TRIBOLOGICAL PROPERTIES OF THIXOFORMING AL-ALLOY A356 AND INFLUENCE OF HEAT TREATMENT

A. Rac[1], K.-D. Bouzakis[2], A. Vencl[1], A. Tsouknidas[2]

1. Laboratory for Tribology, Mechanical Engineering Department, University of Belgrade
2. Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department, Aristoteles University of Thessaloniki

ABSTRACT
Aluminium alloys have attractive physical and mechanical properties and that makes these alloys very interesting for the automotive industry where they can successfully replace steel and cast iron parts.
Tribological properties of usually used Al-alloys are not satisfactory for application where good wear resistances are required, so some improvements have to be done. Modification of production technology is one of the possible solutions, and thixoforming technology is one of the most used and investigated.
The investigation of tribological properties, for thixocast hypoeutectic Al-Si alloy A356, has been done using pin-on-disc tribometer and two sets of specimens were tested. First was taken from original alloy billet and second from thixocast alloy. Heat treatment was applied on both sets of specimens and their friction and wear characteristic were investigated.
The results show that thixocasting, as well as heat treatment improve tribological properties of investigated alloy.

KEYWORDS: Al-Si alloy, thixocasting, tribological properties, heat treatment

1. INTRODUCTION

Aluminium alloys and other lightweight materials have increasing applications in the automotive industry, with respect to reducing the fuel consumption and protecting the environment, where they can successfully replace steel and cast iron parts. These alloys have attractive physical and mechanical properties and that makes them very interesting for producing components or whole engine cylinder blocks. Use of Al alloys, besides positive aspects such as reduction of mass, has their shortcomings reflected, first of all, in inappropriate tribological properties of these materials. In such cases, where good wear resistance are required, there is a need for some improvements. Use of new production technologies and modification of the existing ones is one of the possible solutions.
One of the most used and investigated new technologies is thixoforming i.e. forming parts from the material that is in thixotropic state. Depending on the forming process there are thixocasting, thixoforging and thixoextursion /1/.
The process of stirring alloys during solidification to fabricate nondendritic solid within a slurry and then injecting this semisolid slurry directly into dies as in liquid metal die casting was originally called rheocasting. An alternative process whereby the slurry is first cast as a billet, cut into appropriately sized slugs, and reheated back to the semisolid condition before injecting into the die was termed thixocasting /2/.
Thixoforming as a new manufacturing technology, from the commercial point of view, has it benefits and it drawbacks as it is described by Lowe *et al.* /3/.
In automotive industry thixoforming is already in commercial use for producing: fuel rail (Weber-Italy, Magneti Marelli-Brazil and MKC-USA), steering link (Buhler-Swizerland), automobile wheel (Alumax-USA), suspension subassembly (Stampal-Italy for Alfa Romeo and Alusuisse Singen-

Germany for Mercedes) and engine bracket (Stampal-Italy for Fiat Punto 8V and 16V and Florence&Peillon-France for Peugeot 206) /3-4/, or are in the phase of research: brake drum /5/ and other automotive scroll components /2/.
Concerning friction and wear behaviour of thixoform Al-Si alloys, some investigations show that they can be very similar to cast iron if appropriate process parameters have been used /2/ and that thixoforming and heat treatment generally improves mechanical and tribological properties /6-8/.
Hypoeutectic aluminium-silicon alloy A356, which was investigated in this paper, was produced by thixocasting process. This investigation is just an initial one, with preliminary results and some more experiments are planed to be done to completely understand tribological behaviour of thixocast Al-Si alloy, as cast and heat treated as well.

2. MATERIAL AND HEAT TREATMENTS

Material that has been investigated is hypoeutectic Al-Si alloy A356 (AlSi7Mg0,3) and two sets of specimens were used for testing. First was taken from original alloy billet (ref. as A356) and second from thixocast alloy (ref. as Thixo). The specimens were tested both as-cast and after T6 heat treatment. The chemical composition of the tested specimens is listed in table 1.

