The Influence of Processing Temperatures of (HDPE), (PMMA), (PC+ABS) on Some Mechanical Properties of Items Obtained Through Injection

GHEORGHE RADU EMIL MARIES*, DAN CHIRA, CONSTANTIN BUNGAU
University of Oradea, 1 Universitatii Str., Oradea, Romania

This paper presents the influence of processing temperatures of high-density polyethylene (HDPE), polymethyl methacrylate (PMMA), polycarbonate and acrylonitrile butadiene styrene blend (PC+ABS) on some mechanical properties when obtained through the injection of items from various industries. The HDPE samples were obtained at the following injection temperatures: 180, 190, 200, 210, and 220°C. The PMMA samples were obtained at the following injection temperatures: 220, 230, 240, 250, and 260°C, and PC+ABS samples were obtained at the following injection temperatures: 230, 240, 250, 260, and 270°C. Determining the mechanical properties was made using determining methods of tensile properties, of Izod impact test, and Shore Durometer hardness test. It was observed in the case of the three analyzed polymers that increasing the processing temperature hardly influences their respective hardness. The Izod shock resistance for the three analyzed polymers decreases along with the increase of the processing temperature by injection. The tensile strength at break is influenced by the processing temperature. The increase of the processing temperatures by injection in the case of the three analyzed polymers leads to the decrease of the tensile strength at break. The lowest values of the tensile strength at break occur at the highest processing temperatures.

Keywords: high density polyethylene (HDPE), polymethyl methacrylate (PMMA), acrylonitrile butadiene styrene polycarbonate blend (PC+ABS), tensile tests, Izod impact test, Shore Durometer hardness test

Packaging industry, automotive industry, electrotechnics and electronics industry, office equipment industry, household articles industry, household appliances industry, gaming and toys, etc. are some of the greatest consumers of plastics. The techno-polymers frequently used in the production of the technical items from various industries are: polyethylene, polypropylene, polycarbonates, polyamides, thermoplastic polyurethanes, polyoxy-methylenes, polymethyl methacrylate, cellulose acetate, polyvinyl chloride, acrylonitrile butadiene styrene, etc. The most frequently used processing technology for these polymers is injection. High-density polyethylene is characterised by low density, is easily processed by injection, is an excellent electrical insulator, has great resistance towards chemical agents, has great shock resistance, a insignificant water absorption and can be used in the manufacturing of items that come into contact with foodstuffs [1,2]. Usage: packaging industry (packing cases, foil trays, various types of shuttles, containers, recipients for detergents, plastic bottles, milk cans, barrels, plastic bags, packaging foils), automotive industry (various components of the fuel feed system for engines running on unleaded petrol or Diesel oil by which the risk of electrostatic discharges is reduced, various technical parts), household articles (bowls, cups, buckets, flower pots, washtubs, food boxes), electro-technical and electronics (various technical items), toys, medical items (hip prosthesis) [3], septic tanks [2].

Polymethyl methacrylate is an amorphous polymer with a remarkable transparency (92% light transmission) in the visible spectre from 380 to 780 nm [2,4]. At ambient temperature, it is a hard material, rigid, resistant to aging, to atmospheric agents, and it has a good dimensional stability. It is resistant to organic acids and diluted minerals and weak bases up to 60°C. It is struck by acetone, ethyl alcohol, liquid ammonia, petrol, jet fuel, chloroform, hydrocarbons, carbon tetrachloride, etc. It can be used in the manufacturing of products that come in contact with foodstuffs. Usage: automotive industry (car stops, retro-reflectors, dome lights, signalling lamp, dials for dashboards) [5], aeronautical industry, mobile phone displays, camera lenses, modern furniture, plates for windows, domes, office equipment (squares, rulers), household articles (cooker hoods, parts for household appliances), etc.

The polycarbonate and acrylonitrile butadiene styrene blend is amorphous, opaque, rigid and highly resistant to shock [6]. It is resistant to wear and tear, to breaking; it has a good dimensional stability in a broad range of temperatures, unlimited possibilities for colouring, easily mouldable by injection and a good electrical insulator. It is resistant to acids and weak bases. Usage: automotive industry (rear-view mirror, bumpers, dashboards, chassis for electrical and electro-technical ensembles, car racks, etc.) [7], household appliances (coffee filter parts, carcases for blow-dryers, mixers), office equipment (computer carcases, copy machine carcases, printer carcases), etc.

