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An Experimental Modeling of Steel Surfaces Wear in Injection of Plastic Composites with SGF

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Abstract Consequences of the wear processes at screws and barrels of injection machines and extruders for processing of plastics reinforced with short glass fibers (SGF), arise after a longer time (10,000 cycles). Because of this they are working that through appropriate modeling attempts on the profits to be obtained in a short time as much information relating to both the mechanisms of wear and its size, so that the effect can be easily confuted in practice. Starting from the idea that the greatest pressure and velocity of composite melted is in the die nozzle, was an experimental nozzle with wear samples of sizes and weights which can be measured with precision as good. For a larger accuracy of measurements, we used a method for radiometric measuring, extremely accurate. Different nitriding steels have been studied as nitriding treatments, as well as some special steels and alloyed steels. Besides these, there have been preliminary attempts made to describe and checking corrosive action of termoplastelor on metals. This was another way of checking the wear testing of the semi-cylindrical wear samples, which served to simulate the wear of the top layer of the barrel and screw. The first results showed that wear increases depending on the increased pressure. One of the findings is that in similar conditions of injection, with the same content of glass fiber, polyamide 6.6 produces a wear greater than polycarbonate. It was also found that increasing the concentration of glass fibres increase the surfaces wear of barrels and screws. The aim of the work is to find viable variants of layered thin coating, resistant to wear in terms of processing by injection of polymers with SGF.

Keywords Plastics Moulding, Wear, Composites with Short Glass Fibres, Experimental Modelling, Glass Fibres Content Influence

1. Introduction

Worldwide efforts that are as by appropriate models of tests, should be obtained as much information concerning of the wear mechanisms and their contribution over time, so that the effect can be easily confuted in practice. In this sense, it differs in three main goals: the choice of alloys and steels resistant to wear and corrosion of machine parts manufacturing; evaluating different plastics depending of their wear action, as well as its physical wear causes.

As a result, in the foreground are two objectives: a verification method and a quantitative evaluation on short term of the wear. Verification method of Deuschen Plastic Institute - DKI in Darmstadt [1], is a method that can be done in a short time the affirmations about the resistance to wear of various metallic materials, under the action of melted plastic flows with which they come into contact. Of course there is a problem when you want to put into practice these methods of evaluation in a short time. This testing were designed to wear tests close to the practice, with the help of intense collaboration with relevant industries. Thus, the DKI in Darmstadt has done a nozzle of the injection machine, for tests with lamellae test samples, called the "lamellar apparatus". Since verification methods have been described in detail elsewhere [2], should be further highlighted only the essentials. Plates, metal samples ($15_{-0,02} \cdot 12^{+0,01} \cdot 5^{+0,01}$ mm) polished to a roughness R_t = 2,5 μm, they were mounted by the manner inside the nozzle of an injection machine, that upon exiting the mass processed to form a set of sample with "live corners". The width of this series could be adjusted via a washer. There's a possibility that the material to be injected through an adapter or through a form of injection. By studying the loss of weight of the test plates sample (some up to ± 0.05 mg) could fix easy wear (as weight loss) of the sample. The reproducibility of the measurements is within ± 5%. Subsequent checks of surfaces with the electronic microscope and through measurements of roughness, have provided additional information.

A special importance for exact measurement is sign of a

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cleaning sample test before weighing. Choosing the right cleaning agent for a perfect cleaning of the sample shows some sign of difficulties in thermoplastics, compared to duroplastics, because the metal surface must not be touched when cleaning. The advantages of this method of verification is the following: can highlight simply the geometric shape sign of the sample; the fact that the injection of 10 kg of plastic with fiber can highlight and as already soon lost weight between 0.5 and 40 mg/cm^2, and the possibility of targeted sample sign running back 180°, this can be accomplished two tests.

