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Transfer of Plastic Materials with SGF in linear Dry Contact on Steel Surfaces

Lucian Capitanu[1*], Virgil Florescu[2], Liliana – Laura Badita[3]

[1]*Tribology Department, Institut of Solid Mechanics of te Romanian Academy, Bucharest, Romania*
[2] *Mechanical Department, Institute of Civi Engineering, Bucharest, Romania*
[3*] *INCD-Mechatronics & Measurement Tecnique, Bucharest, Romania*

ABSTRACT

Often, modelling of specific tribological processes raises special problems in the laboratory studies. One such problem is the modelling of some temperatures and extremely high contact pressures, allowing modelling of temperatures and pressures at which the injection or extrusion processing of thermoplastic materials takes place. Tribological problems occur mainly in thermoplastics materials reinforced with glass fibres. They produce an advanced wear to the barrels and screws of processing machines, in short time. Obtaining temperatures around 210^{0}C and higher, as well as pressures around 100 MPa is very difficult in the laboratory. This paper reports a simple and convenient solution to get these conditions.

Keywords: Plastic with glass fibres, visco-plastic transition, dry friction, linear contact, contact temperature, contact pressure, experimental simulation.

INTRODUCTION

Preventive maintenance guide barrel / screw to combat wear of the barrel in extrusion and injection moulding of Xaloy Inc. Company [1] mentions that in the wear of the injection machine are involved four main factors: alignment of the screw and the barrel; conditions of the processing such as the pressure, temperature and geometry of the screw; processed material characteristics such as the lubrication ability of the molten resin and the presence and nature of any additives, fillers and contaminants, and last but not least, the metals used to produce the barrel and the screw. In consideration of the four main factors mentioned, the three main wear types of the barrel and screw are adhesive, abrasive and corrosive wear.

Adhesive wear is the result of metal to metal contact between the screw and the barrel's wall. With the naked eye, a new screw and barrel seem to have very smooth, bright surfaces. But an enlarged cross-sectional view shows that the real surface consists of a series of ridges and valleys. If the top of a ridge on the surface of the screw encounters the top of a ridge on the barrel's wall, the collision energy is sufficient to cause momentary adherence, in the form of a thin weld. If the screw continues to rotate, the welding is sheared. After repeated collisions, particles begin to be removed from the surface that becomes a source of abrasive wear. For example, the severity of adhesive wear is related to incompatibility between the screw and the barrel materials. Thus, a screw of Stellite 6, which has been used for four months in the cylinderor in the X-800, a composite of tungsten carbide particles in a nickel alloy matrix, was found to be an inconsistent combination that is not recommended. Materials differ substantially in their trends of adherence to each other. The use of compatible materials is one of two key ways to combat adhesive wear. The other is to minimize the metal to metalcontact between the screw and barrel.

Good alignment will minimize metal to metal contact. Ideal is that the screw to be perfectly straight, the barrel to be perfectly straight, and their alignment to be perfect. Significant investments were made to have resistant screws and barrels, but even the perfectly straight screw, perfectly aligned in a straight barrel, cannot prevent absolutely metal to metal contact. The reason is that in real mode,

***Address for correspondence:**

lucian.capitanu@yahoo.com

during the work, other forces are involved. One of them is related to the misalignment due to the heat. Because they do not have the same size and shape, the screw and the barrel are inherently a different warm source of the mass. Also, they usually are made of different materials. This leads to different rates of thermal expansion, which produces misalignment. Another source of metal to metal contact is screw's buckling, caused by the discharge of pressure at its front end. Effects of length (L) and diameter (D) of the screw are particularly important on buckling and on the contact with the barrel's wall. For example, the length of the screw, with L/D ratios of 24:1 or 30:1, is especially prone to buckling effects. Also, the smaller diameter of the spindle of the most screws is a new factor in the buckling effect. Physical laws, also produce a third potential source of contact between screw and barrel deformation under its own weight. Being supported only at one end, a screw is, of course, a cantilever device. Deflection of the lever arm is proportional to its length at power 4. As a result, the length of screw is liable to deformation. Applying the formula for the deflection of lever arm, a screw extruder with an L/D ratio of 24:1 will deform by 1.5 mm. Of course, it cannot deviate more, because it stops on the barrel's wall. A 200 mm thick screw would deviate a little more, about 11.6 mm, if it would be free to do so. When the barrel is filled with molten plastic under pressure, the melt separates the screw from the barrel's wall and acts as lubricant.

However, two precautionary measures should be noted [2]. One is that the barrel is completely filled with molten plastic. If during processing it contains un-melted or partially melted particles, the intermittent contact between the screw and the barrel's wall can take place. Another relates to taking into consideration the fact that the plastic materials melts differ in lubrication properties of melting. Rheological curves of linear polymers, such as, high or low density polyethylene, show the continuity of the flow to a certain level of shearing stress. Then, there is a ridge on this curve. This discontinuity can cause disruption of the melted film and can increase the adhesive wear.

