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CRITERIA OF MAINTENANCE FOR ASSESSING THE SUITABILITY OF ALUMINUM ALLOYS FOR THE PRODUCTION OF INTERCHANGEABLE PARTS INJECTION MOLD

EKSPLOATACYJNE KRYTERIA OCENY PRZYDATNOŚCI STOPÓW ALUMINIUM DO PRODUKCJI WYMIENNYCH CZĘŚCI FORM WTRYSKOWYCH*

With increasing production of plastics crop up also the need to improve their processing abilities. New methods and materials in the construction of forms are examined. Low weight and easy machinability predestines aluminium alloys for use as a material for the production of injection moulds for manufacturing of small series production. The paper deals with the verification of the suitability for selected aluminium alloys for the production of mould inserts based on problem, which occurred at real injection mould used for small series production. Massive wear of material at contact of ejector pin made from 1.1203 and insert made of Al-alloy caused deformations at final moulding. At next experiments were four types of Al alloys used. At following materials hardness and wear of materials was evaluated. To simulate the adhesive wear of friction pairs 1.1203 - Al alloy with and without greasing was adhesive wear test machine AMSLER used with simulation of surface contact. Wear intensity was evaluated by the coefficient of friction.

Keywords: *injection mould, aluminum alloy, friction pairs, adhesive wear, friction coefficient.*

Z powodu zwiększenia produkcji różnorodnych elementów z tworzyw polimerowych zauważana jest konieczność poprawiania procesów przetwórczych, w tym konstrukcji maszyn i narzędzi do ich przetwórstwa. Dlatego badane są nowe metody i materiały w budowie form używanych w procesie wtryskiwania. Niska waga i dobra obrabialność stopów aluminium sprawiają, że materiały te są chętnie stosowane w produkcji form wtryskowych do produkcji małoseryjnej. Artykuł dotyczy weryfikacji przydatności wybranych stopów aluminium do produkcji wymiennych części form wtryskowych pod kątem zapewnienia jak najdłuższej prawidłowej eksploatacji narzędzi. Zagadnienie przedstawione w artykule dotyczy rzeczywistych problemów, które wystąpiły w formach wtryskowych stosowanych do produkcji krótkich serii. Występujące znaczne zużycie materiału na styku wypychacza wykonanego ze stali 1.1203 i części formy wykonanej ze stopów aluminium, oraz deformacje stopu aluminium wpływają na jakość przedmiotów produkowanych z tworzyw polimerowych. W kolejnych eksperymentach przetestowano cztery rodzaje stopów Al. Wyznaczono twardość materiałów i zużycie ścierne. Aby symulować współpracę węzłów tarcia 1.1203 – Al przeprowadzono testy z i bez użycia środka smarnego za pomocą urządzenia AMSLER.

Słowa kluczowe: *wtryskiwanie, stopy aluminium, pary cierne, zużycie adhezyjne, współczynnik tarcia.*

1. Introduction

The growing demand for tools for plastics processing intense the development of new types of plastics, as well as the rapid development of manufacturing, in particular, their application in various sectors of industrial activity. Of particular importance is that the production of elements of polymeric and the associated need for producing a growing number of tools for shape them is a significant factor in the various sectors of industrial activity.

The design of tools for forming the metal and plastics is one of the most challenging and difficult areas of engineering. Among most constructional and technologically sophisticated tools are included tools for deep drawing of sheets, tools for aluminium pressure forming and tools for plastic injection moulding – injection moulds [4, 7].

Moulds are complicated technical devices that must withstand high pressure, must provide high mouldings pressure while maintaining the precision cooperate of the various parts of the mould. Correctly constructed mould must ensure high repeatability of dimensional manufactured of elements, including mutually perpendicular planes forming, while allowing easy removal products or mouldings, from the mould. Injection moulds work automatically. Design forms and methods of production are therefore a large field of knowledge and creation of new forms of injection involves significant financial costs.

Due to the high hydraulic pressure prevailing in the hydraulic system responsible for the correct operation of the mould, which translates into a much higher pressure in the mould cavity at injection mould, very important is quality of workmanship of the mould. Various maintenance conditions of the mould, under high load may cause deformation of the mould, when they are improperly designed [3, 5]. In order to ensure long-term and reliable maintenance of the mould, it is important to correct the submission of a few technical aspects such as mould design, selection of materials for its production intended for particular types of polymer materials and the optimization of processing conditions [2, 11, 15].

