy absorption. Due to the MRE implementation, the new solution accommodates such factors as vehicle's velocity and driver's mass.

General Motors has developed a system, which absorbs energy during the crash [1]. It can be installed inside headrests, seats, dashboard, and doors or over drivers and passengers' heads. This patented solution is composed of a rigid base and an elastic cover. In between them, there are the cylindrical elements made of magnetorheological elastomer and the coil is reeled on them. The whole system is equipped with the sensors and a control system.

The main aim of this paper is the application of a magnetorheological elastomer in an aviation structure. Magnetorheological elastomers are suitable for engineering aviation solutions, such as variable shape structures called morphing structures used in aeronautical engineering. Morphing structures enable the change of aerodynamic properties of the lift and steering surfaces during the flight, increasing the efficiency of the flight. The morphing structure can be identified as structure in which form and surface can be controlled continuously (without any discrete point) [8].

The idea to change the wing surface during flight requires a suitable material that can modify its parameters under the action of external stimuli. This work covered the properties of magnetorheological elastomer, which meets the criterion stated above. Its deflection can be controlled with a varying magnetic field strength. To increase mechanical properties of the magnetorheological elastomers, the natural rubber matrix where applied. A sample of such material (Fig. 1) has been manufactured and used for the purpose of this research. The magnetorheological material is described in the next part of this paper. Then a test stand, results of investigations are presented and discussed.

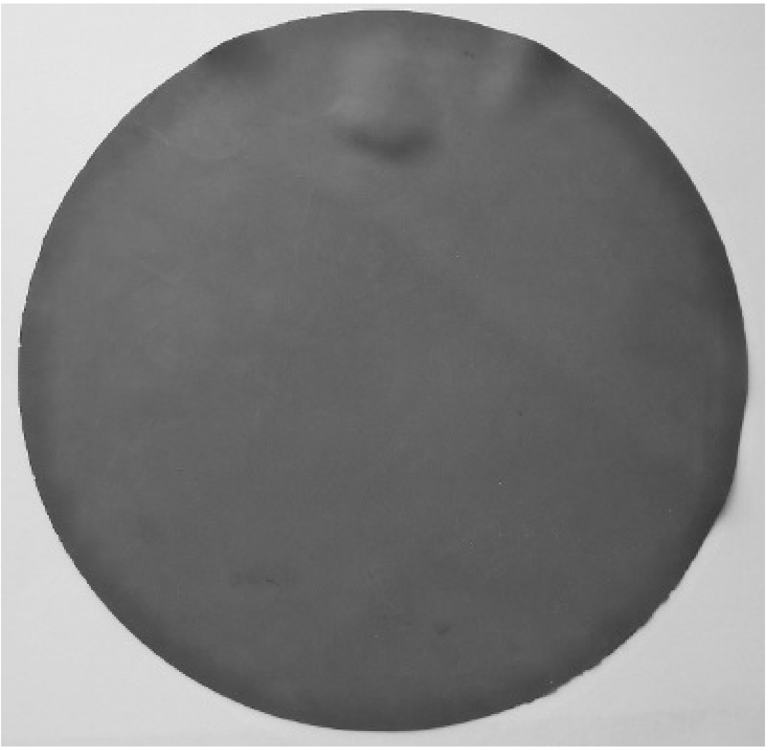


Fig. 1. A sample of a magnetorheological elastomer

2. Methodology

2.1. Magnetorheological elastomer

The fabricated magnetorheological elastomer consisted of the two main components: first carbon iron powder HS, produced by BASF, and was used for fabrication of the samples. It has a spherical shape and average diameter 1.8-2.3 μm. This type is pure iron particles (>99%). As a second component a natural rubber (NR) type SVR 3L produced by Brenntag was used.

Using a laboratory mill the NR masterbatch was obtained containing no carbon iron particles. Then, using a mixer the masterbatch was mixed with appropriate quantities of ferromagnetic filler.

The vulcanization of the compound was performed using a laboratory press. Plates were vulcanized at 145°C, at a pressure of 17 MPa. The obtained plates were cut into discs with a diameter of 20 mm.

The morphological studies of vulcanizes were performed using a scanning electron microscope (SEM, Gemini LEO 1530). Micrograph of the sample is shown in Fig. 2, where we can observe carbonyl iron particles (CIP) suspended in the polymer matrix.