The second of the three wear forms found in plastics processing machineries is the abrasion. Two types of abrasion produce in the machine's cylinder. One is abrasion with two bodies as a result of axial movement of the filler particles (for reinforcement) or glass fibres (GF) in the extruder. Because the barrel and screw materials are highly resistant to wear, the effect of two bodies wear is not of great interest. If the abrasive particles become trapped in the space between the screw mounted on the cantilever and the barrel's wall, the three bodies wear appears. As a result of the deflection force acting on the cantilever screw, the particles become quite efficient cutting tools, resulting generally in grooves and scratches in the direction of screw's motion.

The third type of wear encountered in plastics processing equipment is the corrosion wear. This type of wear is encountered in situations like processing of fluoro-polymers, fire-resisting resins and composite resins containing volatile corrosion substances. Solution against corrosive wear is mainly a matter of selecting the materials for the barrel and screw. Experience has shown that X-309 alloy is the best material for resistance at corrosion wear. Dominghaus [3] presented severe abrasion and corrosion wears of some screws and barrels of 30, 45 and 60 mm in melting and kneading areas. Knappe and Mahler [4] have reported the wear of different alloys coated with nitride in PA6.6 injection with 35% SGF in a space of screw-barrel interference δ = 0.2 mm, an external pressure P_a = 1,100 kp/cm, injection time T_s = 6 s, injected volume V_s = 25 cm^3, plastics injected temperature of approximately 310 ^{0}C. The worst behaviour had 18550 DIN nitrided steel in the bath. They have shown that corrosion occurred at PA 6.6 + 35% GF injection for 20 h, at a temperature of 280 ^{0}C and a pressure of 100 MPa. Ladwig and Sommer [5] analysed the wear of some screws after 20,000 functioning cycles, showing its dependence on the execution manner of the screw. Mc Candless et al [6] reported on a comprehensive analysis of the wear and corrosion behaviour of barrels and of screws for plastics processing machines. All these works relate to quantitative and qualitative observations made on processing machines. Boey et al [7], from the University of Newcastle, UK, studied the effect of temperature on the abrasive wear of the deposited layers and of hybrid surfaces treatments of the working parts from injection processing machines produced at processing of polymers composites with glass fibres, adapting ASTM G65/1994 standard.

In an injection machine, the polymer pellets are pushed and move along the barrel due to the action of a rotating screw, while they are heated and melted. As a result, the barrel and the screw will be in contact with the composite solid polymer pellets, with the semi plasticized polymer and the melted one, the contact differing on the length of screw-barrel assembly. As a result of the high mechanical stresses to which it is subjected and its mode of construction, the screw will have aninherent vibration in the barrel, which leads to the metal/ metal contact and appearance of adhesive wear.

The occurrence of corrosion wear is also possible due to the action of the polymeric material or other additives on metal surfaces, in particular at temperatures above 200-250 ^{0}C registered against the cylinder nozzle and the mould in which this is injected. Thus, Boey et al. [7] realized these tests in order to rank abrasion resistance of the materials, treatments and metallic coatings of the working parts of the processing by injection machines, although the test conditions do not provide modelling of all wear forms. The experimental installation was achieved by adjusting the scheme with rubber (ASTM G65) rotary wheel. But, the wheel has been replaced by one of the same steel used to manufacture the screw of processing by injection machine. Periphery of the steel wheel was heated to the desired temperature by blowing hot air, ensuring a deviation of about ± 10 ^{0}C to the operating temperature. The wheel is streaked and allows training of the plasticized material, which acts at the interface with test samples (heated by a thermo-resistance). The test sample is depressed by a light load, on the plastic material layer, by means of a pivoting system with lever and weights. In order to increase the efficiency of the heating process and to reduce the heat losses, by convection, nozzles were used for blowing hot air and its focus on the grooves of the wheel. Test sample holder was heated independently of the wheel, the temperature being controlled with an accuracy of ± 2 ^{0}C.

Compared to the ASTM G65/1994 test, the abrasive sand has been replaced by polymer granules, supplied from a bin into the interference between the drum and the test sample. In static conditions, it is maintained at a short distance from the wheel by means of a flat spring. The spring allows the transmission of the load on the granules passing through the contact area. The pressure and duration of contact may be changed by changing the load and the speed of the wheel. Striations practiced on the wheel surface are designed to enhance the driving ability of the granulated polymer and thus to reduce the possibility of metal to metal contact appearance. For the simulation and limitation of direct contact of the screw with the barrel of processing by injection machine, a flat spring mounted at one end of the loading lever-arm was used, the other end being embedded in a solid stop. Changing the spring stiffness leads to space adjustment between the test sample and the wheel. Normally, this space is so determined as to be smaller than the size of the composite material grains.

