František GREŠKOVIČ*, Ľudmila DULEBOVÁ*, Emil SPIŠÁK*, Branislav DULEBA*, Ján VARGA*

ADHESIVE WEAR OF SELECTED TOOL STEELS USED FOR INJECTION MOULDS MANUFACTURING

ZUŻYCIE ADHEZYJNE WYBRANYCH STALI NARZĘDZIOWYCH STOSOWANYCH NA FORMY WTRYSKOWE

Key words:

tribology, adhesive wear, tool steel, rubbing, PA6 polymer

Słowa kluczowe:

tribologia, zużycie adhezyjne, stal narzędziowa, tarcie, polimer PA6

Summary

The aim of this work is to test and select appropriate types of tool steel for the production of mould inserts for plastic forming. The contribution is focused on the adhesive wear of mould inserts used for forming PA6 plastics. The wear of five types of tool steels were evaluated by weight decrease before and after the experiment, while change of the friction coefficient of rubbing airs

* Technical University of Košice, Faculty of Mechanical Engineering, Department of Technologies and Materials, Mäsiarska 74, SK- 040 01 Košice, phone: +421 556023504, email: frantisek.greskovic@tuke.sk

and change of the roughness. The mating components adhesive wear of tool steels was determined experimentally that has given the wear figures for injection moulds.

INTRODUCTION

Intensive development of new types of plastics, the rapid development of theirs industrial production in recent years and especially their application in various sectors of industrial activity have resulted in a rapidly increase in the demand for tools to process them. Metal and plastic forming mould tools are one of the most demanding areas in engineering **[L. 1]**. Injection moulds are often complicated technical devices that must withstand high pressure. They are designed to produce a mould corresponding to exact shapes and sizes that are easy to eject.

MATERIALS USED IN INJECTION MOULDS MANUFACTURING

Injection moulds consist of functional and auxiliary components that are manufactured with high precision, which is reflected in their cost. Materials for forms must fulfil the required operational conditions, temperature, pressure and abrasion resistance. The temperature at the thermoplastic injection varies from 120 to 330°C depending on the type of material. Emphasis on resistance to abrasion is given to the material of functional parts, especially in processing plastics with abrasive fillers.

Obviously, it is impossible to achieve all the above mentioned features with one material. Therefore, the most important properties are selected in terms of shape, size and the accuracy of mouldings and in terms of the size of the production batch. For moulds and related parts, the most commonly used tool steels are, structural carbon steels and alloyed steel. Tool steels are mainly used for the production of functional parts, such as the core and cavity. Tool steel can also be used for auxiliary parts, where it is necessary **[L. 2]**. Greater use of structural steel is often favoured due to its lower price and, the wider, availability and range of products. Required surface properties of forms include surface quality, corrosion resistance, fatigue resistance, wear resistance, the ability to easily remove mouldings, and a reduced tendency to create sediments in the form.

Surface wear of injection moulds

For wear resistance, the most suitable steel is ledeburitic steel of grade Cr-V-W-Mo and X210Cr12. They are followed by steel grade 100MnCrW4, 80WCrV3 and steel with good resistance in the following order: Cr-Mo-V, steels with cemented surface and steel of grade 62SiMnCr4 **[L. 1]**.

The conditions affecting wear are as follows:

- External conditions include the working environment (temperature, pressure, chemical activity), the working medium (flow rate, particle content, hardness, shape and the numbers of particles, and the conditions of impact on surface), and the dynamic loading of functional surface.
- Internal conditions include the suitability of form to the estimated function, the appropriateness of the material selection, the suitability of production technologies, the occurrence of flaws that distort the proper functioning of components.
- Working conditions include a comparison of the real conditions of operation with prescribed conditions, the continuous or intermittent overloading of working conditions, and possible operators errors **[L. 10, 11].**

EXPERIMENTAL WORK

Samples were of materials selected for their, properties, which suitable for producing of injection mould inserts.

The specific test materials (flat tongues) were follows:

- Tool steel type 1.2842 - 90MnCrV8,
- Tool steel type 1.2714 - 56NiCrMoV7,
- Tool steel type 1.2842 - 90MnCrV8,
- Tool steel type 1.2080 - X210Cr12,
- Tool steel type 1.2343- X38CrMoV5-1.

The specific plastic test material (material of friction roundel) was PA6 Polyamide Ravamid B-NC (unfilled plastic).

