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**TRIBOLOGICAL ASPECTS FOR INJECTION PROCESSING
OF THERMOPLASTIC COMPOSITE MATERIALS WITH
GLASS FIBER**

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Abstract

The melted polymer's relative movement, with high speed and under great pressure, upon the metallic surfaces of the snail, cylinder and mould create a environment adequate to the appearance of the wear phenomenon. The abrasive effect of the glass fibre fitting as well as the aggression of the chemical compounds freed from the melted plastic material is added to the factors mentioned above. Industrial materials processors' experience shows that mould's and work devices' wear phenomena are of great importance in processing glass fibre filled materials. The studies carried out allowed for the establishing of a correlation between the wear produced to the steel by thermoplastic compound materials with glass fibre, experimentally proved on linear contact couple and the wear produced by compound polymers melts in viscous flow on the metallic surfaces of the injection machines. The comparative coefficients' values for the wear produced by different compound plastic materials to injection mould have been determined. Regression curve equations of these K and K^ coefficients as well as absolute values' domains for the used V_u volume and the thickness of the used h_u steel are shown.*

Keywords: *friction, wear, composite thermoplastics, comparative wearing coefficient*

**1. SLIDING AND FRICTION OF
POLYMERS IN VISCOUS FLOWING
STATE ON A SOLID BODY'S SURFACE**

Any polymer in viscous flowing state can be found in different temperature and pressure conditions. The tribological behaviour of the metal/plastic material couple, in the case of viscous flowing state of the plastic material, is a particular case, very little studied. Bartenev and Lavrentiev [1] show that as a consequence of the slight deformations of the polymers in such conditions a fictive contact area, comparable as a notion with solid bodies' nominal contact surface, is formed at the separation surface with a solid body. In this situation, even for small adhesions of the polymer with the solid's surface, tangential shearing efforts, that exceed the value of maximum shearing efforts from the fluid material's volume, appear on the contact

area. This makes for the pure external friction not to manifest itself, which is one of the experimental difficulties in studying this kind of friction.

Out of general physical grounds it results that along with the temperature's increase the polymer loses its rigidity and the forces of molecular adhesion with the solid body's surface decrease. This leads to localizing the friction process especially in the volume, passing from external to internal friction, characterized by very big friction forces between the polymer's molecules and low friction forces between the polymer and the solid body's surface. Fundamental friction laws still stand in this case.

The only distinguished feature is that that at external friction molecules' sliding is done in relation with the solid surface while at internal friction molecules slide one from the others.

Quantitatively, this is expressed through a different energy activation value for the two processes.

In external friction the contact surface's geometry is also important, being necessary to take into consideration the real contact surface, as well as the normal charge's influence upon the friction force. When the other conditions remain unchanged, it is necessary for the realization of external friction that the specific shearing effort is smaller than the polymer's flowing limit and greater than the tangential effort on the polymer's separation surface from the solid body. From a molecular point of view, it is necessary that the polymer's chain energy of adhesion with the solid surface's asperities is smaller than the cohesion/adherence energy of the polymer's molecules.

For disperse (multi-component) systems, a category, which also includes some polymer, melts, sliding phenomena on the separation surface are more complicated and in general, some researchers [1] talk about a "sliding against the wall" phenomenon. Even though typical adhesion decreases with the temperature increase, the polymer's external friction in viscous flowing state on the solid surface is characterized by high friction coefficients.

The flowing polymer's temperature decrease leads to adhesion increase on the solid surface, but in parallel both an increase of the polymer's resistance to flowing and an increase of the polymer's molecular network resistance take place which causes the friction to become purely external.

The analysis of sliding systems' disperse mechanism allows for the outlining of the following possible cases adequate for polymers melts:

- sliding is manifested through internal friction of the disperse environment layers;
- sliding is produced on the geometrical separation surface of the disperse environment layers, by the particles that are nearest to it ;
- sliding takes place against the wall, similar to the movement of a rolling bearing's spheres, in a presumptive limited friction [1], Bloom's model (fig.1). According to Rebinder, the role of the sliding against increases with the disperse phase's concentration increase.

Considering a molecular fluid layer, the following relation gives its sliding velocity on a solid body's surface, in the meaning of the sliding against the wall theory:

$$v = d \cdot dv/dr \quad (1)$$

where d is the average free molecular distance/route of the molecules that move in thermal motion from one equilibrium position to another, and dv/dr is the velocity gradient on the normal to the solid body's surface.