Moulds consist of functional and auxiliary parts. Each of these parts is manufactured with high precision, which is reflected in their cost. The material used in the manufacture of injection moulds must meet the required operating conditions, including temperature, pressure and abrasion resistance. The temperature of thermoplastic mate-

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** rial witch flowing into the mould die during the injection moulding process is very diverse. Depending on the type of material generally ranges between 120 and 300°C. The increased temperature and high pressure on the mold material, make it necessary to determine the abrasion resistance of the mold functional unit. This is particularly important in the processing of polymeric composites having a reinforcement material of high abrasive, e.g. quartz, graphite or other hard materials [12, 6, 10].

2. Non-ferrous materials used in the manufacturing of injection molds

For the production of moulds and its parts is the most commonly used tool steel, structural carbon steel and alloy steel. Nowadays are more and more non-ferrous materials used in the production of injection moulds [8]. The main reason for growing interest on the use of these materials is the pressure from the market to improve product quality and shorten production times [5, 12].

Non-ferrous metals, especially copper alloys and aluminium alloys are capable by its high conductivity to meet requirements for the production of these forms [13]. Non-ferrous materials also found their use in pre-production stages such as materials for moulds for small series production. These prototype forms become the subject of tests that will provide the necessary information for planning of their manufacturing and maintenance [6, 9, 12].

3. The problem and aim of the research

Figure 1 shows the portion of functional the injection mould, the insert forming the a casting cavity. Presented insert before the final surface treatment. The shaped insert is produced, as a part, to quickly modify casting cavity of injection mould. Replacement of only one part of the mold allows for a quick regulating the production of various elements in small series. You can easily verify the technology of production and change the parameters for injection molding. The choice of material for the production shown in Figure 1a shaped inserts based on the following assumptions: easy mechanical processing of the material and to determine future production batches of a small series of no more than 1,000. Based on these principles to produce inserts for injection mould selected material EN AW-1100.

Injection mold, with produced insert constructionally suited to the location of the die of plasticizing unit injection was mounted in the injection moulding tool arrangement at injection moulding machine Demag 25–80. For whole mould only one ejector pin was needed, located at the centre of the mould opposite to inlet. Ejector pin is responsible for the removal of the moulding from the mould cavity after the end of the injection cycle. Such prepared form has been tested consisting in the operation of the injection mould inserts by performing the injection moulding process.

a) b)

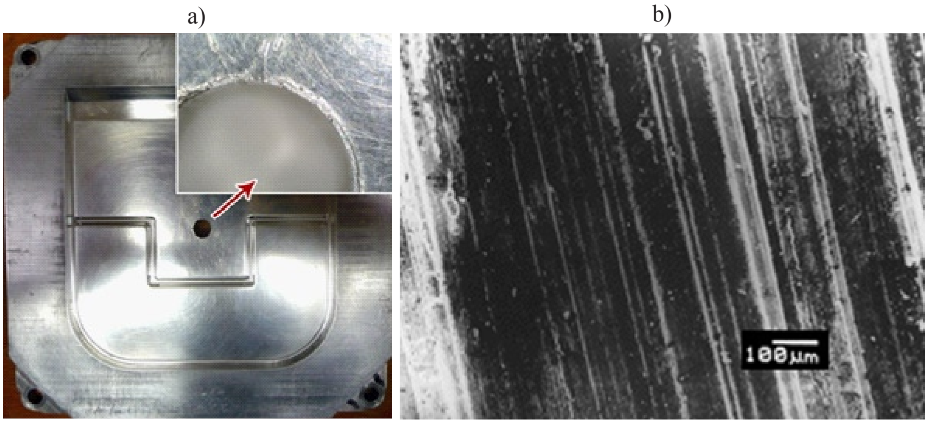


Fig.1. Insert for injection molding with highlighted damaged surface

After production of the first batch of 100 cycles was considerable surface wear (inequalities and distortions) in place of contact of cavity and ejector from steel 1.1203. By analysis of the problem it was found that the material for the production of the cavity shape is insufficient for the resistance to the injection pressure, and by the contact with ejector material was breakaway. These micro-cracks consequently caused small deformations. These microcracks as a consequence, the continued operation of the mold, resulted in a small distortion of the material consisting of the formation of defects in the material due to wear and plastic deformation in some cases (Fig. 1b).