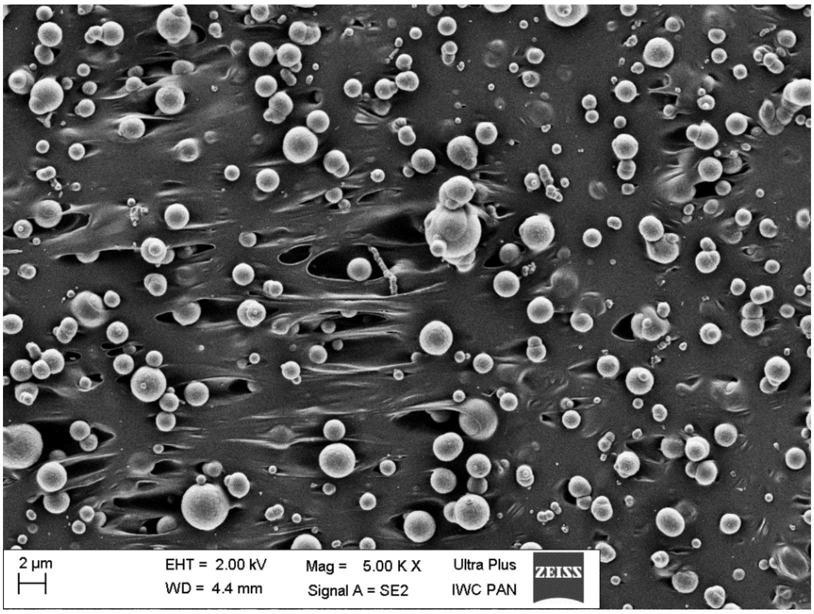


Fig. 2. SEM microstructure of MR elastomer revealed on a surface of sample containing CIP HS

2.2. Research stand

This innovative work required a cutting-edge technology for accurate evaluation of the aerodynamic performance. In order to fully understand the effect of such structural change on an aerial profile, a new research stand was designed and manufactured for the purposes of this research in the Institute of Aviation. This is an open-return tunnel with a 2.8:1 contraction ratio. The test section is 0.3 x 0.3 m in cross section and 0.7 m long. In order to ensure a laminar airflow, a honeycomb layer was placed at the front of the throat. The maximum available airspeed that can be generated by a 3 kilo-watt 8-bladed fan is 50 m/s. However, for the purpose of the experiment the airspeed was set to 14.56 m/s in order to achieve the Reynolds number equal to 299 000. The airspeed was measured using pitot static tube placed in front of a model in a test section. Temperature was also measured in order to determine the average value of air density, which is a crucial parameter while determining both Reynolds number and Lift/Drag coefficients. The fundamental element of this research stand was two-component balance, which measured both vertical and horizontal forces acting on a tested object.

Figure 3 shows the schematic of the research stand.

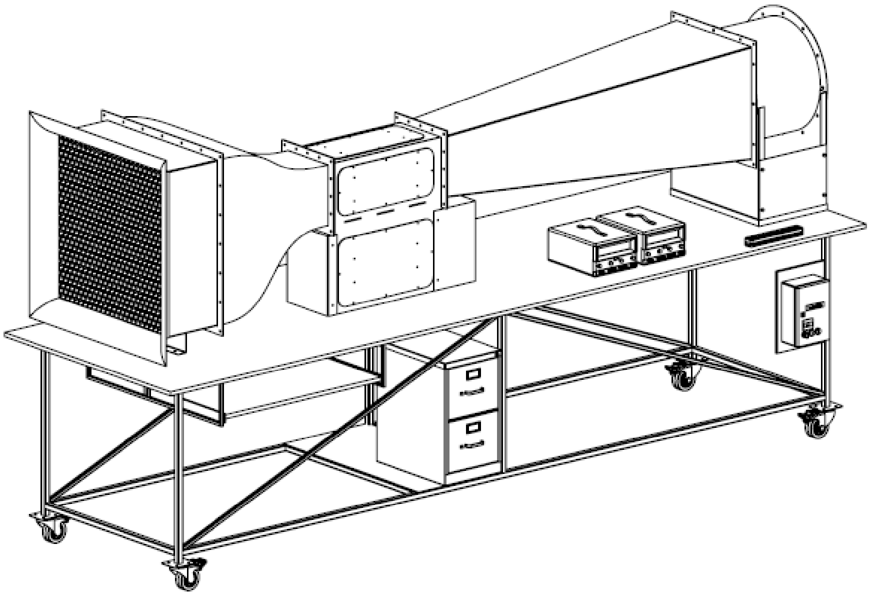


Fig. 3. Schematic of a research stand for the investigations

2.3. Wing profile

For the purpose of this investigation, an E214 aerofoil has been selected. The aerodynamic characteristic of this particular aerofoil has been already tested and documented in [7].