A special importance for an exact measurement of higher attainment is the sign of a cleaning test before weighing. Choosing the right cleaning agent for cleaning of the sample shows some sign of dificaultati from thermoplastics because metallic surfaces should not be touched at cleaning. The advantage of this method of verification is the following: the sign of a simple geometric shape of the sample; the fact that the injection of 10 kg of plastic with glass fibre can highlight and already in a short time as loss of weight between 0.5 and 40 mg/cm^2, and the possibility of targeted sample sign running back 180^0 through it reusindu to carry out two tests. In the process of pressing, casting forms provided with cleats can be processed without the appearance of outstanding wear, being provided as corrosive degradation do not exist. In the process of molding the inevitable wear of plasticizing cylinder and nozzle occurs [3]. It was used as the nozzle to be deemed to be a genuine element of wear and tear and searched as a constructive point of view, the change has to be as easy [4].

If you follow in chronological the wear appearance of plastic processing machines, extruders are to be directed at all the attention. By filling of the moulding forms with thermoplastic materials, parts that can be damaged more or less are barrels and screws, depending on the method of choosing the materials from which they are manufactured, as well as processing procedures. In this case the loosening reason of the components not only appeared through mechanical wear, but due to corrosion. These chronological chases have led specialists to develop a wealth of recipes and types of high temperature resistant alloys, and last but not least to analyse their behaviour to corrosion at high temperatures.

Unfortunately, many of the individual observations of processors and manufacturers of machinery and raw materials were not centralised somewhere, so that numerous discussions in this respect to firms in the processing times in the literature, to recognize that uzurile arising from the active ingredients of plastics processing machines represents a complex problem [5]. Very rarely can identify a unique exact cause wear and tear, so it is very important to establish and further provided with tools of causality.

Wear the solid processing of screws and barrel area of extruders screws and barrels, are the overwhelming of mechanics nature [6]. In most cases it is the erosion of the screw wings. Melting area wear is influenced by the pressure, temperature at which wear is produced, together with the effect of corrosion.

Considerably, on this area is very high wear and may result in a few weeks or months to damage of the injection machine. Development and improvement of steels, new finishing methods, as well as lightweight alloys, have resulted in raw materials characterized by high resistance to wear and chemical action.

Wear in the solid processing area of screws of extruders and pistons of injection machines, are the overwhelming nature of mechanics [6]. It is in most cases of erosion on the flanks of the advance of snecului. It is in most cases of erosion on the advance flanks of the screw. Melting area wear is influenced by the pressure, the temperature at which the wear, with the effect of corrosion. Considerably, on this area is very high wear and may result in a few weeks or months to the machine damage. Development and improvement of steels, new finishing methods, as well as lightweight alloys, have resulted in raw materials characterized by high resistance to wear and chemical action.

In an attempt to determine the resistance to wear of the metal surfaces in contact with the plastic composite flows, reported attempts of modeling through a linear contact between polymer composite with glass fiber on steel surfaces [7, 8, 9]. Starting from the well known as to be wear, there must be two mandatory conditions: mechanical request (contact pressure) and relative motion between bodies in contact (molten polymer and metal surface), the theoretical modelling has tried contact between molten polymer and metal surfaces of the barrel and screw nozzles (barrel and die). This modeling, where was approximate the speed to wall of the melted polymer in rheological flow, was presented in detail in [10]. In this way it was possible an estimate of the wear of metal surfaces in contact with the molten polymer feeds [11].

Research aimed at finding thin coatings for screws and barrels, which will withstand to wear injection processing of the polymer reinforced with SGF.