The material properties of PA6 are as follows: density 1,14 g/cm^3, yield strength 80 MPa, elongation > 50%, hardness = HB 150/DIN 53456, coefficient of friction 0,35 and sliding wear = 0,23 μm/km, content of glass filler 30%.

The evaluation of the wear of the materials for injection moulding was performed using the following methods:

- Hardness test of materials according to EN ISO 6507-1,
- The valuation of surface roughness according to EN ISO 4287,
- The evaluation of adhesive wear – coefficient of friction and weight loss was observed.

The hardness of material was determined by Rockwell hardness test and according to standard STN EN ISO 6507-1 and was measured using hardness tester HPO 250.

The surface roughness was determined using a touch type – profilometer Surftest SJ-301, which works by scanning of the surface using diamond tipped probe with 5 μm diameter, placed on a suspension arm. Microgeometry of the surfaces of the friction pairs was evaluated by standard STN EN ISO 4287. The method and direction of the roughness measurements of the samples from tool steel was chosen for the width labeled S90 and with the length labeled D0.

For evaluation of adhesive wear, an AMSLER test machine with surface contact was used. The samples had the form of flat tongues with proportions 20x15x9 mm and standard roundels with diameter 36 mm and thickness 10 mm. Examined mates were made from tool steel, and the roundel was manufactured from PA6. Support of roundel and mating was regulated to the desired pressure in the contact area by pressing a spring with force of 50 kN. The steel roundels were rotated at a speed 200.min^{-1} and the rubbing time was set to 30 minutes.

Experimental result and discussion

Directions of roughness measurements on metal samples were chosen as follows: Width was marked S90 (angle 90^{O}) and length was marked D0 (0^{o}). Directional hardness values (converted to HRC) of the tested materials are shown in **Fig. 1**. During the adhesive wear test, the coefficient of friction, weight loss and the roughness change of rubbing pairs were observed. The scale reading interval of the friction coefficient was set to 5 minutes. The average results of measurements of friction coefficients related to time for 5 samples of each material are presented in **Table 1** and graphically in **Fig. 2**.

The lowest friction coefficient of 0.74 at the beginning of the test was recorded for steel X38CrMoV5-1.And after 30 minutes of adhesive wear, the lowest coefficient of friction was recorded for steel X38CrMoV5-1 the increase of friction coefficients for all steels had approximately a linear characteristic with a value of reliability 0.8 by linear regression. The values of friction coefficients showed that hardness is not always the determining factor in choosing a suitable type of material for injection moulds.

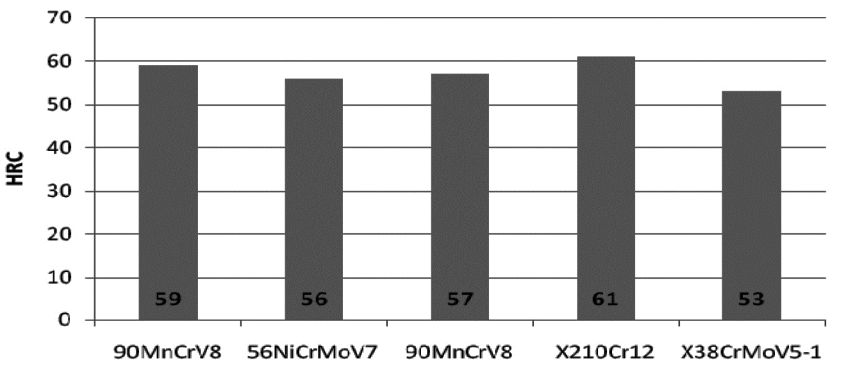


Fig. 1. Directional hardness values of tested materials
Rys. 1. Kierunkowe twardości badanych materiałów

Table 1. Average friction coefficient values in relation to time
Tabela 1. Średnie wartości współczynnika tarcia w zależności od czasu

Material	Friction coefficient µin time periods						
	µ [-] 0min	µ [-] 5min	µ [-] 10min	µ [-] 15min	µ [-] 20min	µ [-] 25min	µ [-] 30min
90MnCrV8	0.084	0.115	0.122	0.152	0.148	0.152	0.152
56NiCrMoV7	0.085	0.115	0.126	0.141	0.152	0.152	0.163
90MnCrV8	0.082	0.126	0.133	0.145	0.167	0.167	0.163
X210Cr12	0.075	0.104	0.115	0.126	0.130	0.141	0.148
X38CrMoV5-1	0.074	0.096	0.107	0.107	0.115	0.119	0.122

