A TRIBOLOGICAL RESEARCH ON A RECIPROCATING SLIDING CONTACT OF ALUMINUM – FERROUS COMPOSITE AGAINST CAST – IRON

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Summary

At the Faculty of Mechanical Engineering of the Gdańsk University of Technology a research was undertaken on new metallic composites of potentially high wear resistance in reciprocating sliding. Composites were composed of ferrous powder or cutting carbon steel (N9) in cast aluminium alloy (AlSi11) matrix. A reaction between aluminium and iron was anticipated to result in the strengthening phases forming in the material.

The composite materials and a reference non – composite were tested on the TPZ-1 tribometer in reciprocating unlubricated sliding against cast – iron. Tests were carried out at 5 MPa surface pressure and speed of 0.1 m/s.

Wear resistance was different for each material tested. The highest wear rate was exhibited by reference aluminium–silicon alloy. In composite materials the wear was slower. The exact influence of factors such as the time of mixing of the iron powder with the aluminium base material on the wear rate remains still to be established.

The friction coefficient characteristics vary with the material tested. The most stable friction coefficient was observed on unmodified aluminium – silicon alloy. A simple relation between the value of the friction coefficient and the wear rate among the tested materials was not observed yet.

1. Introduction

The improvement in tribological characteristics of sliding pairs occurring in the internal combustion engines (e.g. pairs of the piston – cylinder category) is mainly associated with development in materials, frequently aluminium based. These materials are subjected to various processes, which modify their behaviour under sliding friction conditions, wear resistance especially. The results have been shown in successful application of "aluminium" pistons and cylinder liners in many piston engines and similar appliances.

At the Gdańsk University of Technology a materials engineering research combined with tribological research is carried out on modified light metal alloys [5, 6, 7]. The quest for low density and high wear resistance materials has led to the fabrication of aluminium--silicone cast alloy matrix composite material with ferrous modifying additive.

The concept of a cost effective production of composite material by *in situ* precipitation of reinforcement in the metal matrix has been developed during the last years [5]. During the fabrication process the liquid matrix alloy is mixed with a selected solid metal or non-metal powders. An exothermic chemical reaction between the matrix alloy and the powders leading to the precipitation of reinforcing phases, so the new material may have the advantages of improved strength, modulus of elasticity, abrasion resistance etc.

The *in situ* reinforcing additive particles have very clean surfaces enabling better wetting end bonding between them and the matrix. Sub-micron size of the precipitates is possible, helping to avoid brittleness of the material, and may constitute the effective reinforcement once their properties (e.g. stiffness) and the morphology (e.g. aspect ratio) are well selected.

In situ particulate-reinforced aluminium based composites may be successfully fabricated by several techniques – as hot pressing and reaction sintering, reaction pressing and extrusion, reactive gas injection or stir-casting [5]. The last of them was applied to produce the composite materials which were examined in tribological tests described in the paper.

2. Specimens preparation

Schematic of the set-up for composites fabrication is shown in Fig. 1. The eutectic Al-Si alloy (11% Si , signed AlSi11) was used as matrix material. The particles of reinforcements were obtained by precipitation *in situ*, as a result of self propagating reaction between the liquid aluminium alloy and selected precursor elements for intermetallics, introduced in the form of powders. The powders were gradually added into the liquid alloy (i.e. AlSi11) while stirring the mixture continuously (265 r.p.m.).