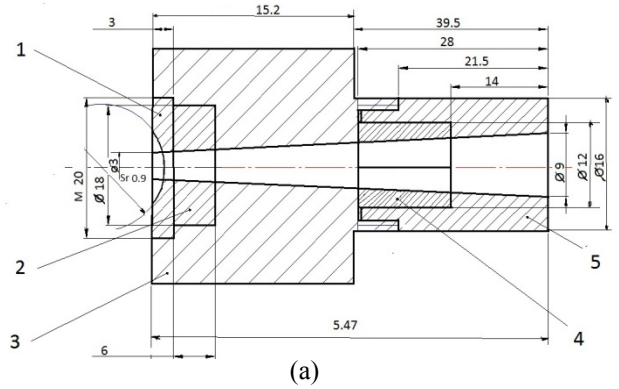
2. Material and Methods

2.1. Materials

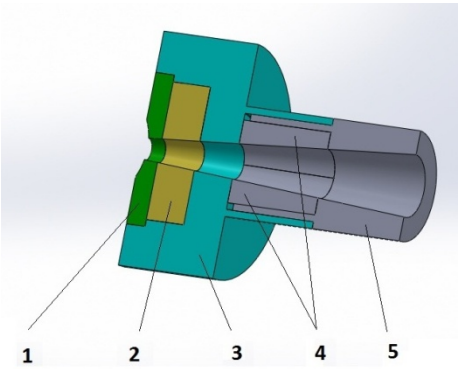
Were tested four thermoplastics reinforced with glass fibre: Maranyl Polyamide with 20% SGF [12], Noryl Polyamide with 20% SGF [13], Nylonplast AVE Polyamide with 30% SGF [14], Lexan Polycarbonate with 20% SGF [15] and two unreinforced material, Makrolon Polycarbonate [16], Technyl Polyamide and two allied steels: C120 (steel of similar of 1.8550 steel DIN 17007, or 34 of CrAlNi7 (V) - after DIN 17006) and Rp3 (tool steel). Both were tempered steels, resulting in a hardness of 58 HRC (710 HV) for C120 and 62 HRC (790 HV) for Rp3. Chemical composition and mechanical properties of these steels have been presented elsewhere [16]. Since these steels can be superficialy hardened through the thin coatings layers of TiN and CrN, have made such wear samples to study the influence of the coating on the wear resistance. Wear samples TiN coated had

hardness of 64 HRC (840 HV), and hardness of samples coated with CrN was 41.3 HRC (900 HV).

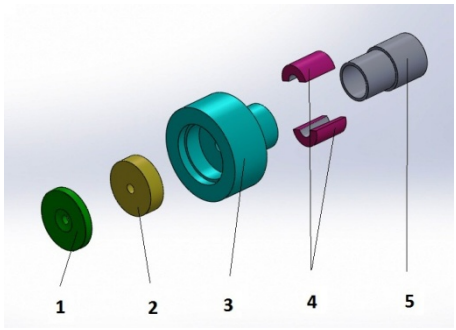
2.2. Experimental Modeling



(a)



(b)



(c)

Figure 1. Drawing of the execution of experimental modular nozzle for a mold for injection (a); (b) a 3D representation and (c) an expanded representation, looking parts. Parts 2 and 4 are the wear samples

Experimental modeling was inspired by the method of verification in the short term by Deuschen Kunststoff Institut - DKI in Darmstadt [1]. I opted for the design and implementation of a modular experimental nozzles for a mold for injection (Fig. 1). This solution was adopted because it was not possible to amend a nozzle of industrial injection machine, very expensive. In addition, this solution can allow analysis technique of the area with the highest speed and pressure in the injection cycle time. Modularity was necessary because the nozzle to have two samples for wear inside, with little weight, which allows the measurement of wear, with acceptable precision, after a certain number of cycles of injection of plastic materials reinforced with glass fibre. In Fig. 1 are shown the drawing of the nozzle assembly (Fig. 1a), a 3D representation of the nozzle (Fig. 1b) and an expanded representation of the nozzles. This solution was adopted in the idea of some test samples to wear with low weight (positions 1 and 4 in Figs. 1 (a), (b) and (c), which could allow the use of gravimetric measurement method of weight loss. The initial weight of the samples of each item. pos. 4 (Fig. 1) is around 1.5 - 1.6 g and of the sample and pos. 3 (Fig. 1) is approximately 11.7 - 11.8 g. The nozzles were made of steel C120, a steel for moulds, which can be hardened both through hardening (58 HRC), but which can be subjected to tough layer coatings (TiN, CrN). The initial weights of wear samples were approximately 11.7 g (sample 1), respectively 1.5 and 1.6 g (samples 4).