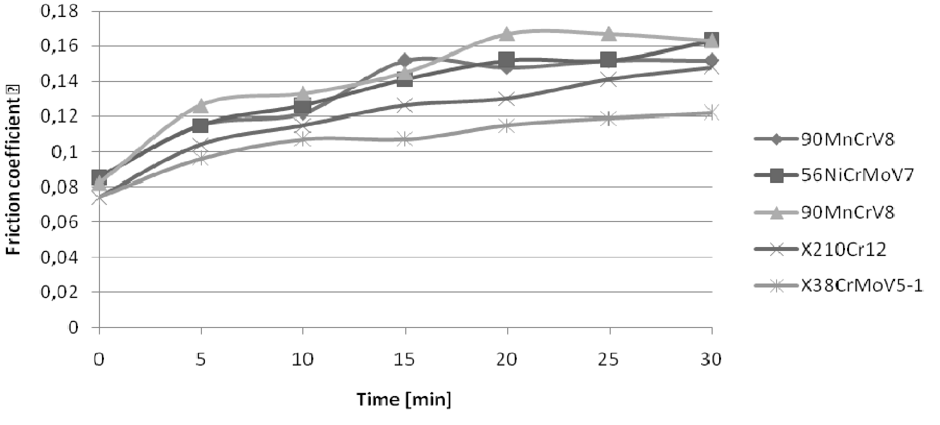
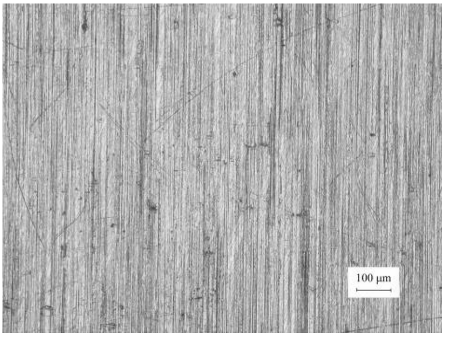
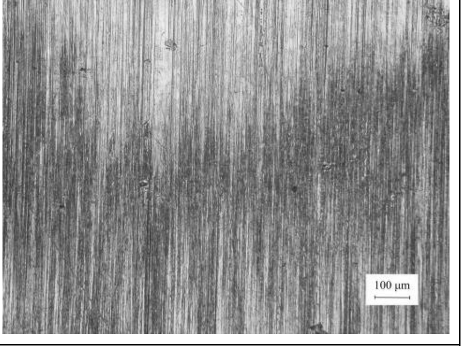
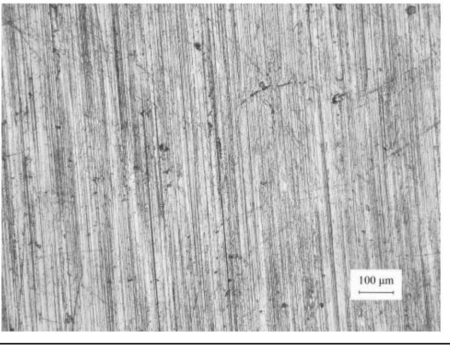
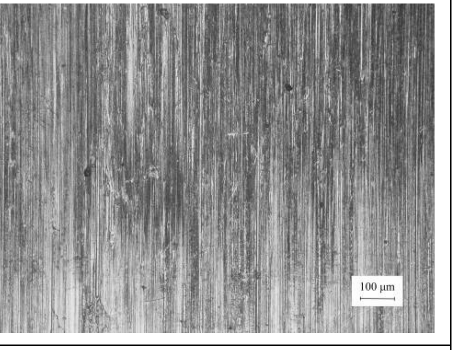
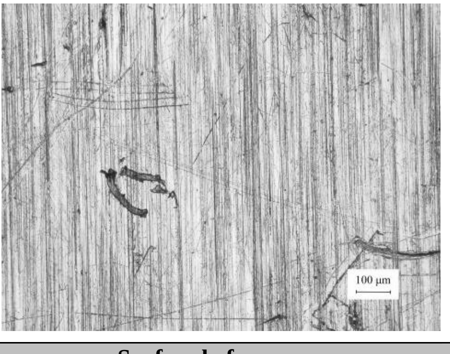
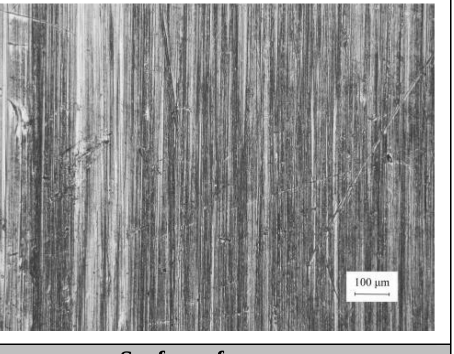