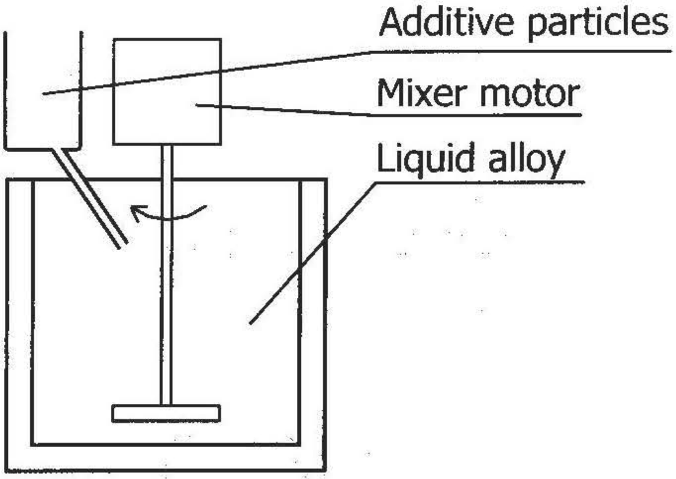
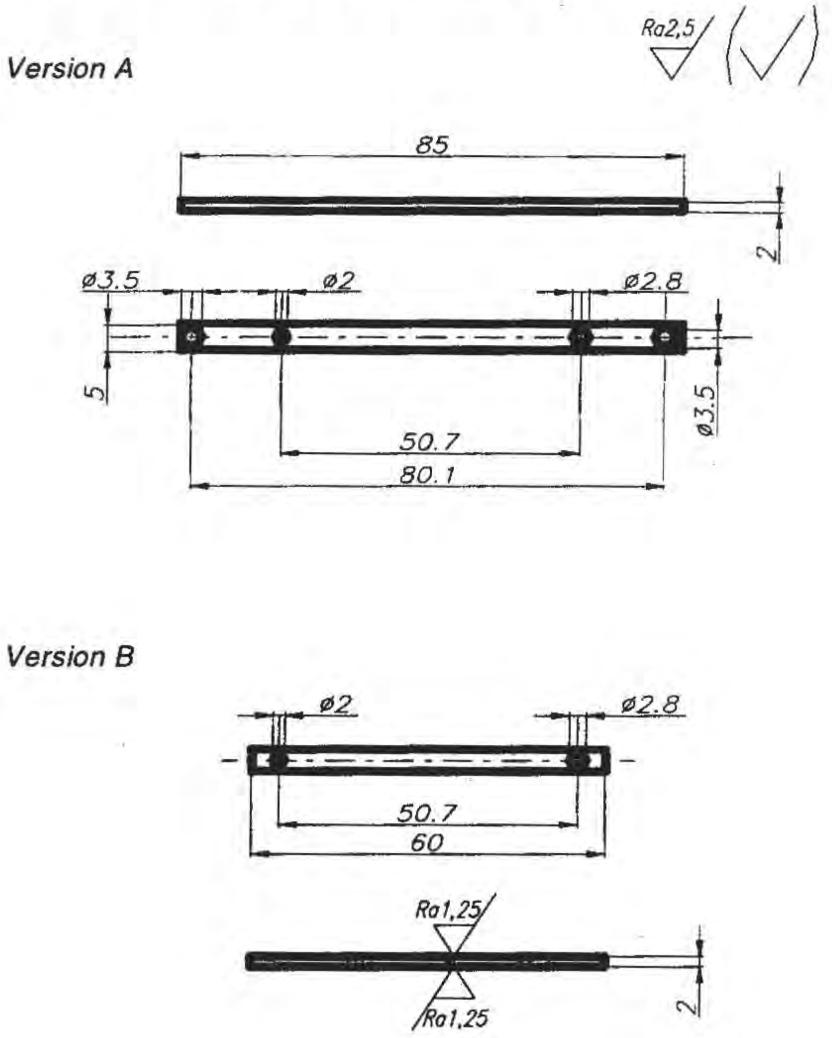


Fig. 1. Schematic of the experimental set-up for composites fabrication [5]

Two types of modifying additives were used: ferrous powder and cutting tool carbon steel (N9) powder. A single concentration of the powder additive (10 % mass) was tested, but several specimens were prepared for various mixing periods before setting the material in a mould. The following materials were made and later used in tribological testing:

1) eutectic aluminium – silicone alloy AlSi11 – marked „**A 12**" (reference material),
2) composite material „**17**", obtained by adding 10 % (mass) of ferrous powder to liquid AlSi11 aluminium – silicone alloy at a temperature of. 740°C; mixing time 15 min.,
3) composite material „**E**", obtained by adding 10 % (mass) of ferrous powder to liquid AlSi11 aluminium – silicone alloy at a temperature of. 740°C; mixing time 40 min.,
4) composite material „**H**", obtained by adding 10 % (mass) of ferrous powder to liquid AlSi11 aluminium – silicone alloy at a temperature of. 740°C; mixing time 100 min.,
5) composite material „**N 9.2**", obtained by adding 10 % (mass) of cutting tool carbon steel (N9) powder to liquid AlSi11 aluminium – silicone alloy at a temperature of. 670°C; mixing time 40 min.

