JAMME Journal of Achievements in Materials and Manufacturing Engineering

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Strength properties of the low-melting-point alloys

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Received 11.09.2014; published in revised form 01.11.2014

ABSTRACT

Purpose: The aim of this paper was to determine the strength and elasticity of low melting point alloys. In particular, the laboratory tests were observed to check the shape of the compression curve. This is a result of recrystallization.

Design/methodology/approach: The strength and stiffness of the low melting point alloys was found. The unusual shape of the compression curve was observed. In order to determine if it is the result of crystallization, the samples were cooled in the liquid nitrogen. In the next step another attempt will be perform to the compression.

Findings: The results of the compression tests and their analysis are presented.

Research limitations/implications: Presented research was limited to alloys in the form of small samples. The developed technology of this type of preparation of this type alloys is limited to small volumes because the melts are small and expensive.

Practical implications: The low melting point alloys have many possible applications. First of all they are materials with higher thermal conductivity and electrical conductivity. Conducted research programme showed that these materials exhibit also good the mechanical properties.

Originality/value: Carrying out of the experiment that explaining of the shape of the compression curve for low-melting-points alloys. This experiment may be have a high educational value for the study. This experiment can have high an educational value for the science.

Keywords: Metallic alloys; Mechanical properties; Low melting point alloy; Fusible alloy; Bismuth alloys

Reference to this paper should be given in the following way:

Ł. Wierzbicki, Strength properties of the low-melting-point alloys, Journal of Achievements in Materials and Manufacturing Engineering 67/1 (2014) 26-31.

PROPERTIES

1. Introduction

A low-melting-point alloys are a metals alloys capable of being easily fused. They are easily meltable, at relatively low temperatures. Low-melting point alloys are commonly eutectic alloys, but to this rule there are exceptions. This group of alloys is often called as fusible alloys or low temp alloys.

Bismuth is a main constituent of a number of low-melting-point alloys in which bismuth is usually combined with lead, tin, cadmium, or a combination of these metals. Indium, antimony and silver are also added in some of the alloys [1].

The low-melting-point alloys have various habits on solidification. Some expanding. some shrinking and others having a growth only after solidification, which may continue for approximately 21 to 42 days. Total growth may be as much as 0.2032 mm/mm [2].

Alloys containing appreciable amounts of bismuth (about 50%) expand slightly upon solidification [1]. They have a negative value of shrinkage.

Bismuth is one such element that does not shrink when it solidifies. Water and antimony are two other substances that expand on solidification but bismuth expands more than the former, i.e. 3.3% of its volume [3].

Some scientists [3] splitting the low-melting-point alloys into two groups:

- alloys becoming fluid between 94.5 and 150°C,
- alloys becoming fluid at less than 94.5°C (also called as ultra-low-melting alloys).

The melting point of some alloys with indium content are even lower than 50°C. This is unique, especially as the parent metals in the pure state have their melting points high above alloy's. Although most of the low melting point alloys do not have high strength or hardness, they have many industrial applications.

Alloys having a low melting point are known in numerous forms. These include, for example [4]:

- LBE – eutectic bismuth-lead alloy, melting point 124°C,
- Rose's alloy – 50 % (by weight) bismuth, 28% lead, and 22% tin, melting point 98°C,
- Orion alloy – 42% bismuth, 42% lead, and 16% tin, melting point 108° C
- fast solder – 52% bismuth, 32% lead, and 16% tin, melting point 96°C,
- d'Arcet's alloy – 50% bismuth, 25% lead, and 25% tin,
- Wood's alloy – 50% bismuth, 25% lead, 12.5% tin, and 12.5% cadmium, melting point 71°C,
- Lipowitz' alloy – 50% bismuth, 27% lead, 13% tin, and 10% cadmium, melting point about 80°C,
- Harper's alloy – 44% bismuth, 25% lead, 25% tin, and 6% cadmium, melting point 75°C,
- Cerrolow 117 – 44.7 % bismuth, 22.6% lead, 19.1% indium, 8.3% tin, and 5.3% cadmium, melting point 47°C,
- Cerrolow 174 – 57% bismuth, 26% indium, 17% tin, melting point 78.9°C,
- Field's alloy – 32% bismuth, 51% indium, 17% tin, melting point 62°C,
- Walker alloy – 45% bismuth, 28% lead, 22% tin, and 5% antimony,
- Lichtenberg's alloy – 50% bismuth, 30% lead, 20% tin, melting point about 91.6°C.

