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Influence of Reinforced Plastomers on Injection Moulds Wear

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Abstract

The contribution deals with wear of injection moulds based on aluminium alloy Alumec 89 in friction couples with plastomers reinforced with different glass fibres content. Friction relations in injection moulding were simulated by adhesion dry wear test with help of Amsler equipment with area contact of friction couple. Wear intensity was evaluated by friction coefficient and relative wear by weight loss. Simultaneously, changes of aluminium alloy surface morphology after wear in particular friction couples were analysed.

Key words : injection moulding, wear, friction coefficient

Introduction

Polymer materials present a chemical assembly which is defined by their unusual variability of structures and final matter properties. There are macromolecular substances, which can be formed by heat, pressure or both of them together. Due to their properties, these materials are widely used nowadays. The most expanded plastomer processing technology is injection moulding.[1] Products made by injection moulding are characterized by very good dimensional and shape accuracy and high reproducibility of mechanical and physical properties. Products processed by this technology have a wide range of possible shape and weight. Injection forms must live up to the *technical requirements*, which guarantee thier correct function for required count, quality and precision of mouldings together with *economic requirements* characterized by low acquisition price, easy and fast production and also high utilization efficiency of processed plastomers. Engineering design, configuration of injection moulds and technology of thier production are usually different. Operation conditions of injection moulds loading are as follows: intensity of pressure, tension, wear intensity as well as higher temperatures of plastic processed together with its chemical effects on functional surface. Wear intensity is effected predominantly by the kind of processed polymer, mouldings shape and dimensional complexity, its segmentation and precision together with temperature and pressure of injected polymer.[2, 3] Great attention is paid to high wear resistance of functional parts, mainly when polymers reinforced with abrasive fillers are processed.[4-7] At first filler is - due to normal forces at mutual relative motion in injection moulding - impressed to alloy surface of moulds, where limit factor is impressing hardness. Consequently degradation of mould surface appears, where forces of interatomic bonds and strength of joint between structural compounds on grain boundary plays a decisive role.

Injection moulds operating life is affected by its engineering realization, shape filling blocks using, dimensioning, maintenance and storage. Usage of suitable shape filling blocks for high stressed functional parts of injection moulds extends its operating time with minimum cost. Influence of moulds shape parts surface quality is well known when a moulded piece of complicated shape and ribs is removed from injection mould.

The aim of experimental works[8] was to analyse the resistance of selected aluminium alloy designed for shape moulds parts production against wear in the course of interaction with plastomers reinforced with glass fibres in adhesive wear conditions.

Materials and Experimental Procedures

Wear resistance of moulds shape parts material was determined by adhesive wear test with dry friction. For adhesive wear test, the aluminium alloy **Alumec 89** (marked **A**) as sample of moulds shape part material was selected. Alumec 89 is a high strength and high stability aluminium alloy mainly used for tool production. Alumec can be worked on very well by cutting tools due to the fact that it has low specific weight which makes opening and closing moulds easily. The alloy is characterized by high thermal conductivity and can be covered by hard layers to increase wear and corrosion resistance. Chemical composition of Alumec 89 is shown in Table 1.

Table 1. Chemical composition of Alumec 89 (EN 573-3)

	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Zr	Al
Min	-	-	1.5	-	2.1	-	-	5.7	-	0.10	89
Max	0.12	0.15	2.0	0.10	2.6	0.05	0.05	6.7	0.06	0.16	

Mechanical Properties

Tensile strength R_m = 650 – 720 MPa
Tensile yield strength $R_{p0.2}$ = 600 – 650 MPa
Elongation A_5 = 8 – 11 %
Hardness 199 HV30

The following plastomers were selected as opposite friction material for adhesive wear test:

1. Durethan PA 66 GF30 (reinforced with 30 % of glass fibres)
2. Slovaster B1 GF10 (reinforced with 10 % of glass fibres)
3. Slovamid 66 GF25 (reinforced with 25 % of glass fibres)
4. Slovamid 6 GF30 (reinforced with 30 % of glass fibres)

General properties of selected plastomers are listed in Table 2.

