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Anna GUZANOVÁ, Janette BREZINOVÁ
Technical University in Košice

WEAR DIAGNOSING OF SELECTED MATERIAL COUPLES

The paper deals with the evaluation of material wear of injection moulds made of aluminium alloy Alumec 89 and copper alloy Moldmax HH in friction couples with plastomer materials with various filler contents. The friction relations in injection moulding were simulated in an adhesion dry wear test using an Amsler machine, with an area contact of the friction couple materials. The wear intensity was evaluated by determination of friction coefficient and relative wearing by the mass loss. Surface morphology changes of evaluated alloys after wear were analysed simultaneously.

Keywords: adhesive wear, friction coefficient, mass loss

Introduction

Injection moulding is one of the most widespread polymer processing technologies. It allows producing moulds of both simple and complex form. Products made by injection moulding are characterized by a very good dimensional and shape accuracy and high reproducibility of mechanical and physical properties. An advantage of injection moulding is high efficiency of processed material, which ranks it among closed-cycle technologies. The quality of moulded parts depends above all on the quality of the production tool, i.e. injection mould.

The main function of an injection mould is to give a processed polymer the required shape and cool it to the temperature that allows removing the moulded part without any deformation. The shaped cavity is the most important for injection mould function. Its shape corresponds with the shape of the desired product; the dimensions differ only by the shrinkage value. The injection moulds must conform to the *technical requirements*, which guarantee their correct function for the required number, quality and precision of mouldings together with the *economic requirements* characterized by low acquisition price, easy and fast production and also high utilization efficiency of processed plastomers. Operation conditions of the injection moulds loading are as follows: injection pressure, tension, and wear intensity as well as higher temperatures of processed plastics including their chemical effects on functional surfaces [1÷4].

The lifespan of the injection mould is determined by its engineering design, mould inserts used, dimensioning, maintenance and storage. A mould dissipates heat from the processed polymer and even cooling – a homogeneous temperature field in the injection mould – is required for the properties of a moulding. The usage of suitable mould inserts for extremely stressed mould parts can extend the operating life of the moulds. Mould inserts made of highly thermally conductive materials inserted near the shaped mould cavity increase the heat removal, especially under low annealing temperatures. The aim is to provide a balanced thermal load of both the tool and the moulded piece in the whole volume while increasing productivity. Utilization of mutual relations between the active (water circulating in annealing channels) and the passive annealing medium (mould inserts made of highly thermally conductive material) results in: the thermal balance in the whole volume of the moulded piece at the same time, minimization of the thermal difference in the injection mould, and increasing the crystalline phase ratio by optimal crystallization process in injection moulding of semi crystalline polymers. Other advantages of annealing are: easier processing of products with complicated shape without any creation of cold weld lines, shortening of the moulding cycle time, increasing the moulded piece surface quality by suitable technological timing, and higher functional safety (smoother surfaces, more suitable friction properties). High requirements are imposed to surface quality of shape parts of injection moulds. Great attention is paid to high wear resistance of functional parts, mainly when polymers reinforced with abrasive fillers are processed [5÷7]. Wear intensity is affected predominantly by the kind of processed polymer, moulding shape and dimensional complexity, its segmentation and required precision, and the temperature and pressure of the injected polymer [8, 9].

In processing filled polymers there occur various fibre orientation patterns in the melt. There are a number of distinct layers within the moulding with different fibre alignments. In the skin layer, the fibre orientation is predominantly parallel to the flow direction due to the elongation forces developed during fountain flow at the melt front as well as due to the shear flow after the front has passed. In contrast, a random-in-plane alignment of fibres is observed in the core layer due to slower cooling rate and lower shearing. Just this mutual relative motion of self orienting filler and mould wall causes adhesive-abrasive wear of injection moulds, which leads to necessary renovation or moulds replacement [10÷15]. The aim of the experiment was to carry out complex analysis of the wear resistance of selected aluminium and copper alloys, designed for the production of shape mould parts, in interaction with glass fibre reinforced polymers in adhesive wear conditions.

