International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13092-13095

Aluminium Coated Iron Powder and Fe-Al-Cu Composite: Mechanical Activation and Thermal Properties

Yu.V. Kontsevoi[1*,a], K.I. Oleinik[1], A.S. Bykov[1,c], A.G. Meilakh[1], E.A. Pastukhov[1], I.S. Sipatov[1] and A.B. Shubin[1,g]**

[1]Institute of Metallurgy, Ural Branch of the Russian Academy of Sciences (UB RAS), 101 Amundsen st., 620016, Ekaterinburg, Russia.
[*]Corresponding author

**ORCID 0000-0001-5156-3573, ** ORCID 0000-0001-9357-0317*
[a]Orcid 0000-0001-5156-3573, [c]Orcid : 0000-0002-5640-3568

Abstract

Development of a new composite materials with improved functional properties is important to machine building due to a progressive increase of requirements to assemblies of machines, e.g. friction pairs. Metal composite materials based on Al or Cu demonstrate excellent properties, e.g. high thermal conductivity, high strength and thermal stability, high wear resistance and low friction coefficient. Temperature and heat of phase transitions were measured for obtained by powder metallurgy operations i.e. vibrotreatment and rolling. Thermal analysis of raw materials was also carried out. It was found by differential scanning calorimetry that some activation of powder mixture took place in the result of vibrotreatment and rolling. Al-Fe samples has demonstrated thermal stability up to 600°C. In the case of application of the material as friction one, it requires addition of more refractory and ductile alloying elements, e.g. copper, to enhance thermal stability of the material. The obtained data can be applied for calculation of synthesis parameters of Fe-Al-Cucomposites, which are used for development of sliding bearings.

INTRODUCTION

Development of metal composites having complex of useful properties is an urgent problem of material science [*1*,*2*]. Exacting requirements concerning thermal conductivity and stability [*3-5*], strength [*6*,*7*], hardness and wear resistance [*8*,*9*] are imposed upon the metal composites depending on their application. Powder metallurgy had great potential to produce metal composites combining a number of useful properties [*3*,*10*, *11*]. Our research group develops scientific basis for production of powder metal materials for development of durable antifriction materials by means of methods combination of powder metallurgy and rolling [*12*,*13*]. First explorations devoted to development of such coatings, their microstructure and properties study, have revealed that the process under study was complex. The process is accompanied by active diffusion in solid phase [*14*], intermetallics formation and other phenomena [*15*]. Therefore, we decided to apply thermal analysis for investigation of thermodynamic features of coating material at various stages of its formation. Also we have performed here the DSC investigation of anti-frictional Fe-Al-Cu composite which can be used in sliding bearings for internal combustion engines.

EXPERIMENTAL DETAILS

The temperature and heat of phase transition of samples were measured by differential scanning calorimetry within the temperature range from 30 to 1300 °C using SETARAM MHTC multifunctional thermal analyser. HfDSCdetector and 600 µl high-aluminous crucibles were used. Heating/cooling of samples were at the constant rate (10°C/min) in dynamic argon atmosphere. Argon was puffed in a furnace after preliminary evacuation of the system to a pressure at least 2.5 $\cdot 10^{-2}$Torr. The argon flow was about 10 ml/min.

The blank experiments with empty crucibles were carried out to determine the basis line at the testing conditions. The basis line was used for processing of measurement results.

The DSC unit was calibrated by temperature and susceptibility using standard samples sets from SETARAM and NETZSCH (Pb, Zn, Al, Ag, Au, Ni). Weight of the samples was measured using Sartorius CPA225D balance with the accuracy of 0.01 mg. Mass of the samples for DSC measurements were 66-92 g. Calisto ver. 1.088 software were used to manage measurements and record data.

Four types of samples were used.

- Aluminium powder PA-1. BAZ-SUAL State Standard 6058–73. Size ~140 microns.
- Iron powder PZhR 3.160.28. Technical requirements–14–1–3882–85. Size ~160 microns.
- Powder mixture. Weight ratio of aluminium and iron powders was 1:1. Mixing of powders were carried out in vibroaeratic unit, which has been previously described in [*16*].

- Al-Fe foil. The foil was made of the powder mixture. The foil was produced by fabrication mill DUO LPS – 80 with diameter of 80 mm rolls. Rolling was carried out in one pass with the rate of 0.04 m/s at room temperature. The compactness of powders before and after rolling was 0.33 and 0.92 in respect of cast alloy.
- Fe-Al-Cu composite samples (wt.%, 2.5 − 5 of hardening intermetallide Al_2Fe_5, 10 Pb, 5 Fe, Cu – the rest) were synthesized by sintering of the powders of components at 720-750 °C in hydrogen atmosphere and further rolling at room temperature.

