Influence of Processing Temperatures of Acrylonitrile Butadiene Styrene (ABS), Polyamide 6.6 (PA 6.6) and Polyoxymethylene (POM) on Some Mechanical Properties when Injecting Items Used in the Automotive Industry Based on Mechanical Resistance Tests

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This paper analyses the influence of processing temperatures of acrylonitrile butadiene styrene (ABS), polyamide 6.6 (PA 6.6) and polyoxymethylene (POM) on some mechanical properties when injecting items used in the automotive industry. The ABS specimens were made at the following injection temperatures: 220, 230, 240 and 250°C. The PA 6.6 specimens were made at the following injection temperatures: 280, 290, 300, 310 and 320°C. The POM specimens were made at the following injection temperatures: 180, 190, 200, and 210°C. The mechanical properties were measured using tensile tests, the Izod impact test and the Shore Durometer hardness test. It was observed that for these three polymers, the increase in processing temperature leads to insignificant changes in hardness. The Izod impact strengths of PA 6.6 and POM decrease to a minimum with an increase in processing temperature, while the further increase in processing temperatures leads to an increase in impact strength. Where ABS is concerned, the increase in processing temperature results in an increase in Izod impact strength. The tensile strength at break is influenced by the processing temperature. The highest tensile strength at break for ABS was recorded at 220°C, for PA 6.6 at 310°C and for POM at 200°C. The lowest values were recorded at the lowest and highest processing temperatures.

Keywords: acrylonitrile butadiene styrene (ABS), polyamide 6.6 (PA 6.6), polyoxymethylene (POM), tensile tests, Izod impact test, 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, polyoxymethylenes, 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 salty 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. When polymers are processed through injection, the characteristics of the resulting products are strongly influenced by the temperature of the material, by the pressure with which the fluid material fills up the mold and by the temperature of the mold [5-8].

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The present paper aims to analyse the variation of some mechanical properties depending on the injection processing temperature 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

The temperature measurements of the flowing material were done by means of thermocouples placed on the plastification-injection cylinder. The ABS specimens were made at the following injection temperatures: 220, 230, 240 and 250°C. The PA 6.6 specimens were made at the following injection temperatures: 280, 290, 300, 310 and 320°C. The POM specimens were made at the following injection temperatures: 180, 190 , 200, and 210°C. During the injection of ABS, PA 6.6 and POM samples, all parameters which influence the injection cycles were kept constant and only the injection temperatures were modified. 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.

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).

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

The tests were carried out in accordance with the European Standard SR EN ISO 868:2003 [9] 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.

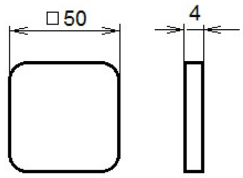

Fig. 3 Specimen model for hardness tests

The Izod impact test

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

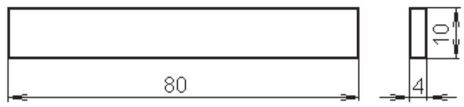

Fig. 4 Specimen model for the Izod impact test

The tests were carried out in accordance with the European Standard SR EN ISO 180 [10] using a pendulum impact tester model PENDOLO P400, manufactured by HAMMEL, England (fig. 5).

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

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. 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 [11] and SR EN ISO 527-2:2000 [12] on specimens such as those illustrated in figure 7.

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

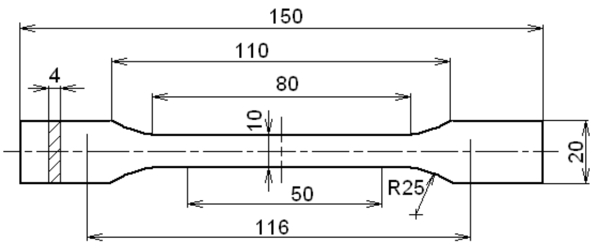

Fig. 7 Specimen model for tensile strength at break testing

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

Table 1
HARDNESS VALUES OF INJECTED ABS MAGNUM 3453 SAMPLES DEPENDING ON THE PROCESSING TEMPERATURE

Processing temperature of ABS MAGNUM 3453 [°C]	Shore Type D hardness [N/mm²]
220	82,896
230	83,032
240	83,312
250	83,096

Tabelul 2
HARDNESS VALUES OF INJECTED PA 6.6 TECHNYL AR218V30 Blak SAMPLES DEPENDING ON THE PROCESSING TEMPERATURE

Processing temperature of PA 6.6 TECHNYL AR218V30 Blak [°C]	Shore Type D hardness [N/mm²]
280	88,504
290	88,648
300	89,208
310	89,080
320	88,896

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

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

where:
F – the force (in N) measured at the break point of the specimen
A – the initial cross-sectional area (in mm²) of the specimen

Results and discussions

After testing samples of ABS, the following results for the Shore Type D hardness test were obtained (table 1).