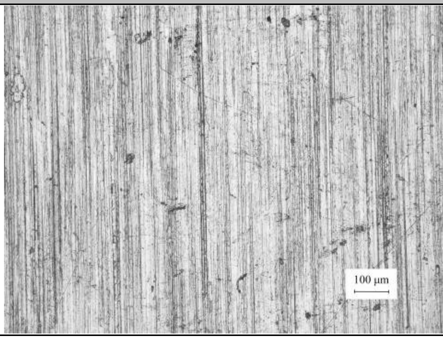
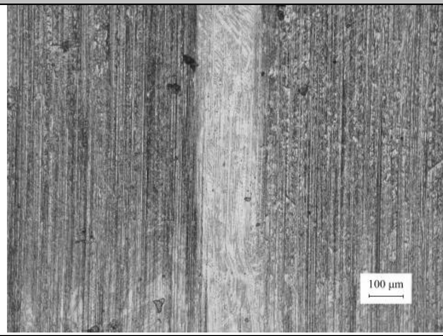
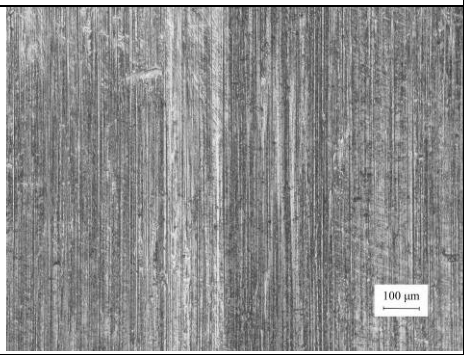
Fig. 2. Dependence of average values of µ in relation to time
Rys. 2. Zawisłość średnich wartości µ w zależności od czasu

Microscopic analysis before and after the wear of tool steel samples is shown in **Table 2** and were performed using an OLYMPUS U CTR30-2light microscope. A magnification of 100x was used for surface observation.

Material X210Cr12 achieved the highest values of hardness (HRC 61) given by the amount of alloying elements and it was therefore possible to assume the highest wear resistance of the material. But during the wear, there was detachment of chromium precipitates from the ledeburitic matrix in the form of pitting, which crucially affected the rate of material wear. The best wear resistance to exhibited specimens is shown material X38CrMoV5-1.

Table 2. HDG sheet surface views
Tabela 2. Wartości mikrogeometrii arkusza powierzchni HDG

Surface before wear	Surface after wear
90MnCrV8	
	
56NiCrMoV7	
	
90MnCrV8	
	
Surface before wear	**Surface after wear**
X210Cr12	

Surface before wear	Surface after wear
	
X38CrMoV5-1	
	

The results of the measurements of the surface roughness of materials are listed in **Table 3** and showed in **Figures 3** and **4**.

Table 3. Measured values Ra, Rz of tested materials
Tabela 3. Zmierzone wartości Ra, Rz badanych materiałów

Direction of measurement	Material	Average Ra [µm]		Average Rz [µm]	
		Before wear	After wear	Before wear	After wear
S90	90MnCrV8	0.26	0.30	1.96	2.11
D0		0.10	0.49	0.65	2.44
S90	56NiCrMoV7	0.32	0.37	2.30	3.02
D0		0.12	0.41	0.83	2.56
S90	90MnCrV8	0.32	0.32	2.43	2.23
D0		0.10	0.21	0.64	1.16
S90	X210Cr12	0.28	0.27	2.15	1.71
D0		0.14	0.10	0.89	0.72
S90	X38CrMoV5-1	0.34	0.29	2.57	1.95
D0		0.13	0.16	0.90	0.99

Another important factor influencing the rate of the material wear is the relief of macro and micro roughness of the contact surface. Frictional contact of materials leads to elastic and plastic deformation of jog peaks of the functional surfaces. During the plastic deformation the surface layers in contact may break. Subsequently, the formation of micro-joints and the accompanying surface firming of surface layers is observed. At the same time, there is a transfer of material particulate to the contact surface, depending on the material characteristics of the rubbing pairs. The amount and size of the grooves was proportional to the hardness of the evaluated materials. Knurling intensity also depends on the phase separation tendency in the interphase of the interface in the polymer material and on the adhesion size of the contact phases.