On processing by injection of polymer materials, the characteristics of the products are highly influenced by the material's temperature, by the pressure used by the flowing material in the mould and the mould temperature [6, 8-10]. In the past years there has been a series of studies with reference to the mechanical behaviour of different types of polymers in different conditions and usage [11-17].

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* *email: maries.radu@rdslink.ro*

This paper proposes to analyse the variation of some mechanical properties depending on the processing temperature by injection, using determining methods of tensile properties, of Izod impact test, and Shore Durometer hardness test, for the high-density polyethylene HDPE type CABELEC XS6114, for the polycarbonate and acrylonitrile butadiene styrene blend PC+ABS type CYCOLOY RESIN XCY620, and for the polymethyl methacrylate PMMA type PLEXIGLAS 8N CRYSTAL.

Experimental part

The following materials have been used in manufacturing the specimens: high-density polyethylene HDPE type CABELEC XS6114, polymethyl methacrylate PMMA type PLEXIGLAS 8N CRYSTAL, and polycarbonate and acrylonitrile butadiene styrene blend PC+ABS type CYCOLOY RESIN XCY620, using an injection machine, KRAUSS MAFFEI KM65-160C1, made in 2001 (fig.1).

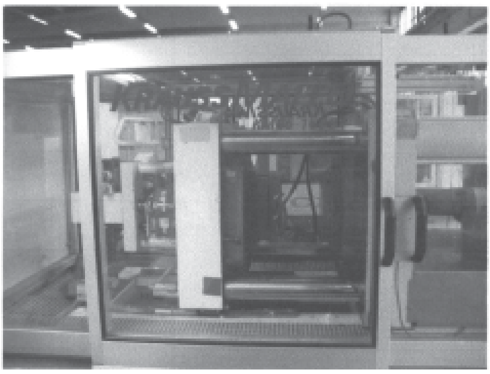

Fig.1. Injection machine KRAUSS MAFFEI KM65-160C1

Measuring the material's temperature in its liquid state was done with the help of thermo switches put on the plasticizing-injection cylinder. Samples of HDPE were obtained at the following injection temperatures: 180, 190, 200, 210, and 220°C. Samples of PMMA were obtained at the following injection temperatures: 220, 230, 240, 250, and 260°C, and samples of PC+ABS were obtained at the following injection temperatures: 230, 240, 250, 260, and 270°C.

During the injection of the HDPE, PMMA and PC+ABS specimens, all parameters that influence the cycles of injection were kept constant, altering only the processing temperatures. Injection of HDPE specimens was done by keeping the following injection parameters constant: subsequent pressure of 850 bar, mould temperature of 20°C, cooling time of 10 s, injection speed of 12 mm/s, and injection cycle of 44 s . Injection of PMMA specimens was done by keeping the following injection parameters constant: subsequent pressure of 450 bars, mould temperature of 70°C, cooling time of 12 s, injection speed of 30 mm/s, and injection cycle of 35.8 s. Injection of PC+ABS specimens was done by keeping the following injection parameters constant: subsequent pressure of 600 bars, mould temperature of 60°C, cooling time of 10 seconds, injection speed of 25 mm/s, and injection cycle of 30.8 s.

All injected specimens underwent the following types of mechanical determinations: determining hardness by penetration with a Shore Durometer, determining Izod shock properties on notched specimens in the case of HDPE and on unnotched specimens in the case of PMMA and PC+ABS, and determining tensile strength at break. All tests were done at room temperature, in the Department of High Quality of S.C. Plastor S.A, Oradea.

Determining hardness by penetration with a Shore type D Durometer

The testing of the injected specimens for the three materials was done by determining the hardness by penetration with Shore type D method, with a type D Durometer, SAUTER HB/Germany model (fig.2). The hardness of all specimens was determined by the method that allows the measurement of the initial penetration and by the instantaneous reading of the values shown by the device (the reading of the values on the device was done in maximum 1s after being pressed).

Fig. 2. Shore type D Durometer, SAUTER HB/ Germany model

Testing was done in accordance with European norms - SR EN ISO 868:2003 [18] - on specimen models with forms and sizes such as those in figure 3. For each specimen there was a number of 25 tests, and the result was expressed as the value of the arithmetic average of the total of tests.