Experimental methods

The material wear resistance of mould shaping parts was determined by adhesive dry wear test. Aluminium alloy Alumec 89 (marked **A**) was used as a sample of mould shaping part material for adhesive dry wear test. Alumec 89 is a high strength and high stability aluminium alloy. It is of low specific weight, which makes opening and closing the moulds easier. The alloy is characterized by high thermal conductivity, good thermal stability, and it can be covered with hard layers to increase its wear and corrosion resistance. Another tested material was copper alloy **Moldmax HH** (marked **M**). It is a high strength material used especially for polymer processing moulds. As a mould insert in steel moulds, it effectively cools hot spots and reduces the need for annealing channels. The chemical composition of the evaluated alloys is shown in Table 1 and their selected mechanical properties are shown in Table 2.

Table 1. Chemical composition of Alumec 89 and Moldmax HH [%]
Tabela 1. Skład chemiczny stopów Alumec 89 oraz Moldmax HH [%]

Alumec 89											**Moldmax HH**		
Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr	Al	Be	Co+Ni	Cu
0.12	0.15	2.0	0.10	2.6	0.05	0.05	6.7	0.06	0.16	89	1.9	0.25	98

Table 2. Mechanical properties of the evaluated alloys
Tabela 2. Właściwości mechaniczne testowanych materiałów

Mechanical properties	**Alumec 89**	**Moldmax HH**
Tensile strength R_m	650÷720 MPa	1280 MPa
Tensile yield strength $R_{p0.2}$	600÷650 MPa	1070 MPa
Elongation A_5	8÷11%	6%
Hardness	199 HV30	400 HV30

Friction mates for the adhesive dry wear test were made of the following polymers: Durethan PA66GF30 (polyamide 66 reinforced with 30% of glass fibres), Slovamid 66GF25 (polyamide 66 reinforced with 25% of glass fibres), **3** Slovamid 6GF30 (polyamide 6 reinforced with 30% of glass fibres), Slovaster B1GF10 (polybutyleneterephtalate reinforced with 10% of glass fibres). The characteristics of polymer composites:

- **Durethan PA66GF30** is characterized by high strength properties, higher temperature shape stability, used for accurate but simple shape mouldings,
- **Slovamid 66GF25** is suitable for high strength and toughness mouldings even for low temperature. It is used in automotive, electrical and machine engineering industry,

- **Slovamid 6GF30** is suitable for high strength and toughness mouldings used in automotive, electrical, machine engineering and consumer industries,
- **Slovaster B1GF10** is characterized by high strength properties – modulus of elasticity in tension and bend, tensile strength, toughness even at low temperatures. It retains its properties also in wet atmosphere. The melt is characterized by very good rheology, which makes it possible to produce mouldings with extremely complex shapes and complicated melt flow trajectory. It is used in automotive, electrical and machine engineering industries.

Adhesive dry wear test was carried out using the Amsler machine with a surface contact between the test samples. In a friction couple the disk was made of selected alloys (diameter ϕ 35 mm, width 10 mm, prepared by turning) and friction mates made of particular plastomers (20x15x8 mm, prepared by milling). Friction couple materials were held together by a spring of normal force $\mathbf{F_n}$ = 500 N, the disk speed **n** was 200 min^{-1}. The adhesive wear was evaluated by the direct method based on mass loss $\mathbf{W_h}$ of the alloy disks. The duration of the friction test was 15 minutes, and the friction moment **M** was observed simultaneously. All test samples were degreased before the adhesion wear test.

Results and discussion

The initial course of friction coefficients for all friction couples corresponded to the running-in phase of contact materials and gradually became stabilized (Fig. 1). The characteristic surface macro and micro relief resulting from the production process influences the initial phases of the adhesive wear. The surface micro-relief is closely related to the structural properties of the surface layers of frictional materials and it changes after mutual running-in of the friction couple. The highest values of the friction coefficient were observed in friction couples A-2 and M-2 – both evaluated alloys in friction couples with Slovamid 66GF25. There was increased resistance against mutual relative motion of evaluated materials. Other friction couples showed lower friction coefficients.

Wear intensity of Alumec after friction with all used plastomers was relatively high in regard to its relatively low hardness. The highest weight loss $\mathbf{W_h}$ was observed after wear in plastomer No. 2, which is in accordance with observed values of friction coefficient. In the course of contact friction of particular plastomers with Moldmax the observed weight loss was lower due to its higher hardness. The highest weight loss was observed again in friction couple M-2, which is in accordance with the observed values of friction coefficients. Besides the volume of the dispersed compound and its arrangement in the matrix, the wear course is significantly influenced by the plastomer matrix hardness and the extent of the interfacial matrix-filler adhesion.

