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Introduction of new ecologically safe material for fusible elements of low voltage fuses

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ABSTRACT

Purpose: In European Union countries the legalisation forbids the production, processing and use of cadmium. By January 2008 at the latest, all articles and products containing cadmium will either have to be withdrawn from sale or an appropriate substitute for this heavy metal will have to be found.

Design/methodology/approach: The present technology of production of fuses in Slovenian firm ETI Elektroelement, and the action thereof are adapted to the existing ecologically harmful alloy of tin and cadmium SnCd20, which ought to be replaced by one or more ecologically safe alloys with technological and application properties as similar as possible to the existing ones.

Findings: In the frame of the presented investigation work we have found that practically all stated problems can be successfully solved by the low melting alloy of tin, bismuth and antimony named ETI-Sn-Bi-Sb.

Research limitations/implications: Alloy ETI-Sn-Bi-Sb is ecologically safe, and by its technical and physical properties (melting point, conductivity, wettability) corresponds to the requirements of the use for fusible elements of low voltage fuses.

Practical implications: Practical implications of our common work is in the introduction of new ecologically safe material for fusible elements, without cadmium in the existing technology of low voltage fuses.

Originality/value: High value and originality and of our engineering work is confirmed by European Union patent and two Slovenian national patents for the ecologically safe low melting alloy named ETI-Sn-Bi-Sb, which received authors of this paper and Slovenian firm ETI Elektroelement.

Keywords: Ecologically safe material; Low melting alloy; Low voltage fuse; Fusible element

MATERIALS

1. Introduction

Practically all manufactured products have ecological impacts during their life-cycles [1]. These arise in products manufacture, use, recycling and disposal [2]. In the past engineers have focussed only on technical and economical aspects when developing new materials and products, taking into account market conditions and their company's resources. However, developing a new materials and products in accordance with ecological demands requires that engineers consider potential influences from all parts of products life cycle [3]. Developing of ecologically safe materials and products gains an increasing importance in science and industry [4].

In European Union countries the legalisation forbids the production, processing and use of cadmium. By January 2008 at the latest, all articles containing cadmium will either have to be withdrawn from sale or an appropriate substitute for this heavy metal will have to be found. That was the main reason that Slovenian firm ETI Elektroelement still in year 2002 started intensive investigation cooperation with the two members of University of Ljubljana: Faculty of Natural Sciences and Engineering, and Faculty of Mechanical Engineering.

The present technology of production of fuses in ETI Elektroelement and the action thereof are adapted to the existing ecologically harmful alloy of tin and cadmium SnCd20, which ought to be replaced by one or more ecologically safe alloys with technological and application properties as similar as possible to the existing ones [5].

2. Technical problem

Low melting alloys are functional components of low voltage high capacity blade-contact fuses (Figure 1).

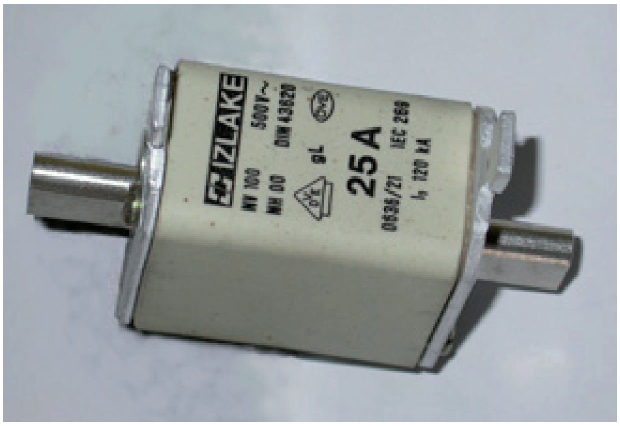


Fig. 1. Low voltage high capacity blade-contact fuse

When an increased current runs through the fuse, the fusible element representing a vital part of the fuse heats up. If the temperature exceeds the melting point of the low melting alloy, the latter melts and begins to melt the fusible element, which is normally made of copper, silver or new silver, at an exactly defined position [6]. The higher is the temperature the faster is melting, which is stopped by the breaking of the fusible element and an interruption of the circuit (Figures 2,3).

When selecting the low melting alloys there should be considered their electrical, technological and ecological properties as well as economy [7,8]. By taking all of them into account, the possibilities if choosing the alloy are relatively limited [9-14]. It has turned out that the most suitable are tin-base alloys with chosen appropriate major alloying elements and a possible addition of minor alloying elements for the correction and optimization of the properties of the alloy.