The aim of experiment was to the identify suitable material for the production of shaped inserts for injection moulds for small series production and comparison with previously used materials EN AW-1100. The suitable material would show better properties, including, inter alia, less wear direct influence on the stability of the mould insert parts.

Process of experiments: determination of the chemical composition of selected materials, comparison of material hardness and comparison of adhesive wear of friction pairs 1.1203 alloy with and without greasing.

Based on these findings, we will be able to identify material that will be quickly and easily machinable, but also suitable for the production of shaped cavities for experimental injection moulds for small series of plastic mouldings. The study will also estimate whether the material can be quickly and relatively easy to process on metal working machines.

4. Experimental part

4.1. The material and experimental methodology

The aim of experiments was to verify the suitability of selected aluminium alloys for the production of shaped inserts for injection forms. Operation in production does not exceed 1,000 pieces moulded of polymeric materials. Based on the experiments, the process of adhesive wear of form parts will be analyze, which effect is closest to wear in these devices and in operating conditions and their suitability for use in maintenance during production process.

Four types of aluminium alloys were used for experiments (chemical composition of this materials are in table 1):

- Alloy Al 324.0 – this type of alloy is used in the production of aluminium parts for automotive engines – marked A.
- Alloy Al 324.1 – composition is similar to alloy A. It differ by amount of alloying addition of Mn, which was reduced in the process of burn-casting up to 0.4%, and higher contents of Zn up to 12% – marked B.
- Alloy EN AB 43500 is alloy with good weld ability. Used for complex, medium-loaded casts like engine parts, compressor parts and so on – marked C.
- Alloy EN AW-1100 is the composition jest kompozycją with the highest content of aluminum over other materials. Aluminium content is 98.5%, which makes this material soft – marked D.

To determine the suitability of these materials, which satisfy the conditions of maintenance, for use in the manufacturing of parts for experimental moulds were done following experiments:

- Vickers hardness measurement,
- adhesive wear test without lubrication,
- adhesive wear test using lubrication.

Studies to determine adhesive wear of the material was carried out on samples of said friction material in the pairs of a disc-shaped counterbody. Friction roll has a 36 mm diameter and thickness of 10 mm (hardened steel

Table 1. Chemical composition of tested materials

Tested material	Contents of elements in materials in [%]											
	Al	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Cr
A – Al 324.0	89.2	0.740	0.295	7.76	0.444	0.668	0.010	1.260	0.038	0.011	0.018	0.010
B – Al 324.1	77.0	0.466	0.449	8.27	0.415	0.420	0.015	1.273	0.023	0.010	0.019	0.007
C – EN AB 43500	88.6	0.029	0.442	10.32	0.287	0.138	0.010	0.065	0.012	0.007	0.004	0.007
D – EN AW-1100	98.5	0.121	0.034	0.88	0.219	0.008	0.010	0.172	0.029	0.009	0.006	0.008

1.1203). The samples was made at the shape of flat splice plate, measuring 20x15x9 mm and made from tested Al alloys

Tribological properties of friction pairs tested were evaluated by measuring the shear friction coefficient, which was calculated from the friction torque [14]. The values of friction torque were recorded. Slip friction was evaluated according to time. The principle of the test is shown on Figure 2.

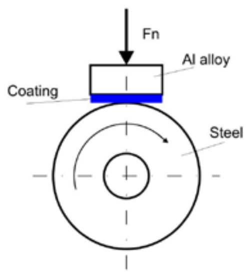


Fig. 2. Test principle of adhesive wear test

Based on the graphical representation, the friction torque was evaluated by the contact force and the disk radius and shear coefficient of friction at the base of the relationship [1]:

$$M_T = r\,F_T \tag{1}$$

$$\mu = F_T / F_N \tag{2}$$

where: M_T – friction torque [Nm], r – radius of the disk [m], F_T – friction force [N], F_N – contact force [N], μ – coefficient of friction shear.

Mounting of friction roll and mating was regulated to pressure in the contact area by compressing the spring by force of 50 kN. Steel roll made of steel was rotating at speed 200 min^{-1}. Deduction interval of friction torque was chosen according to the total time adequately to complete testing of samples depending on the timing of mating seizure of samples. For test of adhesive wear test machine AMSLER was used with surface contact, which allows testing of friction pairs

Friction tests were carried out with and without grease and as lubricant motor oil Madit M2T was used. Oil was applied in a thin layer with a brush on the surfaces of the sample. The whole surface of the sample was covered with a thin layer of oil.