A solid wing section was prepared for the experimental testing. The size of the model was adjusted to the available volume of the test section. Hence, the chord was set to 300 mm whereas span was set to 150 mm. The experimental model was presented in Fig. 4.

Fig. 4. A model of a wing section used during the first experiment

As the aim of the research required the application of a magnetorheological elastomer in an aerial profile, the above-mentioned profile has been further modified. A thin layer of magnetorheological elastomer was placed on the upper side of the reversed wing (starting at 47% chord length). Nine magnets were placed underneath this surface in order to generate a strong magnetic field that would attract the elastomer and therefore change the overall profile of the wing. However, due to the manufacturing limitations, a short 26 mm section between the end of the wooden rib and the trailing edge was altered. The extreme cases (with relaxed and attached elastomer respectively) were only investigated to test the maximum possible difference between two aerofoils. Fig. 5a presents a setup of the experiments with the attached elastomer, and Fig. 5b with the relaxed elastomer.

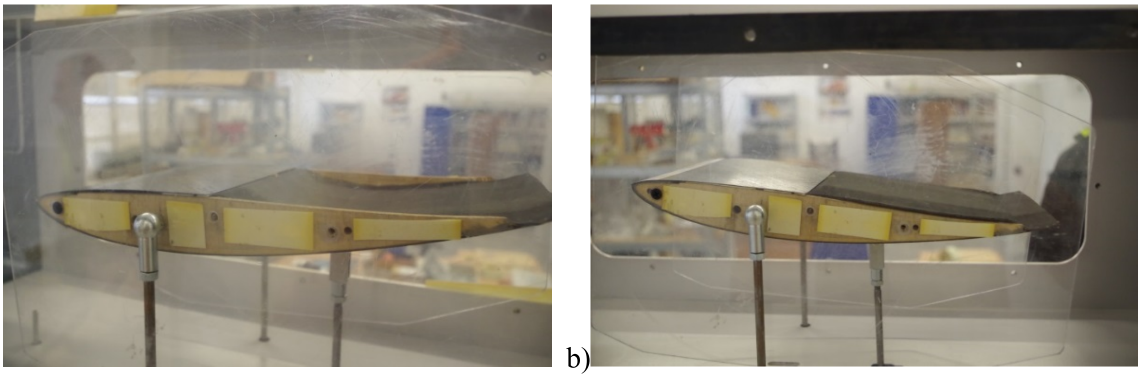
a)  b)

Fig. 5. A setup of the experiment with a) attached elastomer b) relaxed elastomer

3. Results and discussion

The first experiment evaluated the aerodynamic performance of the original E214 profile made of carbon composite (without any magnetorheological elastomer). The aim was to provide reference values of both lift coefficient (Cz) and drag coefficient (Cx) which were later compared with the results obtained for modified profiles.

Initially the wing was placed at the angle of -6°, which was treated as the lowest extreme value. The parameters such as lift, drag, air speed and angle of attack were monitored for approximately 20 seconds in order to collect a sufficient amount of data for averaging purposes. Then, the angle was changed to -4° and the procedure was repeated up to $+10^{\circ}$ (with increments of 2°). Afterwards, the angle was adjusted back to -6° (also with increments of 2°).

A plot showing how Cz and Cx of the original profile vary with the angle of attack was created in Fig. 6. The value of lift coefficient demonstrates a linear regression, which is consistent with aerodynamic theories that lift increases linearly up to the critical angle of about 12°-15° at which stall occurs.

Similarly, the values of Cx seem to follow the same pattern. This is also consistent with aerodynamic theories that drag is proportional to the angle of attack squared. The experimental outcome is satisfactory.