As major alloying elements only bismuth and indium are technologically and economically acceptable [15]. The properties of the alloys comprising these alloying elements are in principle and actually very different from the ones comprising cadmium. Therefore there must be provided additional alloying elements making the essential technological and application properties of the new alloys as similar as possible to SnCd20.

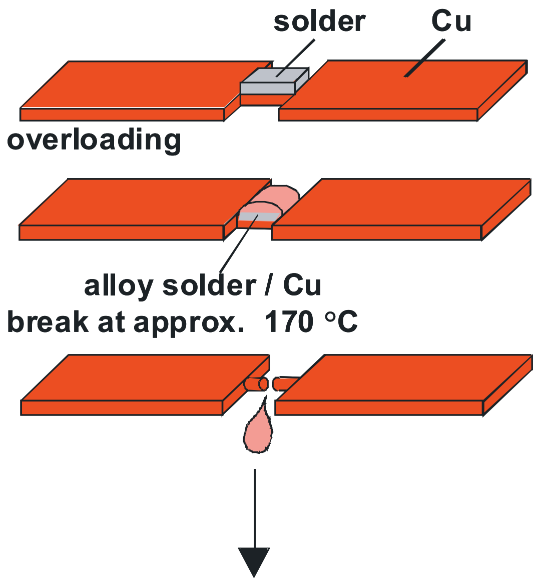


Fig. 2. Fuse element with low melting alloy. Mechanism of breaking and interruption of the electrical current (M – effect)

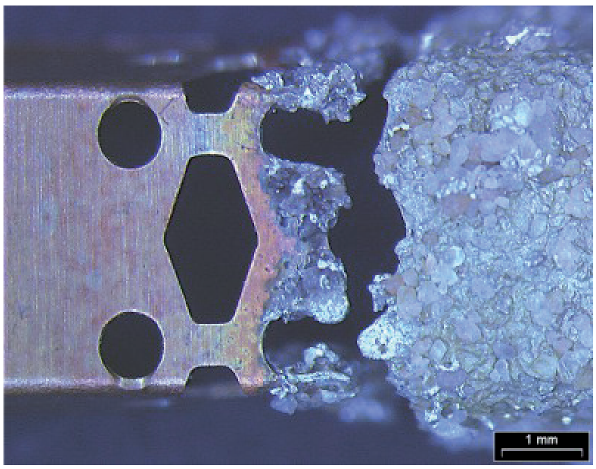


Fig. 3. Fuse element broken to the interruption of the current by the melting phase. The right part of the fuse element is coated with low melting alloy [6]

Thus, there existed a need for a new alloy, which would be environmentally acceptable in its composition and, with regard to its technical and technological as well as physical properties, could replace the existing ecologically harmful alloys for fusible elements of low voltage fuses [16].

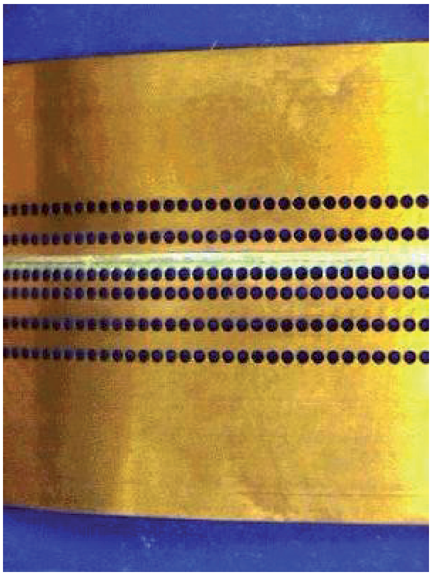


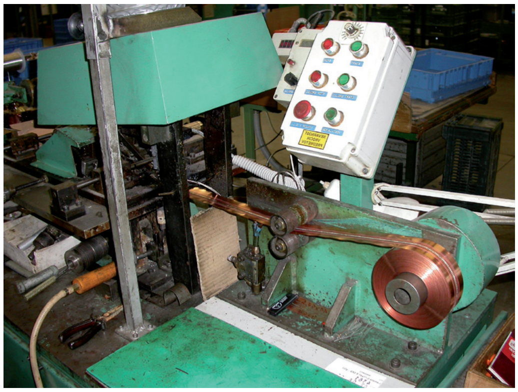
Fig. 4. Band made of technical pure copper and at an exactly defined position a layer of a solder made of a low melting alloy and a few millimeters wide