Durethan PA 66 GF 30 - Polyamide 66 reinforced with 30 % of glass fibres. It is characterized by high strength properties, higher temperature shape stability, used for accurate but simple shape mouldings.

Slovaster B1 GF 10 - Polybutyleneterephtalate for injection moulding reinforced with 10% of glass fibres. It is characterized by high strength properties - modulus of elasticity in tension and bend, tensile strength, toughness even at low temperature. It keeps its properties also in wet atmosphere. Melt is characterized by very good rheology, which makes it possible to produce

Table 2. General properties of selected plastomers

Plastomer properties	unit	Durethan PA 66 GF30	Slovaster B1 GF10	Slovamid 66 GF25	Slovamid 6 GF30
Density	$g.cm^{-3}$	1.36	1.38	1.32	1.33
Processing method	°C	IM*	IM	IM	IM
Melting point DSC	°C	263	200 - 220	260	220
Melt temperature range	°C	290	250-270	280-300	250-280
Mould temperature range	°C	80	50-80	60-90	70-90
Injection pressure	MPa	60-100	60-100	70-120	70-120
Drying: temperature / time	$°C.H^{-1}$	120/4	120/4	80/4	80/4
Manufacturing shrinkage length/width	%		0.99/1.46	0.78/1.18	0.55/1.06
Tensile strength	MPa	185	85	165	170
Elongation	%	4	4	3	3
Modulus of elasticity in tension	MPa	10 600	4800	7800	8600
Modulus of elasticity in bend	MPa	8400	4200	6500	7600
Bending strength	MPa	290	130	210	200
Charpy impact strength 23°C	$kJ.m^{-2}$	90	25	55	65
Charpy notch impact strength 23°C	$kJ.m^{-2}$	10	5	10	12
Heat resistance Vicat B	°C	210	210	250	210
Hardness Shore D	-	85	78	86	83

*IM – injection moulding

extremely shaped complex mouldings with complicated melt flow trajectory. It is used in the automotive, electrical and machine engineering industries.

Slovamid 66 GF 25 – Polyamide 66 reinforced with 25 % of glass fibres, suitable for high strength and toughness mouldings even for low temperature. It is used in the automotive, electrical and machine engineering industries.

Slovamid 6 GF 30 - Polyamide 6 for injection moulding reinforced with 30% of glass fibres. It is suitable for high strength and toughness mouldings applied in the automotive, electrical, machine engineering and consumer industries.

Adhesive Wear Test

Adhesive dry wear test was carried out on Amsler equipment with area contact of tested samples.(9) In friction couple the disk was made of aluminium alloy (diameter ϕ 45 mm and width 10 mm) and friction mates made from particular plastomers were of square shape (20x15x8 mm). Friction couple materials were held together by spring of normal force F_n = 500 N, disk speed was 200 min^{-1}, time of friction test 20 min. During the test , the friction moment μ and aluminium alloy weight loss W_h were observed every 2 minutes. Layout of Amsler equipment and arrangement of friction couple is shown in Figure 1.

Before adhesion wear test all test samples were degreased. The equipment contains dynamometer by which friction moment M was continuously measured. Friction moment M is given by equation (1):

$M = F_t \cdot r$ [N.mm], (1)

where

F_t – friction force [N]

r – disk radius [mm]