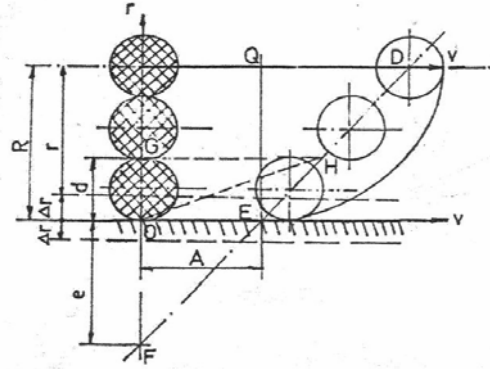


Fig.1: Bloom's model [1] for disperse systems' sliding against the wall

The mobility of the molecules in volume, according to Frenkel's theory [1], is:

$$W = \frac{d^2}{6kT\tau_0} e^{-\frac{U}{kT}} \quad (2)$$

or:

$$W = \frac{(dv/dr)d}{F} = \frac{1}{\eta d} \quad (3)$$

where: k – Boltzman's constant; T – absolute temperature; η - dynamic viscosity – the energy for activating the particles' mobility; τ_0 – shearing effort between the fluid layers.

An analogous expression can be written for the fluid molecules neighbouring the solid body, considering $\tau_0 = \tau_{0,L,S}$ (the shearing effort at the liquid – solid separation interface).

By dividing the mobility of the molecules neighbouring the solid body's surface to the mobility of the molecules in volume it is obtained:

$$\frac{W_{L,S}}{W} = e^{\frac{U-U_{L,S}}{kT}} \quad (4)$$

Frenkel defines the activation energy U as the energy needed for the apparition of a micro void in the liquid volume, where a molecule could fit in. It can be determined through the superficial tension of the micro cavity:

$$U = S \zeta_L$$

where ζ_L is the superficial tension at the liquid – void frontier and $S = \pi d_{ef}^2$ is the real surface of the void with effective diameter d_{ef} .

As it can be seen from Fig. 1, the mobility's ratio depends on the sliding coefficient e :

$$\frac{W_{L,S}}{W} = \frac{(dv/dr)_{L,S}}{dv/dr} = \frac{\overline{GH}/d}{\overline{GH}/(e+d)} = 1 + \frac{e}{d} \quad (5)$$

It results:

$$e = d \left(\frac{W_{L,S}}{W} - 1 \right) \quad (6)$$

Relations (5) and (6) allow for a quantitative evaluation of the sliding against the wall effect, in the case of polymer melts' relative movements on the surface of a solid body.

From a quantitative point of view, relation (6) allows the observing that sliding against the wall increases with the increase of the average free molecular route d and with the decrease of the wetting coefficient, or with the increase of the difference between cohesion and adhesion mechanical works.

For the liquid molecules absorption on the solid body's surface, it can be written:

$$A = K - \Delta F \quad (7)$$

where ΔF is the variation of the solid body's free superficial energy. Since absorption is an exothermic process, ΔF is a negative quantity and, as a consequence, the adhesion mechanical work A is greater than the cohesion mechanical work k . From this it results that $W_{L,S} < W$, which shows that the sliding mechanism is connected, in this case, to the internal friction of the molecules within the absorbed liquid thin coating, to the liquid layers with which it comes into contact.

In some cases of polyethylene melts friction no complete wetting of the solid surfaces is observed and the absorption energy is low. In this situation, it is supposed that a sliding of the liquid takes place on the solid surface.

Yet the sliding against the wall theory developed for polymers does not take into account the fact that the σ tensions that appear at the polymer – solid body separation limit should lead to the decrease of the effective/real sliding process activation energy. In this situation, relation (3) should become:

$$W = \frac{d^2}{6kT\tau_0} e^{-\frac{U-\gamma\sigma}{kT}} \quad (8)$$

where γ represents a proportionality coefficient

For the case of pure sliding on the solid surface, relation (7) shows that the tangential efforts that appear at the contact interface will facilitate the increase of the sliding velocity, in which situation we have a pure external friction.

Based on the sliding against the wall theory, characteristic of disperse systems, the category, which includes polymer melts, Rebinder, Volarovici and Dereaghin [1] have proposed different relations for expressing the dependence of the friction against the wall force on normal charge, on velocity and on temperature. If they have been able to determine a binominal relation for the influence of the normal charge on the friction force, relation that would be verified in practice, no quantitative results were obtained for the velocity's influence on the friction force, because of the lack of some complete and accurate experimental data.