On each fusible element normally made of technical pure copper of very narrow tolerances (up to ± 0.003 mm) and with a conductivity of 58.8 × 10^6 S/m, there is applied, at an exactly defined position, a layer of a solder made of a tin-cadmium alloy and a few millimeters wide (Figure 4). This alloy is very important for a correct action of the fuse since by a correct proportion of the two elements it is achieved that at a defined overload current the fuse interrupts the circuit within the prescribed time and thus protects the installation and the user (transformer, engine ,…) from being destroyed.

It is known that cadmium is an element, which, already in small amounts, is very toxic to natural substances and living beings [17]. In European Union countries the legalisation forbids the production, processing and use of cadmium. By January 2008 at the latest, all articles (colours, batteries) containing cadmium will either have to be withdrawn from sale or an appropriate substitute for this heavy metal will have to be found [18].

There are also known alloys of lead and tin (Pb-Sn), which are also harmful to the environment due to the toxicity of lead. Alloys that do not contain ecologically harmful elements like Cd and Pb, e.g. combinations Zn-Ag-Bi-Cu and Zn-In-Al, are used as well, yet due to their technical and physical properties such as melting point, wettability etc., they are limited only to certain uses. In reference [16] there are described solders from tin - base alloys in combination with bismuth, copper and indium, which, however, are economically doubtful due to the high price of indium.

The present technology of production [19] of fuses (Figure 5) and the action thereof are adapted to the existing environmentally harmful alloy of tin and cadmium SnCd20, which ought to be replaced by one or more ecologically safe alloys with technological and application properties as similar as possible to the existing ones.



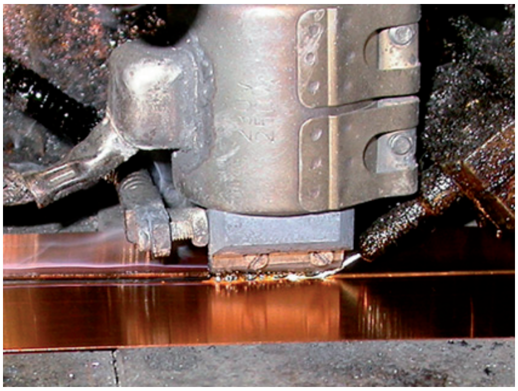


Fig. 5. Production technology

3. Technical solution

We have found that the stated problems can be successfully solved by the low melting alloy of tin, bismuth and antimony ETI-Sn-Bi-Sb, which is ecologically safe and by its technical and physical properties (melting point, conductivity, wettability) corresponds to the requirements of the use for fusible elements of low voltage fuses. The low melting alloy ETI-Sn-Bi-Sb containing from 4.0 % to 17.0 % by weight of bismuth and from 1.0 % to 3.0 % by weight of antimony, the rest being tin. The above disclosed low melting alloy is produced in the form of definite or infinite wire of a round or square longitudinal cross-section of dimensions (diameter or side length) from 0.5 mm to 3.0 mm [20, 21].

On the basis of our long-term experience in synthesis and characterization of metal materials we have decided for the preparation of the set of new ecologically safe low melting alloys of tin, bismuth and antimony. For the master alloys have been used tin and bismuth with the purity of 99.99 %, and antimony with 99.9 %. Single components of the master alloys have been melted in graphite crucibles in electric resistance furnace at the temperature of approximately 350 °C.

Remelted alloys were, at the temperatures between 268 and 280 ^{o}C, casted into the steel mould of cylindrical geometry, with internal dimensions Φ28 x 140 mm, which are corresponding to the internal dimensions of the extrusion tool. The cylinders of the casted low melting alloys were preheated in electric resistance furnace to the extrusion temperature (approximately 140 ^{o}C), and inserted into extrusion tool, which was preheated to the same temperature. We were designed and produced, in the laboratories of our faculties, our own tool for wire extrusion. It is possible to extrude finite or/and infinite wire of round longitudinal cross-section with diameters between 0.5 and 3.0 millimeters (Figure 6).

