Influence of the Grind Percentage on Mechanical Properties of Some Polymers used in the Automotive Industry, by Determining Mechanical Resistances

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This paper analyses the influence of the grind percentage on some mechanical properties of various injection-molded items in the automotive industry, which are made of acrylonitrile butadiene styrene (ABS), polyamide 6.6 (PA 6.6) and polyoxymethylene (POM). The specimens had the following compositions: new material 100%, new material 80% + grind 20%, new material 60% + grind 40%, new material 40% + grind 60%, new material 20% + grind 80% and grind 100%. The mechanical properties were measured using tensile tests, the Izod impact test and the Shore Durometer hardness test. It was observed that the hardness of the three tested polymers is not significantly influenced by the increase in grind percentage. The shock resistance of ABS and PA 6.6 decreases when the grind percentage is increased, while for POM the increase in grind percentage leads to an increase in shock resistance. The tensile strength at break decreases when the grind percentage is increased from 0% to 40% for ABS and POM. The further increase in grind leads to a slight increase in the tensile strength at break. In the case of PA 6.6 the tensile strength at break increases along with the increase in grind percentage.

Keywords: acrylonitrile butadiene styrene (ABS), polyamide 6.6 (PA 6.6), polyoxymethylene (POM), tensile tests, the Izod impact test, the Shore Durometer hardness test

The automotive industry is one of the largest consumers of plastic materials. The most frequently used technopolymers in the manufacture of various auto parts are: polyamides, thermoplastic polyurethanes, polyoxy-methylenes, polypropylene, polymethyl methacrylate, cellulose acetate, plasticised polyvinyl chloride, acrylonitrile butadiene styrene, etc. The most frequently used processing technology for these polymers is injection.

Polyamides have good dimensional stability, high rigidity especially when reinforced with fibre glass, good resistance to compression, wear, shocks and vibrations; they are hard materials, and maintain their hardness at high temperatures, with no visible transformations up to 80-90°C [1, 2]. Fibre glass-reinforced polyamides have better tensile strength, bending resistance, elastic modulus and hardness. They have good resistance to salt water, oil, hydrocarbons, lacquers, weak bases, esters, ethers, alcohols and automotive fuel. They are good electrical insulators. These properties make them suitable for their use in the automotive industry. Uses: water and tanks (glycol resistance, thermal resistance, stiffness, low creep), cooling module (good fatigue behaviour, glycol resistance, thermal resistance, reduction in the number of materials used, good vibration behaviour), water pipes, thermostat housing (heat resistance, glycol resistance), gasoline tanks, carburettor floats, air systems, cylinder head cover (thermal resistance, stiffness, good creep behaviour, good chemical resistance to oil), engine covers, fans, chair frames, support structures for frontal air vent grilles, structural door module, pedals and pedal box (good fatigue and impact behaviour, stiffness), brake fluid reservoir (thermal resistance, stiffness, chemical resistance), handbrake lever, door handle, the gearshift lever support, front wing, exterior mirrors, defroster grill, air vent grille, fuel systems, cable fastening systems.

Polyoxymethylenes are opaque polymers due to their high crystallinity degree [3] and have good dimensional stability in a wide temperature range. The high crystallinity degree gives polyoxymethylenes higher general mechanical properties (especially stiffness) compared to other thermoplastics in the temperature interval of 50-120°C. They have good shock, fatigue, abrasion and wear resistance. They have good resistance to various organic chemical substances (aldehydes, esters, ethers) and are good electrical insulators. Uses in the automotive industry: gears, housings, guides, active parts of oil or diesel pumps, of floats and faucets, windshield cleaning devices, etc. [4].

The most important mechanical properties of acrylonitrile butadiene styrene (ABS) are shock resistance and toughness. ABS is a rigid material, it is resistant to wear and tear, it has good dimensional stability in a wide temperature range, unlimited colouring possibilities, easy forming [5] and it is a good electrical insulator. It has good resistance to weak acids and bases, but weak stability in the presence of esters, ketones, ethers and gasoline. Uses in the automotive industry: seat components, bumpers, enclosures for electrical and electronic parts, car roof boxes, etc.

One current problem of the injection processing of thermoplastic polymers is waste recovery. Waste includes injection channels, incomplete parts, parts with burrs or other manufacturing defects. Their reuse (as grind) in the manufacturing process has been common practice for a very long time, leading to an increase in productivity. The grind can be reintroduced in combination with new material (one that has never been processed through injection before) or it can be injected on its own.