Regarding the wear phenomena of metallic surfaces in contact with plastic materials in viscous flowing, a unitary theoretical basis is not yet determined, on a world scale. Research published up to now approach qualitative and quantitative aspects in particular cases only.

From those presented above the extremely important role of the sliding against the wall stands out, both from a theoretical point of view, for the study of friction and wear, and from a practical point of view, observing that the absence of the sliding against the wall can lead to the interruption of technological processes of plastic materials' manufacturing.

2. STUDY OF THE MOULDSWEAR PROCESS AT THE INJECTION PROCESSING OF THERMOPLASTIC MATERIALS REINFORCED WITH GLASS FIBRES

Since metallic surfaces' wear, in the case of injection processing of thermoplastic materials reinforced with glass, depends on a multitude of technologic and fabric parameters, stabilizing their wear speed was sought comparatively for different material torques. For this purpose, a factory model destined for the moulds wear process was designed, in real conditions of thermoplastic materials injection processing. The theoretical schema of this model is shown in fig. 2.

variation in circular channels of R radius (e.g. in a mould's nozzle).

We have considered the flowing of the polymer's melting through a mould's nozzle as being isothermal. The hypothesis is justified taking into account the small duration of the flowing and the nozzle's high temperature, temperature being kept constant.

The shearing efforts within the polymer melting τ depend on the velocity gradient and velocity varies with the shearing efforts:

$$\tau = K(dv/dr)^n \quad \text{and} \quad v = f(\tau^n) \quad (9)$$

For circular channels the velocity gradient can practically be determined [9] by using the relation:

$$dv/dr = 32 Q/\pi d^3 \quad (10)$$

where Q represents the flow capacity and d is the channel's diameter.

Considering an isothermal flow with $n = 0,5$ as flow parameter inside a circular channel of R radius, the profile of the velocity's variation curve is a parabola, for which situation we have assumed the relation:

$$v = -Cr^2 - br + A \quad (11)$$

The equation is verified in the admitted hypotheses:

$$v_{r=0} = A \quad \text{and} \quad v_{r=R} = -CR^2 - bR + A$$

Based on relation (11) the velocity gradient's relation can be written:

$$dv/dr = -2Cr - b \quad (12)$$

From the condition that the velocity is to be maximum in the centre of the circular channel, it is obtained:

$$(dv/dr)_{r=R} = -2Cr - b = 0 \quad \text{and} \quad b = -2CR$$

Relation (11), becomes:

$$v = -Cr(r - 2R) + A \quad (13)$$

By deriving the previous relation in rapport to the r variable, we have:

$$dv/dr = -2Cr + 2CR = 2C(R - r) \quad (14)$$

and the expression of the shearing effort inside the melting becomes:

$$\tau = K[2C(R - r)]^n = Z(R - r)^n \quad (15)$$

where :

$$Z = K(2C)^n.$$

The (15) expression is also verified by the limit conditions: $\tau_{r=R} = 0$ and $\tau_{r=0} = ZR^n$. Based on some experimental results, the values of τ for different flow indexes (0;0,5;1), lead to allures of the velocities profiles similar to those presented in the specialty literature [29].

Giving the radius R of the flow channel a $\pm \Delta r$ theoretical variation, it can be written:

$$v_+ = -C(r + \Delta r)(r + \Delta r - 2R) + A \quad (16)$$

$$v_- = -C(r - \Delta r)(r - \Delta r - 2R) + A$$

It results:

$$\frac{v_+ - v_-}{2} = 2C\Delta r(R - r) = \Delta v \quad (17)$$

which leads to:

$$C = \frac{1}{2(R - r)}(\Delta v / \Delta r) \quad (18)$$

Introducing C 's expression in relation (13), we have:

$$v = \frac{r}{2(R - r)}(\Delta v / \Delta r)(2R - r) + A \quad (19)$$

From relation (19), the expression of the sliding against the wall velocity is obtained:

$$A = v - \frac{r(2R - r)}{2(R - r)}(\Delta v / \Delta r) \quad (20)$$

From the resemblance of the EQD and FOE triangles from fig.1, it can be observed that $v/A = R/e$, from which it results:

$$A = ve/R \quad (21)$$

According to relation (6), the sliding coefficient e depends on the report between the particles' mobilities at the liquid - solid separation surface $W_{L,S}$ and respectively from the volume W_L . Since in processing through injection conditions $W_{L,S} \ll W_L$, it results that in order to allow the sliding against the wall to take place it is necessary that $e = -d$, the minus sign denoting that the value is measured in the negative sense of the ordinate's axis.