Elements	Si	Mg	Fe	Ti	Mn	Zn	Ni	Cu	Al
Percentage	7,27	0,31	0,10	0,10	0,02	0,04	0,01	-	Remaining

Table 1: Chemical composition (wt. %) of Al-Si alloy A356

2.1 Process of material production (Thixocast process)

The base material used in thixo–forming is mainly produced in cylindrical billets though magnetohydrodynamic (MHD) stirring. This involves electromagnetically stirring in the semi-solid state and hence without the contamination, gas entrapment and stirrer erosion involved in mechanical stirring to break up the dendrites of the produced base material. Depending on the stirring which is used in this procedure (rotary, linear or helicoidally), the mechanical properties of the final product can differ, despite the use of the same chemical composition of the base material. Furthermore, the cooling of the billets may also affect their mechanical properties.
The semi-solid forming process itself is an innovative process, gaining importance in recent time due to its advantages in comparison to conventional die casting and forging forming methods, such as near – net shape manufacturing, reduction of porosity, less filling defects, uniform solidification, superior material properties, etc. Through this process the base material is heated up electromagnetically in the form of cylindrical billets. These billets are then placed in a high pressure die casting press and injected directly into the die. Due to the high viscosity, i.e. greater than that of the liquid, the flow pattern does not become turbulent flow, so that there are less gas defects in the occurring material structure and the heat fatigue of the die can be reduced by using a lower initial temperature. The semi – solid process ensures small shrinkage defects as well as high surface quality with better mechanical properties, as the fatigue strength is concerned.

2.2. Structure, physical and mechanical properties

Heat treatment that was applied is T6 with the following parameters: solutioning at 548 °C for 6-8 h, water quenching and artificial ageing at 160±5 °C for 6 h.

Microstructure of the specimens was determined by metallography. Basic material, A356 shows dendritic and rosette structure with nonuniform distribution of size and shape. With heat treatment and thixocasting structure become more rosette and “as like grain” with spheroidized silicon around (figure 1).

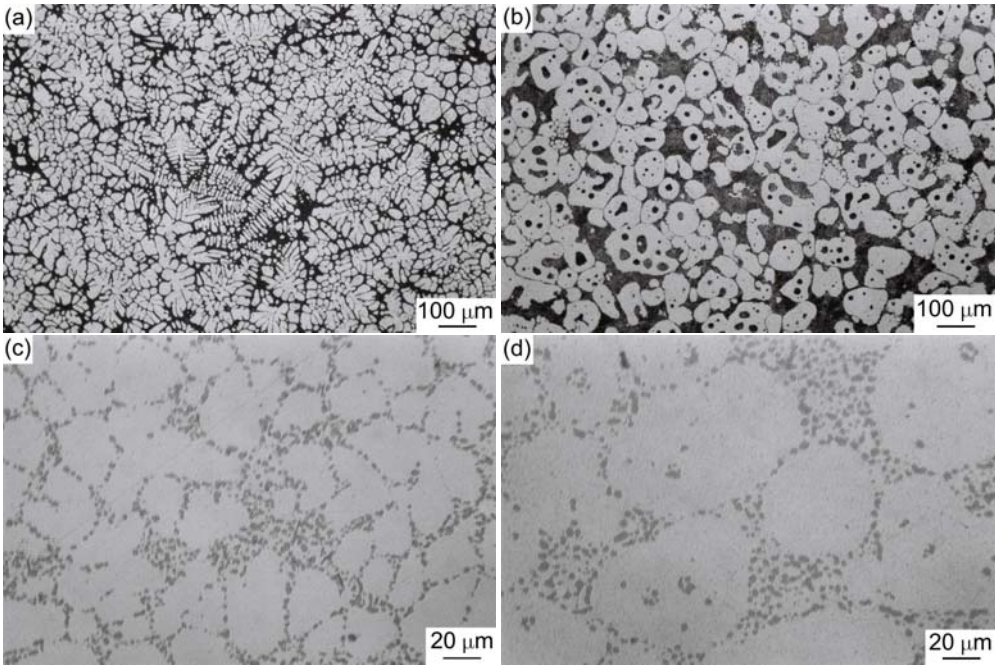


Figure 1: Microstructure of tested materials (a) A356, (b) A356 T6, (c) Thixo and (d) Thixo T6.

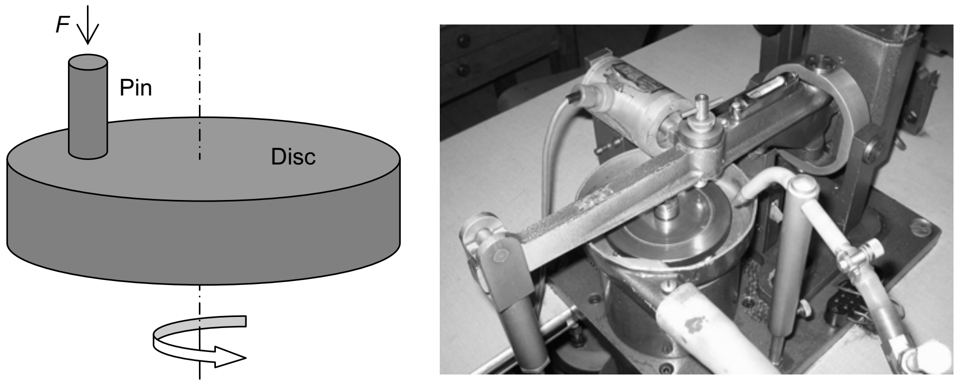
Surface roughness of the all specimens was R_a = 0,6 μm. Hardness and tensile tests of the tested materials are shown in table 2.