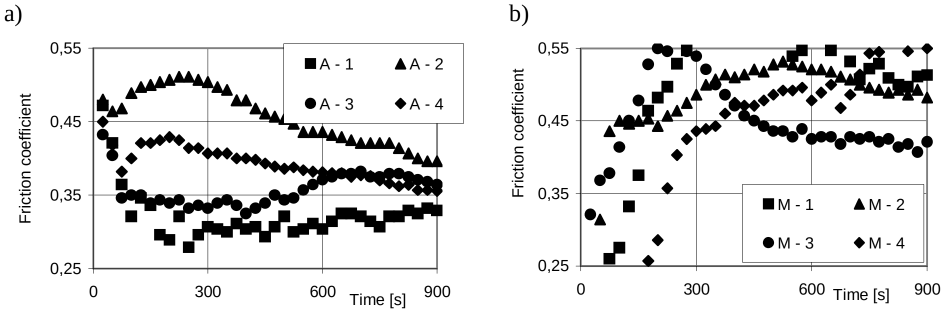


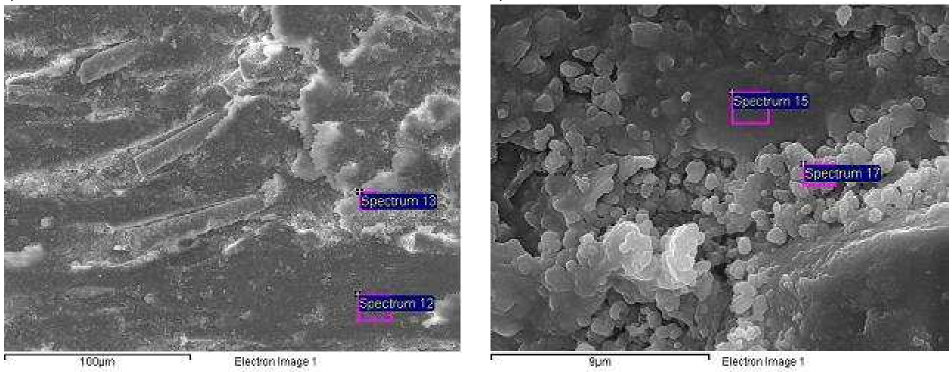
Fig. 1. Time dependence of friction coefficient for Alumec 89 (a) and Moldmax HH (b)

Rys. 1. Zmiany współczynnika tarcia w czasie testu dla stopów Alumec 89 (a) oraz Moldmax HH (b)

SEM micrographs of selected polymer surfaces after wear test with Alumec shows dislodged fibre (Fig. 2a) and crumbling of polymer matrix (Fig. 2b). SEM micrographs of selected polymer surface after wear test with Moldmax shows change of polymer matrix filler orientation from stochastic to direct in the direction of the friction force after wear with Moldmax alloy (Fig. 3). This fact occurs due to higher Moldmax hardness, even fracture of some fibre can be observed (Fig. 3a). Polymer surface contains again metal compound, which separates from alloy surface by abrasive filler effect.

In the first phase of friction, real contact area of friction couple was considerably smaller, because the contact of material surfaces of defined roughness occurred only on roughness peaks. The specific pressure on this area was high and the applied loading deformed the material surface, therefore the contact area of the friction couple was enlarged. Alumec surface peaks were elastically deformed and consequently there arose a new plastically deformed surface. The grooving intensity of Alumec surface was intensified by the presence of a dispersed phase in plastomers – glass fibres. Due to wide differences in the hardness values of structural compounds at the beginning there occurred an intensive wear of polymer matrix, thus increasing the stress on the peaks of the hard compound. The hard abrasive particles – glass fibres consequently stamped into the Alumec surface and caused micro-cutting of the alloy. Simultaneously there was local displacement of material volume on the surface. In the course of friction with polymer composite Slovamid 66GF25 the filler consecutively dislodged from the soft matrix, consequently acting as an abrasive and causing grooving of Alumec surface.

a) b)