RESULTS AND DISCUSSION

Thermal curves are shown in figure 1 for aluminium (a) and iron (b) during heating. The form of the curves was standard.

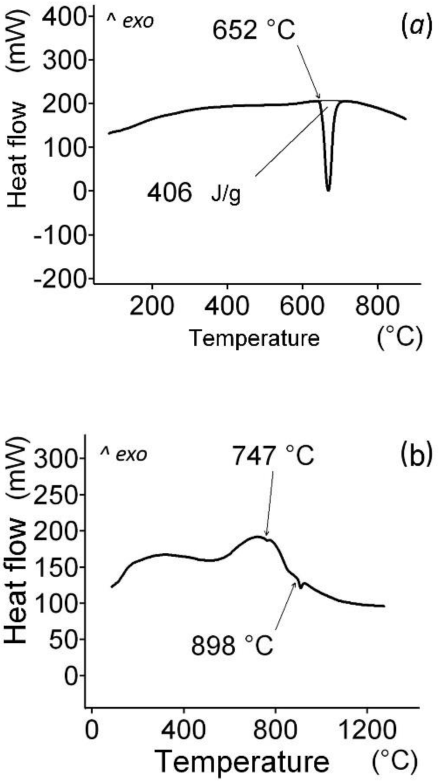

Figure 1: DSC curves for initial powders of aluminium (a) and iron (b)

Endothermic effect for aluminium started at 652 ºC has the value of 406 J/g, that is in accordance with reference data [*17*] about melting point of Al (660ºC and 397 J/g).

It is known [*18]*Kuri point of pure iron is at 769 ºC and α→γ transformation takes place at 910 ºC. Small inflection at 747 ºC is shown in Fig 1 b, it might be attributed to phase transition of type II which is characteristic to magnetic transformations. Besides there is a small endothermic peak at 898 ºC, we suppose that it corresponds to α-iron transformation into austenite.

Some deviation from reference values is caused by commercial purity of the samples. Thermal behaviour of the samples was completely reversible at the cooling.

Behaviour of the powder mixture before and after rolling was different, DSC curves are shown in Fig. 2.a and b, respectively. Exothermic effects were found during samples heating; it was unexpected result.

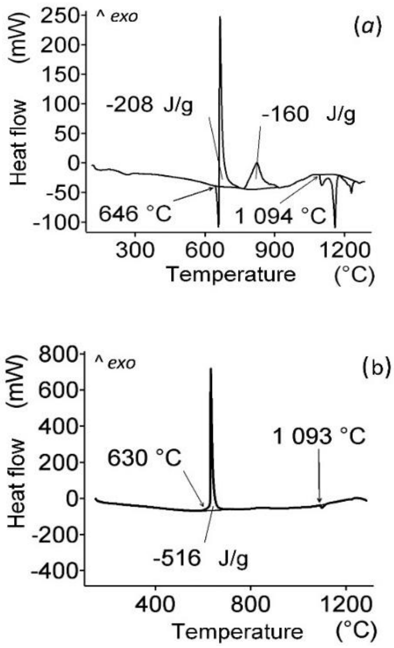

Figure 2: DSC curves of powder mixture before (a) and after (b) rolling

It is clear from Fig.2 a that endothermic effect started at 646 ºC and then it transferred in exothermic process. We assume that endothermic effect corresponds to melting of aluminium constituent of the composite. The total thermal effect is exothermic and it equals -208 J/g. One more calorimetric effect occurs with heat release of - 160 J/g. Series of endothermic effects was registered starting from 1094 ºC.

In general, the DSC curve of the Al-Fe foil is similar to powder mixture. Exothermic effect took place near the aluminium melting point, and high temperature endothermic effect is very small (Fig. 2b).

Running of exothermic transformations is non-typical for materials in equilibrium state during heating. Normally, materials release heat when their state is far from thermodynamic equilibrium. Such materials release excessive internal energy during heating [*19*] Appropriate well known examples are cold crystallization of glasses [*20*], decomposition of metastable supersaturated solid solutions [*21*], etc. One more confirmation of non-equilibrium state of Al-Fe powder mixture before and after rolling is the difference between DSC curves at heating and cooling.

To make a more detailed analysis DSC curves it is required to obtain data about structure and phase composition of the powder composite at various temperatures, e.g. by means of X-ray diffraction. However, we conclude that some activation the metal composite occurs in the result of vibrotreatment and rolling of Al-Fe powder mixture.

Theseriesofsamplesofanti-frictioncomposites obtained as described above shown the best results in functional properties test [9]. The microstructure of typical sample is demonstrated in Fig. 3 (SEM).