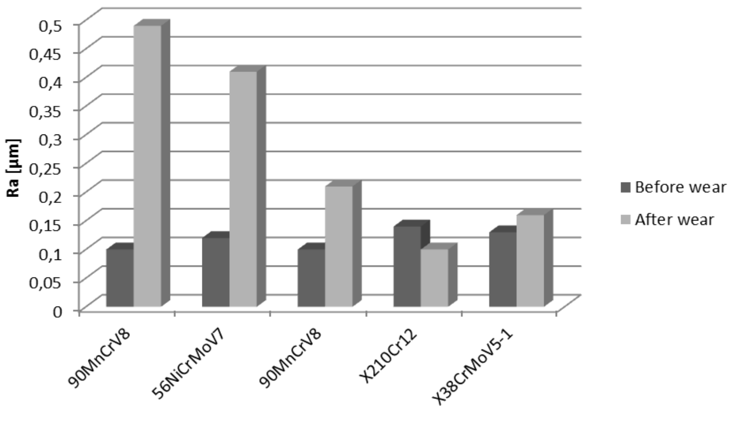


Fig. 3. Average Ra in direction D0 of tested materials
Rys. 3. Średnia Ra w kierunku D0 badanych materiałów

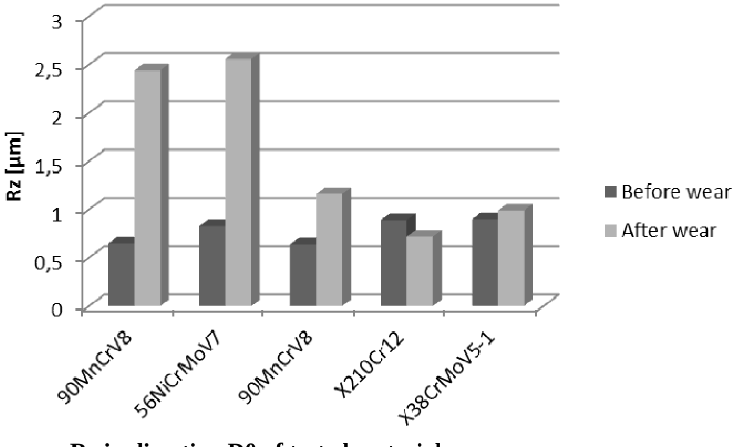


Fig. 4. Average Rz in direction D0 of tested materials
Rys. 4. Średnia Rz w kierunku D0 badanych materiałów

The greatest change of material roughness Ra and Rz in the direction D0 was showed for 90MnCrV8steel **(Fig. 5)** and the smallest change was measured for X38CrMoV5-1 steel. In direction S90, the changes in roughness values showed a smaller displacement, which are shownin **Fig. 6**. The smallest deviations were measured for 90MnCrV8 steel.

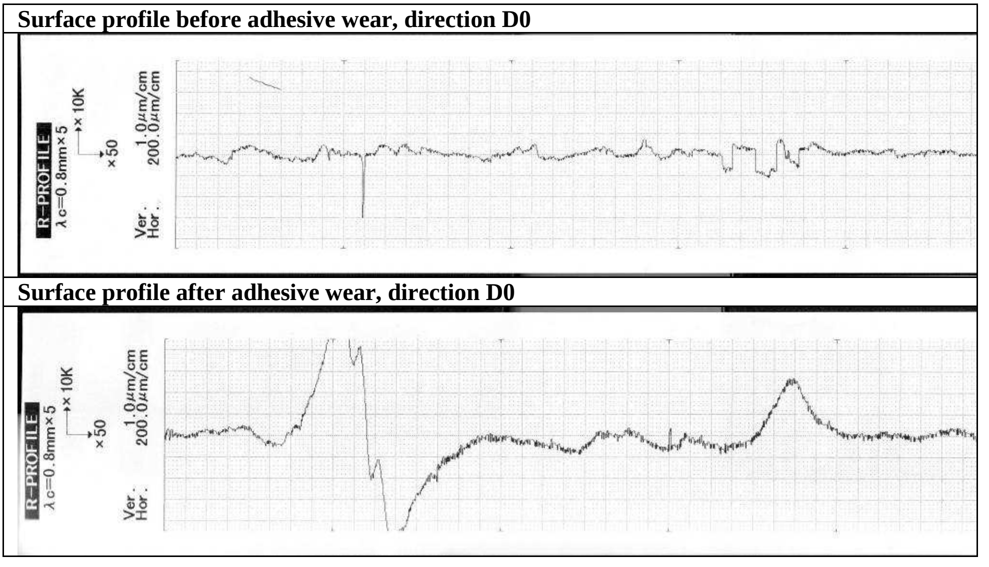


Fig. 5. Roughness of 90MnCrV8-steel surface
Rys. 5. Chropowatość materiału 90MnCrV8