Friction force F_t is given by equation (2) from friction moment M

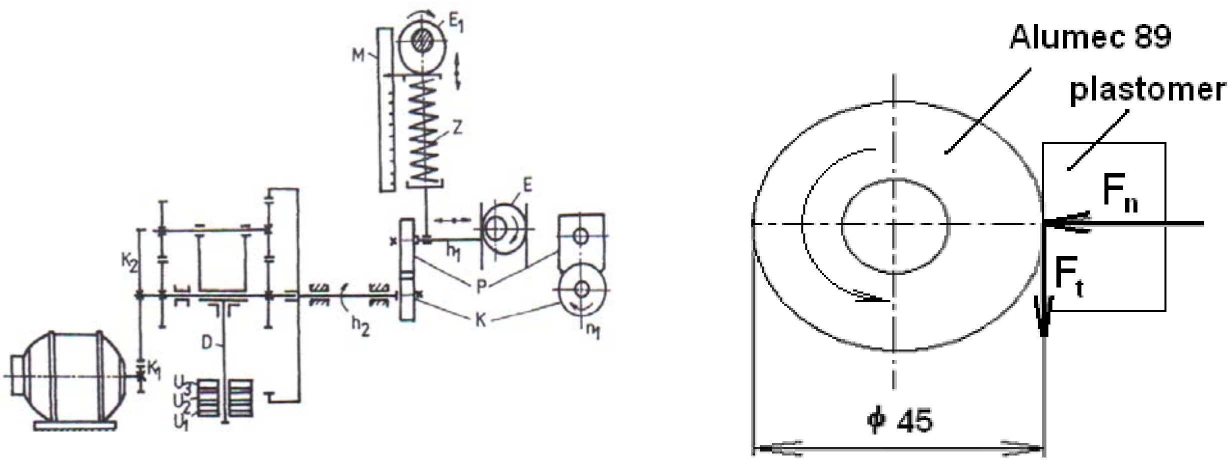
$$F_t = \frac{M}{r} \text{ [N]} \qquad (2)$$

Friction coefficient μ is determined as ratio of friction force and normal force (3)

$$\mu = \frac{F_t}{F_n} \text{ [-]} \qquad (3)$$

Surface Morphology Change Evaluation Method

Surface morphology of aluminium alloy disk before and after wear test was evaluated by roughness measurement with help of stylus profilometer Surftest SJ 301 according to STN EN ISO 4287.(8,10) Monitored parameters were Ra – arithmetical mean deviation of the profile and Rz – maximum height of the profile. Surface roughness was measured parallel with aluminium disk centre line. Adhesive worn surfaces were shown also in 3D view with help of Matlab software.



a) b)

Figure1. a) Layout of Amsler equipment, b) Acting forces in friction couple

Results

Course of friction coefficient μ for particular evaluated friction couples is shown in Figure.2. For polyamide based friction couples at the wear test beginning relative high value of friction coefficient was observed. It means friction couple adjusting. Up to 8 minutes friction coefficient decreased, friction couple contact stayed. Course of friction coefficient for polybutyleneterephtalate based friction couple was different – gradual increase of friction coefficient value. The highest friction coefficient (0,39) was observed in friction couple A – 2 (Alumec 89 - Slovaster B1 GF10). This finding denotes enhanced resistance against mutual materials motion. For other friction couples (A – 1, A – 3 and A - 4) after 20 minutes of adhesive wear test the friction coefficient was lower (0,28 – 0,31). Wear intensity of aluminium alloy disk during wear test was evaluated by weight loss W_h, Figure.3. The highest weight loss was registered for friction couple A – 2, which is in accordance with friction coefficient values.