As you could see ,they have been known for many years and have been called by many different names. Some of these have more than one name, but usually we used inventor's name – like Wood's, Lipowitz's, Newton's, Roses and so on metals or alloys. On the other hand, many of these alloys are sold under their trade names or proprietary numbers – melting point value in Fahrenheit degrees (like Cerrolow 117).

The compositions and names of some most popular low melting point alloys are determined by national standards, like ASTM B774-00 "Standard Specification for Low Melting Point Alloys" or PN-91/H-87203, "Low Melting Point Alloys" (in Polish).

The specific characteristics of this group of alloys is primarily responsible phase system elements with the highest concentration – bismuth, lead and tin. Phase diagram for Bi-Pb-Sn is shown in Fig. 1. There are, of course, fusible alloys systems with melting points much lower than those reported for the bismuth-lead-tin system, the most famous of which are those found in the quaternary bismuth-lead-tin-cadmium [5]. However, their phase systems are much more difficult to describe in two-dimensional space of the paper.

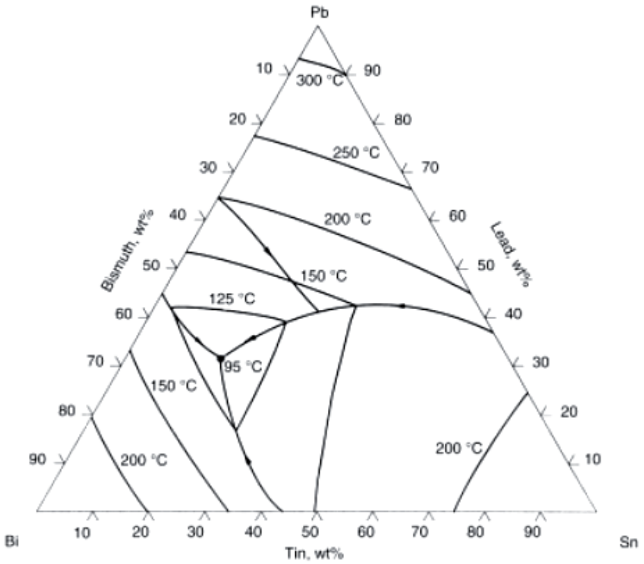

Fig. 1. Phase diagram for the Bi/Pb/Sn system showing a ternary eutectic at 95°C. Compositions are in weight percentages [4,16]

Effect of changes in concentrations of the Bi/PB/Sn on the some mechanical, thermal properties and quality of solidification presented also in the articles [6,7].

Significant and frequent industrial applications of low point we can split in two groups [2]. First of them is "construction uses" like [2,8-12]:

- fusible links and vents,
- electric fuses,
- automatic sprinkling devices,
- safety plugs in boilers,
- seals,
- soldering,
- radiation and electro-magnetic shielding,
- metal ink for 3D printing.

The second group is "non-construction uses", like [2,8,9]:

- anchoring,
- tube bending,
- lens blocking,
- heat transfer fluids in high temperature,
- fusible core technology,
- installing tools, punches, bearings, etc.

For several years, researchers successfully use low melting point alloys as fillers in the modification of polymeric materials. Studies of such composites are presented in the articles [9,13-16].

In many cases, low melting point alloys are used as substitutes of mercury or lead.

The reason for this article, there was a small amount of information about the strength of the low-melting-point alloys.