2.3. Gravimetric Method

Gravimetric method is very close of Deuschen Kunststoff Institut – DKI in Darmstadt [1], except that the wear samples were placed in the mould nozzle, and not die in the nozzle of the barrel, due to the technical difficulties of installation, dismantle and reinstakkatin of this nozzle on processing machine. The method consists in measuring the weight difference of wear samples, before and after the injection of a certain quantity of plastics reinforced with a certain percentage of glass short fibers (SGF).

Weight measurements were made with an electronic analytical balance, accurate to ± 0.01 mg. Due to the difficulty of cleaning the nozzle after injection a reinforced plastic reinforced with glass fibre, were executed 5 identical nozzles, one for each of the four plastics reinforced with short glass fibers injected, the fifth nozzle being preserved for possible verification measurements.

Weight measurements were made with an electronic analytical balance, accurate to 0.01 mg.

Due to the difficulty of the nozzle cleaning after injection a fiber-reinforced plastic with glass fibre, were made 5 identical nozzles, one for each of the four plastics reinforced with glass short fibers injected, fifth of the nozzle being preserved for possible verification measurements. In injecting a volume of 460 cm^3 polyamida reinforced with 30% SGF, differences in weight (loss of material through wear) of wear samples 4 of Fig. 1, were $10 - 17 \cdot 10^{-5}$ g. As an example.

Figure 2 shows the images of nozzle made out of C120 steel, used for injecting the has 460 cm^3 Nylonplast AVE Polyamide + 30% SGF, an operation which lasted 18 sec. Detailed results will be presented in further section of results and discussion.

Because weight loss measured gravimetrically are very low and are not excluded and human errors of measurement and interpretation, as well as to the dificulty in perfect cleaning of wear samples, for validation was adopted a method much more expensive, but very precise: radiometric

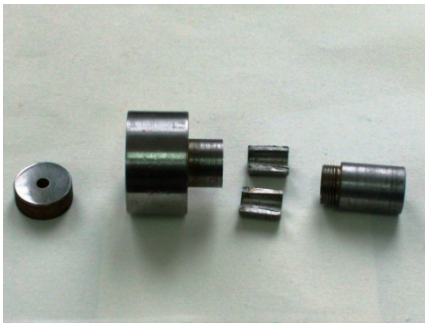
method. Drawing of the execution of experimental modular nozzle for a mold for injection (a); (b) representation of 3D and (c) an expanded representation, looking parts. Parts 2 and 4 represents the wear samples.



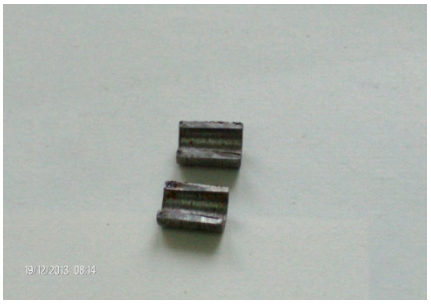
(a)



(b)



(c)



(d)

Figure 2. The nozzle made of steel C120, after injection of 460 cm^3 Nylonplast AVE Polyamide with 30% SGF. (a) shows the whole nozzle, after ultrasound cleaning in solvent, (b) the tightening nut (c) a image of the components of the nozzle (d) are presented only of the wear samples

Despite the high costs and the necessary protection measures, the method was applied for all combinations of materials Nylonplast AVE Polyamide + 30% SGF on C120 and Rp3 steel, Noryl Polyamide + 20% SGF on C120 and Rp3 steel, Maranyl Poliamide + 20% SGF on C120 and Rp3 steel and Lexan + 20% SGF on C120 and Rp3 steel.

2.4. Radiometric Method

The radiometric method consists of superficial irradiation of the metal sample, collection of the wear particles, measurement of its activity and its comparison with the activity of a standard weight, irradiated in the same conditions as the metal sample. Through irradiation, most elements, steel components, react with slow neutrons, in a nuclear reaction that lead to the formation of radioactive isotopes. Experimental measurement equipment from Fig. 3 provides the possibility to study the wear behavior also through a radiometric technique, which is extremely accurate.