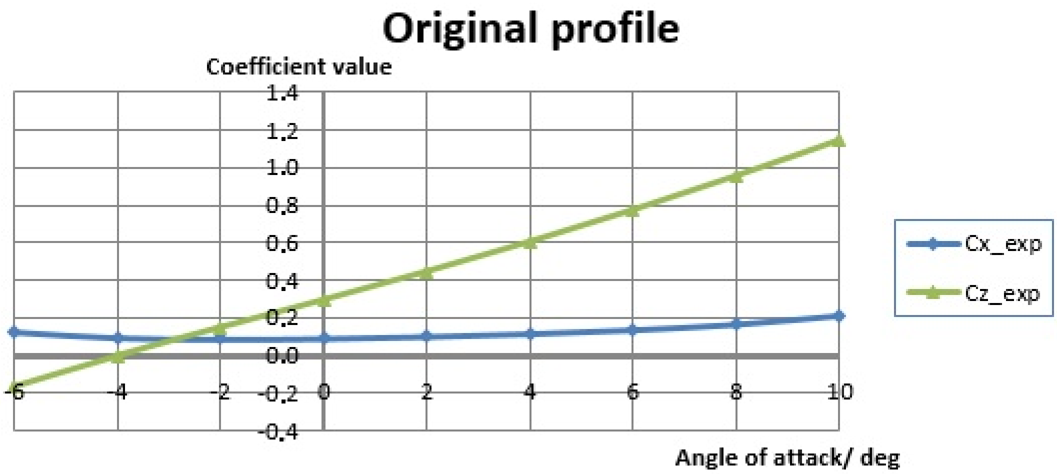


Fig. 6. The relationship between Cz and Cx versus angle of attack for the original profile E214

The second experiment evaluated the aerodynamic performance of the profile with the magnetorheological elastomer placed on its upper surface. A thin piece of elastomer was attached to the rib of the wing with an aid of a strong magnetic field. The experimental procedure covered the same steps as mentioned for the original E214 profile tests. The experimental setup (Fig. 5a) as well as the obtained results (Cz and Cx) are presented in Fig. 7.

It can be observed that Cz values follow a linear regression model, which is consistent with theoretical predictions. On the other hand, there are still the same issues with the value of drag coefficient.

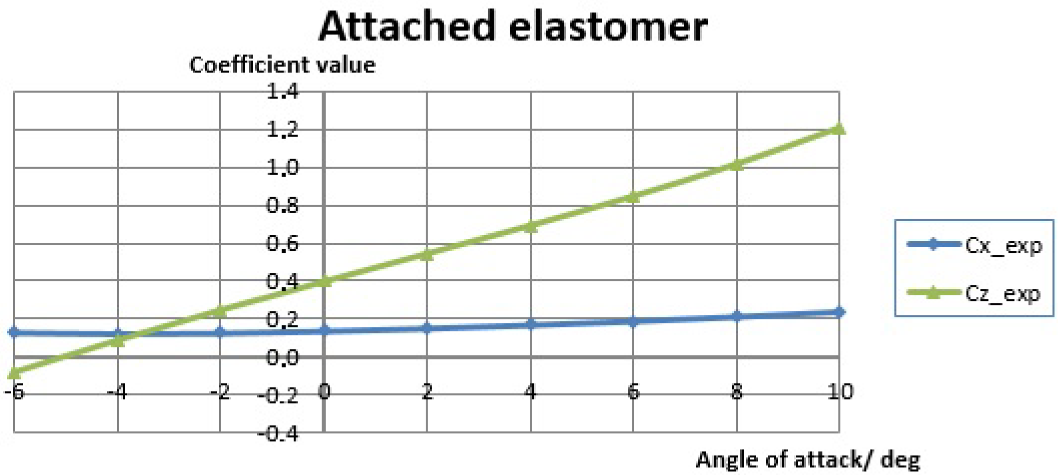


Fig. 7. The relationship between Cz and Cx versus angle of attack for a profile with attached elastomer

The third experiment covered the same test procedure as the one presented above. The crucial difference was that elastomer was not attached to the rib of the wing anymore. The photo showing the experimental setup (Fig. 5b) as well as the graph demonstrating obtained results (Fig. 8) can be found below.