When the lever-arm is loaded, the test sample holder produces the bending of the flat spring, thus appearing a force opposite to the normal stress of the test sample. Bending is indeed very small compared to the thickness of granular material layer and therefore under static conditions it does not result in direct metallic contact between the wheel and the test sample. When a polymer granule is taken by the grooved drum and placed in the contact area, the flat spring is not loaded and the test load is fully applied to the polymer particle. The metal/metal contact can be prevented for any static load applied by controlling the stiffness of flat spring and the position of the attachment point. Bending of the spring during testing is monitored by a transducer in order to determine the size of the metal/metal contact. This occurs over a period of less than 5% of the total time of the test, which is compatible with observations made on processing by injection machines.

The maximum operating temperature is of 250 ^{0}C and was carried out by heating with hot air system and by heating the test sample holder by means of two heating resistances of 75 W. Directing the hot air blown through the nozzle of a compressor placed at an angle of 90^0 to the surface of the wheel is carried out by means of a reflective mirror. This led to a strong increase in temperature of the wheel while reducing the heat losses. Maximum temperature of the wheel can reach 300 ^{0}C, while supporting plate of the test sample can reach 316 ^{0}C. But practically, the maximum temperature of the test should not exceed 250 ^{0}C, value at which the polymer starts to degrade.

The wear rate of the samples was measured by loss of mass and volume. The measurements of mass lossare generally highly accurate, but in the case of tests carried out at temperatures around 200 ^{0}C or more, they are not conclusive, because the polymer melt is trapped in the pores of the microstructure and in cracks, and cannot be removed by ultrasonic cleaning. Therefore, for a better assessment of the wear rate it is also necessary to measure the volume of worn material. All these methods [4, 7] are very difficult to reproduce in a tribology laboratory especially due to very high temperature at which the tests should be made. Therefore, a method has been designed to provide the temperature of polymer/metal contact by dissipation of the power lost by friction, which converts into an increase in temperature of contact surfaces.

MATERIALS AND METHODS

In order to study the metallic counter-part's wear in dry contact with glass fibres reinforced plastic materials Timken type friction couples (with linear contact), cylinder on flat are used. This allows attaining high contact pressures, hence high contact temperatures. In this matter it is possible to observe, whether and in which conditions the plastic material transfer to the metallic surface takes place, as well as the influence of the glass fibres filling during this phenomenon, and its effect on the surface's wear. As it is not followed the polymer's wear, but only the polymer's friction influence over the samples' metallic surfaces wear, the unidirectional sliding movement is used [8, 9].

Experimental Methods

The tests are performed using experimental equipment containing a Timken type couple with linear dry friction contact, continuously controlling the normal and friction loads, and contact temperature. The unidirectional movement and the linear contact allow attaining very high contact pressures and temperatures. The friction couple is built out of a plastic cylinder -Nylonplast AVE polyamide + 30% glass fibres, which rotates at different speeds against the polished surface of a steel plan disk. The cylinder has an outer diameter of 22.5 mm and 10 mm height. Steel flat disks with 18.2 mm diameter and 3 mm thickness were chosen as sample.

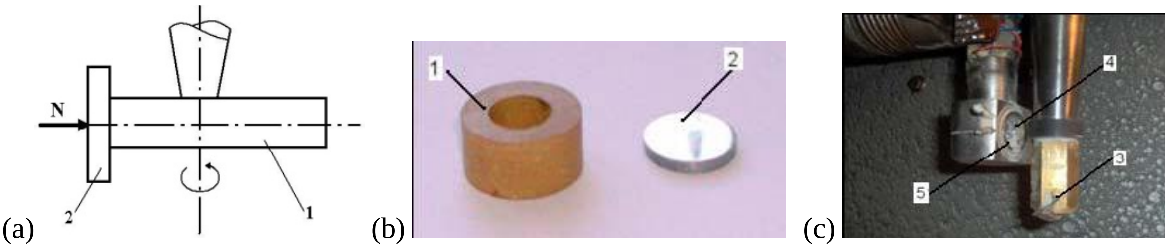


Figure1. *Functional scheme (a) the way how the liner moves against the disk, (b) friction couple, and (c) its installation in the experimental equipment, where (1) cylindrical liner; (2) steel flat disk sample; (3) nut; (4) hole and (5) knife-edge*

The metallic disks' surfaces were polished successively using sandpaper of different granulations (200, 400, 600 and 800) and, finally, were polished on the felt with diamond paste. Mirror polished surfaces, with roughness R_a of 0.05 μm were obtained. This metal surface's quality allows eliminating the influence of the metallic surface’s state on the friction coefficient’s evolution and visualization, to make measurements using optical microscopy and to accurately record the wear traces appeared on the metallic surfaces. Figure 1 shows the functional scheme (a), friction couple (b), and its installation within the experimental equipment (c). The way in which the liner moves against the plane sample is illustrated in Figure 1a.