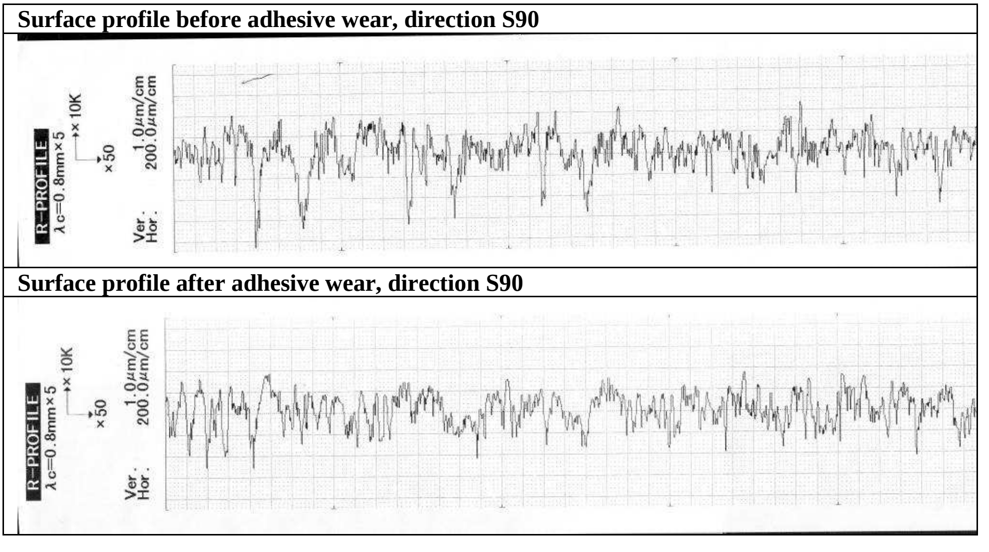


Fig. 6. Roughness of X38CrMoV5-1-steel surface
Rys. 6. Chropowatość materiału X38CrMoV5-1

The experiment also evaluated the weight loss of tested tool steels materials. The results are shown in **Table 4**.

Table 4. Measured weights of samples before and after adhesive wear
Tabela 4. Zmierzone masy próbek przed i po zużyciu adhezyjnym

Material	Weight before test [g]	Weight after test [g]	Mass loss [g]
90MnCrV8	23.4651	23.4351	0.0300
56NiCrMoV7	23.6400	23.5941	0.0459
90MnCrV8	23.4843	23.4733	0.0110
X210Cr12	23.2788	23.2635	0.0153
X38CrMoV5-1	23.3606	23.3600	0.0006

CONCLUSIONS

Based on the results of experiments on five types of tool steels with polymer counterparts of PA6, we can conclude the following:

- After the evaluation of hardness tests, we can conclude that all of selected tested tool steels are suitable for use in the manufacturing of injection moulds, next evaluation of adhesive wear evaluated the mechanical ruggedness of selected steels in contact with PA6.
- The surface of the tested tool steels were machined by rubbing corresponding to content of glass filler. After rubbing were visible defects on surfaces of the tested steels, as seen on the microscopic documentation (Table 2). Traces of plastic deposited by friction and colour changes of the contact area can be seen on the worn surfaces of tested tool steels.
- The largest mass removal of material was for 56NiCrMoV7 steel. The lowest mass removal of the material was for X38CrMoV5-1 steel.
- The highest coefficient of friction was recorded for 56NiCrMoV7 and the lowest coefficient of friction was recorded for X38CrMoV5-1.
- The largest change in surface roughening at evaluated parameters Ra, Rz was found in tool steels 90MnCrV8, 56NiCrMoV7 by friction to disc from PA6 plastic. Smaller changes at measured parameters Ra, Rz were evaluated in the direction of S90 as in the direction D0.