Assuming that the spherical particles have a diameter between $10^{-4} \div 10^{-3} \text{ cm}$ and that the circular channel's radius is of 10^{-1} cm order, we have:

$$A = (0,001 \div 0,01)v \quad (22)$$

By calculating for the real case of injecting a volume of 50 cm^3 of Maranyl polyamide with 20% glass fibre into a two-nested mould, the time requested for filling the mould being of 7 s and the nozzle's medium diameter being of 6 mm , we have: $v = 101,4 \text{ cm/s}$. The variation domain of the sliding against the wall relative velocity results: $A = (0,1 \div 0,01) \text{ cm/s}$.

In the case of injecting a product with a volume of 460 cm^3 of Noryl polyamide + 20% glass, the filling of the mould being done in 15 seconds and the nozzle's medium diameter being of 5 mm it results that: $v = 625 \text{ cm/s}$, respectively $A = (0,6 \div 6,25) \text{ cm/s}$.

From the examples presented it results that the value of the sliding against the wall velocity depends on the nature of the injected material,

the volume and configuration of the product and on the injection cycle's parameters, generally having small values.

Comparing the experimental results from tab.1, obtained on the factory model, with those presented for Timken type couple, plastic material reinforced with glass/steel fibre, it can be observed that wear speeds values differ very much.

Wear speeds obtained on the factory model are approximately 10^3 times smaller than those obtained on the laboratory model having Timken type couple. This difference comes is derived from the different durations of the trials carried out on the two experimental models.

In order to justify the statement above three trials were carried out on Timken type couple, Nylonplast AVE polyamide + 30% glass/ C 120, at a speed of 18,56 cm/s, 2 daN charge (pressure of 231 daN/cm²) and at a total trial duration of 50 hours.

Experiments were done in special conditions, the couple being held in a continuous cold air draught in order to limit the temperature growth in the contact area at 70° C and to preserve the socket's, preponderant elastic, deformation. The trials have lead to the appearance of some wear imprints with medium widths between 1,961 and 2,087 mm.

By calculating with the help of linear contact couple relations, values of the impression's medium transversal surface with values between (17,845 ÷ 18,983) .10⁻⁵ mm² are obtained, as well as medium depths of the wear impressions with values between (8,4106 ÷ 8,6372) . 10⁻⁴ mm and values of the wear

volumes that are found between (17,845 ÷ 18,98) . 10⁻⁴mm³.

By dividing the values above by the trial's duration (50 hours), medium wear speeds of 0,1704 . 10⁻⁴ mm/h, respectively 3,68 . 10⁻⁸ cm³/h are obtained.

It can be observed that the values above are almost 4 times smaller than those obtained on the factory model. We estimate that the difference between the results obtained on the two experimental models is due to the fluid state of the plastic material in the factory model trials' case.

Taking into account the fact that laboratory trials on Timken type couple were done at a relative sliding velocity with values between 18,56 and 153,6 cm/s, values calculated based on the sliding against the wall theory in the case of injecting some thermoplastic material products reinforced with glass fibre previously presented, in melted state, the glass content has the greatest proportion not the polymer's fluid state. This conclusion is justified by the small difference (less than 16%) between results obtained in the same experimental conditions on the factory model and on the laboratory model with Timken couple.

Considering the observation above and the mould's temperature through the temperature of the metallic element of the Timken type friction couple, located in the same domains, it results that the study of the mould's wear, mould used at injection processing of thermoplastic materials, can be done using Timken type couple – plastic material/steel in good precision conditions.

Tab.1. Results of the trials carried out on the real model for determining moulds' wear rate

A- Injected material; B – Mould's number of nests; C – Volume of injected material cm³; D– Duration for filling the mould sec ;E– Nozzle's medium diameter mm ;1 –Maranyl polyamide +20% glass; 2 –Noryl polyamide +20% glass; 3 –Nylonplast AVE polyamide +30% glass; 4 –Lexan polycarbonate +20% glass