Figure 2 shows the scheme of the experimental equipment. The friction couple is build out of a cylindrical liner (1) and a flat disk type sample (2). The liner is fixed with the help of a nut (3) on the driving shaft (4).

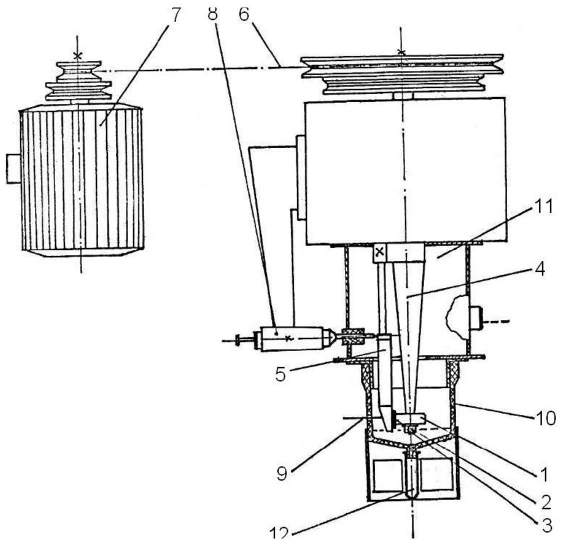


Figure2. *The scheme of the experimental equipment with linear contact friction couple, Timken type*

The disk sample is placed in a special hole made within the elastic blade (5). The sample disk base is built in such a manner so that the base allows the sample to make small rotations around the edge of a knife fixed in the sample’s holder, perpendicularly on the driving shaft. In this way a uniform repartition of the load on the entire linear contact between the liner and steel sample is ensured, even if there are small buildings or assembling imperfections. An electric motor (7) puts the shaft (4) into a rotation movement using trapezoidal transmission belts (6). The normal and tangential (friction) stresses through resistive converter strain gauges, assembled on the elastic blade (5).

The use of a pair of converters strain gauges connected within the circuits of two strain gauges bridges, offers the possibility to make simultaneous measurements, while separately, gives the possibility to measure the normal and friction forces. The normal load to the elastic blade (5) is applied through a calibrated spring system (8). The installation allows registering the friction force on an *X-Y* recorder. The tests’ time is controlled through an alarm clock, and the contact temperature is measured with the help of a miniature thermocouple (9), connected to a millivoltmeter calibrated in mV. The installation offers the possibility to study the wear behaviour by using also several other radiometers techniques. For this purpose, the installation includes a tank (10) assembled on a base (11) and a tube collecting the radioactive wear particles (12).

The unidirectional testing was used because the purpose of investigations was the study of metallic surface’s wear. The tests are performed, based on Hooke's law, at normal loadings of 10, 20, 30, 40 and 50 N, loadings which are adequate to some contact pressures, all calculated considering the elastic contact hypothesis, that is: 16.3, 23.5, 28.2, 32.6 and 36.4 MPa (for Nylonplast AVE polyamide with 30% glass fibres), Respectively, sliding speeds are used, adequate to the diameter of the plastic composite sample, which are: 0.1856, 0.2785, 0.3713, 0.4641, 0.5570, 1.114 and 1.5357 m/s, and which resulted as a consequence of electric motor’s speed and the belt pulleys’ primitive diameters.

Analitical Method

The Timken frictional couple (with linear contact) under loading reveals the appearance of some wear trace on the plane surface of the metallic material. The wearing trace is produced by the penetration of the plane semi couple material by the cylindrical liner (Figure 3).

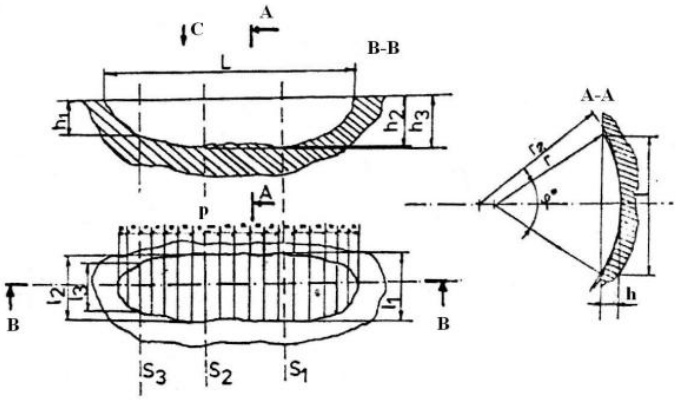


Figure3. *The elastic deformation of the cylindrical liner on the contact area (bottom) for friction couples (a) theoretical, and (b) practical*