4.2. Discussion of measured results

4.2.1. Evaluation of hardness of tested materials

Hardness of the tested samples was measured according to Vickers measuring method – HV 10 and the results are shown in Figure 3.

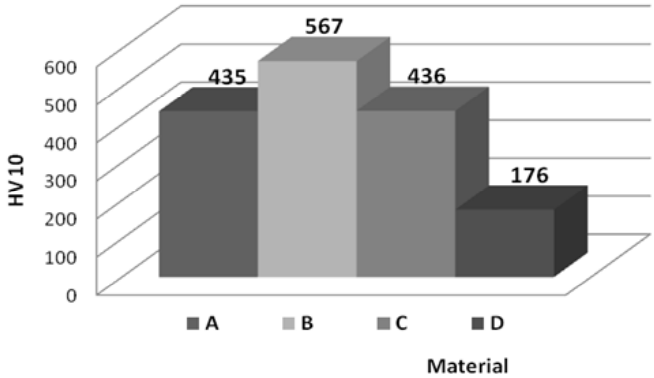


Fig. 3. Comparison of hardness of Al alloys

4.2.2. Evaluation of adhesive wear of friction pair metal – Al alloy

Friction pair: 1.1203 – Al 324.0 (sample A)

Crowding of material was observed during the test of adhesive wear without greasing - plastic displacement in the direction of the friction roll. Traces of the adhesive wear were also visible at the surface. They expressed themselves as transferred parts of material from the samples to surface of friction roll. Material transferred to the roll but also cause abrasive wear marks, showed as scratches. Sample A.1 seized after 17 seconds without greasing. Slip of sample with fixture occurred after seizure of sample.

During the test of adhesive wear with lubrication the duration to seizure several times extended. The results of friction torque, friction coefficient and the time intervals of data input are shown in Table 2. Figure 4 shows the progress of friction torque in dependence on time for samples with and without lubrication till seizing of samples. The sample and also friction roll have traces of abrasive wear, accrued as a result of interaction of ripped particles from the sample and adhering to roll. Duration of experiment until seizing was 58 minutes. Friction roll and the sample was exposed to high temperature generated by friction and it accelerated the process of ripping the particles from sample and its adhering to roll. These connections during the test caused abrasive wear of friction roll as well as its counterpart in the friction pair.

Friction pair: 1.1203 – Al 324.1 (sample B)

When measuring the friction torque without greasing the traces of abrasive wear were observed on sample caused by the rapture of the material from sample and sticking to the roll. In terms of tribology, we can say that this is a tearing mechanism. Interval till seizing of samples was 83 seconds. Slip of sample with fixture occurred after seizure of sample.

By measuring the friction torque using greasing the duration to seizure several times extended. On the sample surface are visible scratches incurred as a result of plastic displacement and scaly marks caused by delamination. Adhesive wear was also accompanied by abrasive wear. Abrasion was caused by material sticked to roll through

Table 2. The measured values of friction pair steel – material A with lubricant

Material	Values of friction torque M [N.m] and friction coefficient μ on time [sec]									
	1000 [sec]		4000 [sec]		4650 [sec]		4750 [sec]		5130 [sec]	
	M	μ	**M**	μ	**M**	μ	**M**	μ	M	μ
A.1	12	0.13	23	0.25	33	0.37	53	0.59	73	0.81
A.2	15	0.17	20	0.22	40	0.44	61	0.68	79	0.89
A.3	11	0.12	18	0.20	18	0.20	50	0.56	70	0.78

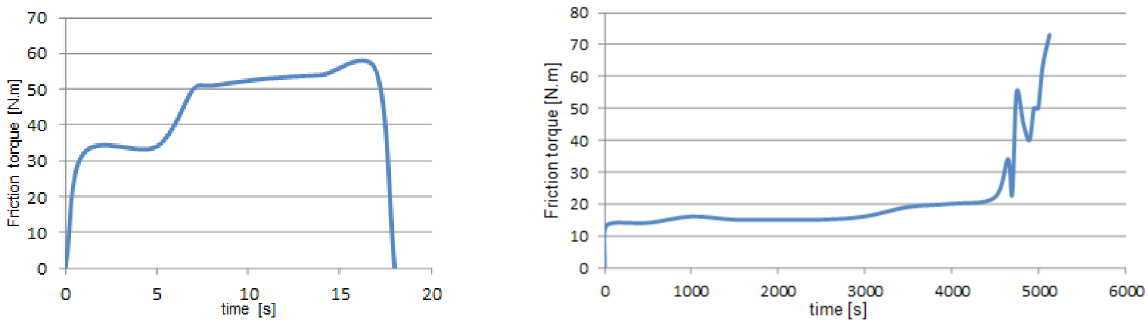


Fig. 4. Curve of friction torque vs. time- sample A.1 a) without lubrication , b) with lubrication

micro joints between roll and material samples. By creation of micro joints ripping of material from sample was observed.