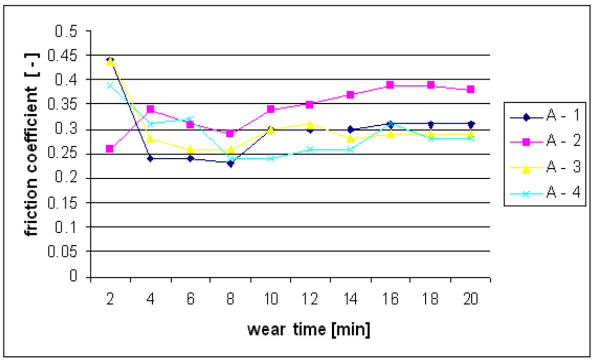


Figure 2. Time dependence of friction coefficient

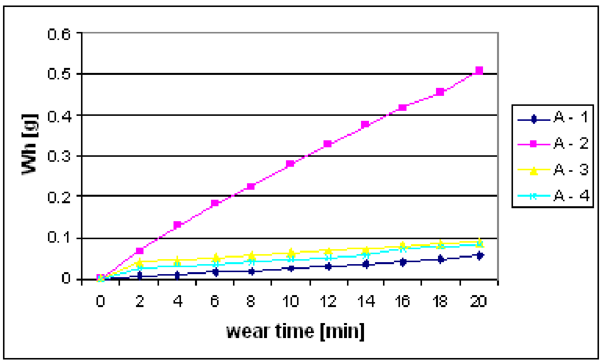
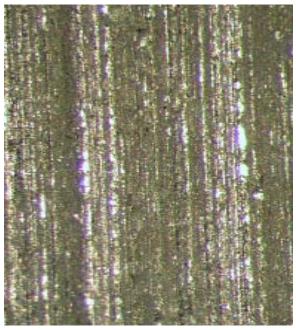


Figure 3. Time dependence of aluminium alloy weight loss

In the first phase of evaluated material couple contact elastic deformation of aluminium alloy surface irregularity occurs. When compressive yield strength is achieved, plastic deformation of surface layers consecutively appears. Plastic deformation of aluminium alloy surface caused strengthening of surface layer. As a consequence of aluminium alloy surface strengthening, material already was not able to next plastic deformation and some surface grooving by mate material together with material transfer within friction couple occurs, Figure 4.




Durethan PA 66 GF 30 Slovaster B1 GF 10


Slovamid 66 GF 25 Slovamid 6 GF 30

Figure 4. Photos of particular plastomer surfaces after wear test

Grooving intensity of aluminium alloy surface was amplified by presence of dispersed phase in plastomers – glass fibres. In addition to dispersed compound volume content and its arrangement in matrix, plastomer matrix hardness together with interfacial matrix – filler adhesion also shows significant influence on wear course. Plastomer Slovaster B1 GF10 shows the lowest hardness value of all evaluated plastomers. During friction gradual filler release from soft matrix occurs. Released filler next acts as abrading agent and subsequently caused aluminium alloy surface grooving, Figure 5.

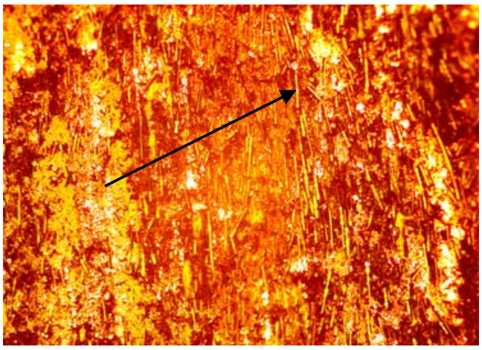


Figure 5. Glass fibres released from polymer matrix

During friction also temperature increases as a result of surface layers plastic deformation and energy transformation in friction couple contact area. This increase of temperature can significantly affect adhesive wear process itself. When temperature increases, plastomers transform from vitreous to rubber state.(11-13)

This transition is characterised by transition temperature (Tg). Transition temperature (Tg) for polyamides ranges within 65-80°C and for PBT around 40°C. From this fact it is possible to assume that during adjusting of friction couple A – 2 (Alumec 89 - Slovaster B1 GF10) plastomer present in rubber state, causing filler release from matrix.

Figure 6 shows profilographs, macro views and 3D views of aluminium alloy disk surfaces