Increasing the processing temperature of ABS from 220 to 240°C results in a slightly increased hardness. The maximum hardness of ABS – 83.312 N/mm² - is recorded at 240°C. The further increase in processing temperature leads to a decrease in hardness.

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

Increasing the processing temperature of PA 6.6 from 280 to 300°C results in a slightly increased hardness. The maximum hardness of PA 6.6 – 89.208 N/mm² - is recorded at 300°C. The further increase in processing temperature leads to a decrease in hardness.

After testing samples of POM, the following results for the Shore Type D hardness test were obtained (table 3).

Increasing the processing temperature of POM from 180°C to 200°C results in a slightly increased hardness. The maximum hardness of POM – 86.976 N/mm² - is recorded at 200°C. The further increase in processing temperature leads to a decrease in hardness. It can be observed that the lowest hardness values of the three polymers are recorded at the lowest processing temperatures (ABS - 220°C, PA 6.6 - 280°C and POM - 180°C), when mechanical degradation occurs inside the plastification – injection cylinder. At the highest processing temperatures (ABS - 250°C, PA 6.6 320°C and POM 210°C) thermal degradation occurs, which also leads to decreased hardness values of the three polymers.

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 4).

Where ABS is concerned, increasing the processing temperature from 220 to 250°C leads to an increase in impact strength from 66.475 kJ/m² to 137.825 kJ/m².

Where PA 6.6 is concerned, increasing the processing temperature from 280 to 310°C leads to a decrease in impact strength from 38.850 kJ/m² to 30.475 kJ/m², while

Table 3
HARDNESS VALUES OF INJECTED POM EUROTAL C9 NAT SAMPLES DEPENDING ON THE PROCESSING TEMPERATURE

Processing temperature of POM EUROTAL C9 NAT [°C]	Shore Type D hardness [N/mm²]
180	86.376
190	86.408
200	86.976
210	86.656

Table 4
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 PROCESSING TEMPERATURE

Materials								
ABS MAGNUM 3453			PA 6.6 TECHNYL AR218V30 Blak			POM EUROTAL C9 NAT		
Processing temperature [°C]	E_c [J]	a_{iU} [kJ/m²]	Processing temperature [°C]	E_c [J]	a_{iU} [kJ/m²]	Processing temperature [°C]	E_c [J]	a_{iU} [kJ/m²]
220	2.659	66.475	280	1.554	38.850	180	7.093	177.325
230	4.169	104.225	290	1.346	33.650	190	2.935	73.375
240	4.970	124.250	300	1.316	32.900	200	2.931	73.275
250	5.513	137.825	310	1.219	30.475	210	3.668	91.700
			320	1.280	32.000			

increasing the temperature to 320°C leads to an increase in impact strength to the value of 32.000 kJ/m².

When POM is concerned, increasing the processing temperature from 180 to 200°C leads to a decrease in impact strength from 177.325 kJ/m² to 73.275 kJ/m², while increasing the temperature to 210°C leads to an increase in impact strength to the value of 91.700 kJ/m².

After tensile tests conducted 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 5).

Where ABS is concerned, increasing the processing temperature from 220 to 230°C leads to an increase in the tensile strength at break of the specimen, from 1531.2 N to 1705.6 N. The further increase in temperature leads to a decrease in the tensile strength at break of the specimen.

Where PA 6.6 is concerned, increasing the processing temperature from 280 to 310°C leads to an increase in the tensile strength at break of the specimen, from 5280.0 N to 6124.8 N. The further increase in temperature leads to a decrease in the tensile strength at break of the specimen.

POM displays the same behaviour. Increasing the processing temperature from 180 to 200°C leads to an increase in the tensile strength at break of the specimen, from 2532.8 N to 2558.4 N. The further increase in temperature (to 210°C) leads to a decrease in the tensile strength at break of the specimen (2531.2 N).

The graphical representations of the tensile strength at break variation (σ) depending on the processing temperature for the three studied polymers are illustrated in figures 8-10.

Based on the three graphical representations of the tensile strength at break variation (σ) depending on the processing temperature, we can draw the conclusion that the lowest values of tensile strength are recorded at the lowest and at the highest processing temperatures. These thermal extremes cause mechanical (at low temperatures) and thermal (at high temperatures) degradations in the polymer mass which influence tensile strengths.