Based on the measured values, we can conclude, which tool steel is more suitable for the production of shaped inserts in combination with tested PA6 plastic. The most suitable was X38CrMoV5-1 tool steel.

SUMMARY

During the design of the shape inserts of injection moulds from tool steels, the selection of suitable materials is important. The shape insert must verify technical, functional and economic requirements. The functional aspects of the shape inserts include strength, toughness, dimensional accuracy, wear resistance, chemical resistance and the others. The technological aspects require simplicity and the ease of manufacturing. The economic aspects include the cost production methods and the selection of more available materials.

This paper presents the results of the tribological properties of selected types of tool steels. The materials were chosen on hardness, chemical composition and structural bases. Experiments were realized by the simulation of adhesive wear using laboratory equipment (Amsler), which allows the testing of dry rubbing pairs. Rated rubbing pairs consisted of tool steel and a PA 6 roundel. At tool steel samples were monitored for mass loss after 10 minutes of contact with the plastic roundel. The size of wear was also evaluated by the change of friction coefficient and changes in the morphology of the contact surfaces.

From obtained results it can be stated that the decisive factor is the type, distribution and mutual bond of the structural constituent of materials and then the hardness of materials. The size of wear also is affected by the microroughness of contact surfaces and material combinations of rubbing pairs.

Acknowledgments

This paper is the result of the project implementation: PIRSES-GA-2010--269177 supported by The international project realised in the range of Seventh Frame Programme of European Union (FP7) and Project VEGA 1/0500/12: Research on Quality Improvement when Milling Formed Surfaces by Advanced Coated Tools.

REFERENCES

1. Greškovič F., Spišák, E., Dulebová Ľ., Varga J.: Nástroje na spracovanie plastov vstrekovacie formy/ Košice : TU, SjF – 2010. – 220 s.
2. Greškovič F., Spišák E.: Materiály foriem na spracovanie plastov: Acta Metallurgica Slovaca. roč. 9, (2003), s. 41–48.
3. Stachowiak G., Batchelor A.: Engineering Tribology (Third Edition), Elsevier Inc., Oxford, UK, 2006.
4. Bajer J., Janecki J.: Charakterystyki tribologiczne łatwo usuwalnego smaru plastycznego dla przemysłu spożywczego, Tribologia, nr 6, s. 123–136, Bibliogr. 17, 2003.
5. Neska P., Piwoński I.: Wear and friction behaviour of alumina thin coatings prepared by sol-gel methods, Tribologia, nr 1, s. 117–124, Bibliogr. 3, 2011.

6. Kozdrach R., Bajer J., Drabik J.: Wpływ rodzaju zagęszczacza na charakterystyki tribologiczne smarów plastycznych, czasopismo Tribologia, nr 1, s. 73–83, Bibliogr. 20, 2011.
7. Palabiyik M., Bahadur S: Tribological studies of polyamide 6 and high-density polyethylene blends filled with PTFE and copper oxide and reinforced with short glass fibers, Wear 253 (2002) 369–376.
8. Rabinowicz E.: Friction and Wear of Materials. New York, p. 336, 1995.
9. Bajer J.: Charakterystyki tribologiczne niektórych smarów plastycznych poddanych ugniataniu w obecności wody, Tribologia, nr 1, s. 7–21, Bibliogr. 13, 2009.
10. Gawędzki W., Lepiarczyk D., Tarnowski J.: Laboratoryjna identyfikacja procesu tarcia w skojarzeniu ciernym żeliwo–żeliwo, Tribologia, nr 1, s. 53–64, Bibliogr. 7, 2011.
11. Kozdrach R., Drabik J., Pawelec E., Molenda J.: Wpływ dodatku modyfikującego AR na właściwości tribologiczne ekologicznych smarów plastycznych, Tribologia, nr 1, s. 27–39, Bibliogr. 8, 2010.

Streszczenie

Celem pracy było przetestowanie i wybór właściwej stali narzędziowej do wytwarzania form wtryskowych do elementów z tworzyw sztucznych. Publikacja jest zogniskowana na zużyciu adhezyjnym form stosowanych do formowania tworzywa PA6. Zużycie pięciu rodzajów stali narzędziowej zostało określone przez wyznaczenie spadku masy przed i po przeprowadzeniu testu, przy czym określono też współczynnik tarcia chropowatości. Zużycie adhezyjne stali narzędziowych zostało określone eksperymentalnie, co dało wartości zużycia dla form wtryskowych.