A	B	C	D	E	Initial weight of the study samples (g)			Cycles	No. Pieces	Wear ΔG (10 ⁻⁵ g)				Wear volume of the sample ΔV 10 ⁻⁶ cm ³	Total wear volume ΔV _i = 4ΔV 10 ⁻⁶ cm ³	Wear rate V _u 10 ⁻⁸ cm ³ /h
					G ₁	G ₁	G ₁			ΔG ₁	ΔG ₂	ΔG ₃	ΔG			
1	2	50	7	6	1,51070	1,59706	11,77733	0	0	0	0	0	0	0	0	0
	2	50	7	6	1,51067	1,59705	11,77732	5,1 .10 ⁵	5,1 .10 ⁵	3	1	1	5	37,88	151,52	15,28
	2	50	7	6	1,51066	1,59703	11,77732	0,9 .10 ⁶	0,9 .10 ⁶	4	3	1	8	60,61	242,44	13,85
2	1	460	15	5	1,51023	1,59694	11,77682	0	0	0	0	0	0	0	0	0
	1	460	15	5	1,51015	1,59688	11,77680	5,0 .10 ⁵	5,0 .10 ⁵	8	6	2	16	125,98	503,92	24,19
	1	460	15	5	1,51012	1,59684	11,77679	1,3 .10 ⁶	1,3 .10 ⁶	11	10	3	24	188,98	755,92	13,95
3	1	460	18	5	1,50915	1,59664	11,77565	0	0	0	0	0	0	0	0	0
	1	460	18	5	1,50910	1,59660	11,77564	5,3 .10 ⁵	5,3 .10 ⁵	5	4	1	10	74,07	296,28	11,18
	1	460	18	5	1,50907	1,59657	11,77563	1,0 .10 ⁶	1,0 .10 ⁶	8	7	2	17	125,93	503,72	10,07
4	2	50	7	6	1,51070	1,59706	11,77733	0	0	0	0	0	0	0	0	0
	2	50	7	6	1,51067	1,59705	11,77732	4,9 .10 ⁵	4,9 .10 ⁵	3	1	1	5	37,88	151,52	15,28
	2	50	7	6	1,51070	1,59706	11,77733	1,0 .10 ⁶	1,0 .10 ⁶	0	0	0	0	0	0	0

Starting from this conclusion, variation diagrams of the wear coefficient previously defined, for moulds made out of C120 steel, quenched 59-60 HRC were traced based on the vaster experimental results obtained in the laboratory and presented in [3]. These diagrams are shown in fig. 3, 4, and 5.

By analysing the diagrams shown in fig. 3, 4, and 5 it can be observed that the variation with the speed of the wear coefficient is cvasi-linear. The fact that the K^* coefficient's decrease with the increase of velocity is faster than the decrease of the K coefficient.

We consider that this is due to the plastic material's deformation under charge, which leads to the more emphasised increase of the wear imprint's width than of its depth, in the case of the Timken type couple.

From the diagrams shown it can be observed that the wear coefficient's values of the metallic element of the thermoplastic material reinforced with glass fibre/steel belong to the $(10^{-11} \div 10^{-12}) \text{ cm}^3/\text{cm}$, respectively 10^{-9} mm/cm interval.

Thermoplastic materials that are not reinforced generate a very low wear of the metallic surfaces, a wear of the $(10^{-15} \div 10^{-16}) \text{ cm}^3/\text{cm}$ order, and that is why it has not been presented in detail in this paper.

The diagrams shown in fig. 3, 4 and 5 have a special practical importance, as they allow for the determination of moulds' maximum wear, under different technologic conditions (the injected material, glass fibre content, the injection cycle's parameters, the overall dimension and configuration of the injected material).

3. CALCULATING THE MOULDS' WEAR RATE AT INJECTING THERMOPLASTIC MATERIALS WITH GLASS FIBRES

The calculation method realised is based on using the wear coefficient, whose variation with charge and velocity is shown in fig. 3, 4 and 5.

Considering the real case of injecting in a mould with one nest, made out of C 120 steel

and hardened 59 HRC, a volume of 460 cm^3 Nylonplast AVE +30% glass polyamide, the moulds' filling taking place in 18 seconds and the medium nozzle's diameter being of 5 mm , the suggested calculation method implies the algorithm presented next.