The materials were later machined into a set of 5x2 mm section rods either 85 or 60 mm long (depending on the length of the raw material) (Fig. 2).



Version A

Version B

Fig. 2. Shape and dimensions of the aluminium alloy and composite material specimens

After machining the working surfaces of the specimens were polished with a sand paper in order to decrease the roughness reaching about 1,25 µm average (Fig. 2).

Counter specimens were machined from modified cast iron (350), tempered to a hardness of 35 HRC. Dimensions of the counter–specimens are shown in Fig. 3; The working surface is a rectangle 2x5 mm with the sliding direction parallel to the longer edge of the surface.

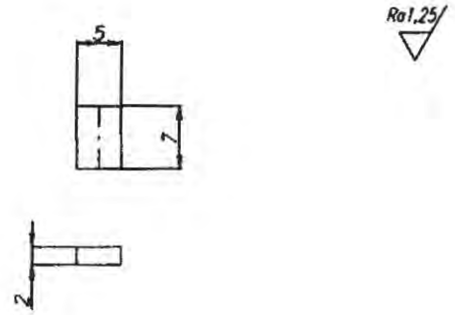


Fig. 3. The shape and dimensions of the cast iron counter specimen

3. Reciprocating sliding friction testing

The test were carried out on a TPZ-1 reciprocating tribometer. Design details and the principle of operation of the test rig were presented in detail in earlier works [1,...,4, 6, 7].

