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COEFFICIENT OF FRICTION OF HYPEREUTECTIC Al-Si ALLOY: PRELIMINARY INVESTIGATION

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Abstract: *This study represents a preliminary investigation of the mechanical and friction properties of hypereutectic Al-18Si alloy. Tribological experiments, under the linear reciprocating movement, show a decrease in the coefficient of friction with the increase of normal load. These findings provide valuable insights into the behaviour of the coefficient of friction and represent a starting point for further investigation and application of hypereutectic Al-Si alloys.*

Key words*: hypereutectic Al-Si alloy, coefficient of friction, linear sliding, reciprocating motion*

1. INTRODUCTION

The field of tribology plays an important role in understanding the interactions between surfaces in relative motion and is significant in various engineering applications. Among the materials investigated for their tribological properties, aluminium-silicon (Al-Si) alloys have drawn attention due to their favourable mechanical properties and widespread industrial applications. There are three categories of Al-Si alloys, based on their silicon percentage: hypoeutectic, eutectic and hypereutectic Al-Si alloys. Hypereutectic aluminium-silicon (Al-Si) alloys are materials that contain a Si content higher than 13 wt. %. Hypereutectic Al-Si alloys exhibit favourable characteristics, including a reduced thermal expansion coefficient, excellent weldability, good wear resistance and increased strength at high temperatures. These characteristics can be attributed to the presence of primary silicon within the aluminium alloy [1,2]. Properties of Al-Si alloys depend on the microstructure, i.e. distribution of primary Si, intermetallic phases and eutectic Si in the Al alloy. One way to achieve good microstructure is to select the appropriate production method. Miladinović et al. [3] have done a review of hypereutectic Al-Si piston alloys and composites observing production methods, and mechanical and tribological characteristics. It was observed that the semi-solid fabrication method had the best cost-to-quality ratio.

Birol [4] investigated die-casted and thixocasted samples, as well as heat-treated thixocasted Al-17Si alloy. Thixocasted samples had a uniform distribution of Si particles in Al alloy and no porosity was detected. Hardness was higher for thixocasted when compared to die-casted samples. After T5 and T6 heat treatment hardness increased, and it was concluded that thixocasting is an effecting production route for Al-17Si alloy. Birol and Birol [5] investigated the wear behavior of Al-16Si and Al-20Si in an as-casted state and heat-treated conditions. In the microstructure of thixocasted samples eutectic Si plates and needles modified into blocky particles, while the matrix was consisted of uniformly distributed small α-Al globules. T6 heat treatment influenced the rounding of the Si particles, while primary Si particles and Fe/Cu-based intermetallics, did not change during the treatment. Hardness increased with the increase of Si amount and also after T6 treatment. The specific wear rate was noticed to increase with the increase of Si. After T6 heat treatment specific wear rate for Al-16Si alloy was lower than in the as-casted state, while for Al-20Si alloy there was an increase in the specific wear rate. In general Al-20Si alloy had a higher specific wear rate than Al-16Si alloy.

There are not a lot of investigations of reciprocal linear tribological behaviour of hypereutectic Al-Si alloys. Reddy et al. [6] investigated the tribological behaviour of stir-casted hypereutectic Al-Si alloy. The contact geometry was pin-on-plate and test conditions were dry sliding, a normal load of 10 to 40 N and a sliding speed of 0.2 m/s. With the increase in normal load, the wear rate increased and it was lower for stir-casted samples when compared to the conventionally casted samples. Walker et al. [7] investigated the tribological behaviour of electron beam melted (EBM) hypereutectic Al-Si alloy under dry sliding, normal load of 5 N, initial Hertzian contact stress of 87 MPa and pin-on-plate contact geometry at reciprocating motion. The wear rate of the EBM-treated samples was higher than for the untreated samples.

The primary objective of this investigation is to characterise the frictional behaviour of the Al-18Si alloy through experimentation with a linear reciprocating sliding motion tribometer.

2. EXPERIMENTAL PROCEDURE

Hypereutectic Al-18Si alloy was produced at the Institute of Nuclear Sciences "Vinca" by semi-solid route (thixocasting process). Material macrohardness measurements were done at the Faculty of Engineering at the University of Kragujevac on a WPM Leipzig hardness tester. The force for indentation of the Vickers diamond pyramid was 294.2 N.

Tribological experiments were done on a tribometer with linear reciprocating sliding movement at the Faculty of Mechanical Engineering of the University of Niš. Figure 1 shows a block diagram of the tribometer function structure.

