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Hybrid magnetic elements prepared by gluing

Summary — This article describes an experiment for investigation of the tensile strength of adhesives used in production of electric motors. The study was conducted for an application of adhesives in production of hybrid components composed from various materials. Composite elements were made from iron powder and Nd-Fe-B alloy powder. Hybrid elements may consist of layers of different physical properties. The test is also expected to answer the question whether the type of layers used can influence the bond strength. In addition, the article describes an attempt to compare tensile strengths of hybrid elements made in different techniques, such as one-step pressing and gluing of hybrid elements. The study confirms that the type of surfaces and adhesives influences the strength of the hybrid element.
Keywords: powder metallurgy, adhesives, bond strength, hybrid elements, mechanical properties.

HYBRYDOWE ELEMENTY MAGNETYCZNE WYTWARZANE METODĄ KLEJENIA
Streszczenie — W artykule opisano eksperyment, którego celem jest zbadanie wytrzymałości na rozciąganie różnych klejów stosowanych w produkcji silników elektrycznych. Badania prowadzono pod kątem zastosowania tych klejów do produkcji komponentów hybrydowych złożonych z elementów kompozytowych wykonywanych ze spajanych proszków żelaza oraz magnesów trwałych otrzymanych poprzez spajanie proszku ze stopu Nd-Fe-B. Ponieważ elementy hybrydowe mogą składać się z warstw o różnych właściwościach fizycznych, badano czy rodzaj zastosowanych warstw może wpływać na wytrzymałość spoiny. W artykule opisano także próbę porównania wytrzymałości na rozciąganie elementów hybrydowych wykonanych za pomocą jednoetapowej techniki prasowania lub techniki klejenia elementów hybrydowych. Badania potwierdziły, że zarówno rodzaj klejonej powierzchni jak i typ kleju wpływają na wytrzymałość elementu hybrydowego wykonywanego metodą klejenia.
Słowa kluczowe: metalurgia proszków, kleje, wytrzymałość spoiny, elementy hybrydowe, właściwości mechaniczne.

INTRODUCTION

In classical electric machines soft parts of magnetic circuits are manufactured mainly from electrical steel sheets, while hard magnetic parts of magnetic circuits are made mainly from sintered ferrite magnets or sintered rare earth permanent magnets. Such permanent magnets are either placed inside or on the surface of the rotating part of the magnetic circuit. Powder metallurgy offers new solutions to designers. Powder metallurgy allows the production of magnetic circuits with a layered structure — called hybrid magnetic elements. Such elements are composed of layers with different physical properties from various materials, made in one manufacturing process, without additional gluing, welding or soldering. Hybrid technology offers numerous possibilities allowing reducing time and cost of electric motors production. As a result, electric motors manufactured with powder composites will become cheaper and more energy-efficient. Such technology requires the use of complex dies [1—3]. It also requires the use of high pressure hydraulic presses. Sometimes the motors need to consist of several elements.

The hybrid technology is still evolving. Bonding with an adhesive is inevitable in such production. This method can be applied particularly in case of materials which are difficult to compress, and materials with different curing temperatures. Individual elements are prepared in separate processes. The advantage of bonding with an adhesive is the ability to create elements of complex shapes and large sizes. Bonding hard magnetic materials to surfaces of soft magnetic materials with an adhesive is a popular solution used in brushless direct current (BLDC) motor. Gluing is used for constructing of elements with large surfaces, which cannot be produced in one die. This way the elements are connected in order to obtain complete stators. In both cases it is necessary to ensure high strength of the adhesive bond. In preparing hybrid elements in one process as well as in preparing hybrid element by gluing, mechanical strength of these elements is very important [4, 5].

Therefore, the strength of elements prepared by gluing different materials and by pressing layers in one pressing process has to be known.

The main objective of the study is to compare mechanical properties of double-layered hybrid elements prepared by different methods, namely by gluing two elements and making in one pressing process.

EXPERIMENTAL

Materials and sample preparation

For research purposes two types of elements, made of soft magnetic powder Somaloy 500 + 0.6 % LB1, produced by Höganäs AB and magnetically hard powder MQP-B produced by Magnequench were used. For preparation of hybrid elements the compression molding technology was used. Soft and hard magnetic powders with a binding agent were pressed and then „green compact" was cured. Composite elements were pressed under the pressure of 900 MPa. „Green compact" was cured in a laboratory oven at 180 °C for two hours.

The soft magnetic material in this case was iron powder coated with layers of a binding agent. Grains of iron coated with a ceramic substance are resistant to oxidation, and coatings with dielectric properties lower the eddy current losses in high frequency.

