

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

DAN CHIRA, GHEORGHE RADU EMIL MARIES*, CONSTANTIN BUNGAU

University of Oradea, 1 Universitatii Str., 410087, Oradea, Romania

This paper presents the influence of subsequent pressure 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 subsequent pressure: 800 bar, 900 bar, 1000 bar, 1100 bar, and 1200 bar. The PMMA samples were obtained at the following subsequent pressure: 450 bar, 550 bar, 650 bar, 750 bar, and 850 bar, and PC+ABS samples were obtained at the following subsequent pressure: 500 bar, 600 bar, 700 bar, 800 bar, and 900 bar. 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 subsequent pressure when injecting HDPE leads to a slight increase of hardness, and in the case of PMMA and PC+ABS blend, an increase in the subsequent pressure leads to a decrease in hardness. The Izod shock resistance for HDPE and PMMA decreases along with the increase of the subsequent pressure. In the case of PC+ABS, an increase of the subsequent pressure from 500 bar to 700 bar leads to a decrease in the shock resistance from 68.675 kJ/m₂ to 51.475 kJ/m₂. A further increase in the subsequent pressure to 900 bar leads to an increase in the shock resistance up to 63.900 kJ/m₂. The tensile strength at break is influenced by the subsequent pressure. An increase in the subsequent pressure in case of HDPE and PC+ABS blend leads to an increase in the resistance of the tensile strength at break, whereas in the case of PMMA, an increase in the subsequent pressure leads to a decrease in the resistance of the tensile strength at break.

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, polyoxymethylenes, 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, carcasses for blow-dryers, mixers), office equipment (computer carcasses, copy machine carcasses, printer carcasses) etc.

Processing by injection is a process in which the molten polymer must flow in a closed, cold cavity of desired shape, which allows the material's solidification under pressure.

* email: maries.radu@rdslink.ro

The process is influenced by many parameters. The main factors that determine the forming process of thermoplastic materials are: physical, chemical, and flowing properties in the conditions specific to the process of injection, set temperatures, set pressures, and time needed for their formation [6,8-11]. Melting the thermoplastic material is done by transmitting heat from the barrel's wall to the material and by the transformation through friction of the mechanical energy into thermal energy [11]. The pressure done by the reciprocating screw transports the plastic in liquid form from the barrel, through the nozzle and the mould channels until it fills the mould cavity. The pressure from the mould reaches maximum values at the end of its course and depends on the force done by the reciprocating screw, polymer's viscosity and the course's hydraulic resistance. In injection moulding the following types of pressures are defined: external pressure, inner pressure, subsequent pressure, sealing pressure and remanent inner pressure [8,12,13]. In the recent years there has been a series of studies regarding the mechanical behaviour of different types of polymers in different conditions and usage [14-20].

This paper proposes to analyse the variation of some mechanical properties depending on the subsequent pressure of injection, using determining methods of tensile properties, of Izod impact test, and Shore Durometer hardness test, for the high-density polyethylene HDPE type CABELEK 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 CABELEK 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

The HDPE samples were obtained at the following subsequent pressure: 800 bar, 900 bar, 1000 bar, 1100 bar, and 1200 bar. The PMMA samples were obtained at the following subsequent pressure: 450 bar, 550 bar, 650 bar, 750 bar, and 850 bar. and PC+ABS samples were obtained at the following subsequent pressure: 500 bar, 600 bar, 700 bar, 800 bar, and 900 bar.

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 subsequent pressure.

Injection of HDPE specimens was done by keeping the following injection parameters constant: injection temperature 220°C, 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: injection temperature 260°C, 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: injection temperature 270°C, mould temperature of 60°C, cooling time of 10 s, 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).

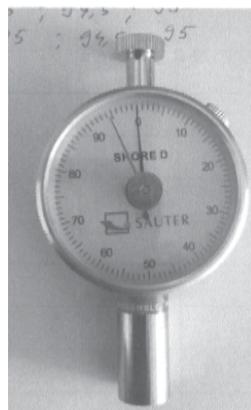


Fig. 2. Shore type D Durometer, SAUTER HB/Germany model

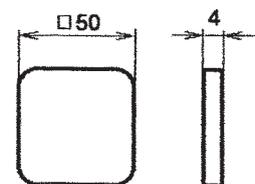


Fig. 3 Specimen model for hardness tests

Testing was done in accordance with European norms - SR EN ISO 868:2003 [21] - 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.