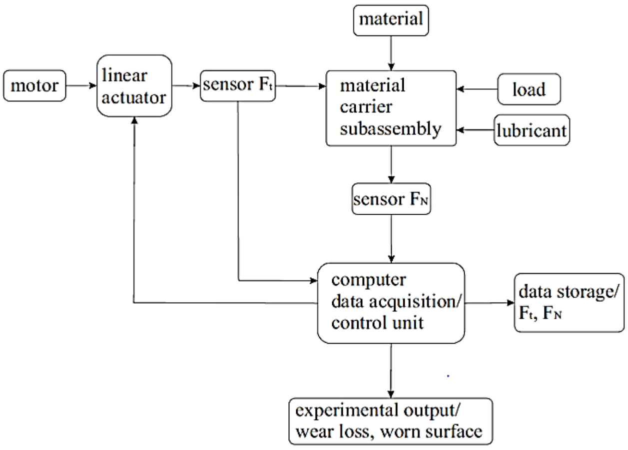

Fig.1. Block diagram of tribometer function structure

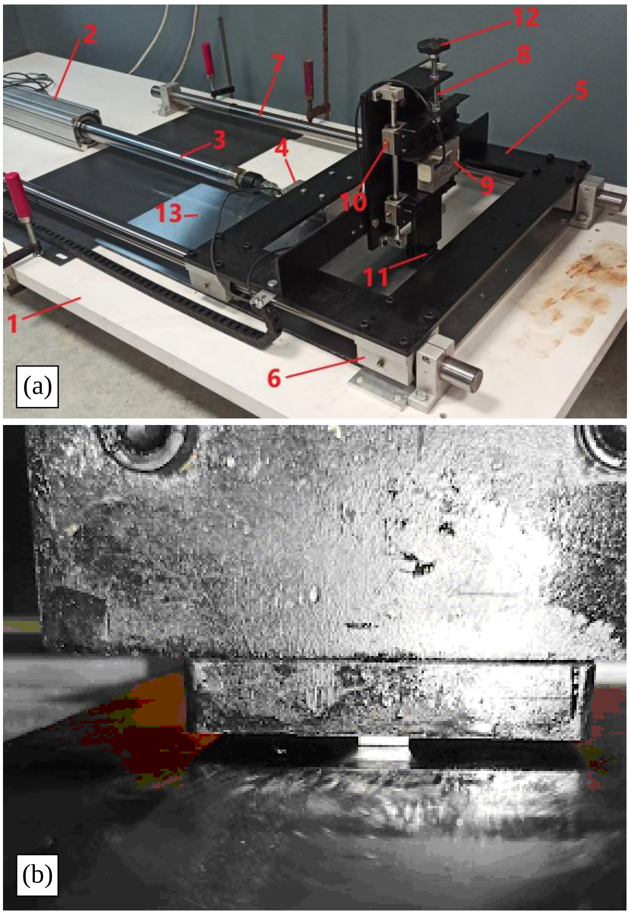

Fig.2. Tribometer: (a) general view and (b) contact pair

Figure 2a presents a tribometer used for this investigation. It consists of table 1, an actuator connected with AC servo motor 2 and rod 3. Rod is further connected to sensor 4 which measures friction force, and the sensor is connected to scatter 5 on which is mounted the subassembly of material carrier. Scatter is mounted on linear bearings 6 and guides 7 that enable linear movement [8]. This subassembly consists of threaded spindle 8 that is used to introduce normal load on investigated material, sensor for normal load 9, linear bearings 10 and material holder 11. The normal load is adjusted by rotating the knob 12. The counter-body is in the form of a plate and marked with 13. The actuator and sensors are connected to the computer and data is stored with appropriate software. The electric actuator is a MiSUMi SMC type ball screw drive with 600 mm maximum stroke, positioning accuracy of ± 20 μm, working temperature of 5 – 40 °C, and maximal horizontal and vertical load of 100 kg and 50 kg, respectively. The sensor for the normal load was HBM S2M type with a maximum load of 500 N, accuracy and error of 0.02 %, and operating temperature range of –10/+70 °C. The samples were with dimensions 16 × 12 × 6 mm. A 16 × 6 mm side surface of the sample was in contact with a plate made of 42CrMo4 steel (dimensions 600 × 300 mm), with their contact shown in Figure 2b.