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In recent years several studies on the mechanical behaviour of various types of polymers in different stress conditions have been published [1,6,7]. The present paper aims to analyse the variation of some mechanical properties depending on the percentage of grind (one time injected polymer), using tensile tests, the Izod impact test and the Shore (durometer) hardness test for PA 6.6 TECHNYL AR218V30 Blak polyamide, POM EUROTAL C9 NAT polyoxymethylene and ABS MAGNUM 3453 acrylonitrile butadiene styrene used in the manufacturing of items in the automotive industry.

Experimental part

The specimens contain the following materials: ABS MAGNUM 3453 acrylonitrile butadiene styrene, PA 6.6 TECHNYL AR 218V30 Blak polyamide and POM EUROTAL C9 NAT polyoxymethylene. An ENGEL CC 100 Type ES 80/50 HL injection machine manufactured in 1995 was used (fig. 1).

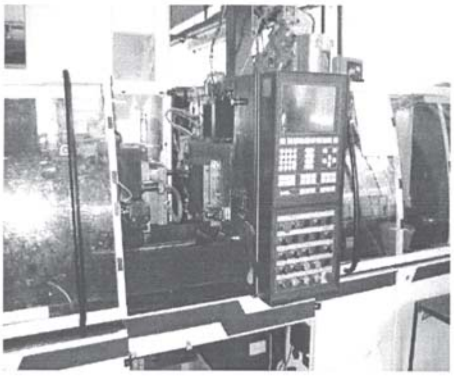

Fig. 1 ENGEL CC 100 Type ES 80/50 HL injection machine

Six samples with variable content were injected for each type of material. They are shown in table 1.

The injection of ABS MAGNUM 3453 was carried out according to the following parameters: injection temperature of 230°C, mold temperature of 50°C, injection pressure of 800 Bar, holding pressure of 300 Bar, injection speed of 30mm/s, injection cycle time of 43s, cooling time in the mold of 20s, injection time of 2.87s and holding pressure time of 6s. During the injection of the six samples the injection parameters remained constant.

The injection of PA 6.6 TECHNYL AR218V30 Blak was carried out according to the following parameters: injection temperature of 300°C, mold temperature of 85°C, injection pressure of 370 Bar, holding pressure of 300 Bar, injection speed of 100mm/s, injection cycle time of 26s, cooling time in the mold of 10s, injection time of 0.94s and holding pressure time of 3s. During the injection of the six samples the injection parameters remained constant.

The injection of POM EUROTAL C9 NAT was carried out according to the following parameters: injection temperature of 200°C, mold temperature of 50°C, injection pressure of 1000 Bar, holding pressure of 300 Bar, injection speed of 20mm/s, injection cycle time of 32.60s, cooling time in the mold of 15s, injection time of 4.2s and holding pressure time of 5s. During the injection of the six samples the injection parameters remained constant.

All the injected samples were subject to the following mechanical measurements: the Shore Durometer hardness test, the Izod impact test on unnotched specimens and the tensile strength at break test. The tests were conducted at ambient temperature, in the Quality Department of S.C. Plastor S.A. Oradea.

Table 1
CONTENT OF THE SAMPLES USED

Samples	Sample content
Sample 1	100% new material
Sample 2	80% new material + 20% grind
Sample 3	60% new material + 40% grind
Sample 4	40% new material + 60% grind
Sample 5	20% new material + 80% grind
Sample 6	100% grind

The Shore Type D Durometer hardness test

The injected samples for the three materials were subject to the Shore Type D hardness test, using a Type D Model SAUTER HB/Germany Durometer (fig. 2). The hardness of the samples was determined by measuring the initial penetration and by the instant recording of the values indicated by the device (less than 1s from pressing).

The tests were carried out in accordance with the European Standard SR EN ISO 868:2003 [8] on specimen models such as those illustrated in figure 3. A number of 25 tests were performed on each sample, and the result is expressed as the arithmetic mean of the number of tests.