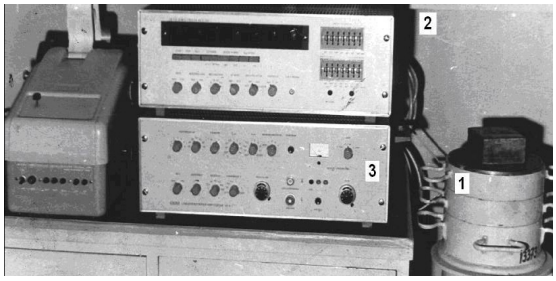


Figure 3. Overall view of the measurement radiometric device: (1) Pb container with scintillation counter; (2) impulses contor; and (3) data recorder

The specific activity Λ_i obtained after time t of irradiation for a certain component element is:

$$\Lambda_i = \Lambda_\infty \left(1 - e^{\lambda_i T}\right) \tag{1}$$

where Λ_i is the limit activity obtained after a long period of irradiation; λ_i is the disintegration constant of radioactive isotope.

Because steels are in fact alloys formed of several elements, their total activity Λ_0 will be:

$$\Lambda_0 = \sum_{i=0}^{n} \Lambda_{0i} \left(1 - e^{\lambda_i T}\right) C_i \tag{2}$$

where c_i represents the i element concentration.

Deactivating the sample takes place according to the relation:

$$\Lambda_t = \sum_{i=0}^{n} \Lambda_{0i} e^{-\lambda_i T} c_i \tag{3}$$

where, Λ_t is the total specific activity at time, t; Λ_{oi} is the initial activity of component, i.

3. Results and Discussion

In the following (Tab. 1), are presented for example wear test results conducted on injection of the four plastics reinforced with SGF, on experimental model of Rp3 steel nozzle (62 HRC ~ 790 HV). The results are obtained by gravimetric measurements. Graphical test results conducted on hardened steel Rp3 (62 HRC) are shown in Fig.4.

Table 1. The results of tests carried out on the experimental model made from hardened Rp3 steel (62 HRC), to determine the wear rate of the injection nozzle 1. Maranyl Polyamide + 20% SGF; 2. Noryl Polyamide + 20% SGF; 3. Nylonplast AVE Polyamide + 30% SGF; 4. Lexan Polycarbonate + 20% SGF. A - volume of the injected material (cm^3); B - during the filling of the die (s); C - the average diameter of the nozzle (mm)

Mat	A	B	C	Mean samples gravimetric wear ΔG (10^{-5}g)	Mean samples wear volume ΔV (10^{-4} cm^3)
1	0	0	0	0	0
1	25	7	6	2	66.61
1	25	7	6	2	66.61
1	50	7	6	5	151.52
1	50	7	6	8	242.44
2	0	0	0	0	0
2	230	15	8	8	251.96
2	230	15	8	8	251.96
2	460	15	16	16	503.92
2	460	15	24	24	755.94
3	0	0	0	0	0
3	230	18	6	6	148.14
3	230	18	6	6	148.14
3	460	18	10	10	296.28
3	460	18	17	17	503.72
4	0	0	0	0	0
4	230	16	17	17	519.15
4	230	16	16	16	488.61
4	460	16	22	22	671.84
4	460	16	22	22	671.84

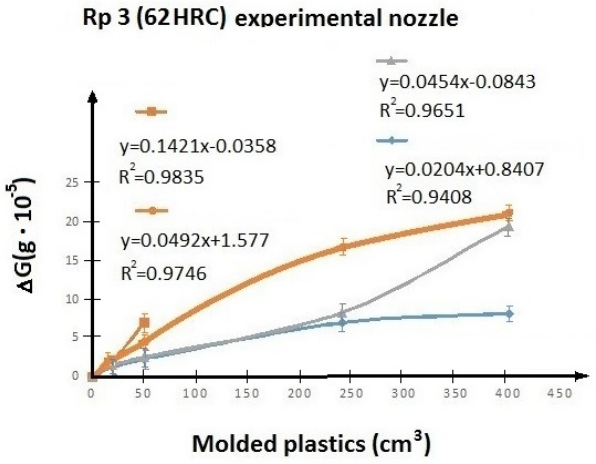


Figure 4. Results of the wear tests carried out at the injection of the four plastic materials reinforced with SGF, on the experimental model of nozzle made of Rp3 steel (62 HRC ~ 790 HV): ■ Maranyl Polyamide + 20% SGF; ● Noryl Polyamide + 20% SGF; ▲ Nylonplast AVE Polyamide + 30% SGF; ♦ Lexan Polycarbonate + 20% SGF

To simplify the presentation, the results of the wear tests conducted with the nozzle made of mold steel C120 (59 HRC ~ 710 HV) are presented only graphically in Fig. 5.