Using relation (10), it is obtained:

$$dv / dr = 32Q / \pi d^3 = 2082 \text{ s}^{-1}$$

In the centre of the circular channel, the fluid current's velocity will be:

$$v = (dv / dr)r = 2082 \cdot 0,25 = 520,5 \text{ cm / s}$$

Using relation (22) the relative velocity for sliding against the wall is obtained:

$$A = (0,001 \div 0,01)v = (0,52 \div 5,2) \text{ cm/s}$$

Based on relation (22), the expression for the covered friction road length's dependence on the fluid flow's limit layer at the contact surface of the latter with the circular channel (L_0) and the (L) distance covered by the current's medium fibre can be written:

$$L_0 = (0,001 \div 0,01)L;$$

$L = vt = 520,5 \cdot 18 = 9369 \text{ cm / injected piece}$

$$L_0 = (0,001 \div 0,01) \cdot 9369$$

$$= (9,369 \div 93,69) \text{ cm / injected piece}$$

Using the $V_u = KL$ relation, it can be written:

$$V_u = (9,369 \div 93,69) K \text{ cm}^3 / \text{injected piece}$$

From the diagram shown in fig. 3, for the injection pressure of 231 daN/cm^2 , corresponding to the 2 daN charge, by prolonging the variation curves of the K wear coefficient, considering its cvasi - linearity, the following values are obtained:

$$K = 0,678 \cdot 10^{-11} \text{ cm}^3/\text{cm}, \text{ for } v = 0,2 \text{ cm/s}$$

$$K = 0,640 \cdot 10^{-11} \text{ cm}^3/\text{cm}, \text{ for } v = 5,2 \text{ cm/s}$$

It results: $V_u = (0,635 \div 5,996) 10^{-10} \text{ cm}^3 / \text{injected piece}$. For a production level of 10.000 pieces, it results that $V_u = (0,635 \div 5,996) 10^{-6} \text{ cm}^3$.

Since during the injection of the 10.000 pieces the theoretical duration of the friction contact between the nozzle and the melted plastic material is of 50 hours, it results that the moulds' maximum wear speed is:

$$V_{u_{\max}} = (1,27 \div 11,99) 10^{-8} \text{ cm}^3/\text{h}.$$

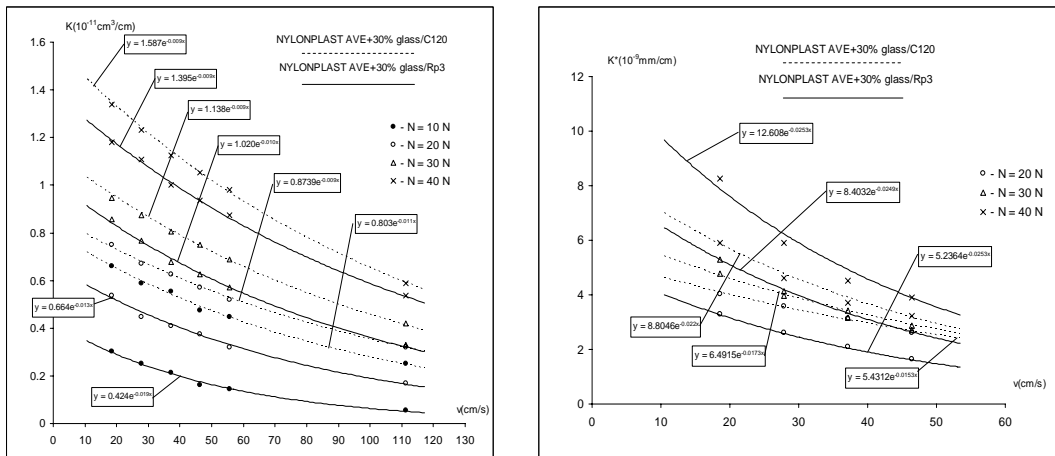


Fig. 3: K and K^* wear coefficients' variation with charge and velocity for the polyamide + 30% glass/steel couple