Alloy	Yield stress $R_{p\ 0,2}$, MPa	Tensile strength R_m, MPa	Elongation A_5, %	Hardness HB 5/250/30
A356	206,7	235,3	17,7	68
A356 T6	276,0	304,3	13,7	105
Thixo	307,7	339,5	7,3	107
Thixo T6	-	341,5	9,2	115

Table 2: Mechanical properties of the tested specimens

3. EXPERIMENTAL PROCEDURE

Investigation was conducted on pin-on-disc tribometer under dry sliding conditions in the ambient air at room temperature (≈ 25 °C). Cylindrical pins of 2,5 mm diameter and 30 mm length from tested materials were prepared and used as wear test samples. Disc (hereafter referred to as counter body) was made from steel (EN 25CrMo4, HRC 23), having 100 mm diameter and 10 mm thickness. Diagram of the load, pin, disc and the direction of the rotation and the photography of tribometer are shown in figure 2.



(a) Schematic diagram. (b) Photography.

Figure 2: Pin-on-disc tribometer.

Before and after testing, both the pin and the counter body (disc) were degreased and cleaned with petroleum benzine. At the end of the experiment the test pin was weighed to calculate the mass loss. Friction force was monitored during the testing and through acquisition system stored into the PC. Coefficient of friction was calculated, from friction force, during the tests. Measure of the mass loss was done with precision of 10^{-4} g.
Test conditions were: sliding speed of 0,3 m/s and sliding distance of 1000 m, which were constant and four different normal loads of 1 / 2,3 / 3,5 and 5 N (with contact area of approximately 5 mm^2 that gives specific load of 0,2 / 0,46 / 0,7 and 1MPa respectively). After testing, the worn surface of the pin and disc was examined by optical microscopy.

4. RESULTS AND DISCUSSION

Before performing the tests with all specimens, pre-testing with A356 specimens under reference condition (p = 0,46 MPa), was performed to test the reproducibility. The results were with standard deviation of 0,26458 and the error was between the limits of 10 %. The results, in terms of friction coefficient, are given in figure 3. The results indicate good reproducibility of the wear and friction results.
Friction test results show that, in the investigated loads range, heat treatment of the specimens don't have significant effect on the coefficient of friction (table 3). It could also be noticed that thixocast materials show less friction for smaller loads (figure 4). This effect is not present for higher loads i.e. tested materials show very similar values for friction. This could be explained by the appearance of the pin surface plastic deformation for the specific loads of 0,7 and 1 MPa.

		Specific load, MPa			
		0,2	0,46	0,7	1
Alloy	A356	0,239	0,305	0,364	0,386
	A356 T6	0,230	0,328	0,391	0,236
	Thixo	0,054	0,122	0,378	0,336
	Thixo T6	0,048	0,116	0,380	0,336

Table 3: Mean value of the friction coefficient

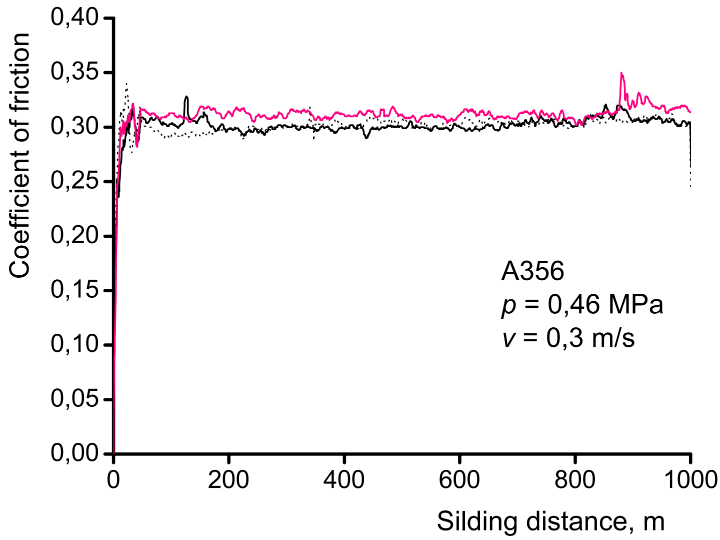


Figure 3: Diagram showing reproducibility of wear tests (Coefficient of friction vs. sliding distance).