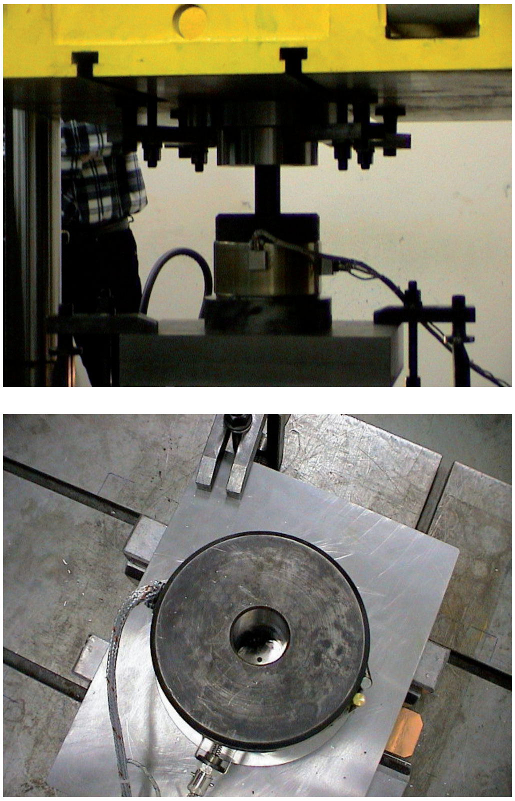


Fig. 6. Extrusion tool

Extrusion of low melting alloys were carried out on the universal static-dynamic testing machine INSTRON 1255 [22]. All tests were done at elevated temperatures equal approximately 140 ^{o}C.

Basic extrusion parameters of two alloys from the group of the patented ecologically safe alloy ETI-Sn-Bi-Sb: SnBi5Sb1.5 and SnBi10Sb1.5, extruded into infinite wire with diameter equal 1.0 millimeter are collected in Table 1.

The most important testing parameter of low voltage fuses is I-t (electric current – breaking time) characteristics. In the frame of our investigation work a complex analysis of a different compositions and dimensions of low melting ETI-Sn-Bi-Sb alloys wires has been carried out [23].

I-t characteristics measurements of the investigated alloys were done on the testing device (Figure 7) in firm ETI Elektroelement. Testing were done at two standard testing electric currents for low voltage fuses: at 56 and 70 A. The optimal (the most similar to the ecologically harmful SnCd20 alloy) results we got with wires of alloy SnBi10Sb1.5 with the diameter of 1.0 mm (Figures 8,9 and Table 2).

The ecologically safe low melting alloy of tin, bismuth and antimony ETI-Sn-Bi-Sb by its technical, technological, physical as well as electrical properties entirely replaces the existing harmful alloy of tin and cadmium SnCd20.

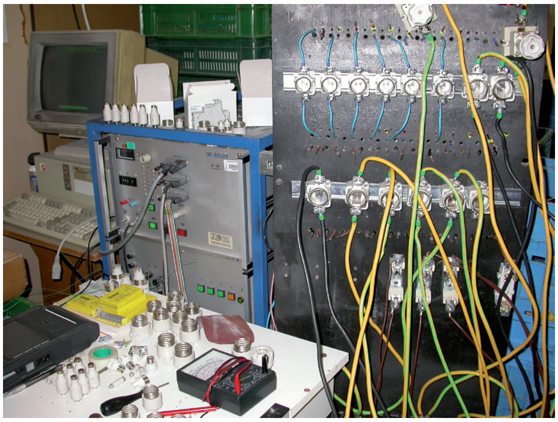


Fig. 7. Testing device for determination I-t characteristics of low melting alloys

Table 1.
Extrusion parameters of SnBi5Sb1.5 and SnBi10Sb1.5 extruded into infinite wire with diameter 1.0 millimeter

Alloy	Load [kN]	Temperature [^{o}C]	Extrusion speed [mm/s]	Extrusion time [min : s]
SnBi5Sb1.5	33.7	137.2	10.0	11:28
SnBi10Sb1.5	34.8	136.4	10.1	10:55

Table 2.
Basic properties of ecologically safe alloy SnBi10Sb1.5 in comparison with the existing ecologically harmful alloy SnCd20

Alloy	Temperature liquidus [^{o}C]	Temperature solidus [^{o}C]	Wettability angle [^{o}]	Average breaking time [s] at electric current I = 56 A
SnBi10Sb1.5	220.4	184.8	17	1974.2
SnCd20	195.6	185.0	27	1962.7