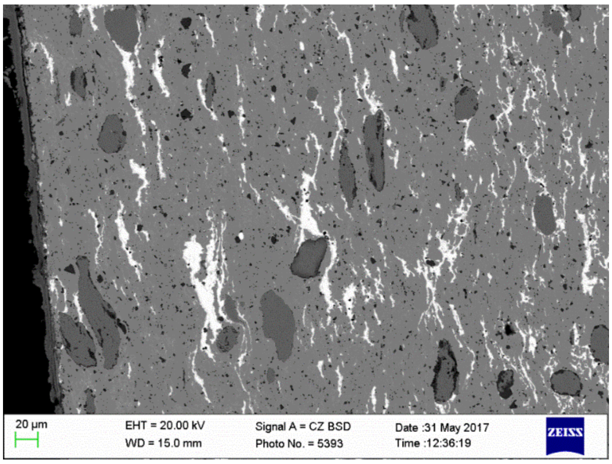

Figure 3: Fe-Al-Cu composite microstructure (SEM) after sintering and rolling. Black particles – Fe-Al powder (mainly of Fe_2Al_5 composition; dark gray particles – Fe powder; gray matrix – copper; white fields – Pb anti-frictional addition)

The previously synthesized Al-Fe powders containing Al_2Fe_5 intermetallic compound (black fields) work as hardening phase. Dark gray fields are Fe particles. Light gray matrix is copper. White fields consist of lead and improve ant-frictional properties.

Thermal analysis of material containing Al-Fe and Fe powders, Pb, and copper as composite matrix was carried out in the temperature range 260-400 ºC (Fig. 4).

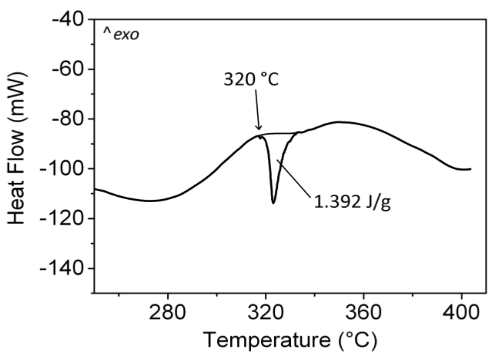

Figure 4: DSC curves for sintered and rolled Fe-Al-Cu composite with Pb addition

The temperature interval taken includes the region of anti-frictional component (lead) melting. The peak at 320 ºC can be identified with Pb melting mentioned above. The DSC curves of Fe-Al-Cu composite material do not show significant heat effects at the temperatures lower than temperature interval considered (Fig.4). The similar results were obtained after a few repeating cycles of heating and cooling and also after tribological tests.

CONCLUSION

It was established by DSC that some activation of Al-Fe powder mixture occurs in the result of vibrotreatment and rolling. Al-Fe samples has demonstrated thermal stability up to ~600ºC. In the case of application of the material as friction one, it requires addition of more refractory and ductile alloying elements, e.g. copper, to enhance thermal stability of the material. The obtained data can be applied for calculation of synthesis parameters of Fe-Al-Cu composites, which are used for development of sliding bearings [22].

DSC analysis of synthesized Fe-Al-Cu anti-frictional composite shows temperature stability of its thermal properties before fusible component (like Pb) melting. This fact allows us to use Fe-Al-Cu as experimental material for slide bearings working under heavy loads.

ACKNOWLEDGEMENTS

This work was supported by Russian Science Foundation, project No. 15-13-00029. The equipment of Ural-M Shared Research Centre was used to make this study.

REFERENCES

[1] Repka M., Dörr N., Brenner J., Gabler C., McAleese C., Ishigo O., Koshima M. Lubricant-surface interactions of polymer-coated engine journal bearings, Tribol. Int. 109 (2017) 519–528. doi:10.1016/j.triboint.2017.01.017

[2] Ahmad F., Lo S.H.J., Aslam M., Haziq A. Tribology behaviour of alumina particles reinforced aluminium matrix composites and brake disc materials, Procedia Eng. 68 (2013) 674–680. doi:10.1016/j.proeng.2013.12.238

[3] Gao X., Yue H., Guo E., Zhang H., Lin X., Yao L., Wang B. Mechanical properties and thermal conductivity of graphene reinforced copper matrix composites, Powder Technol. 301 (2016) 601–607. doi:10.1016/j.powtec.2016.06.045.

[4] Kontsevoi Y. V, Meilakh A.G, Shubin A.B., Pastukhov E.A., Dolmatov A.V., Sipatov I.S. Premixes production for synthesis of wear-resistant composite materials,

Journal of Engineering and Applied Sciences.11 4 (2016) 714-718.

[5] Salih O.S., Ou H., Sun W., McCartney D.G., A review of friction stir welding of aluminium matrix composites, Mater. Des. 86 (2015) 61–71. doi:10.1016/j.matdes.2015.07.071.