Engine oil SAE 5W-30 was used for lubrication, with the characteristics presented in Table 1.

Table 1. Characteristics of engine oil SAE 5W-30 [9]

Characteristic	**Unit**	**Value**
Density at 15 °C	kg/m^3	848
Kinematic viscosity at 100 °C	mm^2/s	11.5
Dynamic viscosity (CCS) at –30 °C	mPas	5900
Viscosity index	–	165
Flash point	°C	230
Pour point	°C	– 39
Evaporation loss (Noack)	% m/m	8
HTHS viscosity (150 °C, 10^{-6} s^{-1})	mPas	3.6
Total base number	mgKOH/g	7

The actuator stroke (amplitude) was 450 mm, of which 50 mm was used for acceleration and 50 mm for deceleration (Fig. 3).

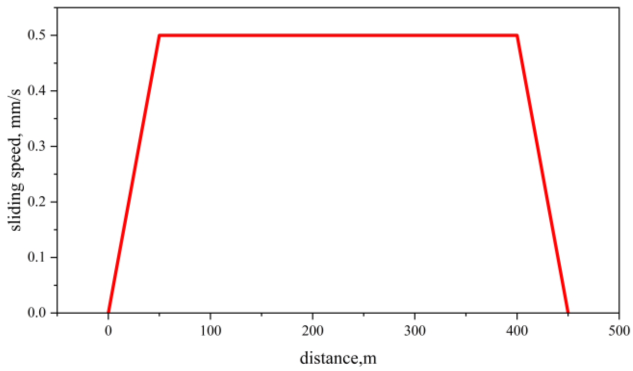

Fig.3. Operating conditions of linear actuator sliding speed vs. distance

The lubrication was performed manually. Conditions of the tests were as follows: a normal load of 100, 200 and 300 N and a sliding speed of 0.5 m/s. The number of cycles was 1111 and the testing time was approximately 2000 s, i.e. sliding distance was 1000 m.

3. RESULTS AND DISCUSSION

3.1. Hardness and coefficient of friction

Macrohardness measurements were done in five repetitions and the average hardness was 66.9 HV 30. Three replicant tribological tests were performed for each load (100, 200 and 300 N) and average values of the coefficient of friction (CoF) are presented in Figure 4. The obtained values of the coefficient of friction (0.15 to 0.4) are very close to the values for metals but under dry sliding conditions which can be 0.4 [10] or (0.2 – 0.52) [11]. Therefore it is obvious that the lubricant and applied lubrication method, for a given test conditions, had a very small influence on the CoF.

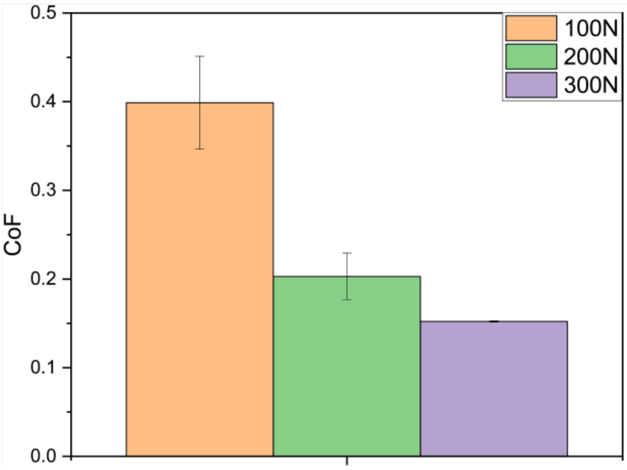

Fig.4. CoF for different normal loads

From Figure 4 it can be observed that with an increase in normal load, CoF decreases. Similar behaviour was found in investigations [12-16]. In [12] investigation was done for aluminium and dry sliding conditions, and CoF decreased with an increase in normal load from 10 to 20 N and was in the range from 0.3 to 0.5. Hypereutectic Al-Si alloy was investigated in [13], where CoF was observed in dry and lubricated sliding conditions for normal loads of 10 – 30 N. CoF for those conditions was in the range of 0.21 – 0.25. For the same alloy in dry sliding conditions and the same normal load, CoF was in the range of 0.185 – 0.285 [14]. An aluminium alloy in lubricated sliding conditions for loads of 10 – 50 N exhibited CoF from 0.064 – 0.16 [16].