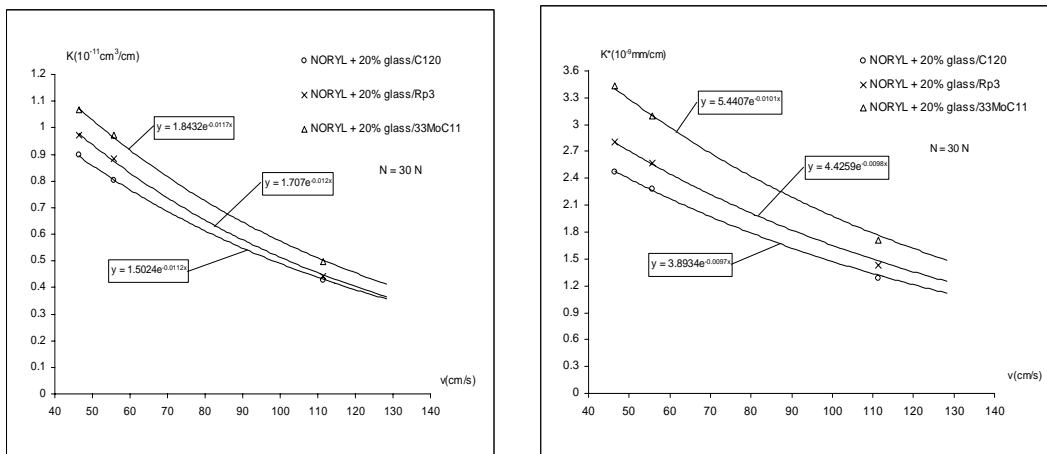


Fig. 4: Wear coefficients' variation with charge and velocity for the polyamide + 20 % glass/steel couple.

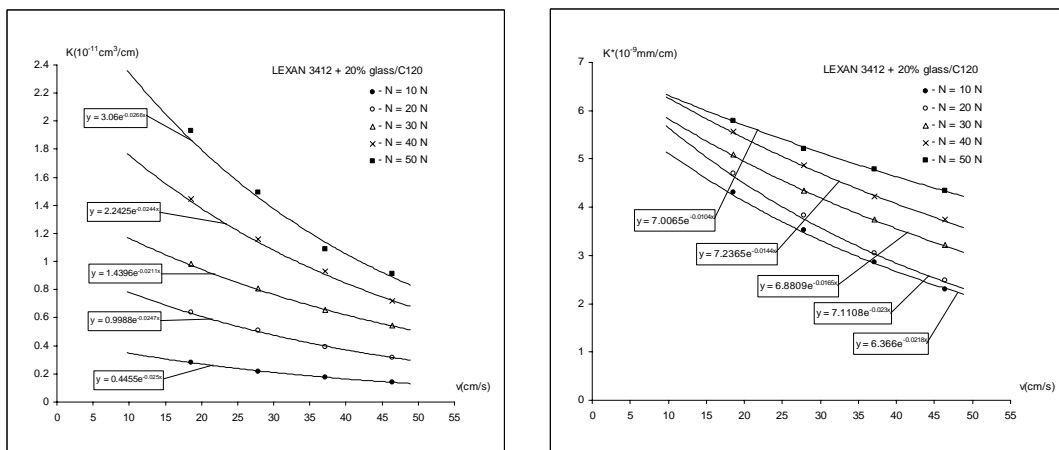


Fig. 5: K and K^* wear coefficients' variation with charge and velocity for the polycarbonate + 20 % glass/steel friction couple

Similarly, for calculating the worn metallic layer's depth, $h_u = K \cdot L$, the following values are obtained:

$$K^* = 4,42 \cdot 10^{-9} \text{ mm/cm, for } v = 0,52 \text{ cm/s;}$$

$$K^* = 4,24 \cdot 10^{-9} \text{ mm/cm, for } v = 5,2 \text{ cm/s;}$$

$$h_u = (4,141 \div 39,724) \cdot 10^{-8} \text{ mm/injected piece.}$$

For a production level of 10.000 pieces, the depths of the metallic layer removed through wear results:

$$h_u = (4,141 \div 39,724) \cdot 10^{-4} \text{ mm.}$$

By dividing these values by the theoretical duration of the friction contact, the mould's maximum wear speed is obtained:

$$h_{u_{max}} = (0,83 \div 7,94) \cdot 10^{-5} \text{ mm/h}$$

Acting in a similar manner, the moulds' wear speeds' maximum values when injecting Noryl + 20% glass polyamide and Lexan 3412 + 20% glass polycarbonate can be obtained.

Thus, for the case of injecting Noryl + 20% glass polyamide in a mould with one nest, made out of

C 120 steel, in the shape of a product with a 460 cm^3 volume, injection lasting for 15 seconds and the moulds' nozzle having a 5 mm diameter, it successively results:

$$dv/dr = 32.460/15 \cdot 3,14 \cdot 0,5^3 = 2499 \text{ s}^{-1};$$

$$v = (dv/dr)r = 2499 \cdot 0,25 = 624 \text{ cm/s;}$$

$$A = (0,001 \div 0,01)v = (0,62 \div 6,25) \text{ cm/s;}$$

$$L = vt = 625 \cdot 15 = 9375 \text{ cm/injected piece;}$$

$$L_0 = (0,001 \div 0,01)L$$

$$= (9,375 \div 93,75) \text{ cm/injected piece;}$$

$$V_u = (9,375 \div 93,75)K.$$

From the diagram shown in fig. 4, for the 213,7 daN/cm^2 ($N=3 \text{ daN}$) pressure, the following values of the wear coefficient result:

$$K = 1,4045 \cdot 10^{-11} \text{ cm}^3/\text{cm, respectively:}$$

$$K^* = 4,352 \cdot 10^{-9} \text{ mm/cm, for } v = 0,62 \text{ cm/s}$$

and:

$$K = 1,351 \cdot 10^{-11} \text{ cm}^3/\text{cm, respectively}$$

$$K^* = 4,180 \cdot 10^{-9} \text{ mm/cm, for } v = 6,25 \text{ cm/s.}$$

It results:

$$V_u = (1,317 \div 12,665) \cdot 10^{-10} \text{ cm}^3/\text{ injected piece;}$$

$$h_u = (4,080 \div 39,187) \cdot 10^{-8} \text{ mm/ injected piece.}$$

For a production volume of 10.000 pieces, the moulds' wear will be between the following values:

$$V_u = (1,317 \div 12,665) \cdot 10^{-6} \text{ cm}^3, \text{ respectively:}$$

$$h_u = (4,080 \div 39,187) \cdot 10^{-4} \text{ mm.}$$

By dividing these values by the theoretic friction contact's duration (41,67 ore), we obtain:

$$V_{u_{max}} = (3,16 \div 30,39) \cdot 10^{-8} \text{ cm}^3/\text{h, respectively:}$$

$$h_{u_{max}} = (0,979 \div 9,404) \cdot 10^{-5} \text{ mm/h.}$$

For the case of injecting the same product for 16 seconds with Lexan 3412 +20% glass polycarbonate, it successively results:

$$v = (dv/dr)r = 2343 \cdot 0,25 = 586 \text{ cm/s;}$$

$$A = (0,58 \div 5,86) \text{ cm/s;}$$

$$L_0 = (9,376 \div 93,76) \text{ cm/ injected piece}$$

From fig.5, for a 239, 1 daN/cm^2 ($n=2 \text{ daN}$) injection pressure, the values of the wear coefficient result:

$$K = 0,918 \cdot 10^{-11} \text{ cm}^3/\text{cm and}$$

$$K^* = 6,645 \cdot 10^{-9} \text{ mm/cm, for the } 0,58 \text{ cm/s velocity}$$

and:

$$K = 0,837 \cdot 10^{-11} \text{ cm}^3/\text{cm and}$$

$$K^* = 6,140 \cdot 10^{-9} \text{ mm/cm, for the } 5,86 \text{ cm/s velocity.}$$

Operating with the values above, it is obtained:

$$V_u = (0,861 \div 7,848) \cdot 10^{-10} \text{ cm}^3/\text{ injected piece;}$$

$$h_u = (6,230 \div 57,569) \cdot 10^{-8} \text{ mm/ injected piece.}$$

The moulds' wear after 10.000 injections, will reach values of the intervals:

$$V_u = (0,861 \div 7,848) \cdot 10^{-6} \text{ cm}^3, \text{ respectively:}$$

$$h_u = (6,230 \div 57,569) \cdot 10^{-4} \text{ mm.}$$

By dividing these values by the theoretic friction contact's duration, the following values for the moulds' maximum wear are obtained:

$$V_{u_{max}} = (1,94 \div 17,67) \cdot 10^{-8} \text{ cm}^3/\text{h, respectively:}$$

$$h_{u_{max}} = (1,40 \div 12,96) \cdot 10^{-5} \text{ mm/h.}$$

4. CONCLUSIONS

The studying and calculating method presented can be extended for the study of the snail – piston couple's wear with the following observations:

- the wear speed of the snail-piston and of the injection machinery's cylinder can be estimated based on the experimental data offered by the using of a factory model similar to the one presented, with the difference that the used nozzle will be the cylinder's nozzle, not the mould's. The wear pieces will be made out of the two materials used for making the snail and respectively the cylinder. These will be

subjected separately to the thermal or respectively thermo-chemical treatments and afterwards will be reassembled in the nozzle. The calculation method for the piston's and the cylinder's wear speed is identical to the one presented before for calculating the moulds' wear rate;

- the calculation method based on using the K wear coefficient, determined with the help of the laboratory model presented, can only be used for the cases where the melted polymer's temperature does not exceed $250^{\circ}C$. Above this contact temperature, laboratory trials' results are no longer conclusive because of the viscous – elastic properties of the polymers, which depend on temperature.

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