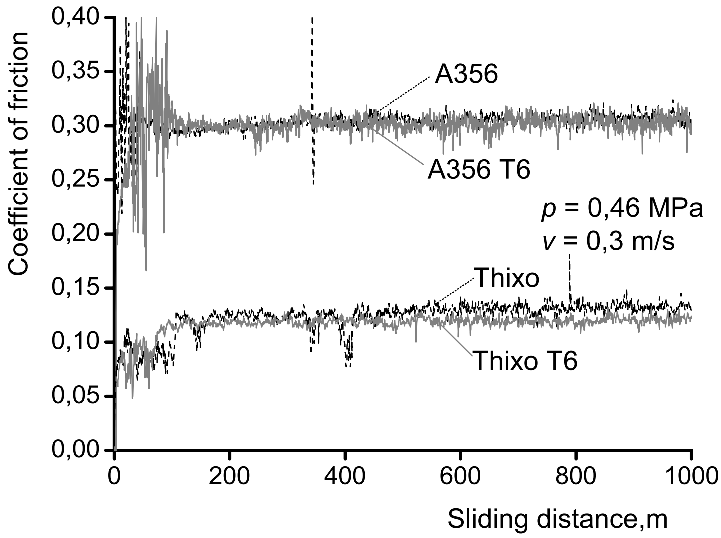


Figure 4: Coefficient of friction vs. sliding distance for p = 0,46 MPa and v = 0,3 m/s.

Mass loss of the tested specimens, caused by the wear, for the different specific loads is shown in figure 5. Heat treated specimens, in the investigated loads range, show better wear resistance comparing to the specimens that have not been heat treated. This is in correlation with better mechanical characteristics of these specimens, first of all with their increased hardness. It could also be noticed that thixocasted A356 specimen (Thixo) show less wear than specimen taken from the original billet (A356).

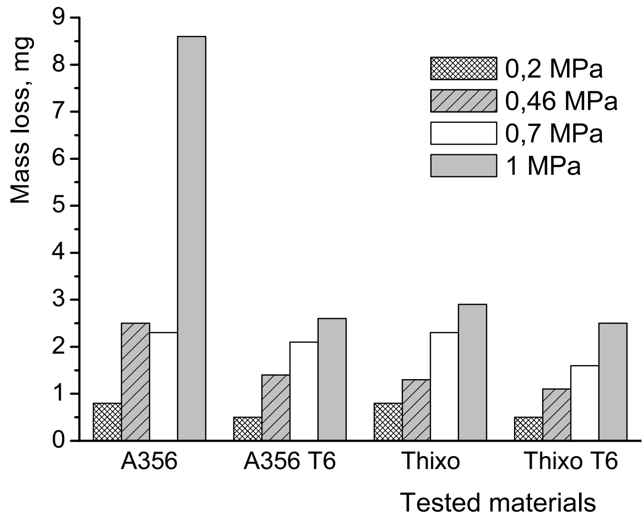


Figure 5: Mass losses of tested materials for different specific loads.

Dependence of the wear rate from the specific load could be qualified as linear (figure 6).

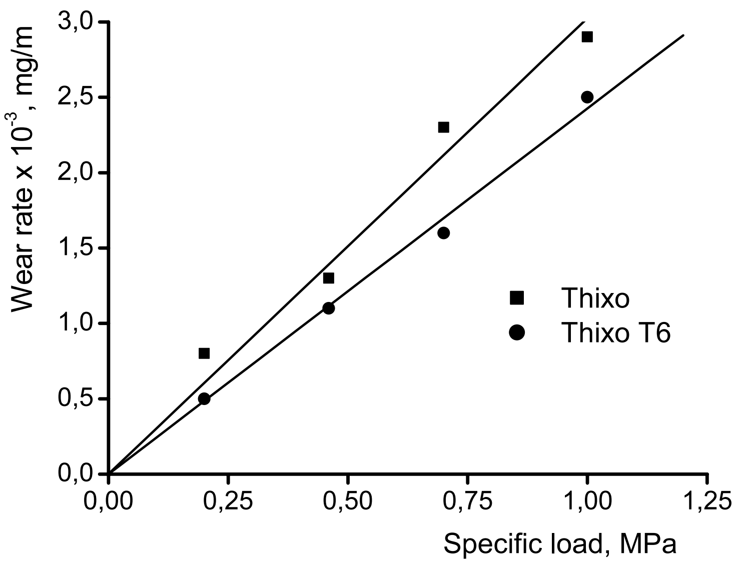


Figure 6: Wear rate vs. specific load for thixocasted specimens.