A small amount of information about the strength of the low-melting-point alloys was the reason for this article.

2. Experimental

The experiments were made with the:

- $Bi_{50}Pb_{25}Sn_{12.5}Cd_{12.5}$ (Wood's alloy),
- $Bi_{50}Pb_{27}Sn_{13}Cd_{10}$ (Lipowit'z alloy),
- $Bi_{50}Pb_{20}Sn_{20}$ (Lichtenber's alloy).

All alloys supplied by "Innovator" Company, Poland.

Alloys were placed in the porcelain beakers and heated up in the dryer to temperature 120°C.

After melting the alloys were cast into the glass tubes with a diameter of 10 mm and a height of 70 mm. The cast and cured cylinders were pulled out from the glass tubes and cut into discs 10 mm thick. The discs were intended to compressive strength tests.

Finally obtained samples of alloys were compression tested using the Zwick/Roell Z020 testing machine.

The cross head speed of 5 mm/min was maintained throughout the test.

The mechanical properties of the alloys were identified in the compression test. The compression strength test is easy to perform, but its interpretation is difficult, especially for high strain values, because complex stress state arises as tension and shear forces act concurrently inside the material. Some authors [17] suggest the correctness of the compression test only for stiff and brittle materials and only for small range of deformation.

The problem with compression strength tests is that the specimens of some materials, specially metals and its alloys, may compress to barrel shapes during the test. This and interpretation of test curve may be a reason of overestimation of tested materials compression strength. For most materials, compression strength is much greater then tensile strength [18].

With this in mind, compression test was applied in this research. The main reason was that it was not possible using casting technology to prepare samples with the dumbbell shape demanded in tensile test. A special mould have to be constructed to enable it. This mould is planned for the next stage of research.

The basic strength characteristic, namely compression strength and Young's modulus were calculated using compression force - strain curves.

3. Results and discussions

Examples of the compression curves are shown in Figs. 2,3 and 4.

An surprising shape of the curves ware obtained for the sample of Wood's alloy (Fig. 2) and Lipowitz alloy (Fig. 3). The first curve shows peculiarity at the point corresponding to stress about 42 MPa. The second curve of this curves shows similar point at 32 MPa. In the case of Lipowitz alloy it is much less visible. At compression curves of Lichtenberg's alloy samples didn't observe similar points (Fig. 4).

The probably reason for this phenomenon is temperature rise above the alloys recrystallization temperature due to energy dissipation. Recrystallization temperature is in the range of 0.4 to 0.6 the melting point of the metal alloy. The research was carried out at 23°C but temperature significantly increase during plastic deformation so proposed explanation seems to be legitimate.

To confirm these suppositions made a second series of strength tests on cold samples. For this purpose, the samples were immersed in liquid nitrogen (LN2). The samples were cooled 5 minutes, each. The temperature of boiling liquid nitrogen is -196°C.

The compressive test time with assembly of the sample, after removing the samples from the liquid nitrogen, was about 1.5 minute. Short duration of the compression test results that the temperature of the sample grew slightly. The resulting curves have a regular and typical shape, as presented in Fig. 5.