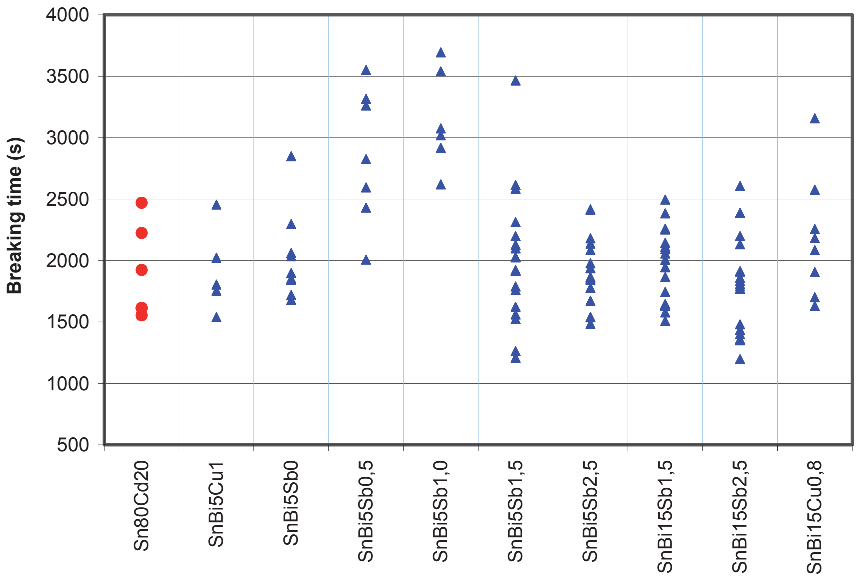


Fig. 8. Breaking time at electric current I = 56 A

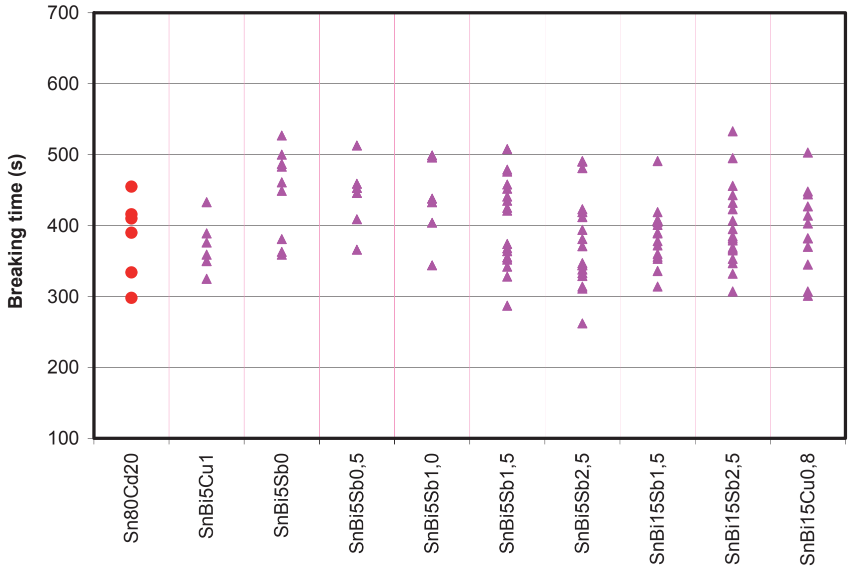


Fig. 9. Breaking time at electric current I = 70 A

4. Conclusions

In the frame of our investigation work we have found that the stated problems can be successfully solved by the low melting alloy of tin, bismuth and antimony named ETI-Sn-Bi-Sb, which is ecologically safe and by its technical and physical properties (melting point, conductivity, wettability) corresponds to the requirements of the use for fusible elements of low voltage fuses.

Alloy ETI-Sn-Bi-Sb by its technical and technological as well as physical and electrical properties entirely replaces the existing harmful alloy of tin and cadmium SnCd20 for fusible elements of low voltage fuses

For the ecologically safe low melting alloy ETI-Sn-Bi-Sb authors of this paper and firm ETI Elektroelement received two Slovenian national patents and European Union patent.

Additional information

The presentation connected with the subject matter of the paper was presented by the authors during the 14th International Scientific Conference on Achievements in Mechanical and Materials Engineering AMME'2006 in Gliwice-Wisła, Poland on 4th-8th June 2006.

References

[1] L.S. Jawahir, O.W. Dillon Jr., K.E. Rouch, K.J. Joshi, A. Venkatachalam, I.H. Jaafar, Total Life-Cycle considerations in product design for sustainability, Proceedings of the 10th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2006, Barcelona – Lloret de Mar, 2006, 1-10.