Powder from Nd-Fe-B melt-spun ribbon was used as the hard magnetic material. As a bonding material epoxy resin Epidian 100 produced by Organika Sarzyna was applied.

All elements were made in the same die, which is presented in Figure 1.

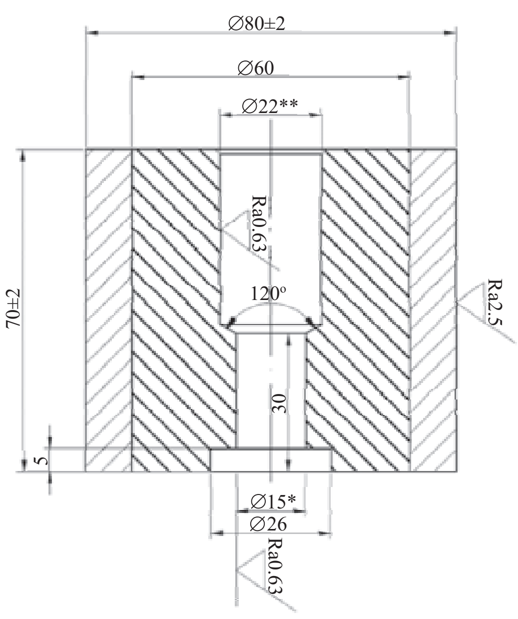

Fig. 1. Scheme and dimensions of die for the production of test samples

The prepared samples consisted of two composite elements and layers of an adhesive. In each case, an adhesive was applied to the surfaces previously cleaned and degreased with acetone and sandpaper.

The strength of glued elements depends on the type of glue used. In cooperation with the Institute of Industrial Chemistry, investigation has been conducted into the selection of a suitable adhesive material. The studies compared the strength of joints made with modern commercial adhesives. Selected adhesives were used in the manufacture of electric motors. Five commercial adhesives for metal connecting were used:

— Poxipol — two-component epoxy paste adhesive, produced by FENEDUR S.A.;

— Araldite 2014 — two-component epoxy paste adhesive, produced by Huntsman Advanced Materials [6];

— Auto Weld CX-80 — two-component epoxy paste adhesive, produced by CX-80;

— Araldite 2021 — two-component toughened methacrylate adhesive system, produced by Huntsman Advanced Materials [7];

— Bison EPOXY METAL — two-component epoxy adhesive, produced by Bison International B.V. [8].

Glued samples were placed in a holder, which allowed their compression with an equal force. Thickness of the bonding line was about 0.1 mm.

There were made additional samples containing three layers. The upper part of the element located in the handle is made of soft magnetic powder Somaloy 500, while the lower part of the cylinder is made of the hard magnetic powder. This part of the element was prepared in a single-step hybrid pressing process. The third layer was made of Somaloy 500 powder and glued using Araldite 2014. This sample was designed as hybrid + Araldite 2014. Figure 2 presents all types of samples used in experiments.

Bonding was performed first with components made of the same material and then with components made from powders characterized by different magnetic properties. Elements made with a single-step hybrid technology were used as well.

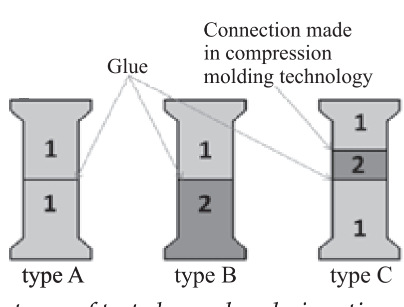

Fig. 2. Three types of tested samples; designations of materials: 1 — soft magnetic material, 2 — hard magnetic material

Testing method

The research of tensile strength was conducted by a specially developed method based on DIN 53288:1979 standard [9]. Measurements of tensile strength of glued elements were taken at the room temperature, 24 hours after the weld. Strength tests were carried out on a universal testing machine — INSTRON model 1115. First, the strength of welds between tested magnetically hard and magnetically soft materials was determined. The investigation of the tensile strength of the hybrid components was also performed. Figure 3 shows the sample ready for tensile strength tests, installed in the handles.

Fig. 3. A sample placed in the tensile test machine handles

Scanning electron microscope (SEM) JSM-7600F, produced by JEOL company was applied to investigate the morphology of materials.

RESULTS AND DISCUSSION

Materials used in this work were examined using a SEM microscope. In Figure 4 it can be seen that the grains of iron powder are smaller than 100 μm in diameter, while for the material based on melt-spun Nd-Fe-B ribbon the grains diameter was smaller than 200 μm.