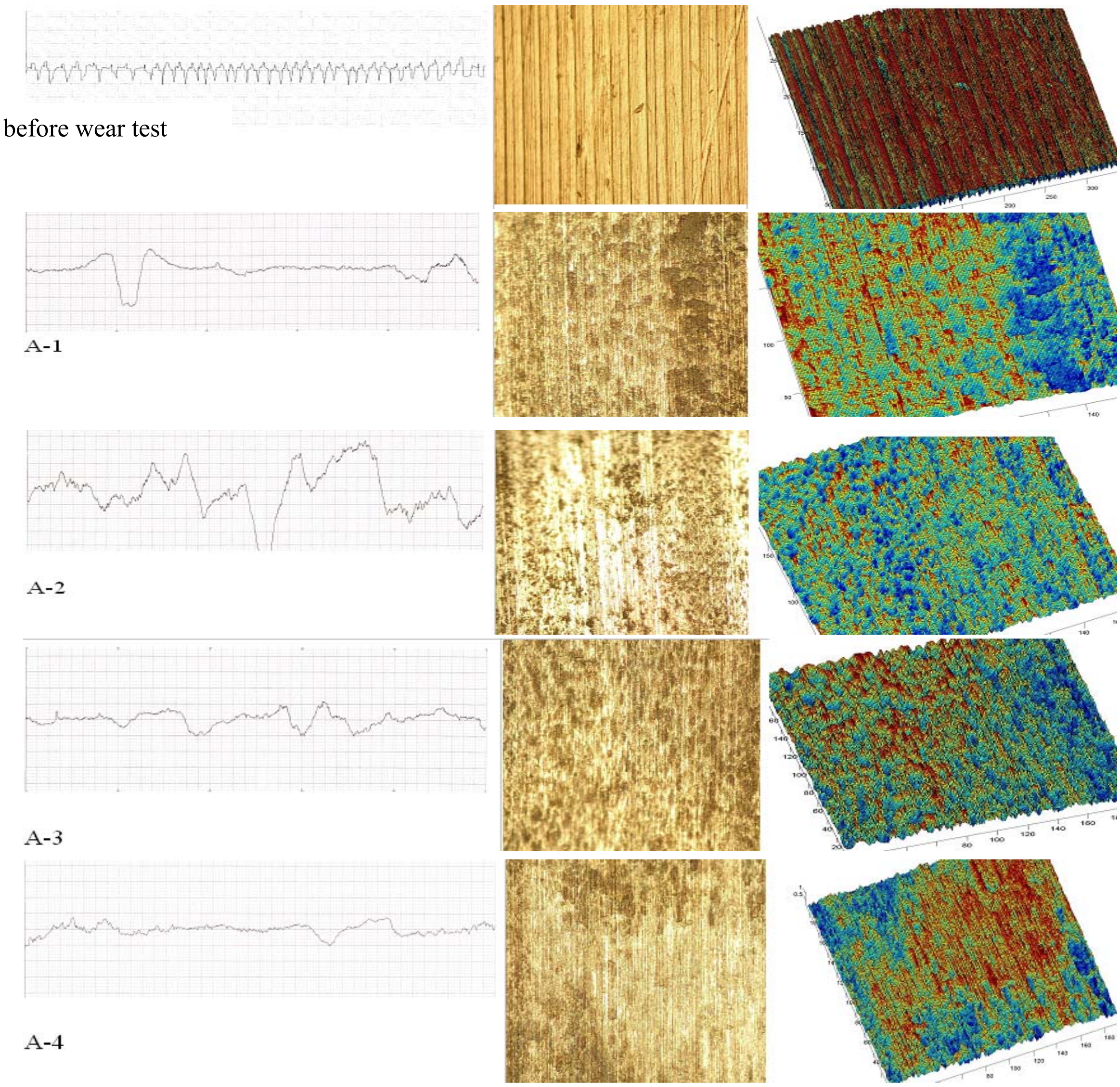


Figure 6. Profilographs of disk surfaces before and after wear, macroscopic views (mag. 100x) and 3D views

before and after friction couple with selected plastomers. Profilograph and macro view of disk in initial state show signs of surface production technology – turning. Grooves are oriented in line with main turning motions. In comparison between worn surfaces profiles and initial surface profile, the change of roughness profile characteristic for particular friction couple is visible. Aluminium alloy surface profiles after wear test are considerably irregular. Macro views and 3D views shows surface grooving by mate material and signs of aluminium alloy pitting.

Initial roughness values of aluminium alloy disk was as follows: Ra = 0,70 μm, Rz = 4,11 μm. Disk surface roughness change after wear test (20 minutes) in comparison with initial state is shown in Figure 7. Maximum roughness change occurs in friction couple A – 2, which confirms previous results. Roughness values of aluminium alloy disks A – 1, A-3 and A – 4 after wear are nearly equal.