The results of friction torque, friction coefficient and the time intervals of data input are shown in Table 3. Figure 5 shows the progress of friction torque in dependence on time for samples with and without lubrication till seizing of samples.

Friction pair: 1.1203 – EN AB 43500 (sample C)

Interval till seizing of samples without lubrication was 20 seconds. After seizing of sample adhesive wear occurred a consistent delamination of surface of sample. On friction roll particles transferred from sample were found.

During the test of adhesive wear with lubrication the duration to seizure several times extended. On sample was visible delamination and sideways displacement of material - plastic crowd-out effect. Material was not sticking to the friction roll. The test material was torn off in the form of small swarf. Swarf immediately after breakaway falls off and further wasn't being sticked to friction roll.

The results of friction torque, friction coefficient and the time intervals of data input are shown in Table 4. Figure 6 shows the progress of friction torque in dependence on time for samples with and without lubrication till seizing of samples.

Friction pair: 1.1203 – EN AW-1100 (material D)

Interval till seizing of samples without lubrication was 6 seconds. Due to the low hardness of the material plastic displacement occurred almost immediately after starting the device and seizing of sample went through strong Van der Waals forces.

By measuring the friction torque using greasing the duration to seizure several times extended. Clearly visible delamination of surface with flaking particles of lamellar shape was observed on surface. The material was crowding out the sides and after loss of plastic abil-

Table 3. The measured values of friction pair steel – material B with lubricant

Material	Values of friction torque M [N.m] and friction coefficient μ on time [sec]									
	50 [sec]		**100 [sec]**		**250 [sec]**		**350 [sec]**		446 [sec]	
	M	μ	**M**	μ	**M**	μ	**M**	μ	M	μ
B.1	25	0.28	30	0.33	43	0.48	47	0.52	69	0.76
B.2	20	0.22	32	0.35	39	0.43	50	0.56	67	0.74
B.3	27	0.30	29	0.32	34	0,38	52	0.58	63	0.70

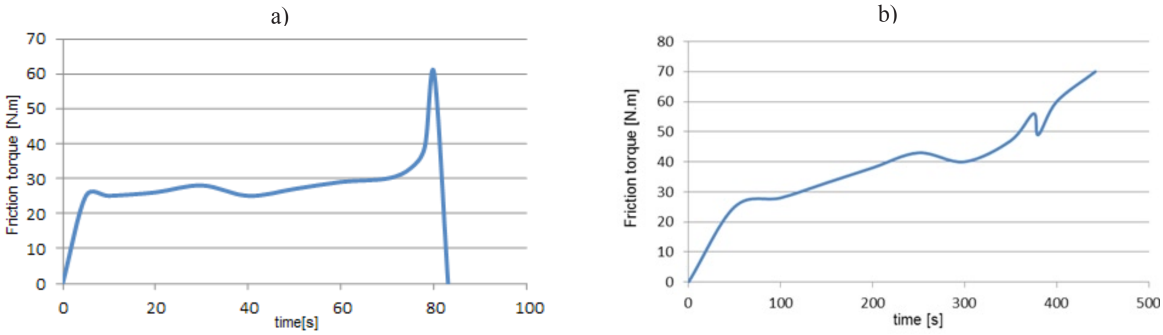


Fig. 5. Curve of friction torque vs. time – samples B.1 a) without lubrication , b) with lubrication

Table 4. The measured values of friction pair steel –material C with lubricant

Material	Values of friction torque M [N.m] and friction coefficient μ on time [sec]									
	500 [sec]		2000 [sec]		3500 [sec]		4250 [sec]		4790 [sec]	
	M	μ	M	μ	M	μ	M	μ	M	μ
C.1	18	0.20	17	0.19	23	0.26	28	0.31	72	0.80
C.2	15	0.17	20	0.2	32	0.36	38	0.42	65	0.72
C.3	12	0.13	15	0.17	26	0.29	25	0.28	60	0.67

a) b)