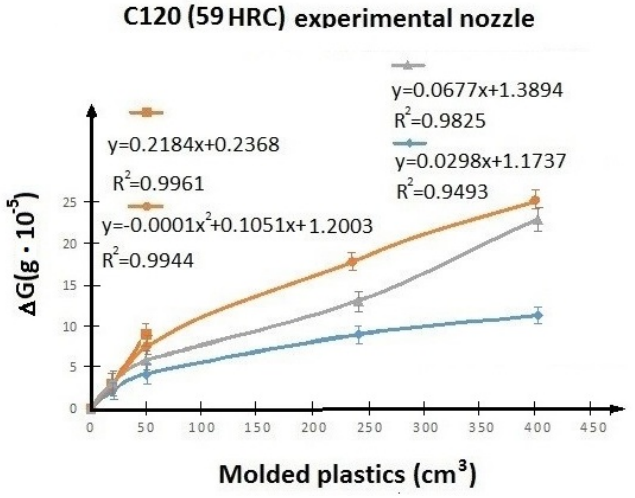


Figure 5. Results of the wear tests carried out at the injection of the four plastic materials reinforced with SGF, on the experimental model of nozzle made of Rp3 steel (62 HRC ~ 790 HV): ■ Maranyl Polyamide + 20% SGF; ● Noryl Polyamide + 20% SGF; ▲ Nylonplast AVE Polyamide + 30% SGF; ♦ Lexan Polycarbonate + 20% SGF

By comparing the curves in Fig. 4 and 5, it results the same hierarchy of the wear produced to the nozzles by injected plastic materials, with a decrease of the wear in the case of nozzle made of Rp3 steel due to its higher hardness, but the curves shape indicates large questions concerning the accuracy of results. Thus, polyamides with 20% glass fibers seem to have produced higher wear to both steels than polyamide with 30% glass fibers, hard thing to understand. Because the results regarding the nozzles wear are of the same order of magnitude (10^{-5} g), further we gave up the use of Rp3 steel nozzles, due to its difficult machinability.

Table 2. The radiometric results of tests carried out on experimental model made from Rp3 hardened steel (62 HRC) to determine the wear rate of the injection nozzle at injection of 230 cm^3 A: Nylonplast AVE Polyamide + 30% SGF; B: Noryl Polyamide + 20% SGF, C: Maranyl Polyamide + 20% SGF and D: Lexan Polycarbonate + 20% SGF. Ge = 3.92 mg; Re = 36989 imp/min; K = Ge / Re = 1.0598·10-4 mg·min/imp

Plastic material	Counting speed *R* (imp/min)	Fond *F* (imp/min)	R – F (imp/min)	Gravimetric wear G = K·(R-F) [10^{-4} mg]
A	462	379	83	88.792
B	397	378	19	20.139
C	420	267	43	57.228
D	405	378	27	32.852

Further, Nylonplast AVE Polyamide + 30% SGF, Noryl Polyamide + 20% SGF, Maranyl Polyamide + 20% SGF and Lexan Polycarbonate + 20% SGF were injected through Rp3 steel nozzles and C120 steel nozzles, whose wear samples (position 4 in Fig. 1) were irradiated with a flow of slow neutrons. Radioactive metallic wear products were embedded in the molten polymer injected. Radiometric method was used. From the quantity of 460 cm^3 polymer

injected of each plastic material, through each of the two nozzles, one sample of approximately 0.5 cm^3 was taken, whose radioactivity was evaluated in the way described in section 2.4. Eight nozzles were used, four made of Rp3 steel and four made of C120 steel, with semi-cylindrical samples activated by irradiation. Radiometric measurements results are shown in Tables 2 and 3.