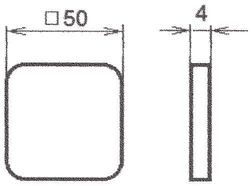

Fig. 3 Specimen model for hardness tests

Determining Izod shock properties

Determining Izod shock properties was done on unnotched specimens (fig.4) in the case of PMMA and PC+ABS and on notched specimens (fig.5) in the case of HDPE.

Testing was done in accordance with European norms - SR EN ISO 180 [19] - using a pendulum tester, PENDOLO P400 model, manufactured by HAMMEL, England (fig.6).

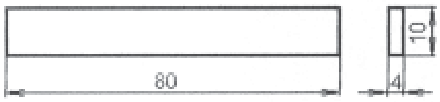

Fig.4 Unnotched specimen model for Izod shock properties testing

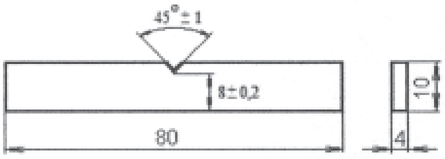

Fig.5 Notched specimen model for Izod shock properties testing

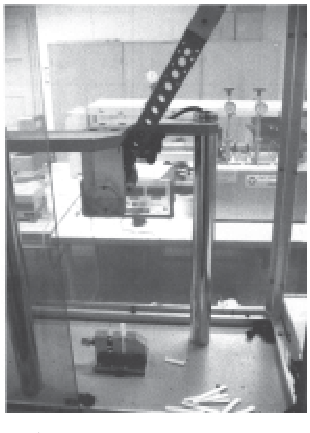

Fig. 6. Device for determining Izod shock properties, PENDOLO P400 model, HAMMEL/ England

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 notched and unnotched specimens (a_{iU}) is based on the following equation:

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

where

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

h – the specimen thickness (in mm)

b – the specimen width (in mm)

In the case of PENDOLO P400, its software 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 average.

Determining 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.7).

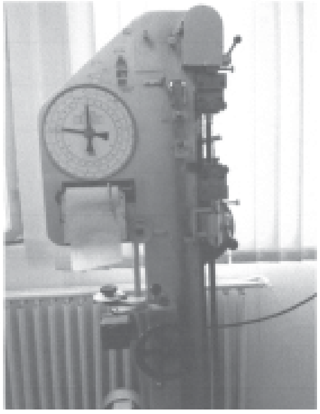

Fig. 7 WPM – VEB Thuringer Industriewerk, Ranenstein gerat R 37, Typ 2092 tensile testing machine

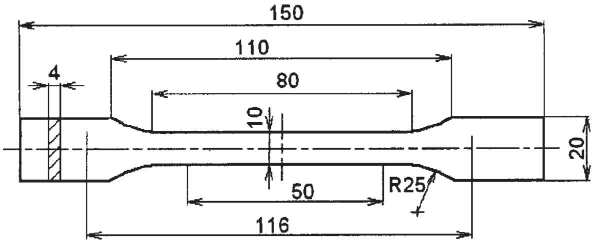

Fig. 8 Specimen model for tensile strength at break testing

Testing was done in accordance with the European Standard SR EN ISO 527-1:2000 [20] and SR EN ISO 527-2:2000 [21] on specimens such as those illustrated in figure 8.

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

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

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

where:

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

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

Results and discussions

After testing HDPE samples, the following results for hardness by penetration with a Shore type D Durometer were obtained (table 1).

Table 1

THE HARDNESS OF INJECTED SPECIMENS OF HDPE CABELEC XS6114 PROCESSED BY INJECTION DEPENDING ON THE PROCESSING TEMPERATURES

Processing temperature of HDPE CABELEC XS6114 [°C]	Shore type D hardness [N/mm²]
180	67.571
190	67.984
200	68.017
210	68.31
220	68.453

Table 2

THE HARDNESS OF INJECTED SPECIMENS OF PMMA PLEXIGLAS 8N CRYSTAL PROCESSED BY INJECTION DEPENDING ON THE PROCESSING TEMPERATURES

Processing temperature of PMMA PLEXIGLAS 8N CRYSTAL [°C]	Shore type D hardness [N/mm²]
220	94.609
230	94.625
240	94.625
250	94.734
260	94.390

It is observed that by increasing the processing temperature by injection of HDPE from 180 to 220°C leads to a slight increase in hardness. Maximum HDPE hardness is recorded at the temperature of 220° and it is 68.453 N/mm^2.