[6] Kontsevoi Y.V., Pastukhov E.A., Dolmatov A.V., Sipatov I.S., Shubin A.B., Meylakh A.G., Effect of deformation rate and gradient on creep and structure of the metal under uni-axial tension, Int. J. Appl. Eng. Res. 11 (2016).

[7] KontsevoiYu.V., MeilakhA.G., ShubinA.B., Ignat'evaE.V., PastukhovE.A., SipatovI.S., Modification of Structure and Mechanical Properties of Fragile Intermetallic Layer of Steel with Aluminium Surface, The 2nd International Conference on Nanomaterials: Fundamentals and Applications,PavolJozefŠafárik University, Košice, Slovakia.(2015) 50.

[8] Miyajima T., Tanaka Y., Iwai Y., Kagohara Y., Haneda S., Takayanagi S., Katsuki H., Friction and wear properties of lead-free aluminum alloy bearing material with molybdenum disulfide layer by a reciprocating test, Tribol. Int. 59 (2013) 17–22. doi:10.1016/j.triboint.2012.07.017.

[9] Kotenkov P., Kontsevoi Y., Mejlakh A., Pastukhov E., Shubin A., Goyda E., Sipatov I., Antifriction coating of Cu-Fe-Al-Pb system for plain bearings, AIP Conf. Proc. 20088 (2017). doi:10.1063/1.5002985.

[10] Kontsevoi Y.V., Meilakh A.G., Shubin A.B., Pastukhov E.A., Sipatov I.S., Interaction of iron and aluminium in the plastic deformation and fast heating of laminar Fe–Al composite, Steel Transl. 46 (2016). doi:10.3103/S0967091216070093.

[11] Ignat’ev I.E., Sipatov I.S. Particular properties of micron size powder particles, *Butlerov Communications.* 2013. Vol.34. No.5. P.60-66

[12] Kontsevoi Y. V, Meilakh A.G., Shubin A.B., Pastukhov E.A., Sipatov I.S. Designing of Laminated Structure of Antifriction Powder Composite, Int. J. Appl. Eng. Res. 12 (2017) 6045–6049.

[13] Pastukhov E.A., Vatolin N.A., KontsevoiYu.V., Ignat’ev I.E., Rjabova R.F. Method of steel strip coating by aluminium. Patent RF №218219, BI № 13, 2002.

[14] ShubinA.B., KontsevoiY. V., MeilakhA.G., KotenkovP. V., SipatovI.S., PastukhovE.A., Multi-phase Al-Fe alloys with layer structure: synthesis and properties, Kov. Mater. 55 (2017) 205-209.

[15] KontsevoiYu., MeilakhA., PastukhovE. Producing of Premixes for Synthesis of Wear-Resistant Composite Materials. The 2nd International Conference on Rheology and Modeling of Materials. Book of Abstracts. Miskolc-Lillafüred. Hungary, October 5-9, 2015. Igrex Ltd, Igrici,Hungary, 2015, p. 89.

[16] KontsevoiYu.V., Pastukhov E.A., Ignat’ev I.E., Bulanov V. Ya., Ignateva E.V. Vibroaeratic powder mixing in gas atmosphere Report 1. Developing a method and theoretical foundations for vibroaeratic powder mixing and destroying conglomerates Russian Journal of Non-Ferrous Metals 2009. 50 4 390-394

[17] Dinsdale A.T. SGTE Data for Pure Elements. CALPHAD, 1991, Vol. 15, pp. 317-425

[18] Elements properties Reference book. Ed. Dric M.E. Moscow, Metallurgy, 1985.

[19] ShestakYa. Thoery of thermal analysis: Physicochemical properties of solid inorganic substances. Moscow, Mir, 1987. (in Russian) 456.

[20] UporovS.A., BykovV.A., YagodinD.A.Thermophysical properties of the Al83Co10Ce7 glass-forming alloy in crystalline and liquid states, J. Alloys Compd. 589 (2014) 420–424. doi:10.1016/j.jallcom.2013.11.228.

[21] UporovS.A., UporovaN.S., BykovV.A., KulikovaT. V., PryanichnikovS. V. Effect of replacing RE and TM on magnetic properties and thermal stability of some Al-Ni-based amorphous alloys, J. Alloys Compd. 586 (2014) 5–8. doi:10.1016/j.jallcom.2012.09.093.

[22] Kontsevoi Y. V, Meilakh A.G., Shubin A.B., Pastukhov E.A., Sipatov I.S. New Bimetal Bearing Shell for Internal Combustion Engine, Int. J. Appl. Eng. Res. 12 (2017) 4474-4477.