Theoretically, considering the bush as rigid and accounting for the generally low non-uniformity of the imprint, this could be considered as being formed by a series of cylindrical sectors having the length *q*. Assuming that, the area of the lateral surface of the cylindrical sector is a circle segment, it results:

$$S_i = 0.5r^2\left(\pi\varphi_i^0/180^0 - \sin\varphi_i\right) \tag{1}$$

where, S_i is lateral surface of the crystal sector; φ_i is the angle and r is the circle radius. The radius r could not be identified with the cylindrical bush radius for the plastic/ metal couples. This fact is possible due to the elastic deformation of the bush under loading conditions, which has as effect the increasing of the radius in the contact area. We illustrate this by the sketch plotted in Figure 4. Using r_1 for the undeformed liner radius and r_2 for the radius in the contact area of the deformed liner, we could notice from Figure 4b that $r_2 \succ r_1$. Increasing the bush radius in the contact area conducts to the decrease of the depth of the wearing trace from h_1 (Figure 4a), which would appear if the elastic deformation of the bush would be neglected, to the value h (Figure 4b), with the quantity h_2:

$$h_2 = h_1 - h \tag{2}$$

Using l for the width of the wear imprint, from Δ ABC, it results:

$$(2r_1 - h_1)h_1 = l^2/4 \tag{3}$$

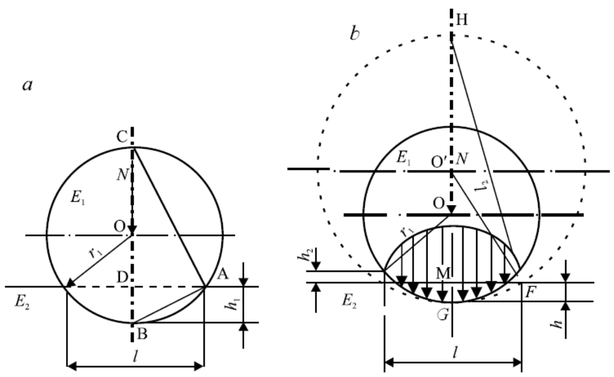


Figure4. *The elastic deformation of the cylindrical liner on the contact area (bottom) for friction couples (a) theoretical, and (b) practical*

Because the value of the depth h_1 is very small, the term is negligible and we could write:

$$h_1 = l^2 / 8r_1 \tag{4}$$

Similarly, in Δ FGH, we have:

$$(2r_2 - h_2)h_2 = l^2 / 4 \tag{5}$$

Using the same assumption, for the term h_2, we obtain:

$$h_2 = l^2 / 8r_2 \tag{6}$$

Introducing Eqs. (4) and (6) in Eq. (2) it results:

$$h = l^2 (1/r_1 - 1/r_2)/8 = l^2 (r_2 - r_1)/8r_1r_2 = l^2 / 8r \tag{7}$$

where *r* is the equivalent curvature radius given by:

$$1/r = 1/r_1 - 1/r_2 = (r_2 - r_1)/r_1r_2 \tag{8}$$

From (6) it results:

$$(r_2 - r_1)r_1r_2 = l^2 / 8h_2 \tag{9}$$

Considering that the frictional couple is loaded in the elastic domain with an elliptic distribution of stresses, the Hertz formula for computing the width of the wear imprint is:

$$l^2 / 4 = 8Nr(1 - \nu^2)/ \pi EL \tag{10}$$

where, *ν* is Poisson ratio; *L* is the length of the wear imprint; *E* is equivalent Young modulus.

Using index 1 for quantities related to the cylindrical bush, and index 2 for those related to plane half-couple, the equivalent elasticity modulus is given by:

$$1/E = 0.5\left[(1 - \nu_1^2)/E_1 + (1 - \nu_2^2)/E_2\right] \tag{11}$$

$$E = 2E_1E_2 / 0.91(E_1 + E_2) \tag{12}$$

From Eq. (10), we could express the width of the wear imprint:

$$l = 4\left[2Nr(1 - \nu^2)/ \pi EL\right]^{1/2} \tag{13}$$

Introducing in Eq. (13) the equivalent elasticity modulus and the equivalent radius expressions, the numerical value of Poisson ratio, one could obtain:

$$h_2 = 0.527 \ N(E_1 + E_2)/ LE_1E_2 \tag{14}$$

Considering Eqs. (3) and (13), we have for the depth of the wear imprint the expression:

$$(2r_1 - h_1)h_1 = l^2 / 4 \tag{15}$$

Assuming that the wear imprint is the sum of some cylindrical sectors, expanding in series the relation (1), neglecting the high-order terms and reducing the similar terms we could obtain, for the area of the lateral surface of a sector, the expression:

$$S_i = r^2 \varphi^3 / 12 \tag{16}$$

Replacing in the relation above the angle φ with the ratio l / r and accounting for Eqs. (8) and (9), we obtain:

$$S_i = l^3 (r_2 - r_1) / 12\, r_1 r_2 = 2 l h_2 / 3 \tag{17}$$

Replacing the value of $h_2$obtained from Eq. (15) in Eq. (17) we could obtain the expression for the area of lateral transversal surface of a cylindrical sector:

$$S_i = 0.35\, l (E_1 + E_2) N l \,/\, E_1 E_2 L \tag{18}$$

The volume of worn metallic material will be:

$$V_u = \sum_{i=1}^{n} (S_i q_i) = 0.35\, (E_1 + E_2) N l_m \,/\, E_1 E_2 \tag{19}$$

where, l_m is the mean width of the wear imprint. Practically, it is needed to measure the width of wear imprints in three points established before, computing then the mean value of this width. With this value we could obtain the volume of worn metallic material V_u and the mean depth of the removed layer h_{mu} .