Table 3. The radiometric results of tests carried out on experimental model made from C120 hardened steel (59 HRC) to determine the wear rate of the injection nozzle at injection of 230 cm^3 A: Nylonplast AVE Polyamide + 30% SGF; B: Noryl Polyamide + 20% SGF, C: Maranyl Polyamide + 20% SGF and D: Lexan Polycarbonate + 20% SGF. Ge = 3.92 mg; Re = 36989 imp/min; K = Ge / Re = 1.0598·10-4 mg·min/imp

Plastic material	Counting speed *R* (imp/min)	Fond *F* (imp/min)	R – F (imp/min)	Gravimetric wear G = K·(R-F) [10^{-4} mg]
A	504	379	125	133.309
B	404	378	26	26.4613
C	444	367	77	81.3022
D	421	378	43	47.6312

The numerical results of Tables II and III are shown in Fig. 6. As expected, the polymer with a higher content of SGF (30%) leads to higher wear of steel surfaces than in the case of polymers with 20% SGF. The dependence of the wear of the wear samples surfaces on its hardness was also ascertained. As expected, metallic surfaces made of Rp3 steel have worn less than those made of C120 steel, due to their higher hardness.

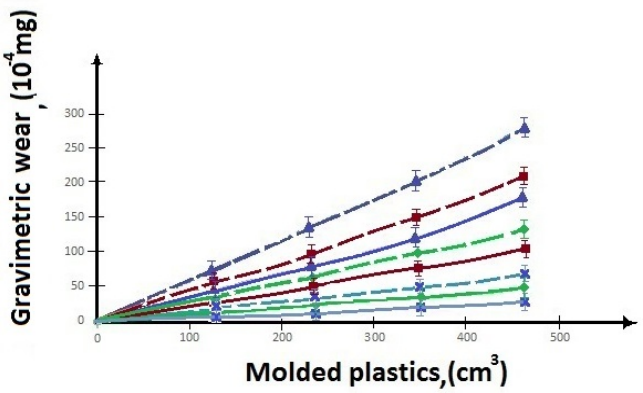


Figure 6. The radiometric results of tests carried out on the experimental model made from tempered steel ── Rp3 (62 HRC) and ─ ─ C120 (59 HRC) to determine the wear rate of the injection nozzle at injection of 230 cm^3 Nylonplast AVE Polyamide + 30% SGF; ■ Maranyl Polyamide + 20% SGF; ● Noryl Polyamide + 20% SGF; ▲ Nylonplast AVE Polyamide + 30% SGF; ♦ Lexan Polycarbonate + 20 % SGF

Other eight nozzles were used, four made of Rp3 steel, and four made of C120 steel, with semi-cylindrical wear samples having coatings with irradiated TiN or CrN thin layers. TiN coated wear samples had microhardness 64 HRC (840 HV) and microhardness of CrN coated ones was 66.5 HRC (900 HV). To avoid cluttering this paper, the results of radiometric measurements for TiN and CrN coatings on C120 steel are shown in Tables 4 and 5, respectively. Fig. 7 graphically shows the results of radiometric wear tests of TiN and CrN coatings on wear samples made of Rp3 and C120 steel.

Table 4. The radiometric results of tests carried out on experimental model made from C120 hardened steel (59 HRC) covered withTiN coating (64 HRC ~ 840 HV) to determine the wear rate of the injection nozzle at injection of 230 cm^3 A: Nylonplast AVE Polyamide + 30% SGF; B: Noryl Polyamide + 20% SGF, C: Maranyl Polyamide + 20% SGF and D: Lexan Polycarbonate + 20% SGF. Ge = 3.92 mg; Re = 36989 imp/min; K = Ge / Re = 1.0598·10-4 mg·min/imp

Plastic material	Counting speed *R* (imp/min)	Fond *F* (imp/min)	R – F (imp/min)	Gravimetric wear G = K·(R-F) [10^{-4} mg]
A	410	379	31	85.792
B	393	363	30	20.139
C	385	367	18	57.228
D	377	373	4	32.854