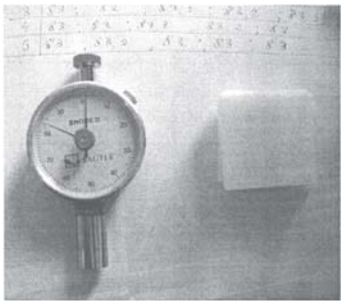

Fig.2 Shore Type D Durometer, Model SAUTER HB/Germany

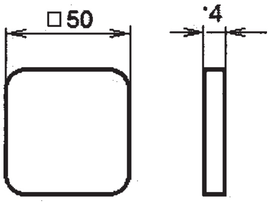

Fig. 3 Specimen model for hardness tests

The Izod impact test

The Izod impact test was performed on unnotched specimens (fig. 4).

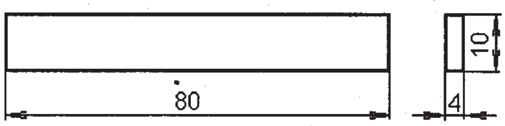

Fig. 4 Specimen model for the Izod impact test

The tests were carried out in accordance with the European Standard SR EN ISO 180 [9] using a pendulum impact tester model PENDOLO P400, manufactured by HAMMEL, England (fig. 5).

According to the user manual, the initial potential energy of the pendulum is 7.5 J and the initial angle of the pendulum arm is 150°C.

Fig. 5 Izod impact tester, Model PENDOLO P400, HAMMEL/England

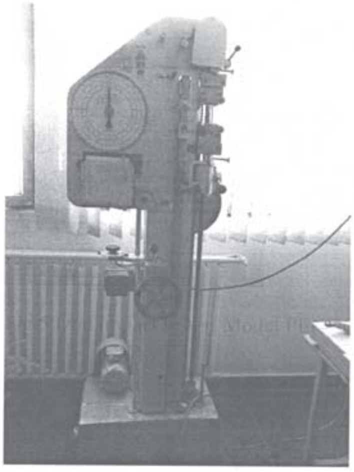

Fig. 6 WPM – VEB Thuringer Industrie werk, Ranenstein gerat R 37, Typ 2092 tensile testing machine

According to SR EN ISO 180, the Izod impact test on unnotched specimens (a_{iU}) is based on the following equation:

$$a_{iU} = \frac{E_c}{h \cdot b} \times 10^3, \qquad [kJ/m^2] \qquad (1)$$

where:

E_c – the energy (in J) absorbed when the specimen breaks

h – the specimen thickness (in mm)

b – the specimen width (in mm)

The software of the PENDOLO P400 device automatically displays the values of the energy absorbed when the specimens break. The specimens were fixed in parallel mode. Ten specimens were tested for each sample and the result was expressed as arithmetic mean.

Measurement of the tensile strength at break

The tests for the three materials were conducted on the WPM – VEB Thuringer Industrie werk, Ranenstein gerat R 37, Typ 2092 tensile testing machine (fig. 6).

The tests were carried out in accordance with the European Standard SR EN ISO 527-1:2000 [10] and SR EN ISO 527-2:2000 [11] on specimens such as those illustrated in figure 7.

The test speed for all samples was 200mm/min. 10 specimens were tested for each sample and the result was expressed as arithmetic mean.

The tensile strength at break was calculated using the following equation:

$$\sigma = F/A, \qquad [MPa] \qquad (2)$$

where:

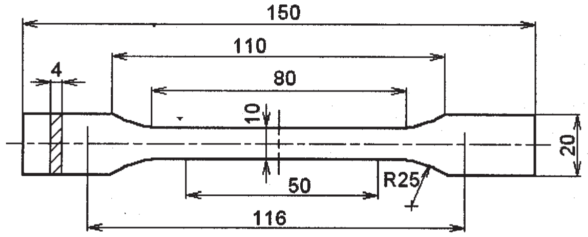

Fig. 7 Specimen model for tensile strength at break testing

F – the force (in N) measured at the break point of the specimen

A – the initial cross-sectional area (in mm^2) of the specimen

Results and discussions

After testing samples of ABS, PA 6.6 and POM the following results for the Shore Type D hardness test were obtained (table 2).

After testing these three materials, we can draw the conclusion that the increase in grind percentage from 0% to 100% leads to an insignificant variation of the hardness values of these polymers; in other words, mixing grind with new material does not influence the hardness of the manufactured item in a significant way. In the case of ABS an increase in grind percentage from 0 to 40% leads to a slight decrease in hardness from 83.032 to 82.960 N/mm^2, while an increase in grind percentage from 60 to 100% results in a slight increase in hardness from 82.960 to 83.096 N/mm^2. The same behaviour is displayed by POM.