The studies concerning the metallic sample’s wear are generally based on the elastic contact hypothesis. For these plane half-couple the values for the equivalent elasticity module are: A. Nylonplast AVE polyamide + 30% glass fibres [10]; E_{2A} = 40.25 MPa. B. Noryl polyamide + 20% glass fibres [11]; E_{2B} = 31.76 MPa. C. Lexan polycarbonate + 20% glass fibres [12]; E_{2C} = 42.08 MPa.

Assuming that the plastic liner does not crush, the condition $p$max< 0.5 H is imposed, where H stands for the Brinell hardness. The required condition allows establishing the following values of the maximum loadings (contact pressure) of the couple:

p_{A1} = 16.3 MPa; p_{A2} = 23.5 MPa; p_{A3} = 28.2 MPa; p_{A4} = 32.6 MPa; p_{A5} = 36.4 MPa;

p_{B1} = 12.3 MPa; p_{B2} = 17.4 MPa; p_{B3} = 21.4 MPa; p_{B4} = 24.6 MPa; p_{B5} = 27.6 MPa;

p_{C1} = 16.9 MPa; p_{C2} = 23.9 MPa: p_{C3} = 29.3 MPa; p_{C4} = 33.8 MPa; p_{C5} = 37.8 MPa.

The experimental tests are performed considering broader domains to vary the relative speed and normal loadings, or contact pressures. Couples with liner made from thermoplastic material with linear contact on a hardened steel surface (C120, Rp3, a.s.o.) are used.

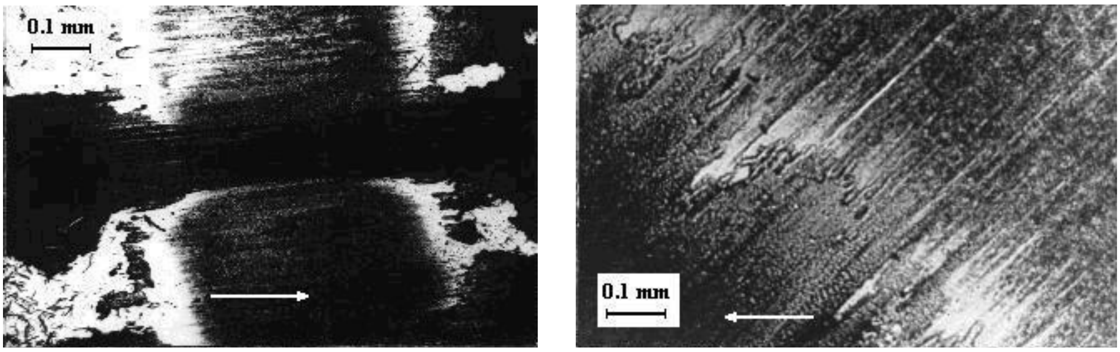
Tests have aimed in addition to the wear of metallic surface and coefficient of dry friction and contact temperature following friction at different loads (contact pressures) and sliding speeds.

RESULTS AND DISCUSSION

The wear tests were presented in detail elsewhere [9]. While measuring the wear traces widths with the help of optical microscopy, microphotographs were also taken, in order to identify the plastic material’s transfer and the metallic surfaces’ wear mechanisms. These microphotographs prove that the wear mechanisms vary from one couple to another, due to surfaces’ nature: metallic and composite plastic material, especially their hardness (59 HRC for C120 hardened steel and 62 HRC for Rp3 hardened steel), the glass fibres content, 30% and 20%, the composite plastic materials’ elasto-plastic characteristics while in contact with metallic surfaces.

The mechanical behaviour of polymers is governed by the combination of elasticity and viscosity. At small deformations, polymers behave as the Hook elastic body ($\sigma = E\varepsilon$, where σ and ε is stress and strain, and E is the modulus of elasticity) modelled with a spring and Newtonian fluid ($\sigma = \eta d\varepsilon / dt$, where η is the viscosity and t is the time); the latter is presented by a damper. The combination of these elements gives a simple description of visco-elasticity [13].