[2] R. Nowosielski, A. Kania, M. Spilka, Development of ecomaterials and materials technology, Journal of Achievements in Materials and Manufacturing Engineering 21 (2007) 27-30.

[3] E. Abele, R. Anderl, H. Birkhofer, Environmental - friendly product development - Methods and Tools, Springer Verlag, London, 2005.

[4] M. Harsch, M. Schuckert, P. Eyerer, K. Saur, Life-Cycle Assessment, Advanced Materials and Processes 149 6 (1996) 43-46.

[5] B. Kosec, M. Bizjak, L. Kosec, V. Martincic, Introduction of ecologically sound materials for fusible elements of low voltage fuses, Quality 2005, Conference Proceedings, Fojnica, 2005, 571-578.

[6] J. Kovac, M. Koprivsek, The phenomena controlling the melting phase of a fuse element during a break, Materials and Technology 38 1-2 (2004) 123-128.

[7] P. Gramatyka, R. Nowosielski, P. Sakiewicz, Recycling of waste electrical and electronic equipment, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 535-538.

[8] L.A. Dobrzański, J. Mikuła, D. Pakuła, J. Kopac, M. Sokovic, Cutting properties of the ceramic tool materials based on Si_3N_4 and Al_2O_3 coated with PVD and CVD process, Proceedings of the 12th Scientific International Conference „Achievements in Mechanical and Materials Engineering" AMME'2003, Gliwice-Zakopane, 2003, 249-252.

[9] L.A. Dobrzański, Technical and economical issues of materials selection, Silesian University of Technology, Gliwice, 1997.

[10] G. Humpston, D.M. Jacobson, Principles of soldering and brazing, ASM International, Materials Park, Ohio, 1993.

[11] G. Lojen, I. Anzel, A.C. Kneissl, A. Krizman, E. Unterweger, B. Kosec, M. Bizjak, Microstructure of rapid solidified Cu-Al-Ni shape memory alloy ribbons, Journal of Materials Processing Technology 162 15 (2005) 220-229.

[12] Alloy Phase Diagrams, ASM International Handbook Vol. 3, Materials Park, Ohio, 1992.

[13] L.A. Dobrzański, Synergetic effects of the scientific cooperation in the field of materials and manufacturing engineering, Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 9-20.

[14] L.A. Dobrzański, Significance of materials science for the future development of societes, Journal of Materials Processing Technoogy 173 (2006) 133-148.

[15] R. Nowosielski, A. Zajdel, Recycling's technology, Journal of Achievements in Materials and Manufacturing Engineering 21 (2007) 85-88.

[16] L. Kosec, B. Kosec, M. Bizjak, Introduction of alloy ETI-Sn-Bi-Sb, Technical Report, University of Ljubljana, Faculty of Naural Sciences and Engineering, Ljubljana, 2005 (in Slovene).

[17] R. Rudolf, T.Z. Hartner, New dental alloy for porcelain technics, IRT3000, 1 4 (2006) 40-41 (in Slovene).

[18] M. Sokovic, K. Mijanovic, Ecological aspects of the cutting fluids and its influence on quantifable parameters of the cutting process, Journal of Materials Processing Technology 109 (2001) 181-189.

[19] Z. Kampus, Tool for extrussion low melting alloys, Technical Report, University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, 2005.

[20] L. Kosec, M. Bizjak, B. Kosec, V. Martincic, Low melting alloy of tin, Bismuth, and Antimony for Fusible Elements of Low Voltage Fuses, RS, Ministrstvo za gospodarstvo, Urad RS za intelektualno lastnino, Patent No. 21705 and Patent No. 21706, 2005 (in Slovene).

[21] L. Kosec, M. Bizjak, B. Kosec, V. Martincic, Low melting alloy of tin, Bismuth, and Antimony for Fusible Elements of Low Voltage Fuses, European Patent Office, Patent No. 04468014.8, Munich, 2005.

[22] B. Kosec, Z. Kampus, L. Kosec, F. Kosel, Macroscopic modelling and simulation of two-phase copper matrix materials subjected to tensile deformation, Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 114-119.

[23] B. Kosec, M. Sokovic, L. Kosec, M. Bizjak, Z. Kampus, Case of introduction of new ecologically safe material, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 85-88.