After testing PMMA samples, the following results for hardness by penetration with a Shore type D Durometer were obtained (table 2).

It is observed that by increasing the processing temperature by injection of PMMA from 220 to 250°C leads to a slight increase in hardness. Maximum PMMA hardness is recorded at the temperature of 250°C and it is 94.734 N/mm^2. Further increase of the processing temperature to 260°C leads to a decrease in hardness to 94.390 N/mm^2.

After testing PC+ABS samples, the following results for hardness by penetration with a Shore type D Durometer were obtained (table 3).

It is observed that by increasing the processing temperature by injection of PC+ABS from 230 to 250°C leads to a slight increase in hardness. Maximum PC+ABS hardness is recorded at the temperature of 250°C and it is 86.562 N/mm^2. Further increase of the processing temperature leads to a decrease in hardness. It can be observed that at the lowest processing temperatures (HDPE - 180°C, PMMA - 220°C, and PC+ABS - 230°C), when in the plasticizing-injection cylinder occurs mechanical wear and tear, in the case of the three tested polymers, the lowest hardness values are recorded. At the highest processing temperatures (HDPE - 220°C, PMMA - 260°C, and PC+ABS - 270°C) thermal wear and tear occurs in PMMA and PC+ABS, which leads to a decrease in hardness

Processing temperature of PC+ABS CYCOLOY RESIN XCY620 [°C]	Shore type D hardness [N/mm^2]
230	86.171
240	86.250
250	86.562
260	85.946
270	85.765

Table 3
THE HARDNESS OF INJECTED SPECIMENS OF PC+ABS CYCOLOY RESIN XCY620 PROCESSED BY INJECTION DEPENDING ON THE PROCESSING TEMPERATURES

Materials								
HDPE CABELEC XS6114			PMMA PLEXIGLAS 8N CRYSTAL			PC+ABS CYCOLOY RESIN XCY620		
Processing temperature [°C]	E_c [J]	a_{iU} [kJ/m^2]	Processing temperature [°C]	E_c [J]	a_{iU} [kJ/m^2]	Processing temperature [°C]	E_c [J]	a_{iU} [kJ/m^2]
180	1.158	36.187	220	0.590	14.750	230	2.700	67.500
190	1.050	32.812	230	0.571	14.275	240	2.627	65.675
200	0.826	25.812	240	0.557	13.925	250	2.550	63.750
210	0.728	22.750	250	0.557	13.925	260	2.505	62.625
220	0.720	22.500	260	0.557	13.925	270	2.436	60.900

Table 4
THE IZOD SHOCK RESISTANCE AND THE ENERGY ABSORBED AT SAMPLE BREAK FOR HDPE CABELEC XS6114, PMMA PLEXIGLAS 8N CRYSTAL AND PC+ABS CYCOLOY RESIN XCY620, DEPENDING ON THE PROCESSING TEMPERATURE

Materials					
HDPE CABELEC XS6114		PMMA PLEXIGLAS 8N CRYSTAL		PC+ABS CYCOLOY RESIN XCY620	
Processing temperature [°C]	F [N]	Processing temperature [°C]	F [N]	Processing temperature [°C]	F [N]
180	856	220	2452	230	2108
190	818	230	2432	240	2082
200	781	240	2408	250	2082
210	761	250	2400	260	2048
220	747	260	2396	270	2016

Table 5
VARIATION OF TENSILE STRENGTH AT BREAK (F) FOR HDPE CABELEC XS6114, PMMA PLEXIGLAS 8N CRYSTAL AND PC+ABS CYCOLOY RESIN XCY620, DEPENDING ON THE PROCESSING TEMPERATURE

of the two polymers. In the case of HDPE processed at 220°C, the hardness value is the highest, so at this temperature thermal wear and tear is hardly significant. After testing samples of HDPE, PMMA, and PC+ABS, the following results for the absorbed energy at the break point of the specimens (E_c) and for the Izod impact test on specimens (a_{iU}) were obtained (table 4).

In the case of HDPE, an increase in the processing temperature from 180 to 220°C leads to a decrease in the shock resistance from 36,187 kJ/m^2 to 22,500 kJ/m^2. In the case of PMMA, an increase in the processing temperature from 220 to 260°C leads to a decrease in the shock resistance from 14.750 kJ/m^2 to 13.925 kJ/m^2. In the case of PC+ABS, an increase in the processing temperature from 230 to 270°C leads to a decrease in the shock resistance from 67.500 kJ/m^2 to 60.900 kJ/m^2. After tensile tests on samples of HDPE, PMMA, and PC+ABS, the following results, which show the necessary force (F) for breaking the samples, were obtained (table 5).