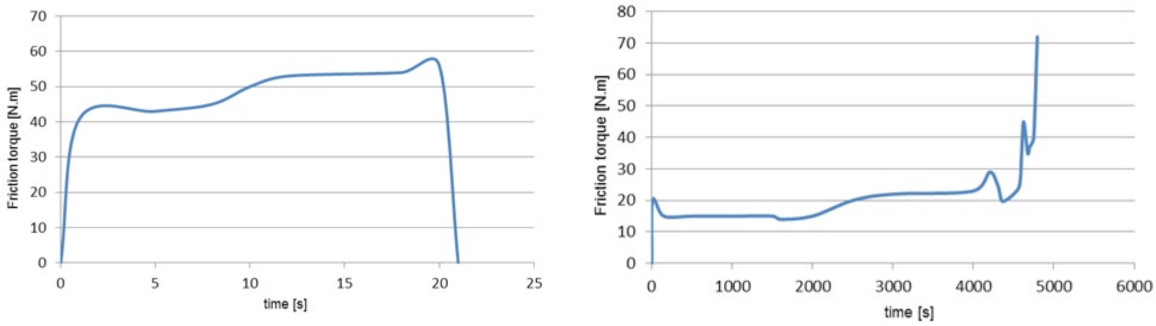


Fig. 6. Curve of friction torque vs. time- samples C.1 a) without lubrication, b) with lubrication

Table 5. The measured values of friction pair steel – material D with lubricant

Material	Values of friction torque M [N.m] and friction coefficient μ on time [sec]									
	30 [sec]		55 [sec]		80 [sec]		130 [sec]		180 [sec]	
	M	μ	M	μ	M	μ	M	μ	M	μ
D.1	27	0.30	30	0.33	32	0.35	35	0.39	64	0.71
D.2	25	0.28	32	0.35	35	0.39	38	0.42	67	0.74
D.3	20	0.22	29	0.32	29	0.32	37	0.41	62	0.69

a) b)