As stated in [15], with an increase in load and thus contact temperature there is a possibility for an oxide layer to form. This oxide layer provides lubrication and lowers the CoF. In [14] authors have stated that with an increase in normal load and sliding speed, CoF is reduced due to the changes in shear rate. According to [12] The reduction of CoF with the increase in normal load is attributed to surface roughening and the accumulation of a substantial amount of wear debris.

3.2. Future research directions

This investigation is a starting point for future research. The continuation of this investigation would include wear measurements and microstructural characterisation of worn surfaces. Further research would involve more materials, probably composites with an Al-18Si matrix. The most used reinforcements for Al composites are Al_2O_3, SiC and Gr. SiC is a widely used reinforcement in hypereutectic Al-Si composites due to its excellent hardness, high thermal conductivity, and low thermal expansion coefficient. The hard and wear resistant nature of SiC particles contributes to improved wear resistance in the composite material [17-19]. The Al_2O_3 particles are selected as reinforcements for their high hardness, chemical stability and thermal resistance. The incorporation of Al_2O_3 in hypereutectic Al-Si composites can enhance their wear resistance, thermal conductivity and mechanical strength [20]. Gr is used as a reinforcement in hypereutectic Al-Si composites to improve their lubrication and reduce friction. The addition of graphite can contribute to enhanced self-lubricating properties, making the composite suitable for applications where low friction is crucial [21,22].

4. CONCLUSION

The investigation of hypereutectic Al-18Si alloy has provided valuable insights into its tribological properties. Tribological experiments using a linear reciprocating motion tribometer showed the influence of normal load on the CoF. The findings indicated a decrease in CoF with an increase in normal load, a behaviour consistent with dry sliding contacts, but there are some reports even for lubricated sliding. These results are preliminary and much more investigation needs to be done, like microstructural, mass loss, porosity and others.

REFERENCES

[1] JORSTAD, J., APELIAN, D. (2009) *Hypereutectic Al-Si alloys: Practical casting considerations*, International Journal of Metalcasting, Vol 3, No 3, pp 13-36, DOI 10.1007/BF03355450

[2] WANG, K., WEI, M., ZHANG, L., DU, Y. (2016) *Morphologies of primary silicon in hypereutectic Al-Si alloys: Phase-field simulation supported by key experiments*, Metallurgical and Materials Transactions A, Vol 47, No 4, pp 1510-1516, DOI 10.1007/s11661-016-3358-1

[3] MILADINOVIĆ, S., STOJANOVIĆ, B., GAJEVIĆ, S., VENCL, A. (2023) *Hypereutectic aluminum alloys and composites: A Review*, Silicon, Vol 15, No 6, pp 2507-2527, DOI 10.1007/s12633-022-02216-2

[4] BIROL, Y. (2008) *Cooling slope casting and thixoforming of hypereutectic A390 alloy*, Journal of Materials Processing Technology, Vol 207, No 1-3, pp 200-203, DOI 10.1016/j.jmatprotec.2007.12.071

[5] BIROL, Y., BIROL, F. (2008) *Sliding wear behaviour of thixoformed AlSiCuFe alloys*, Wear, Vol 265, No 11-12, pp 1902-1908, DOI 10.1016/j.wear.2008.05.001

[6] REDDY, T.V.S., DWIVEDI, D.K., JAIN, N.K. (2009) *Adhesive wear of stir cast hypereutectic Al-Si-Mg alloy under reciprocating sliding conditions*, Wear, Vol 266, No 1-2, pp 1-5, DOI 10.1016/j.wear.2008.05.003

[7] WALKER, J.C., MURRAY, J., NARANIA, S., CLARE, A.T. (2012) *Dry sliding friction and wear behaviour of an electron beam melted hypereutectic*

Al-Si alloy, Tribology Letters, Vol 45, pp 49-58, DOI 10.1007/s11249-011-9865-8

[8] BANIĆ, M., STAMENKOVIĆ, D., NIKOLIĆ, M., KORUNOVIĆ, N. (2021) *Design of linear sliding tribometer*, Proceedings of the 10th International Conference on Tribology – BALKANTRIB '20, Belgrade, Serbia, pp 93-94

[9] DESPOTOVIĆ, L., STOJILKOVIĆ, M., BAČEVAC, S. (2016) *Katalog proizvoda*, NIS AD Novi Sad.