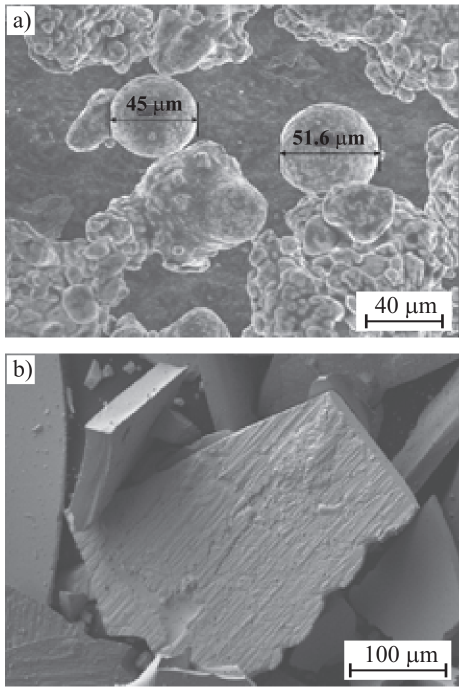

Fig. 4. SEM images of magnetic powders: a) iron powder grains, b) Nd-Fe-B grains

The surface of the compacted hard magnetic material bonded by Epidian 100 and the surface of the element made of Somaloy are shown in Figure 5. The surface structure depends on the type of the magnetic powder, binder and lubricant, as well as on parameters of the production processes.

The results of tensile strength measurements of prepared magnetic elements are shown in Figure 6. The studies have shown that the best type of adhesive was Araldite 2014. The effect of disrupting the bonded joints is shown in Figure 7. In the case of samples made of magnetically soft material, welds underwent breaking at the bonding place and the adhesive remained either on one of the glued surfaces or equally on both.

The elements made with the hybrid technology underwent breaking between magnetically hard and magnetically soft materials connected by powder metallurgy without glue. For all samples the crack was located near the border between the magnetically hard and magnetically soft material. Samples were subjected to strength tests shown in Figure 8.

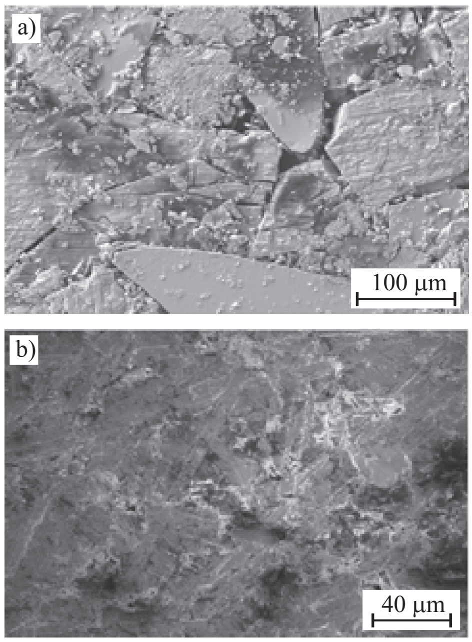

Fig. 5. SEM images of the surface: a) bonded magnet, b) soft magnetic composite

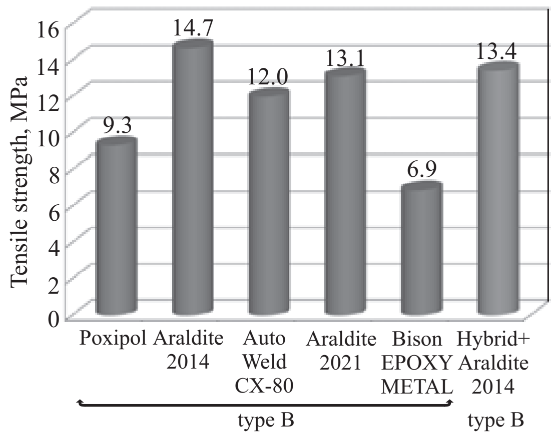

Fig. 6. Results of tensile strength tests for connected iron composite and bonded magnet — type B and C from Fig. 2

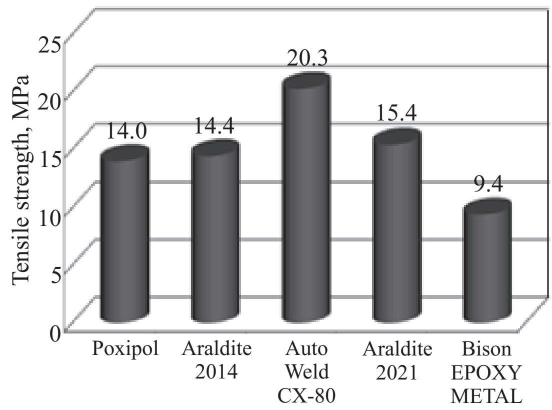

Fig. 9. Results of tensile strength tests for connected iron composite — type A from Fig. 2