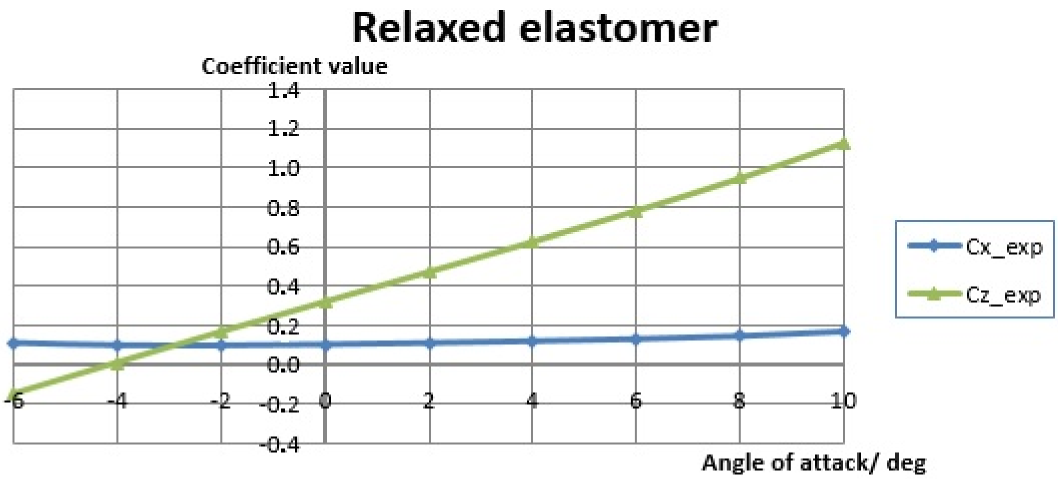


Fig. 8. The relationship between Cz and Cx versus angle of attack for a profile with relaxed elastomer

The profile with attached elastomer had significantly greater lift and drag coefficients (than the original aerofoil) whereas the profile with relaxed elastomer generated slightly lower forces. However, the most important observation is that the change in the position of the elastomer (which can be easily controlled with a set of magnets or electromagnets) has a noticeable impact on the overall aerodynamic performance of the wing.

4. Conclusions

To sum up, the research has been successfully completed. The application of a magnetorheological elastomer in an aviation structure was presented. The results of the investigations were satisfactory. The original, carbon composite model set a reference value of both lift and drag coefficients for an E214 profile. Experiments were conducted in order to evaluate the influence of the magnetorheological elastomer (placed on a surface of a wing) on the overall performance. The most important remark is that the change in the position of the elastomer has a noticeable impact on the overall aerodynamic parameters of the tested object. Hence, it has been proved that this property can be used to modify the structure for a certain parts of flight mission (generating more lift during take-off or minimizing drag during cruise).

In the future, a set of new experiments should be conducted in order to fully understand these changes for different profiles and higher Reynolds numbers.

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References

[1] Barvosa-Carter, W., Johnson, N. L., Browne, A. L., *Reversibly expandable energy absorbing assembly utilizing actively controlled and engineered materials for impact management and methods for operating the same*, US patent 7.140.478 B2, 2006.

[2] Bica, I., Anitas, E. M., Averis, L. M. E., *Tensions and deformations in composites based on polyurethane elastomer and magnetorheological suspension: Effects of the magnetic field*, Journal of Industrial and Engineering Chemistry, 28, pp. 86-90, 2015.

[3] Dyniewicz, B., Bajkowski, J. M., Bajer, C. I., *Semi-active control of a sandwich beam partially filled with magnetorheological elastomer*, Mechanical Systems and Signal Processing, 60-61, pp. 695-705, 2015.

[4] Han, Y., Hong, W., Faidley, L. E., *Field-stiffening effect of magneto-rheological elastomers*, International Journal of Solids and Structures, 50, pp. 2281-2288, 2013.

[5] Klukowski, C., *Steering column for a motor vehicle*, US patent 20090033082 A1, 2009.

[6] Schwartz, M., *Smart Materials,* CRC Press Taylor & Francis Group, 2009.

[7] Selig, M. S., et al., *Summary of Low-Speed Airfoil Data*, Vol. 1, Virginia: SoarTech Publications, 1995.

[8] Skalski, P., *Materiał inteligentny do zastosowania w strukturach lotniczych*, Logistyka, 6, 2014.

[9] Sun, T. L., Gong, X. L., Jiang, W. Q., Li, J. F., Xu, Z. B., Li, W. H., *Study on the damping properties of magnetorheological elastomers based on cis-polybutadiene rubber*, Polymer Testing, Vol. 27, pp. 520-526, 2008.

[10] Zhao, X., Jaeyun, K., Cezar, A. C., Huebsch, N., Lee, K., Bouhadir, K., Mooney, D. J., *Active scaffolds for on-demand drug and cell delivery*, Proceedings of the National Academy of Sciences of the United States of America, Vol. 108, No. 1, pp. 67-72, 2011.