Influence of the Grind Percentage on Some Mechanical Properties of Three Types of Polyamide 6.6 Reinforced with Different Percentages of Fiber Glass, Polymers Used in Different Industries, by Determining Mechanical Resistances

GHEORGHE RADU EMIL MARIES*
University of Oradea, 1 Universităţii, 410087, Oradea, Romania

This paper analyses the influence of the grind percentage on some mechanical properties, obtained by the injection of different technical items, which are made of polyamide 6.6 Grivory HTV-3H1 noir 9205, polyamide 6.6 Grivory HTV-45H1 noir 9205 and polyamide 6.6 Grivory HTV-6H1 noir 9205. The specimens are made of 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 has been observed that the hardness of the three tested polymers is hardly influenced by the increase in grind percentage. The shock resistance decreases along with the increase in the grind percentage, and the tensile strength at break increases along with the increase in the grind percentage.

Keywords: polyamide 6.6 (PA 6.6), tensile tests, the Izod impact test, the Shore Durometer hardness test

Along with the most frequently utilised polymers in the production of the technical items from various industries, can be enumerated: polyethylenes, polyamides, thermoplastic polyurethanes, polyoxymethylenes, polypropylene, polymethyl methacrylate, cellulose acetate, polyvinyl chloride, polystyrene and its derivates, etc. The most frequently used processing technology for these polymers are injection, thermoforming, exudation, etc.

Polyamides are characterized by good dimensional stability, a high level of rigidity especially when reinforced with fibre glass, resistant to compression, wear and tear, shocks and vibrations; they are hard materials, and maintain their hardness when under high temperatures without visible transformations up to 80-90°C [1,2]. They are translucent when injected in items with thin walls, and opaque in items with thick walls. By adding glass fibres, the polyamides have better tensile strength, bending resistance, elastic modulus and hardness. Uses: mechanical engineering (friction parts, cogwheels, plastic bandages) automotive industry (engine covers, fans, complex gear, gas tanks, hubs, flexible lays, brake fluid reservoir), electrical industry, household appliances (fruit juicer, kitchen robots, cutlery handles), sport and tourism resources industry (ski boots, roller skates, tents, mountaineering cords, protection helmets, mechanisms of avoiding the derailment of the bicycle derailleur), shoe industry (shoe soles) [3].

One current issue regarding the injection processing of thermoplastic polymers is waste recovery. Waste includes the following: injection channels, incomplete parts, parts with burrs or other manufacturing defects [4,5]. 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.

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 polyamide 6.6 Grivory HTV-3H1 noir 9205, polyamide 6.6 Grivory HTV-45H1 noir 9205 and polyamide 6.6 Grivory HTV-6H1 noir 9205, used in the manufacturing of various technical items in different industries.

Experimental part

The following materials have been used in manufacturing the specimens: polyamide 6.6 Grivory HTV-3H1 noir 9205 (polyamide 6.6 armed with 30% glass fibres), polyamide 6.6 Grivory HTV-45H1 noir 9205 (polyamide 6.6 armed with 45% glass fibres) and polyamide 6.6 Grivory HTV-6H1 noir 9205 (polyamide 6.6 armed with 60% glass fibres), by using an ENGEL CC 100 Type ES 80/50 HL injection machine made in 1995 (fig.1).

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

* *email: maries.radu@rdslink.ro; Tel.: 0745825804*

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

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

The injection of polyamide 6.6 Grivory HTV-3H1 noir 9205 was carried out after the material was dried beforehand at 80°C for 4 h. It was carried out according to the following parameters: injection temperature of 330°C, mould temperature of 85°C. During the injection of the six samples the injection parameters remained constant.

The injection of polyamide 6.6 Grivory HTV-45H1 noir 9205 was carried out after the material was dried beforehand at 80°C for 4 h. It was carried out according to the following parameters: injection temperature of 340°C, mould temperature of 85°C. During the injection of the six samples the injection parameters remained constant.