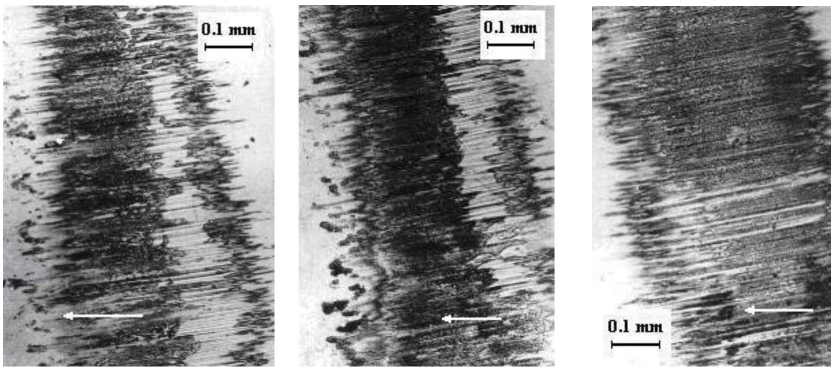
Considering the same loading conditions, the two couples to which is made reference have a different behaviour. On C120 steel sample (Fig. 5), at a normal load of 20 N and a contact temperature of 150 ^{0}C, there are plastic material transfer bridges, crossing on the wear traces (Fig. 5a), as well as the glass-fibres torn from the polymer matrix.



(a) (b)

Figure5. *Wear, glass fibres and plastic material transfer on C120 steel surface, following the friction with Nylonplast AVE polyamide reinforced with 30% fine glass fibres (a), in experimental conditions (sliding direction is indicated by the arrow): v = 27, 85 cm/s; N = 20 N; T = 150 ^{0}C; t = 60 min and (b) in experimental conditions v = 27.85 cm/s; N = 30 N; T = 175 ^{0}C; t = 60 min.*

Considering the same mechanical stress conditions (load and relative speed), the microscopic inspection of the Rp3 steel samples, while in friction contact, with the same composite plastic material, reveals a less pronounced plastic material transfer through adherence onto the metallic surface, visible on the left side in Figs. 6a and 6b.



(a) (b) (c)

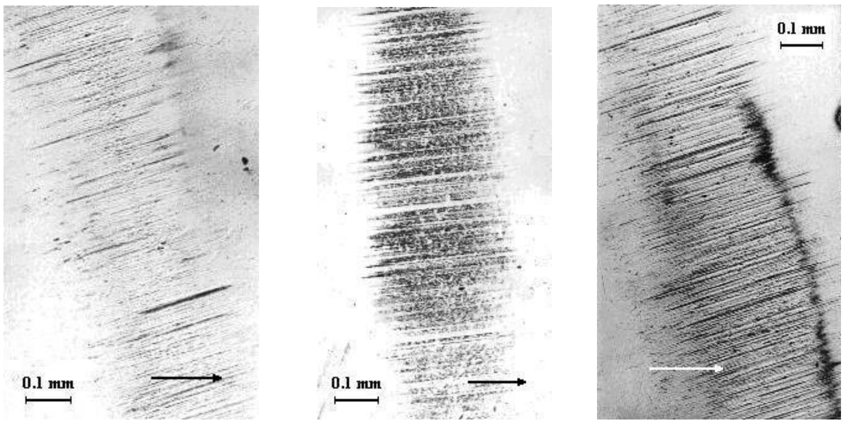
Figure6. *Wear and plastic material transfer on C120 steel surface, following the friction with Nylonplast AVE polyamide reinforced with 30% short glass fibres (sliding direction is indicated by the arrow)*

(a) v = 27.85 cm/s; N = 40 N; t = 60 min; T = 217 ^{0}C. (b) v = 27.85 cm/s; N = 30 N; t = 120 min; T = 175 °C (c) v = 27.85 cm/s; N = 40 N; t = 120 min; T = 237 ^{0}C

If the test duration is double (120 min), practically there is no plastic material transfer, as one can see in Fig. 6c.

It is considered that due to high registered contact temperature (237 ^{0}C) the transfer takes place for sure, but the transferred material is subsequently removed through friction from the contact area, under the form of wear particles following the glass fibres abrasive action. After this stage, the abrasive wear due to glass fibres becomes predominant. It is possible that the less pronounced plastic material transfer emphasized on the Rp3 steel surfaces to be due to this steel’s chemical composition and structure.

We detect the same findings in the case of Noryl polyamide + 20% glass fibers in friction on the same steels, but to a lesser scale. In the case of Lexan 3412 polycarbonate reinforced with 20% glass fibers friction onto the same metallic surfaces and considering the same stress conditions, generally speaking there is no plastic material transfer, Figs. 7a and 7b. The transfer appears only if the load reaches 40 N, which corresponds to a contact pressure of 33.8 MPa, and when the contact temperature reaches 251 ^{0}C (Fig. 7c).



(a) (b) (c)

Figure7. *Wear and plastic material transfer on Rp3 steel surface, following the friction (sliding direction is indicated by the arrow) with Lexan 3412 polycarbonate reinforced with 20% short glass fibers. (a) v = 27.85 cm/s; N = 20 N; t = 60 min; T = 164 ^{0}C. (b) v = 27.85 cm/s; N = 30 N; t = 120 min; T = 185 ^{0}C. (c) v = 27.85 cm/s; N = 40 N; t = 120 min; T = 251 ^{0}C*

We consider that probably the polycarbonate has a lesser transfer capacity than the polyamide.