Table 5. The radiometric results of tests carried out on experimental model made from C120 hardened steel (59 HRC) covered with CrN coating (71 HRC ~ 900 HV) to determine the wear rate of the injection nozzle at injection of 230 cm^3 A: Nylonplast AVE Polyamide + 30% SGF; B: Noryl Polyamide + 20% SGF, C: Maranyl Polyamide + 20% SGF and D: Lexan Polycarbonate + 20% SGF. Ge = 3.92 mg; Re = 36989 imp/min; K = Ge / Re = 1.0598·10-4 mg·min/imp

Plastic material	Counting speed *R* (imp/min)	Fond *F* (imp/min)	R – F (imp/min)	Gravimetric wear G = K·(R-F) [10^{-4} mg]
A	395	380	15	11.775
B	373	369	4	4.239
C	387	378	9	9.338
D	375	374	1	10.598

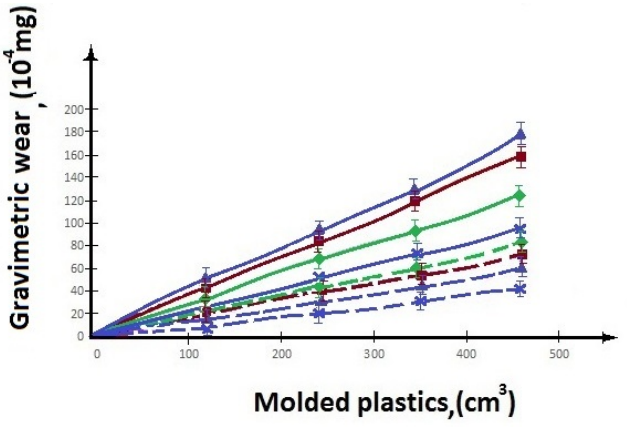


Figure 7. The radiometric results of tests carried out on the experimental model made from tempered steel ── Rp3 (62 HRC) and ─ ─ C120 (59 HRC) coated with CrN to determine the wear rate of the injection nozzle at injection of 230 cm^3 Nylonplast AVE Polyamide + 30% SGF; ■ Maranyl Polyamide + 20% SGF; ● Noryl Polyamide + 20% SGF; ▲ Nylonplast AVE Polyamide + 30% SGF; ♦ Lexan Polycarbonate + 20% SGF

You may notice that both the coatings TiN and CrN, lead to decreased wear of steel surfaces. Unfortunately, the coating of CrN on Rp3 steel presented a clear trend of massive speeling, so that this steel can no longer be taken into consideration for this application. More than likely that this behavior is due to an inappropriate report hardness / Young's module.

Analysing the results obtained by the radiometric method of intensity compared to those reported by Knappe and Mahler [2], you need to see the same linear weight variation

of wear, depending on the amount of plastic material with SGF injected. Values in our research by the radiometric method on the C120 steel (similar of DIN steel 1.8550-17007, or of CrAlNi7V-34 after the DIN 17006) coated with TiN, (64 HRC ~ 840 HV), are relatively similar to those of the wear measured in the Deuschen Kunststoff Institut – DKI in Darmstadt [1].

4. Conclusions

In these respects there are clearly several conclusions. Thus, it is clear that a higher content of SGF of polymer leads to a higher wear of working parts surfaces of processing machines, screws, barrels and molds. Wear is manifested as an evolutionary process, by adhesion, abrasion and corrosion. In order to ensure the high durability of screws and barrels, it is absolutely necessary the choice of the appropriate base alloys, but also of hard coatings are compatible with ensuring an optimum ratio between hardness and modulus of elasticity of the material.

In this context, the C120 steel (steel for hot working tools, similar to 1.8550 steel - after DIN 17007, or CrAlNi7V after DIN 17006) covered with TiN, 64 HRC (~ 840 HV), presented the best results.

How no is it possible to stop the process of wear, delay its evolution is essential, because the metallic wear particles driven by melted polymer emphasizes evolution process toward catastrophic stage.

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