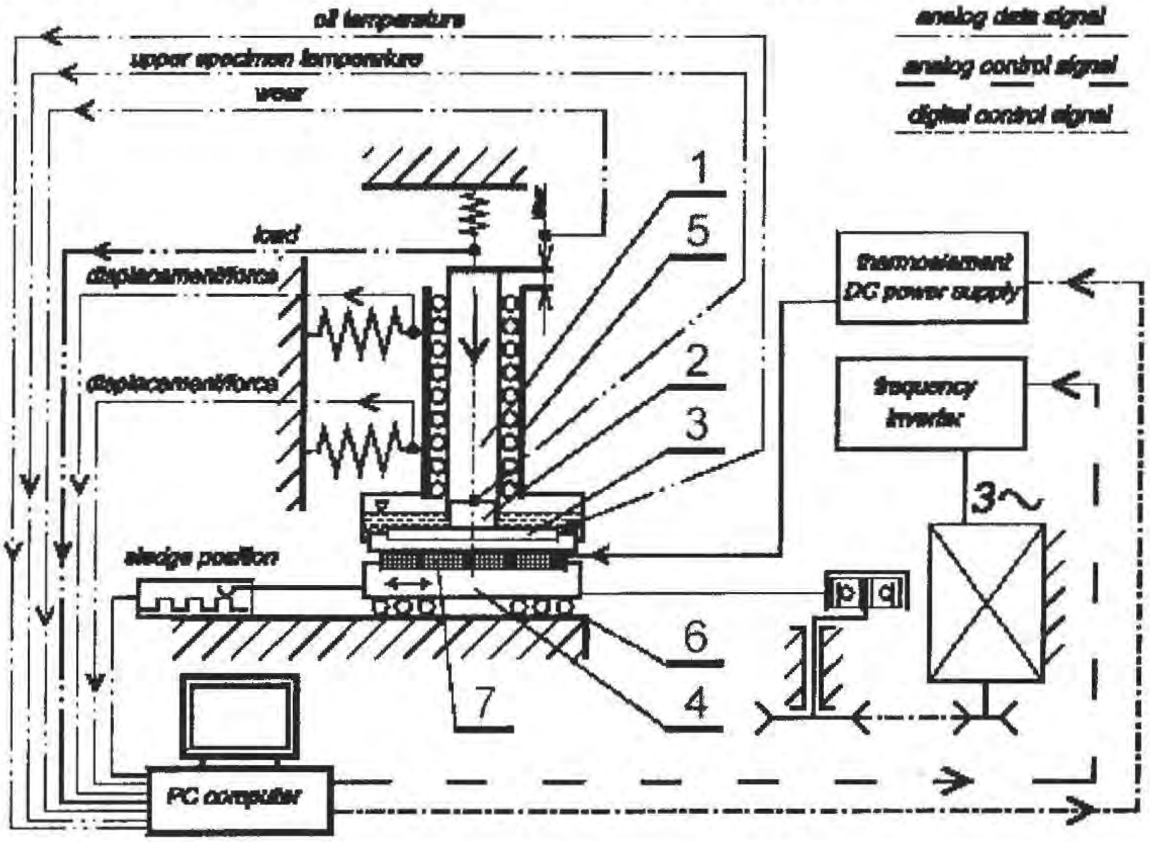


Fig. 4. Schematic of the TPZ-1 reciprocating tribometer test head and control system: 1 - push rod, 2 - upper (passive) specimen, 3 – lower (reciprocating) specimen, 4 - sledge, 5 - push rod holder, 6 - machine body. „z" stands for summary linear wear of specimens

The cast iron counter–specimen was attached to a plunger supported on linear roller guides and its motion was restrained in the sliding direction during the tests. The test load was acting on the top end of the plunger. The working face of the counter–specimen was in a loaded contact with the aluminium alloy oscillating specimen.

The tests were carried out with no lubrication under the conditions of load, velocity and temperature listed below:

- contact surface stress/load:	constant, 5 MPa, (50 N on a 10 mm^2 surface area),
- sliding velocity:	constant 0,1±0,02 m/s (excluding reversal points),
- temperature:	not regulated, ambient 20°C.

The machined specimens working surfaces were lapped on a 1200 grade sandpaper and afterwards all the components of the test set up were degreased in alcohol.

Each separate test run lasted 30 minutes divided into three 10 minute intervals. At the end of each interval the test rig was stopped and the aluminium alloy (composite) specimen was dismantled from its seat and a surface profile was taken across the wear mark on the specimen surface. Wear was measured as the depth of the wear mark and expressed in µm [6, 7]. In Fig. 4 photographs are shown of aluminium specimens with wear marks visible after the completion of the test.

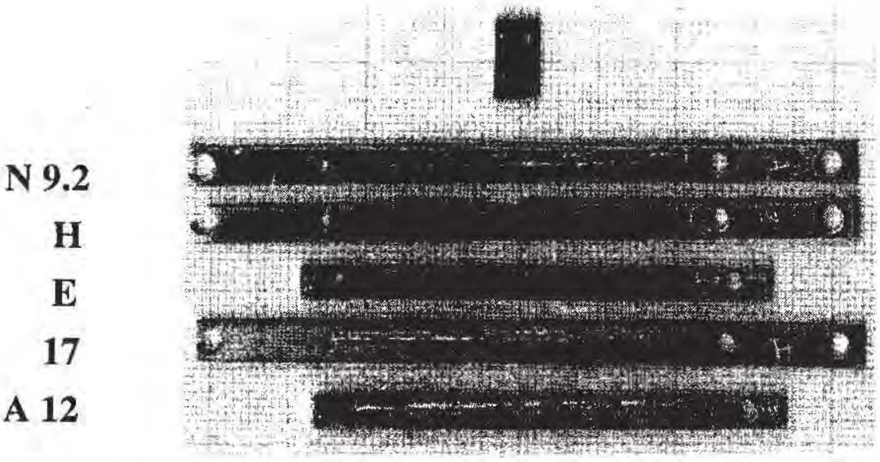


Fig. 5. Aluminium composite specimens (designated: N 9.2, H, E, 17) and a reference (A12) specimen after reciprocating sliding tests. A cast–iron counter-specimen shown at the top. Background reference grid spacing – 1 mm.

The following signals were registered continuously: slide displacement, load, friction force, temperatures of specimen and counter–specimen, and linear wear of the friction pair.

4. Wear measurement results

The wear of aluminium alloy specimens was calculated on the basis of data obtained in digital files from a computerised profilographometer. The profile taken across the wear mark was processed to obtain the cross – sectional area of the worn groove. Average depth of the groove was then established in order to generate wear curves gathered and presented in Fig. 6.