Slovamid 66GF25 – Alumec Slovamid 6GF30 – Alumec

Fig. 2. SEM micrographs of polymer surfaces after friction with Alumec alloy
Rys. 2. Obrazy skaningowe powierzchni tworzyw po teście tarcia ze stopem aluminium Alumec

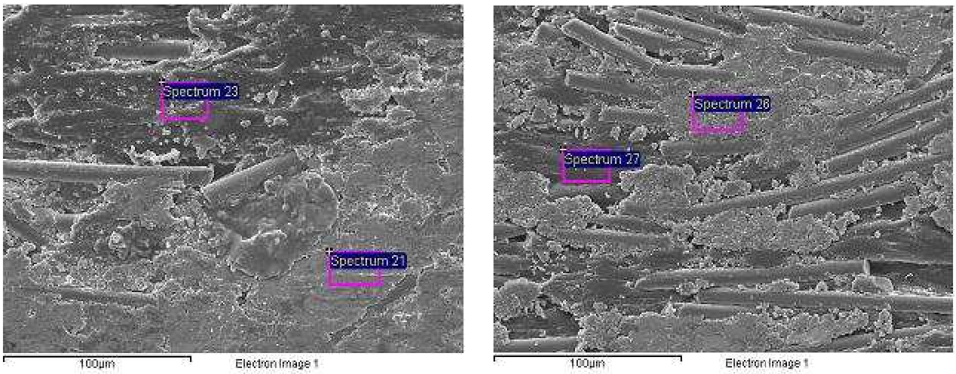
In friction couples M-1, M-2 and M-3 there occurred smoothing of the initial turned surface, the surface of Moldmax alloy after contact with composite 4 remained significantly unchanged owing to the low hardness of polymer friction mate 4. In this case the oriented surface of Moldmax alloy was replicated on the surface of polymer 4. The cohesive strength in the surface layers of Moldmax alloy was lower than the adhesive strength of the micro-welds.

Conclusion

The paper deals with the study of aluminium alloy Alumec 89 and copper alloy Moldmax HH resistance against adhesive wear in interaction with polymer composites reinforced with glass fibres. After the initial running-in and consequent stabilization of friction couples the highest value of friction coefficient was observed in both evaluated alloys in friction couples with polymer composite Slovamid 66GF25, which indicates the highest wear intensity. This was also confirmed by the evaluation of mass loss. In some cases there occurred a temperature increase and material transmission within the friction couples. Observed wear mechanism for aluminium alloy to be the grooving and pitting formation caused by the abrasive effects of the dispersed filler, and for copper alloy the surface smoothing effect.

The experimental works show that polymer composite No. 1 – Slovamid 66GF25 reinforced with 25% of glass fibres caused the most intensive wear of both evaluated alloys. The wear of Alumec 89 alloy was more intensive than the wear of Moldmax HH. Despite its higher thermal conductivity, Alumec 89 is not suitable for mould inserts production designed for injection moulding of reinforced polymer composites, due to its hardness.

a) b)



Slovamid 66GF25 – Moldmax Slovamid 6GF30 – Moldmax

Fig. 3. SEM electron micrographs of polymer surfaces after friction with Moldmax alloy
Rys. 3. Obrazy skaningowe powierzchni tworzyw po teście tarcia ze stopem miedzi Moldmax

Although material hardness is generally one of decisive factors for wear resistance evaluation, the wear intensity also considerably depends on the kind, arrangement and mutual adhesion of particular structural elements. The interaction between particular phases and the adhesion on matrix – glass fibre boundary plays the crucial role in the wear mechanism.

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DIAGNOZA ZUŻYCIA ŚCIERNEGO WYBRANYCH PAR MATERIAŁÓW

Opracowanie zawiera wyniki oceny zużycia ściernego części form wykonanych ze stopu aluminium Alumec 89 oraz stopu miedzi Moldmax HH podczas wtryskiwania materiałów polimerowych z różną zawartością wypełniaczy. Proces wtryskiwania był symulowany podczas testowania na maszynie wytrzymałościowej Amsler par materiałów w warunkach tarcia suchego. Intensywność zużycia była określana poprzez wartość współczynnika tarcia oraz poprzez ubytek masy próbek. Jednocześnie, po zakończeniu testu dokonano oceny zmian morfologii powierzchni próbek.

Słowa kluczowe: zużycie ścierne, współczynnik tarcia, ubytek masy

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