[10] VENCL, A., VUČETIĆ, F., BOBIĆ, B., PITEL, J., BOBIĆ, I. (2019) *Tribological characterisation in dry sliding conditions of compocasted hybrid A356/SiC$_p$/Gr$_p$ composites with graphite macroparticles*, The International Journal of Advanced Manufacturing Technology, Vol 100, No 9-12, pp 2135-2146, DOI 10.1007/s00170-018-2866-0

[11] SAGALOVYCH, A., SAGALOVYCH, V., POPOV, V., DUDNIK, S., OLIJNYK, O. (2022) *Tribological characteristics of samples made from titanium alloy VT5 nitrided in plasma glow discharge*, Tribology and Materials, Vol 1, No 3, pp 106-113, DOI 10.46793/tribomat.2022.013

[12] CHOWDHURY, M.A. KHALIL, M.K. NURUZZAMAN, D.M., RAHAMAN, M.L. (2011) *The effect of sliding speed and normal load on friction and wear property of aluminum*, International Journal of Mechanical and Mechatronics Engineering, Vol 11, No 1, pp 53-57

[13] AL-SAMARAI, R.A., HAFTIRMAN, AHMAD, K.R., AL-DOURI, Y. (2012) *The influence of roughness on the wear and friction coefficient under dry and lubricated sliding*, International Journal of Scientific and Engineering Research, Vol 3, No 4, pp 1-6

[14] AL-SAMARAI, R.A., HAFTIRMAN, AHMAD, K.R., AL-DOURI, Y. (2012) *Effect of load and sliding speed on wear and friction of aluminum-silicon casting alloy*, International Journal of Scientific and Research Publications, Vol 2, No 3, pp 1-4

[15] KATHIRESAN, M., SORNAKUMAR, T. (2010) *Friction and wear studies of die cast aluminum alloy‐aluminum oxide‐reinforced composites*, Industrial Lubrication and Tribology, Vol 62, No 6, pp 361-371, DOI 10.1108/00368791011076263

[16] XIA, J., ZHAO, J., DOU, S. (2022) *Friction characteristics analysis of symmetric aluminum alloy parts in warm forming process*, Symmetry, Vol 14, No 1, paper 166, DOI 10.3390/sym14010166

[17] PHANEENDRA, Y., MOHAN RAO, I., VIJAYA KUMAR, P., KUMARI, P.S., BABU, K.S., AVINASH BEN, B., DHANUNJAYARAO, B.N., SWAMY NAIDU, N.V., HEMALATHA, S. (2023) *Enhancement of tribological properties of AA7075 aluminum alloy using nano-silicon carbide reinforcement: A detailed wear analysis and microhardness study*, Materials Today: Proceedings, Article In Press, DOI 10.1016/j.matpr.2023.08.135

[18] PAL, M.K., VIKRAM, A., BAJAJ, V. (2019) *Enhanced microstructure and mechanical properties of SiC particle reinforced aluminium alloy composite materials*, Acta Metallurgica Slovaca, Vol 25, No 4, pp 253-258, DOI 10.12776/ams.v25i4.1359

[19] SHARMA, A.K., BHANDARI, R., PINCA-BRETOTEAN, C. (2021) *Impact of silicon carbide reinforcement on characteristics of aluminium metal matrix composite*, Journal of Physics: Conference Series, Vol 1781, Paper 012031, DOI 10.1088/1742-6596/1781/1/012031

[20] MURTHY, B.V., AURADI, V., NAGARAL, M., VATNALMATH, M., NAMDEV, N., ANJINAPPA, C., PATIL, S., RAZAK, A., ALSABHAN, A.H., ALAM, S., QAMAR, M.O. (2023) *Al2014-alumina aerospace composites: Particle size impacts on microstructure, mechanical, fractography*, and wear characteristics, ACS Omega, Vol 8, No 14, pp 13444-13455, DOI 10.1021/acsomega.3c01163

[21] KHATKAR, S.K., SURI, N.M., KANT, S., PANKAJ (2018) *A review on mechanical and tribological properties of graphite reinforced self lubricating hybrid metal matrix composites*, Reviews on Advanced Materials Science, Vol 56, No 1, pp 1-20, DOI 10.1515/rams-2018-0036

[22] ZAMANI, N.A.B.N., ASIF IQBAL, A.K.M., NURUZZAMAN, D.M. (2019) *Mechanical and tribological behavior of powder metallurgy processed aluminum-graphite composite*, Russian Journal of Non-Ferrous Metals, Vol 60, No 3, pp 274-281, DOI 10.3103/S1067821219030179

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