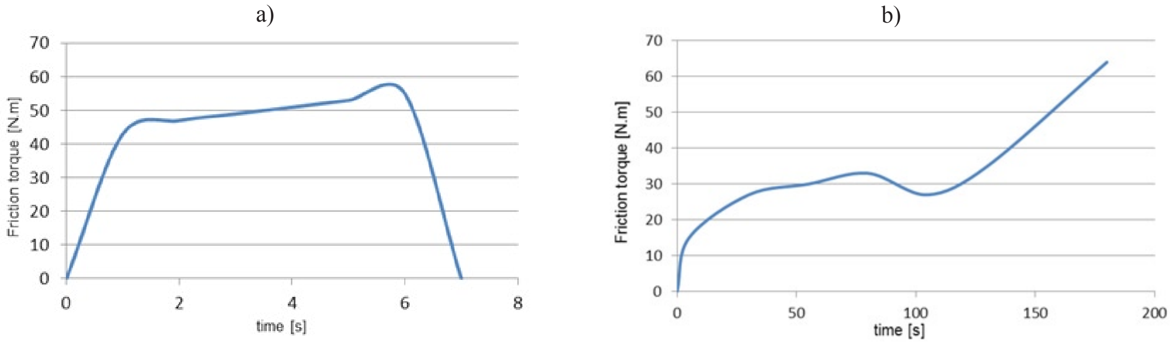
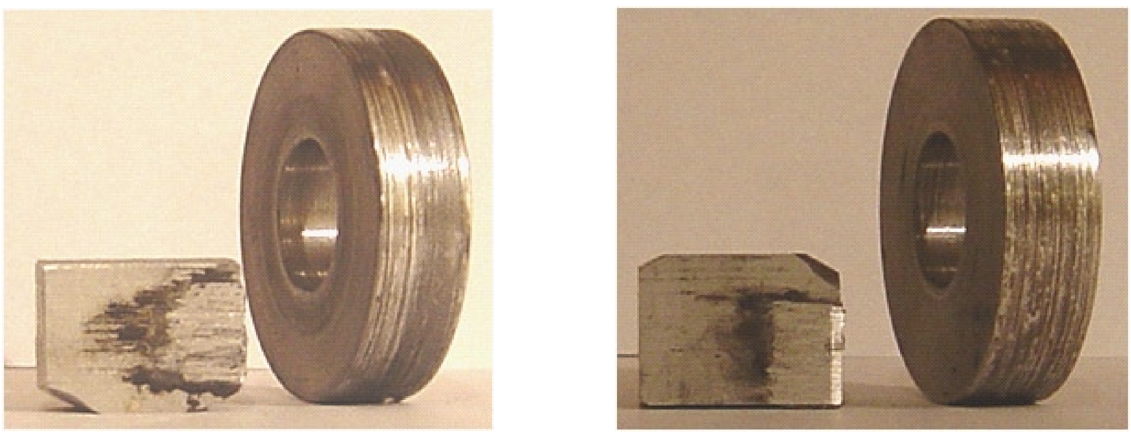
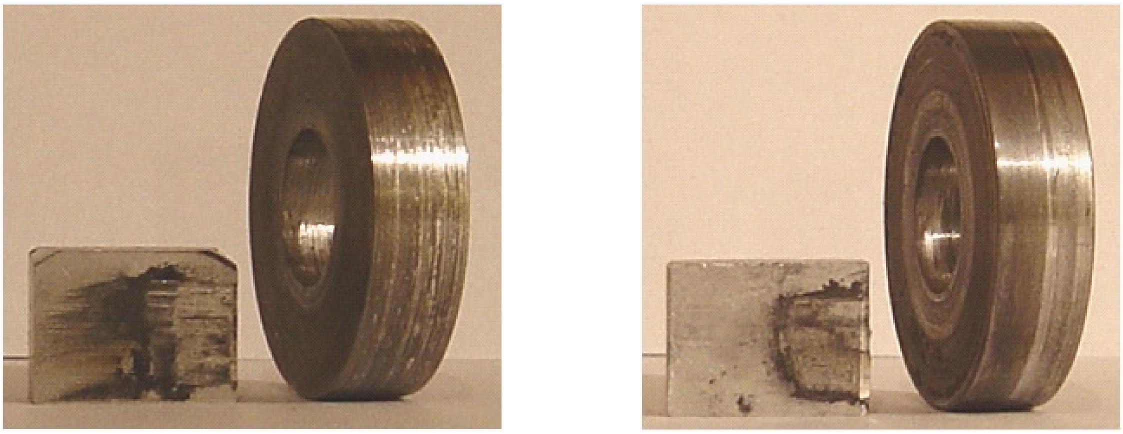


Fig. 7. Curve of friction torque vs. time – sample D.1 a) without lubrication , b) with lubrication



Material A *Material B*

Fig. 8. Tested materials after wearing test



Material C *Material D*

Fig. 8. Tested materials after wearing test

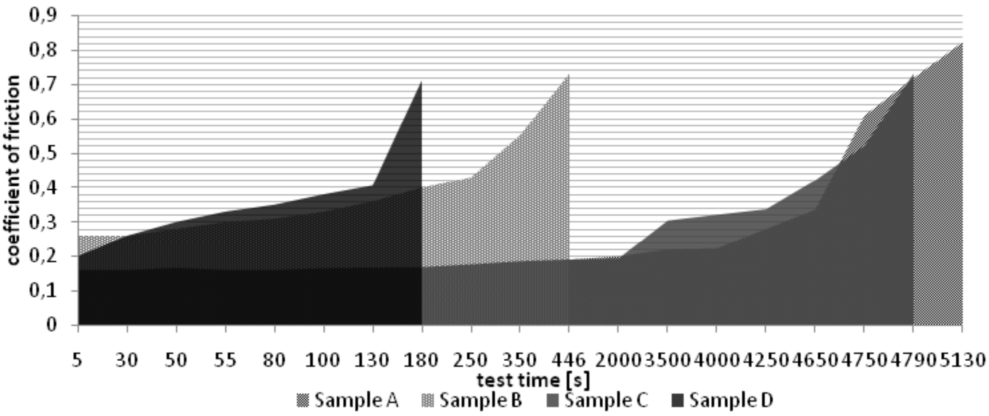


Fig. 9. The progress of the friction coefficient in dependence on the time

ity the disrupt of surface integrity began. There was no visible wear on the surface of roll.

The results of friction torque, friction coefficient and the time intervals of data input are shown in Table 5. Figure 7 shows the progress of friction torque in dependence on time for samples with and without lubrication till seizing of samples.