A parallel can be drawn between the tensile strength at break variation (σ) depending on the processing temperature for PA 6.6 and POM and the variation of the storage module depending on the processing temperatures for the same polymers [7,13]. The lowest values of the storage module are recorded at the same temperatures at which the highest tensile strength at break values are

Table 5
VARIATION OF TENSILE STRENGTH AT BREAK (F) OF THE SPECIMENS OF ABS MAGNUM 3453, PA 6.6 TECHNYL AR218V30 Blak AND POM EUROTAL C9 NAT, DEPENDING ON THE PROCESSING TEMPERATURE

Materials					
ABS MAGNUM 3453		PA 6.6 TECHNYL AR218V30 Blak		POM EUROTAL C9 NAT	
Processing temperature [°C]	F [N]	Processing temperature [°C]	F [N]	Processing temperature [°C]	F [N]
220	1531.20	280	5280.00	180	2532.80
230	1705.60	290	5446.00	190	2534.00
240	1656.80	300	5552.00	200	2558.40
250	1598.80	310	6124.80	210	2531.20
		320	5840.00		

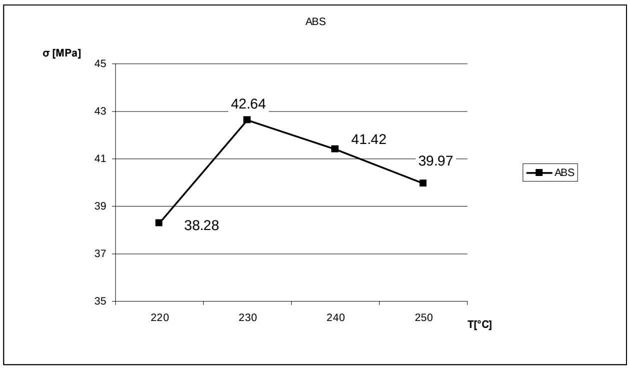

Fig. 8 The tensile strength at break variation (σ) depending on the processing temperature for ABS

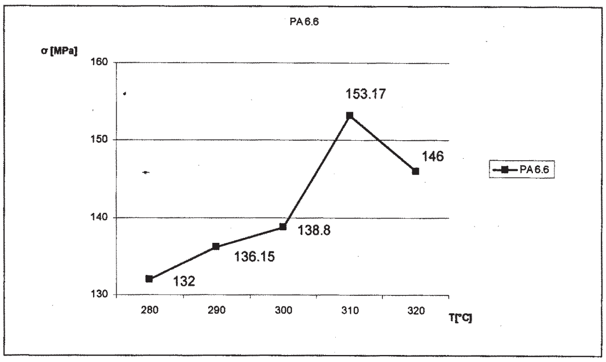

Fig. 9 The tensile strength at break variation (σ) depending on the processing temperature for PA 6.6

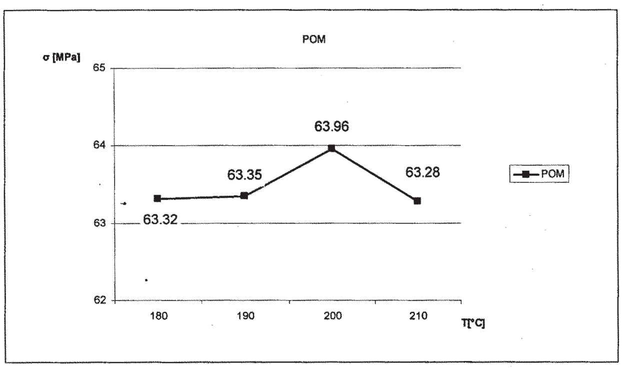

Fig. 10 The tensile strength at break variation (σ) depending on the processing temperature for POM

recorded. At these temperatures the material has the highest elasticity, as well as the highest tensile strength.

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 injection processing temperature. The ABS specimens were made at the following injection temperatures: 220, 230, 240 and 250°C. The PA 6.6 specimens were made at the following injection temperatures: 280, 290, 300, 310 and 320°C. The POM specimens were made at the following injection temperatures: 180, 190, 200, and 210°C. The samples were injected on an ENGEL CC 100 Type ES 80/50 HL injection machine.

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 processing temperature leads to insignificant changes in the hardness of the polymers.

The Izod impact test was performed on unnotched specimens, using a pendulum impact tester, Model PENDOLO P400, manufactured by HAMMEL, England. The impact strengths of PA 6.6 and POM decrease to a minimum with the increase in processing temperatures, while the further increase in temperature leads to an increase in impact strength. Where ABS is concerned, the increase in processing temperature leads to an increase in impact strength.

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 is influenced by the processing temperature. The highest value of tensile strength at break for ABS was recorded at 220°C, for PA 6.6 at 310°C and for POM at 200°C. The lowest values of tensile strength at break were recorded at the lowest and at the highest processing temperatures.

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