During the experiment investigation the state of the surfaces exposed to wear was also observed, by optical microscope, and adhesion and abrasion wear were noticed.

For the evaluation of the wear coefficient Archard equation has been used,

$$I_w = k\frac{F}{H}, \tag{1}$$

where I_w is wear rate in mm^3/m, k is wear coefficient, F is normal load in N and H is material hardness HB.

Diagram shown in figure 7 is drawn on the basis of this equation. From this diagram, for known load and hardness, it can be evaluated the value of the wear rate for tested materials.

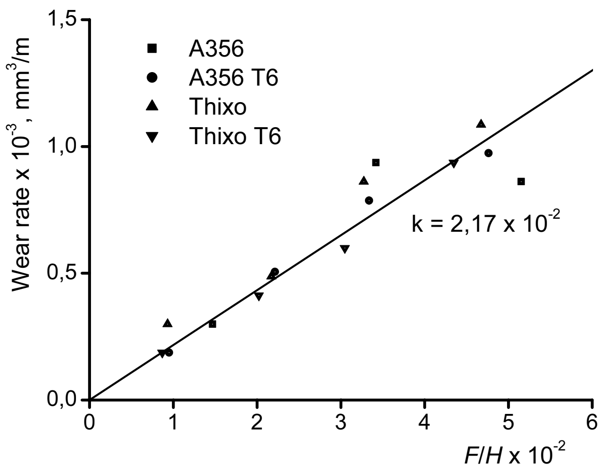


Figure 7: Wear coefficient for tested materials.

5. CONCLUSIONS

Thixocast materials show less friction and wear compared to the basic materials.
Dependence of the wear rate from the specific load, in the investigated loads range, is linear.
For smaller loads heat treated and thixocasted specimens had lower friction coefficient than for higher loads.
The laboratory investigation demonstrated the possibility of determining the wear coefficient and, for tested materials, value of $2{,}17 \times 10^{-2}$ could be accepted.
Predominate wear mechanisms, under the used test conditions, were adhesive and abrasive wear.

Acknowledgements

This work has been performed under the EUREKA programme project E! 3240. Help from the partners of the project (DROMEAS S.A., Greece for providing the material and Petar Drapšin, Serbia, for preparing the test specimens) as well as financial support received from Republic of Serbia, Ministry of Science and Environmental Protection, are gratefully acknowledged.

6. REFERENCES

1. Kopp R., Winning G., Möller T., Thixoforging of Aluminium Alloys, Institute for Metal Forming, RWTH-Aachen, Publication, www.rwth-aachen.de/sfb289/Ww/pdf/pub_ibf_metec99.pdf
2. Kang C.G, Jung H.K., A study on Solutions for Avoiding Liquid Segregation Phenomena in Thixoforming Process: Part II. Net Shape Manufacturing of Automotive Scroll Component, Metallurgical and Materials Transactions, 32B (2001) 129-136.
3. Lowe A., Ridgway K, McCarthy I.,Atkinson H., An evaluation model for determining the business process benefits of thixoforming, Journal of Engineering Manufacture, 214B (2000) 11-23.
4. Fan Z., Semisolid metal processing, International Materials Reviews, 47 (2002) 49-85.
5. Kapranos P., Kirkwood D.H., Atkinson H.V., Rheinlander J.T., Bentzen J.J., Toft P.T., Debel C.P., Laslaz G., Maenner L., Blais S., Rodriguez-Ibabe J.M., Lasa L., Giordano P., Chiarmetta G., Giese A., Thixoforming of an automotive part in A390 hypereutectic Al–Si alloy, Journal of Materials Processing Technology, 135 (2003) 271–277.
6. Lasa L., Rodriguez-Ibabe J.M., Effect of composition and processing route on the wear behaviour of Al–Si alloys, Scripta Materialia, 46 (2002) 477–481.
7. Haque M.M., Sharif A., Study on wear properties of aluminium–silicon piston alloy, Journal of Materials Processing Technology, 118 (2001) 69–73.
8. Yasmin T, Khalid A.A., Haquea M.M., Tribological (wear) properties of aluminum–silicon eutectic base alloy under dry sliding condition, Journal of Materials Processing Technology 153–154 (2004) 833–838.