Table 2
HARDNESS OF INJECTED ABS MAGNUM 3453, PA 6.6 TECHNYL AR218V30 Blak AND POM EUROTAL C9 NAT SAMPLES DEPENDING ON THE GRIND USED PERCENTAGE

Samples	Materials		
	ABS MAGNUM 3453	PA 6.6 TECHNYL AR218V30 Blak	POM EUROTAL C9 NAT
	Shore Type D hardness [N/mm²]	Shore Type D hardness [N/mm²]	Shore Type D hardness [N/mm²]
Sample 1	83,032	89,208	86,976
Sample 2	82,984	88,888	86,004
Sample 3	82,960	88,648	85,992
Sample 4	82,960	88,232	86.008
Sample 5	83,024	87,960	86,008
Sample 6	83,096	87,648	86,016

Samples	Materials					
	ABS MAGNUM 3453		PA 6.6 TECHNYL AR218V30 Blak		POM EUROTAL C9 NAT	
	E_c [J]	a_{iU} [kJ/m²]	E_c [J]	a_{iU} [kJ/m²]	E_c [J]	a_{iU} [kJ/m²]
Sample 1	4,169	104,225	1,316	32,900	2,931	73,275
Sample 2	3,474	86,850	1,305	32,625	3,610	90,250
Sample 3	3,453	86,325	1,256	31,400	3,782	94,550
Sample 4	3,452	86,300	1,229	30,725	5,327	133,175
Sample 5	3,345	83,625	1,195	29,875	5,339	133,475
Sample 6	3,205	80,125	1,108	27,700	6,219	155,475

Table 3
IZOD IMPACT STRENGTH AND THE ENERGY ABSORBED AT THE BREAK POINT OF THE UNNOTCHED SPECIMENS FOR ABS MAGNUM 3453, PA 6.6 TECHNYL AR218V30 Blak AND POM EUROTAL C9 NAT, DEPENDING ON THE USED GRIND PERCENTAGE

An increase in grind percentage from 0 to 40% leads to a slight decrease in hardness from 86.976 la 85.992 N/mm, while an increase in grind percentage from 60 to 100% results in a slight increase in hardness from 86.008 to 86.016 N/mm². In the case of PA 6.6 an increase in grind percentage from 0% to 100% leads to a slight decrease in hardness from 89.208 to 87.648 N/mm².

After testing samples of ABS, PA 6.6 and POM the following results for the Izod impact test on unnotched specimens (a_{iU}) and for the absorbed energy at the break point of the unnotched specimens (E_c) were obtained (table 3).

Where ABS is concerned, the introduction of 20% grind in Sample 1 leads to a significant decrease in the impact strength of the material, namely from 104.225 to 86.850 kJ/m². The further increase in the grind percentage in the other five ABS samples leads to a slight decrease in impact strength, namely from 86.850 to 80.125 kJ/m².

Where PA 6.6 is concerned, the increase in grind percentage leads to a slight decrease in impact strength for all six samples, namely from 32.900 kJ/m² for Sample 1 to 27.700 kJ/m² for Sample 6.

Where POM is concerned, the increase in grind percentage leads to a significant increase in impact strength, namely from 73.275 kJ/m² for Sample 1 to 155.475 kJ/m² for Sample 6.

After tensile tests on samples of ABS, PA 6.6 and POM the following results for the tensile strength at break of the specimen (F) were obtained (table 4).

Where ABS is concerned, the increase in grind percentage from 0 to 40% leads to a decrease in the tensile strength at break of the specimen, namely from 1705.6N to 1442.8N. The further increase in grind percentage in Samples 4, 5 and 6 from 60% to 100% leads to an increased strength, namely from 1581.2N to 1704.0N. A similar phenomenon occurs with POM. An increase in grind percentage from 0% to 40% leads to a decreased strength, from 2558.4N to 2518.4N. A further increase in Samples 4, 5 and 6 from 60 to 100% leads to a slightly increased strength, namely from 2518.4N to 2554.0N. Moreover, there is a resemblance between the hardness variation of ABS and POM according to the grind percentage and the variation of the tensile strength at break of the specimen for ABS and POM depending on the grind percentage. Both the hardness and the strength decrease with the increase in grind percentage from 0 to 40%. The further increase in grind percentage in the injected samples from 40% to 100% leads to slightly increased hardness and tensile strength at break of the specimen.