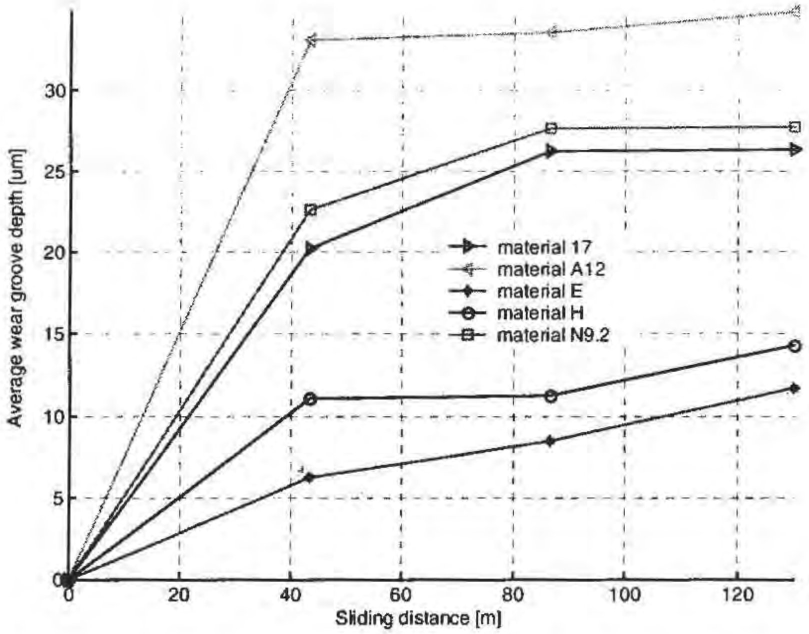


Fig. 6. Wear plots versus sliding distance for the tested sliding couples of aluminium – silicone alloy or aluminium composites sliding against a cast – iron specimen.

Wear plots presented in Fig. 6 clearly depict significantly improved wear resistance of the composite materials as compared to the basic aluminium – silicone AlSi11 alloy. The depth of wear was greatest on unmodified material coded A12. It cannot be established as yet what is the relation between the conditions of preparation of composite materials and wear rate. Among the materials modified by addition of ferrous powder the lowest wear occurred in tests with the material prepared during a 40 minute long mixing (material E). Higher wear was observed on material prepared in a 100 minute long mixing (material H), and the highest on material with the shortest, 15 minute, mixing time (material 17). The latter wearing just slightly slower than the wear of the only composite material containing cutting tool carbon steel powder addition (material N 9.2), which seems a counter – intuitive result.

Obtained results, that addition of ferrous (or steel) powder improves of aluminium alloy wear resistance, are in concordance with earlier literature information, based on data from reciprocating dry sliding wear tests, as well [5].

5. Friction coefficient

Friction coefficient curves were generated for each of the tested materials on the basis of the collected load and friction force signals. Since a reciprocating sliding is the case considered it is obvious, that not only was the friction force varying in a wide envelope during the "sustained" sliding, but also it was reversed at each turning point. For the above reasons only these fragments of the signal were considered, which corresponded to the part of the stroke with the most stable sliding speed. Absolute values of the friction force were calculated to avoid negative resultant friction coefficients. Such abridged sets of data were interpolated in order to obtain a curve depicting a general tendency of changes of the friction coefficient over the entire test run. These curves are shown in Fig. 7 allowing for comparison.

All tested sliding pairs, apart from the one comprising the N 9.2 material, exhibited similar friction coefficient at the beginning of the test, ranging from 0,2 to about 0,23. The lowest observed value of friction coefficient was observed in tests on material E. For the particular material friction coefficient was decreasing monotonously from a starting value of just above 0,22 down to about 0,12 at the end of the test. The initial value of friction coefficient on material 17 was slightly greater than 0,2, it increased to about 0,215 after about 40 m of sliding distance and then gradually decreased to less than 0,16 at the and of the test. The approximation curve encompassing the friction coefficient on material N 9.2 is similar to that for material 17 only the values of the coefficient are generally higher: about 0,265 at the start, 0,295 maximum (after 60 m of sliding) and 0,25 at the end. With an almost identical initial friction coefficient as material 17 the H material exhibited a tendency to increase the coefficient as the test progressed to a value of 0,28 after about 100 m of sliding. During the final 30 m the coefficient decreased to about 0,27. The global increase of the friction coefficient was greatest for material H.