In the case of HDPE, an increase in the processing temperature from 180 to 220°C leads to a decrease in the tensile strength needed to break the sample from 856 N to 747 N. In the case of PMMA, an increase in the processing temperature from 220 to 260°C leads to a decrease in the tensile strength needed to break the sample from 2452 N to 2396 N. It is the same for PC+ABS. An increase in the

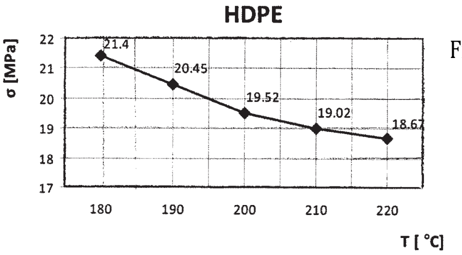

Fig. 9. HDPE tensile strength at break variation (σ) depending on the processing temperature

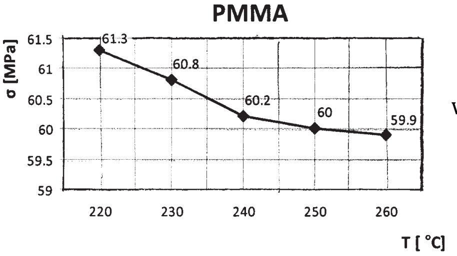

Fig. 10. PMMA tensile strength at break variation (σ) depending on the processing temperature

processing temperature from 230 to 270°C leads to a decrease in the tensile strength needed to break the sample from 2108 N to 2016 N.

Graphic representations of tensile strength at break variation (σ) depending on the processing temperature in the case of the three analysed polymers are shown in figures 9 - 11.

From the three graphic representations of the tensile strength at break variations (σ) depending on the processing temperature, we can conclude that the lowest values of the tensile resistance at break are recorded at highest processing temperatures, when in the polymers' mass that are processed by injection appear thermal wear and tear, which influence the resistance in tensile break.

Conclusions

Variations in the mechanical properties of high-density polyethylene HDPE CABELEC XS6114, polymethyl methacrylate PMMA PLEXIGLAS 8N CRYSTAL, and polycarbonate and acrylonitrile butadiene styrene blend PC+ABS CYCOLOY XCY620, polymers which are used in the manufacturing of various items in their respective industries, have been studied depending on the processing temperature and by injection. The HDPE samples were obtained at the following injection temperatures: 180, 190, 200, 210, and 220°C. The PMMA samples were obtained at the following injection temperatures: 220, 230, 240, 250, and 260°C, and PC+ABS samples were obtained at the following injection temperatures: 230, 240, 250, 260, and 270°C. The samples were injected with an injection machine - KRAUSS MAFFEI KM65-160C1.

After carrying out a Shore Type D hardness test, using a type D SAUTER HB/Germany Durometer, it was observed that the increase in the processing temperature by injection leads to an insignificant variation in hardness.

The Izod impact test was performed both on notched specimens, HDPE specimens, and on unnotched specimens, PMMA and PC+ABS. A pendulum impact tester, Model PENDOLO P400, manufactured by HAMMEL, England, was used. It has been observed in the case of the three tested polymers that the shock resistance decreases along with the increase in the processing temperature. Determining the resistance of the tensile strength at break for the three materials was done with a WPM – VEB Thuringer Industriewerk, Ranenstein gerat R 37, Typ 2092. The resistance of the tensile strength at break is influenced by the processing temperature. An increase in the processing temperatures by injection leads to a decrease in the resistance in tensile strength at break. The lowest values of the resistance of tensile strength at break are recorded at the highest processing temperatures.

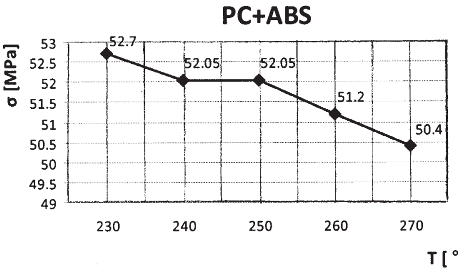

Fig. 11. PC+ABS tensile strength at break variation (σ) depending on the processing temperature

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