Where PA 6.6 is concerned, an increase in grind percentage in the injected samples from 0 to 100% leads to an increase in the tensile strength at break of the specimen from 5552.0N to 7048.8N.

The graphical representation of the tensile strength at break variation (σ) depending on the grind percentage for the three studied polymers is illustrated in figure 8.

The tensile strength at break decreases with the increase in grind percentage from 0 to 40% in the case of ABS and POM. The further increase in grind percentage

Samples	Materials		
	ABS MAGNUM 3453	PA 6.6 TECHNYL AR218V30 Blak	POM EUROTAL C9 NAT
	F [N]	F [N]	F [N]
Sample 1	1705,60	5552,00	2558,4
Sample 2	1526,80	5960,80	2534,0
Sample 3	1442,80	6266,40	2518,4
Sample 4	1581,20	6266,40	2518,4
Sample 5	1616,80	6588,00	2538,4
Sample 6	1704,00	7048,80	2554,0

Table 4
VARIATION OF TENSILE STRENGTH AT BREAK (F) FOR ABS MAGNUM 3453, PA 6.6 TECHNYL AR218V30 Blak AND POM EUROTAL C9 NAT, DEPENDING ON THE GRIND PERCENTAGE USED

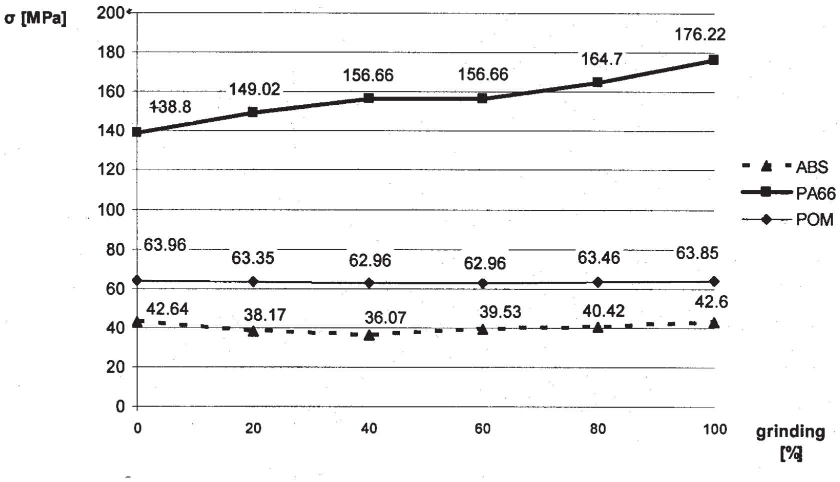

Fig. 8 The tensile strength at break variation (σ) depending on the grind percentage in the tested samples of ABS, PA 6.6 and POM

leads to a slight increase in tensile strength at break. Where the PA 6.6 is concerned, the tensile strength at break increases with the increase in grind percentage.

Conclusions

The object of the present study is the analysis of the modifications suffered by the mechanical properties of ABS MAGNUM 3453 acrylonitrile butadiene styrene, PA 6.6 TECHNYL AR218V30 Blak polyamide and POM EUROAL C9 NAT polyoxymethylene, polymers used in the manufacturing of various items in the automotive industry, depending on the variation in grind percentage (polymer which was processed through injection only once) in the samples. The samples were injected on an ENGEL CC 100 Type ES 80/50 HL injection machine. The specimens had the following compositions: new material 100%, new material 80% + grind 20%, new material 60% + grind 40%, new material 40% + grind 60%, new material 20% + grind 80% and grind 100%. After carrying out a Shore Type D hardness test, using a Type D, Model SAUTER HB/Germany Durometer, it was observed that the increase in grind percentage from 0 to 100% leads to an insignificant variation in hardness. The Izod impact test was performed on unnotched specimens, using a pendulum impact tester, Model PENDOLO P400, manufactured by HAMMEL, England. The impact strength decreases with the increase in grind percentage for ABS and PA 6.6, while an increase in grind percentage leads to increased impact strength for POM. The tensile strength at break tests were conducted on a WPM – VEB Thuringer Industrie werk, Ranenstein gerat R 37, Typ 2092 tensile testing machine. The tensile strength at break decreases with an increase in grind percentage from 0 to 40% for ABS and POM. The further increase in grind percentage leads to a slight increase in tensile strength at break. Where PA 6.6 is concerned, the tensile strength at break increases with the increase in grind percentage.

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