5. Conclusion

The experiments showed that at design of parts for injection moulds from on-ferrous materials (aluminium) are necessary to consider the properties of the alloy.

Based on the performed tests, we came to the following conclusions:

- Pure aluminium had not sufficient properties for a given application, as shown by tests on material EN AW-1100 (material D), which contained up to 98% aluminium. The time until the sample seized and the type of wear and tear, which occurred during the tests, indicate that the high-purity alloys are not suitable for the production of structural parts of the mould by mutual their movement relative to each other during the maintenance of the form.
- Al 324.1 alloy (material B) behaved at friction test better than material EN AW-1100, but the times to seizure and friction coefficient values show that even this alloy is not suitable for use in the manufacturing of moulds. Material contained large amounts of zinc, what caused great hardness of alloy in comparison with other studied alloys –up to 567 HV
- Alloys Al 324.0 and Al 324.0 (material A, C) after tests appeared to be most favorable for the production of parts for forms in terms of maintenance conditions. The optimal composition of the alloy guarantees sufficient operation time.
- The model test results showed that for the production of shaped parts of the mould is the most suitable tested alloy material B (stop Al 324.1). At the end of experiment, the material reached the highest coefficient of friction, the material seized after the longest time of maintenance. In practice, mould parts are not stressed to such an extreme way as samples at model test. Greasing is often permanently secured.

The aim of the experiment was to verify and confirm the practical choice of the most suitable non-ferrous materials from the supplied range of materials for the production of shaped parts of injection moulds. These materials can be used in the production of moulded parts of injection moulds for plastics and will ensure the most no-failure operation in small series production.

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References

1. Blaškovič P, Balla J, Dzimko M. Tribológia. Bratislava: Alfa, 1990.
2. Galetz M, Seiferth S, Theile B, Glatzel U. Potential for adhesive wear in friction couples of UHMWPE running against oxidized zirconium, titanium nitride coatings, and cobaltchromium alloys, Journal of Biomedical Materials Research Part B: Applied Biomaterials, Volume 93B, Issue 2, 2010.
3. Garbacz T, Sikora JW. Selected aspects of coatings production in cellular co-extrusion process. The Polymer Processing Society. Banff, Canada 2010, R01–131.
4. Greškovič F, Dulebová L, Varga J. Technológie spracovania plastov. Vstrekovanie. Košice: SjF TU v Košiciach, 2010.
5. Greškovič F, Spišák E. Materiály foriem na spracovanie plastov. Acta Metallurgica Slovaca 2003; 9: 41–48.
6. Hidveghy J, Dusza J. Nekovové konštrukčné materiály. Košice: TU v Košiciach, 1998.
7. Jachowicz T. Wybrane zagadnienia niezawodności obiektów technicznych. Przetwórstwo tworzyw 2009; 2 (128)/15: 34–45.
8. Kelly L, Mulvaney-Johnson R, Beechey P. The effect of copper alloy mold tooling on the performance of the injection molding process, Polymer Engineering & Science, 2011; 51 (9): 1837–1847.
9. Mandal D, Dutta BK, Panigrah SC. Wear and friction behavior of stir cast aluminium-base short steel fiber rein forced composites. Wear 2004; 7–8 (257): 654–664.
10. McKellop H, Clarke I, Markolf K, Amstutz H. Friction and wear properties of polymer, metal, and ceramic prosthetic joint materials evaluated on a multichannel screening device, Journal of Biomedical Materials Research 2004; 15 (5): 619–653.
11. Michaeli W, Lindner F. Influence of Mould Materials on the Morphological and Mechanical Properties of Injection-Moulded Prototypes, Macromolecular Materials and Engineering 2001; 286 (4): 232–236.
12. Суберляк ОВ, Красінський ВВ, Шаповал ЙМ. Прес-матеріали на основі комбінованого зв'язувального. Технологічні та експлуатаційні характеристики. Хімічна промисловість України 2009; 3: 52–54.
13. Štofko M, Štofková M. Neželezné kovy. Košice: Emilie, 2005.
14. Wojciechowski Ł, Nosal S. The application of free surface energy measurement to valuation of adhesive scuffing. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2010; 1 (45): 83–90.
15. Xu J. Materials for Microcellular Injection Molding, Microcellular Injection Molding, 2010, Wiley, London, ISBN: 978-0-470-46612-4.

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