The injection of polyamide 6.6 Grivory HTV-6H1 noir 9205 was carried out after the material was dried beforehand at 80°C for 4 hours. It was carried out according to the following parameters: injection temperature of 350°C, mould temperature of 85°C. 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.

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

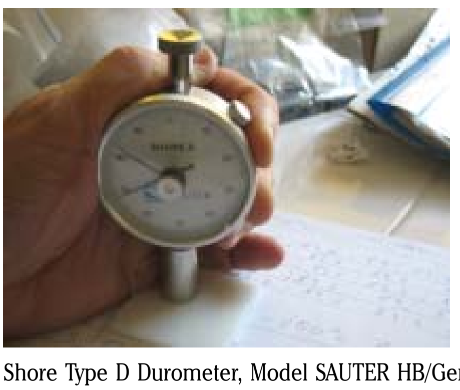

Fig.2. Shore Type D Durometer, Model SAUTER HB/Germany

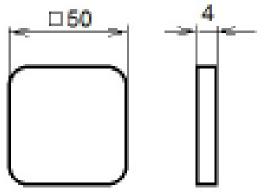

Fig.3. Specimen model for hardness test

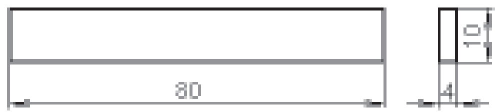

Fig.4. Specimen model for the Izod impact test

25 tests were performed on each sample, and the result is expressed as the arithmetic mean of the number of tests.

The Izod impact test

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

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).

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.

The Izod impact strength of unnotched specimens (a_{iU}) according to SR EN ISO 180 is calculated using 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 (mm);

b – the specimen width (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 Industriewerk, 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. Ten specimens were tested for each sample and the result was expressed as arithmetic mean.

Samples	Materials		
	POLYAMIDE 6.6 GRIVORY HTV-3H1 NOIR 9205	POLYAMIDE 6.6 GRIVORY HTV-45H1 NOIR 9205	POLYAMIDE 6.6 GRIVORY HTV-6H1 NOIR 9205
	Shore Type D hardness [N/mm²]	Shore Type D hardness [N/mm²]	Shore Type D hardness [N/mm²]
Sample 1	89.332	92.552	93.655
Sample 2	89.002	92.332	93.321
Sample 3	88.822	92. 220	93.011
Sample 4	88.434	91.480	92.803
Sample 5	88.100	91.204	92.582
Sample 6	87.923	90.891	92.160

Table 2
THE HARDNESS OF INJECTED POLYAMIDE 6.6 GRIVORY HTV-3H1 NOIR 9205, POLYAMIDE 6.6 GRIVORY HTV-45H1 NOIR 9205 AND POLYAMIDE 6.6 GRIVORY HTV-6H1 NOIR 9205 SAMPLES DEPENDING ON THE GRIND PERCENTAGE USED

Fig.6. WPM – VEB Thuringer Industriewerk, Ranenstein Gerat R 37, Typ 2092 tensile testing machine

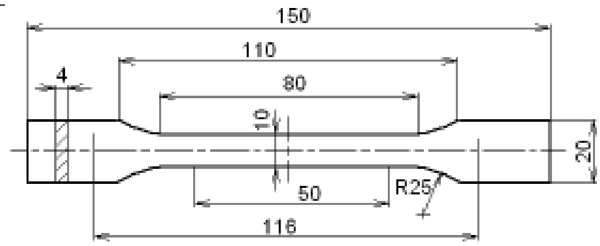

Fig.7. Specimen model for tensile strength at break testing

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

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

where:

F – the force [in N] measured at the break point of the specimen;

A – initial cross-sectional area [in mm^2] of the test-specimen.