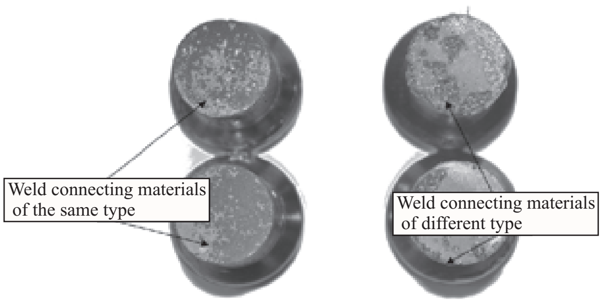

Fig. 7. The surfaces of samples after the tensile test

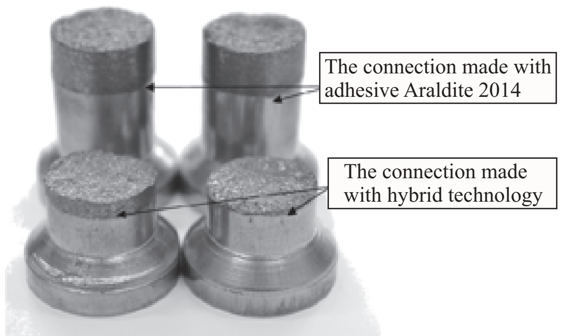

Fig. 8. Samples of type C after the strength tests

Figure 9 shows the results of tensile strength measurements for samples composed of elements made from the same soft magnetic powder. In the case of iron-based materials the best adhesion was achieved for Auto Weld CX-80.

Research has indicated differences in the strength of joints between samples made of the same type of powder and samples made of powders with different magnetic properties. For both tests only adhesives like Araldite 2014 and Araldite 2021 retained high strength parameters, other adhesives showed reduced strength of joints between the magnetically hard and magnetically soft materials. Additionally, during testing a few samples of the hard magnetic material have been completely broken at a place other than the weld. Therefore, it can be concluded that the adhesives applied allow to obtain joints with strength similar to the mechanical strength of the magnets themselves, which is often enough to apply them in electric motors.

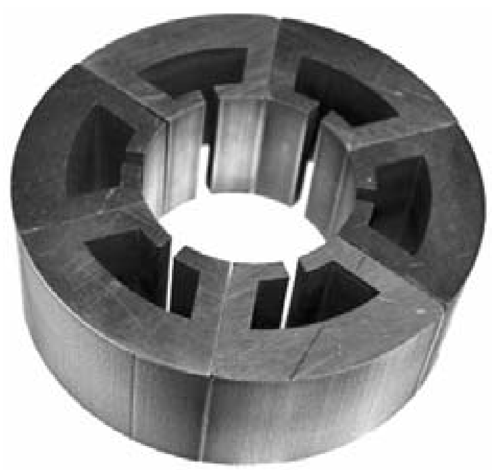

Fig. 10. Stator of the model motor ready for winding

Research allowed starting works on prototypes of electric motors. The stator for the model of electric motor was prepared. Figure 10 shows the stator made in such technology by gluing six parts together.

ACKNOWLEDGMENT

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REFERENCES

1. Kapelski D., Slusarek B., Jankowski B., Karbowiak M., Przybylski M.: „Powder magnetic circuits in electric machines",

Materials of 14th International Conference on Advances in Materials and Processing Technologies, Istanbul, Turkey 2011.
2. Hultman L., Andersson O.: *Met. Powder Rep.* 210, **65**, No. 5, 28.
3. Jack A., Mecrow B., Dickinson P.: „Design and Testing of a Universal Motor Using a Soft Magnetic Composite Stator", Materials of IEEA-IAS, Rome, Italy 2010.
4. Slusarek B., Jankowski B., Kapelski D., Karbowiak M., Przybylski M.: „The Influence of Connecting Method of Hybrid Magnetic Elements for Their Physical Properties", Materials of the International Conference on Advances in Powder Metallurgy & Particulate Materials, San Francisco, USA 2011.
5. Balkova R., Holcnerova S., Cech V.: *Int. J. Adhes. Adhes.* 2002, **22**, 291.
6. Araldite® 2014 Structural Adhesives — technical data sheet, www.intertronics.co.uk/data/ara2014-1.pdf
7. Araldite® 2021 Structural Adhesives — technical data sheet, www.intemag.com/uploads/Araldite_2021_TDS.pdf
8. 6305442 — Bison Epoxy Metal Card — technical data sheet, www.bison.net/static/products/assets/asset_9073_3.pdf
9. LOCTITE Worldwide Design Handbook 1998, „Determination of Strength Value", www.kleje-loctite.pl/book/i218ch12.htm, 20.07.2011

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