Interestingly the friction coefficient calculated from tests on the reference material A 12 (AlSi11) was the most stable in all tests and it oscillated around about 0,22 with a slight tendency to decrease with sliding distance.

The results disclose large differences in the magnitude and course of changes of the friction coefficient in reciprocating sliding on pairs comprising different composite materials. Still more detailed research is necessary to establish a correlation between the manufacturing technology details and the friction coefficient observed.

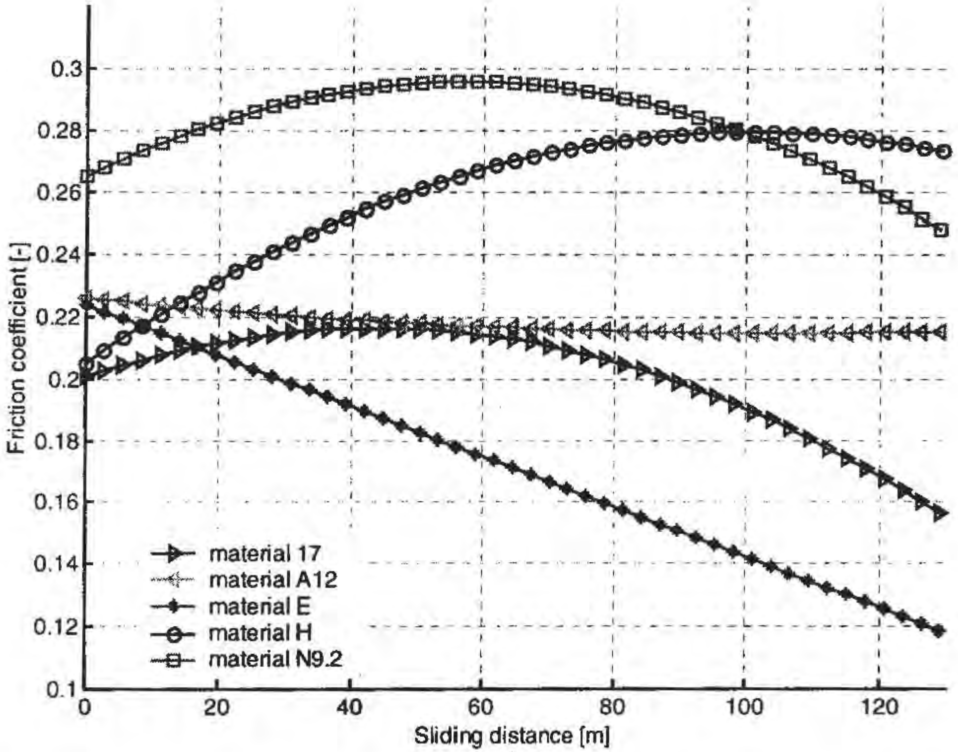


Fig. 7. Mean approximated friction coefficient sliding distance during tests on a TPZ-1 tribometer for specimens from aluminium alloy or aluminium – steel composites.

6. Conclusions

As a result of the tribological research conducted it has been proved, an increase in wear resistance of aluminium – silicone alloy sliding against cast iron can be improved by modifying the aluminium alloy with an additive of either ferrous powder or cutting tool carbon steel powder. The greatest wear rate was observed on unmodified material (A 12). Different composite materials differed in wear resistance, but the exact dependence of wear rate from the conditions of manufacturing will require further testing to be done. The chief parameters being the time of mixing in liquid state, concentration of the modifying additive and the composition of the additive.

The characteristics of the friction coefficient as a function of sliding distance proved to be different for each of the materials tested in both , the magnitude and course of changes. The lowest friction coefficient was observed on material E and the highest on the material N 9.2. The results obtained so far are inconclusive with respect to a possible relation between the course of wear and the friction coefficient. The issue is to be addressed in further research.

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