Results and discussions

After testing samples of polyamide 6.6 Grivory HTV-3H1 noir 9205, polyamide 6.6 Grivory HTV-45H1 noir 9205 and polyamide 6.6 Grivory HTV-6H1 noir 9205 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 polyamide 6.6 Grivory HTV-3H1 noir 9205, an increase in grind percentage from 0% to 100% leads to a slight decrease in hardness from 89,332 to 87,923 N/mm^2. The same behaviour is displayed by polyamide 6.6 Grivory HTV-45H1 noir 9205. An increase in grind percentage from 0% to 100% leads to a slight decrease in hardness from 92,552 to 90,891 N/mm^2. In the case of polyamide 6.6 Grivory HTV-6H1 noir 9205, an increase in grind percentage from 0 to 100% leads to a slight decrease in hardness from 93,655 N/mm to 92,160 N/mm^2. In return one can observe that the increase in glass fibre percentage in the analyzed polymers leads to a slight increase in hardness.

After testing samples of polyamide 6.6 Grivory HTV-3H1 noir 9205, polyamide 6.6 Grivory HTV-45H1 noir 9205 and polyamide 6.6 Grivory HTV-6H1 noir 9205, 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 polyamide 6.6 Grivory HTV-3H1 noir 9205 is concerned the increase of the grind percentage leads to a slight decrease in the in the impact strength of the material for all six samples, namely from 33,500 kJ/m^2 recorded for Sample 1 to 28,300 kJ/m^2 recorded for Sample 6.

Where polyamide 6.6 Grivory HTV-45H1 noir 9205 is concerned the increase of the grind percentage leads to a slight decrease in the in the impact strength of the material for all six samples, namely from 42,475 kJ/m^2 recorded for Sample 1 to 34.000 kJ/m^2 recorded for Sample 6.

Where polyamide 6.6 Grivory HTV-6H1 noir 9205 is concerned the increase of the grind percentage leads to a slight decrease in the impact strength of the material for all six samples, namely from 40.750 kJ/m^2 recorded for Sample 1 to 32.500 kJ/m^2 recorded for Sample 6.

After tensile tests on samples of polyamide 6.6 Grivory HTV-3H1 noir 9205, polyamide 6.6 Grivory HTV-45H1 noir 9205 and polyamide 6.6 Grivory HTV-6H1 noir 9205, the following results for the tensile strength at break of the specimen (F) and for the shock resistance (σ) depending on the grind percentage used were obtained (table 4).

Where polyamide 6.6 HTV-3H1 noir 9205 is concerned the increase in the grind percentage from 0% to 100% leads to an increase in the tensile strength at break of the specimen, namely from 5305,20N to 6801,80N and in the shock resistance from 132,63 MPa to 170,04 MPa.

Table 3
IZOD IMPACT STRENGTH AND THE ENERGY ABSORBED AT THE BREAK POINT OF THE UNNOTCHED SPECIMENS FOR POLYAMIDE 6.6 GRIVORY HTV-3H1 NOIR 9205, POLYAMIDE 6.6 GRIVORY HTV-45H1 NOIR 9205 AND POLYAMIDE 6.6 GRIVORY HTV-6H1 NOIR 9205, DEPENDING ON THE GRIND PERCENTAGE USED

Samples	Materials					
	POLYAMIDE 6.6 GRIVORY HTV-3H1 NOIR 9205		POLYAMIDE 6.6 GRIVORY HTV-45H1 NOIR 9205		POLYAMIDE 6.6 GRIVORY HTV-6H1 NOIR 9205	
	E_c [J]	a_{iU} [kJ/m²]	E_c [J]	a_{iU} [kJ/m²]	E_c [J]	a_{iU} [kJ/m²]
Sample 1	1.340	33.500	1.699	42.475	1.630	40.750
Sample 2	1.329	33.225	1.620	40.500	1.598	39.950
Sample 3	1.280	32.000	1.580	39.500	1.566	39.150
Sample 4	1.253	31.325	1.541	38.525	1.510	37.750
Sample 5	1.219	30.475	1.478	36.950	1.357	33.925
Sample 6	1.132	28.300	1.360	34.000	1.300	32.500

Table 4
VARIATION OF TENSILE STRENGTH AT BREAK (F) AND SHOCK RESISTANCE (σ) FOR POLYAMIDE 6.6 GRIVORY HTV-3H1 NOIR 9205, POLYAMIDE 6.6 GRIVORY HTV-45H1 NOIR 9205 AND POLYAMIDE 6.6 GRIVORY HTV-6H1 NOIR 9205, DEPENDING ON THE GRIND PERCENTAGE USED