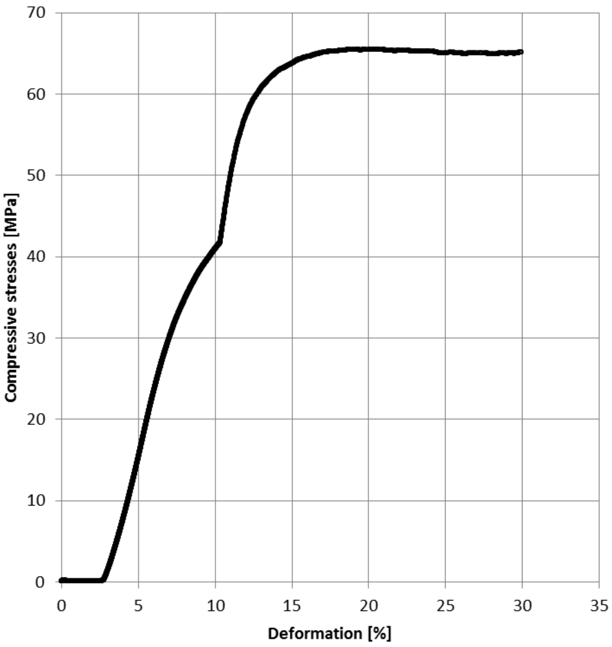

Fig. 2. The testing curve of Wood's alloy

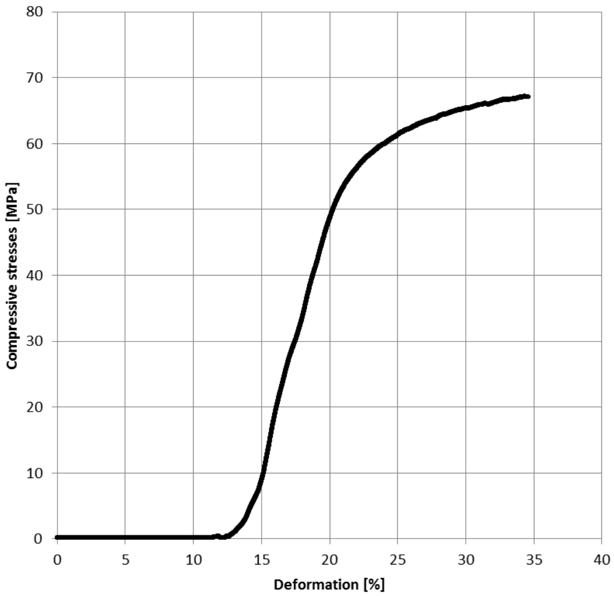

Fig. 3. The testing curve of Lipowitz's alloy

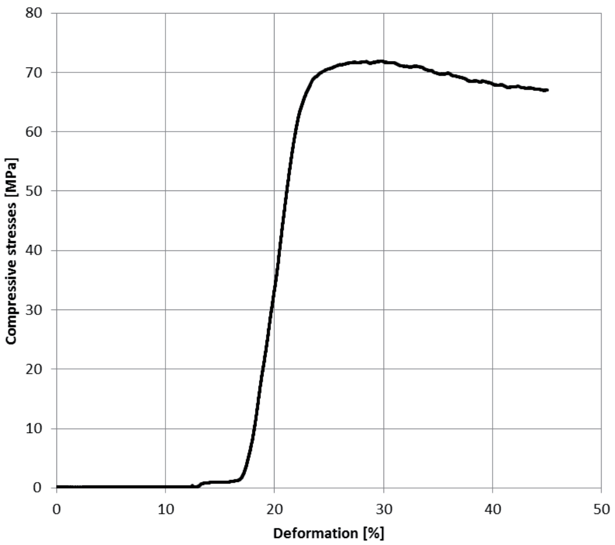

Fig. 4. The testing curve of Lichtenberg's alloy

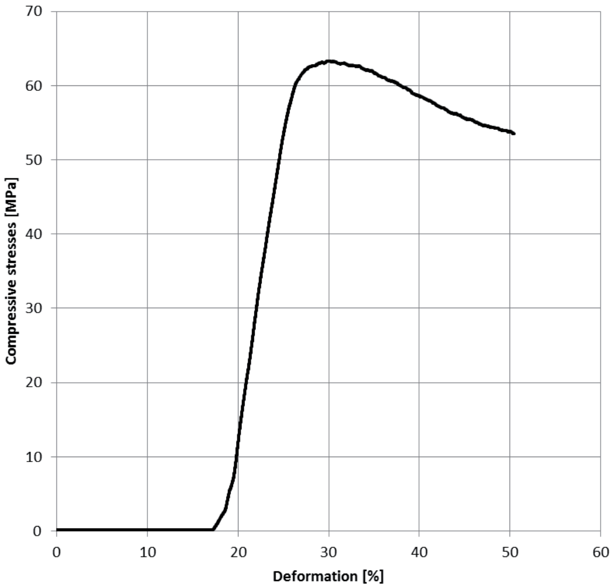

Fig. 5. The testing curve of Wood's alloy sample after cooling in liquid nitrogen

For the test result adopted the average of the five tests samples.