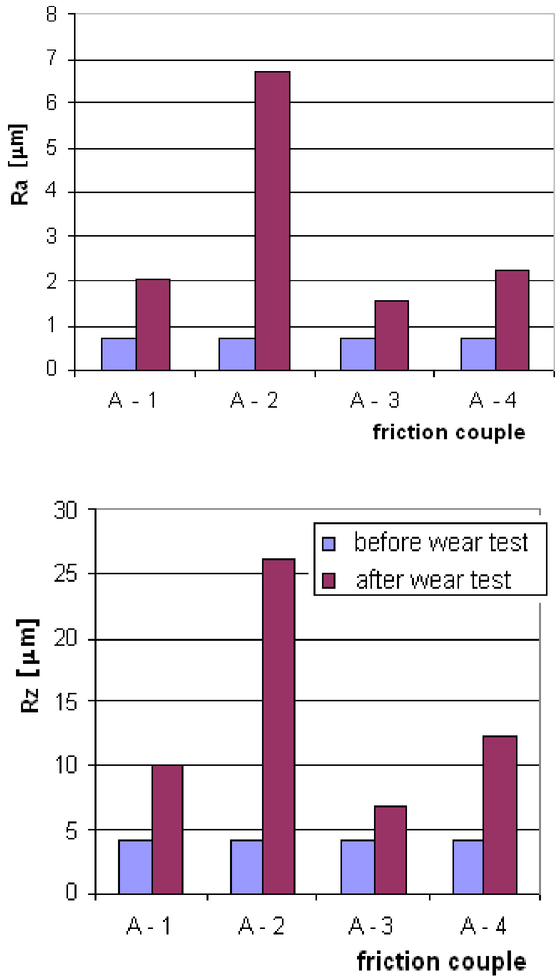


Figure 7. Roughness change of aluminium alloy disk before and after wear test

Conclusions

This contribution deals with problems related to wear of injection moulds shape filling blocks during processing of reinforced plastomers with different filler volume. Wear intensity of aluminium alloy Alumec 89 was studied in course of adhesion contact with four plastomer types reinforced by glass fibres. During adhesion wear test (20 minutes) the friction coefficient was monitored and wear intensity was expressed by weight loss. Simultaneously, selected roughness parameters were monitored. View of aluminium alloy surface in initial state and after wear was documented by macroscopic views and by computer aided 3D visualisation with help of image processing toolbox.

Achieved results may be summarised as follows. After friction couple adjusting and consecutive contact staying the highest friction coefficient in friction couple Alumec 89 - Slovaster B1 GF10 was observed (0,39), it means the highest wear intensity. The highest weight loss was observed again in the same friction couple, which supports determined friction coefficient values. Surface roughness of aluminium alloy after wear test for each friction couple increased, mostly again in friction couple Alumec 89 - Slovaster B1 GF10, which is in consistent with previous results. 3D surface visualisation confirms aluminium alloy wear mechanism by grooving and pitting in consequence of abrasive effect of dispersed phase.

Realised experimental works show that plastomer No.2 – Slovaster B1 GF10- reinforced with 10 % of glass fibres caused the most intensive wear of aluminium alloy Alumec 89. Even material hardness in general is a decisive factor of wear resistance evaluation, and wear intensity of evaluated alloys also depends considerably on arrangement and mutual adhesion of particular structural elements. In spite of the fact, that polyamide based materials shows higher hardness, notch impact and impact strength, they conduce to lower weight loss of Alumec 89 in comparison with PBT material. The assumption that higher volume content of reinforced component in polymeric matrix will be conduce to higher wear intensity of aluminium alloy is unconfirmed. The interaction between particular phases and adhesion on matrix – glass fibre boundary plays a decisive role in this wear mechanism plays.

Results reached by mentioned experimental works can help in injection moulds operating life determination based on known injection time, number of moulded pieces and moulds wear tolerance.

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