Samples	Materials					
	POLYAMIDE 6.6 GRIVORY HTV-3H1 NOIR 9205		POLYAMIDE 6.6 GRIVORY HTV-45H1 NOIR 9205		POLYAMIDE 6.6 GRIVORY HTV-6H1 NOIR 9205	
	F [N]	σ [MPa]	F [N]	σ [MPa]	F [N]	σ [MPa]
Sample 1	5305.20	132.63	6525.39	163.13	7215.07	180.37
Sample 2	5713.25	142.83	7021.29	175.53	7669.68	191.74
Sample 3	6019.00	150.47	7398.37	184.95	8182.90	204.57
Sample 4	6134.41	153.36	7515.32	187.88	8312.79	207.81
Sample 5	6341.72	158.54	7799.30	194.98	8612.88	215.32
Sample 6	6801.80	170.04	8166.50	204.16	8915.00	222.87

Where polyamide 6.6 HTV-45H1 noir 9205 is concerned the increase in the grind percentage from 0% to 100% leads to an increase in the tensile strength at break of the specimen, namely from 6525.39N to 8166.50N and in the shock resistance from 163.13 MPa to 204.16 MPa.

Where polyamide 6.6 HTV-45H1 noir 9205 is concerned the increase in the grind percentage from 0% to 100% leads to an increase in the tensile strength at break of the specimen, namely from 7215.07N to 8915.00N and in the shock resistance from 180.37 MPa to 222.87 MPa.

Conclusions

The modifications suffered by the mechanical properties of polyamide 6.6 HTV-3H1 noir 9205, polyamide 6.6 HTV-45H1 noir 9205 and polyamide 6.6 HTV-6H1 noir 9205, polyamides used in the manufacturing of various items in different industries, 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. It has been observed that the shock resistance decreases along with the increase in the grind percentage in the case of the three tested polymers. The measurements for the tensile strength at break for the three materials were conducted on a WPM – VEB Thuringer Industriewerk, Ranenstein gerat R 37, Typ 2092. In the case of the three tested polyamides, the tensile strength at break increases along with the increase in the grind percentage in the samples.

References

1. MARSAVINA L., CERNESCU A., LINUL E., SCURTU D., CHIRITA C., Mat. Plast., **47**, no. 1, 2010, p. 85.
2. ŞEREŞ I., Materiale termoplastice pentru injectare, tehnologie, încercări, Editura Imprimeriei de Vest, Oradea, 2002, p. 92-104.
3. MĂRIEŞ GH., R., E., Materiale plastice în designul de produs, Ed. Universităţii din Oradea, Oradea, 2008, p.62-71.
4. PICHON J., F., Injection des matieres plastiques, Dunod, Paris, 2001, p. 243-270.
5. CHIRA D., MĂRIEŞ GH., R., E., Mat. Plast., **49**, no 3, 2012, p. 204.
6. VODA M., BORDEASU I., MESMACQUE G., CHITAC V., TABARA I., Mat. Plast., **44**, no. 3, 2007, p. 254.
7. GHITA E., GILLICH G., R., BORDEASU I., VODA M., TROI C., Mat. Plast., **44**, no. 2, 2007, p. 158.
8. *** SR EN ISO 868:2003, Materiale plastice şi ebonită. Determinarea durităţii prin penetrare cu un durometru (duritate Shore).
9.*** SR EN ISO 180:2001, Materiale plastice. Determinarea proprietăţilor de şoc Izod.
10.*** SR EN ISO 527-1:2000, Materiale plastice. Determinarea proprietăţilor de tracţiune. Partea 1: Principii generale
11.*** SR EN ISO 527- 2:2000, Materiale plastice. Determinarea proprietăţilor de tracţiune. Partea 2: Condiţii de încercare a materialelor plastice pentru injecţie şi extrudare

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