The average values of compressive strength of tested low melting point alloys are presented in Fig. 6. Young's modulus results are presented in the Fig. 7. Cooling alloys in the liquid nitrogen before the test, marked "LN2" sign.

The largest scatter of results was observed for values of Young's modulus. For cooled materials scatter of the values was larger than alloys tested in constant temperature. This seems logical because in our study did not use a climatic chamber set up for the testing machine. Thus, the samples were subjected many external interactions.

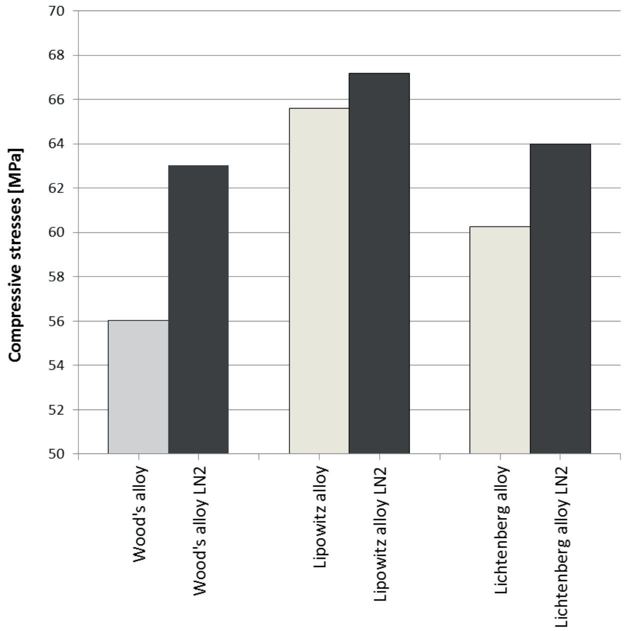

Fig. 6. Compressive strength of tested low melting point alloys

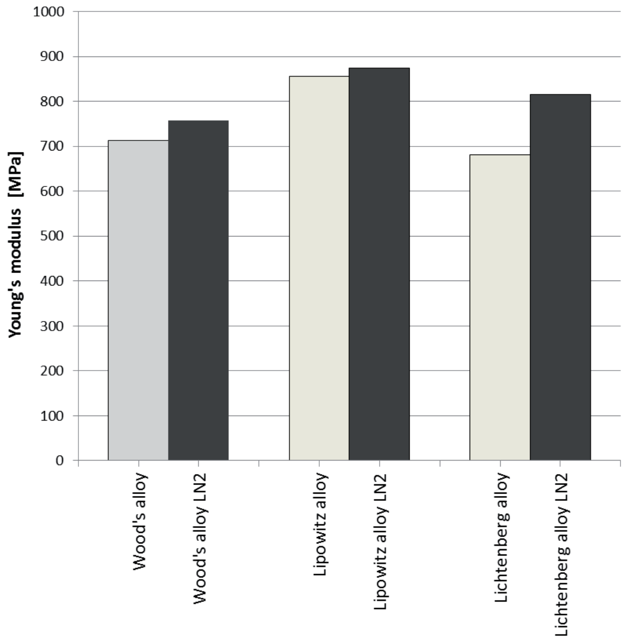

Fig. 7. Young modulus of tested low melting point alloys

4. Conclusions

An experiment confirmed that the observed specific points on the compression curves (Figs. 2 and 3) of low melting point alloys are the result of materials recrystallization during strength test.