In the case of polyamide reinforced with 30% glass fibers plastic transfer on steel surfaces is manifested up to around a temperature of 240 ^{0}C, when it comes to the vitrification state of the plastic bushing surface (glass transition temperature) (Table 1).

Table1. *The range of wear's rate, friction coefficient's and contact temperature's range for tested friction couples to v = (18.56 - 46.41) cm/s; N = (10 - 50) N*

Friction couple	Mean friction coefficient	Volumetric wear rate (10^{-6}cm^3/h)	Linear wear rate (10^{-4}mm/h)	Contact temperat. (^{0}C)
v = (18.56-46.41) cm/s; *N* = (10-50) N				
PA+ 30% SGF / C120	0.51	0.139 - 1.621	0.965 –8.549	155 - 240
PA+ 30% SGF / Rp3	0.47	0.214 – 1.169	2.382 –6.004	150 - 240
PC+ 20% SGF / C120	0.43	0.244 – 1.309	3.592 -6.366	140 - 230
v = (46.41-111.4) cm/s; *N* = (10-50) N				
PA+ 20% SGF / C120	0.40	0.440 – 2.578	3.269 –6.794	145 - 230
PA+ 20% SGF / C120	0.36	0.473 – 2.549	3.792 -6.627	130 - 220

Table 1 summarizes the experimental results concerning the friction coefficient, mean wear rate (linear and volumetric) and contact temperature. Results show the growth of these quantities at increase of glass fibers content, normal load and sliding speed.

Although cannot be made a mathematical correlation between friction coefficient and contact temperature, it is obvious that the contact temperature increases while increasing the friction. Contact temperature increase causes transfer of plastics, whether in the form of transfer bridges, or plastic material depositions and glass fibers on the edge output of the wear scar.

CONCLUSIONS

In order to study the metallic counter-part's wear in dry contact with glass fibers reinforced plastic materials Timken type friction couples (with linear contact), cylinder on flat are used, which allows to attain high contact pressures, hence high contact temperatures.

In this matter, it is possible to observe whether and in which conditions the plastic material transfer to the metallic surface takes place as well as the influence of the glass fibers filling during this phenomenon, and its effect on the surface's wear. As it is not followed the polymer's wear, but only the polymer's friction influence, over the samples' metallic surfaces wear, is used the unidirectional sliding movement.

In the case of sliding friction thimble with linear contact, plastic material on steel, contact temperature increase can achieve in certain stress conditions (contact pressure and sliding speed) elasto-plastic transition temperature of the polymer and even of the vitrification state of its surface.

Presented paper has some limitations. Thus, the contact temperature was measured using a miniature thermocouple inserted into a hole of 1 mm practiced in the middle of the back surface of the flat metallic sample up to 0.5 mm behind the surface friction. Although small, this distance with the friction surface makes that the measured contact temperatures to be relatively lower than the real ones.

Another limitation consists in the fact that the elastic contact hypothesis in which contact pressures were hardly calculated can be accepted in the case of the elasto-plastic transition temperature of the plastic material reinforced with glass fibers.

However, by modeling the linear dry sliding contact, the bush of plastic material reinforced with short glass fibers on flat steel surfaces, were obtained the contact pressures and temperatures similar to those found in processes of processing by injection or extrusion of plastic materials reinforced with short glass fibers.

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AUTHORS' BIOGRAPHY

Lucian Capitanu, In 1970 he graduated from the Polytechnic Institute of Bucharest, Faculty of mechanical engineering. He obtained his PhD in Sciences in 1989. Working for 44 years in scientific research in the area of tribology and biotribology. He has published over 400 papers in specialized journals, 6 monographs and has participated in numerous international conferences. Is a founding member of the Romanian Association of Tribology (ART) and member of the Balkan Tribology Association (BTA). Since 2000 he is Professor and Scientific Director of the Institute of Solid Mechanics of Romanian Academy.

Virgil Florescu, He graduated from the Polytechnic Institute of Bucharest, is Ph.d. in engineering sciences. He has worked in academic scientific research and currently is Director of the Mechanical Engineering Department of the Institute of Civil Engineering from Bucharest. He has published over 200 scientific papers, is author of 4 monographs and has participated in many international conferences in the field of "tribology.

Liliana-Laura Badita, She graduated the Faculty of Physics of the Bucharest University and has a PhD in Engineering Sciences. She is researcher at National Institute of Research -Development in Mechatronics & Measurement Technique from Bucharest, and is specialized in investigating the properties of coatings and nano - coatings with thin layers and biotribology. Is the author of over 150 scientific works and has participated in numerous international collaborations.