The samples was have constant temperature 23°C are tested in a hot deformation condition. The samples at a constant temperature of 23°C was tested in the hot-deformed state. The samples which were cooled in liquid nitrogen immediately before compression tests are plastically cold deformed. Hence result differences in the results of strength and stiffness and the shape of the compression curve for each test series.

The alloys cooled in liquid nitrogen have a greater stiffness as well compressive strength. Strength and stiffness not large but enough for the specific applications of them. Strength and stiffness is not large, but sufficient for specific applications them.

An similarly experiment can illustrate the processes of strengthening metal during deformation, recrystallization and hot and cold plastic deformation, in the learning process of students.

References

[1] S. Guruswamy, Engineering Properties and Applications of Lead Alloys, CRC Press, 1999.
[2] C. Hornbostel, Construction Materials: Types, Uses and Applications, John Wiley and Sons, 1991.
[3] J.P. Kaushish, Manufacturing Processes, PHI Learning Pvt. Ltd., 2010.
[4] Q. Ashton Acton, Heavy Metals - Advances in Research and Application, 2013 Edition, Scholarly Editions, 2013.
[5] W.B. Jensen, Onion's Fusible Alloy, Journal of Chemical Education 87 (2010) 1050-1051.
[6] J. Zhou, Y. Sun, F. Xue, Properties of low melting point Sn-Zn-Bi solders, Journal of Alloys and Compounds 397/1-2 (2005) 260-264.
[7] Y.-S. Kim, K.-S. Kim, C.-W. Hwang, K. Suganuma, Effect of composition and cooling rate on microstructure and tensile properties of Sn-Zn-Bi alloys, Journal of Alloys and Compounds 352/1-2 (2003) 237-245.
[8] R. Kirk-Othmer, Encyclopedia of Chemical Technology, Bismuth and bismuth alloys, Wiley John and Sons, 2007.

[9] J. Stabik, Ł. Wierzbicki, Epoxy resins and low melting point alloy composites, Archives of Materials Science and Engineering 48/1 (2011) 5-11.

[10] L. Wang, J. Liu, Liquid phase 3D printing for quickly manufacturing conductive metal objects with low melting point alloy ink, Science China Technological Sciences 57/9 (2014) 1721-1728.

[11] S. Mudry, I. Shtablavyi, I. Shcherba, Liquid eutectic alloys as a cluster solutions, Archives of Materials Science and Engineering 34/1 (2008) 14-18.

[12] B. Kosec, M. Soković, L. Kosec, M. Bizjak, F. Pusavec, Z. Kampus, Introduction of new ecologically safe material for fusible elements of low voltage fuses, Archives of Materials Science and Engineering 28/4 (2007) 211-216.

[13] J. Stabik, Ł. Wierzbicki, Influence of low melting point alloy on strength properties of epoxy resin, Archives of Materials Science and Engineering 60/1 (2013) 13-23.

[14] Ł. Wierzbicki, A. Pusz, Thermal conductivity of the epoxy resin filled by low melting point alloy, Archives of Materials Science and Engineering 61/1 (2013) 22-29.

[15] M. Trojanowska-Tomczak, R. Stellera, J. Ziaja, G. Szafran, P. Szymczyk, Preparation and Properties of Polymer Composites Filled with Low Melting Metal Alloys, Polymer-Plastics Technology and Engineering 53/5 (2014) 481-487.

[16] G. Humpston, D.M. Jacobson, Principles of Soldering, ASM International, 2004.

[17] T. Brosh, Y. Gaynor, I. Belov, R. Pilo, Analysis of strength properties of light-cured resin composites, Dental Materials 15/3 (1999) 174-179.

[18] C.T. Sun, J. Tsai, Dynamic Compressive Strengths of Polymeric Composites: Testing and Modeling, in: Dynamic Failure of Materials and Structures, Springer, 2010, 107-129.