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.

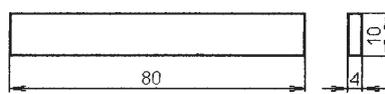


Fig.4 Unnotched specimen model for Izod shock properties testing

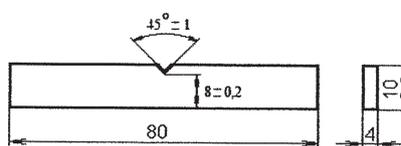


Fig.5 Notched specimen model for Izod shock properties testing



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

Testing was done in accordance with European norms - SR EN ISO 180 [22] - using a pendulum tester, PENDOLO P400 model, manufactured by HAMMEL, England (fig.6).

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:

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

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).

Testing was done in accordance with the European Standard SR EN ISO 527-1:2000 [23] and SR EN ISO 527-2:2000 [24] 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.

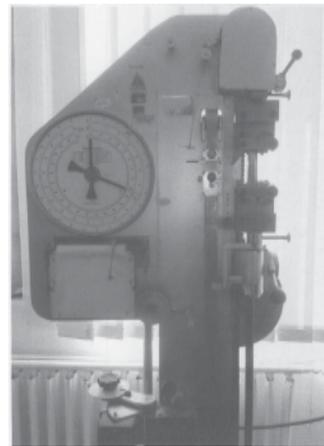


Fig. 7 WPM – VEB Thuringer Industriewerk, Ranenstein gerat R 37, Typ 2092 tensile testing machine

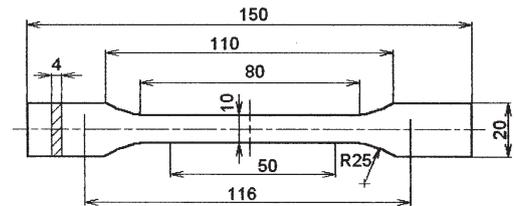


Fig. 8 Specimen model for tensile strength at break testing

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

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

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

It is observed that by increasing the subsequent pressure by injection of HDPE from 800 bar to 1200 bar leads to a slight increase in hardness. Maximum HDPE hardness is recorded at the subsequent pressure of 1200 and it is 68.421 N/mm².

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 subsequent pressure by injection of PMMA from 450 bar to 850 bar leads to a slight decrease in hardness. Minimum PMMA hardness is

Table 1

THE HARDNESS OF INJECTED SPECIMENS OF HDPE CABELECS6114 PROCESSED BY INJECTION DEPENDING ON THE SUBSEQUENT PRESSURE

Subsequent pressure of HDPE CABELECS6114 [bar]	Shore type D hardness [N/mm ²]
800	68.015
900	68.107
1000	68.125
1100	68.194
1200	68.421

Table 2

THE HARDNESS OF INJECTED SPECIMENS OF PMMA PLEXIGLAS 8N CRYSTAL PROCESSED BY INJECTION DEPENDING ON THE SUBSEQUENT PRESSURE

Subsequent pressure of PMMA PLEXIGLAS 8N CRYSTAL [bar]	Shore type D hardness [N/mm ²]
450	94.390
550	94.203
650	94.031
750	93.906
850	93.906

Subsequent pressure of PC+ABS CYCOLOY RESIN XCY620 [bar]	Shore type D hardness [N/mm ²]
500	85.912
600	85.765
700	85.500
800	85.406
900	85.210

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

Materials								
HDPE CABELEC XS6114			PMMA PLEXIGLAS 8N CRYSTAL			PC+ABS CYCOLOY RESIN XCY620		
Subsequent pressure [bar]	E_c [J]	a_{iw} [kJ/m ²]	Subsequent pressure [bar]	E_c [J]	a_{iw} [kJ/m ²]	Subsequent pressure [bar]	E_c [J]	a_{iw} [kJ/m ²]
800	1.085	33.906	450	0.557	13.925	500	2.747	68.675
900	1.000	31.250	550	0.551	13.775	600	2.436	60.900
1000	0.860	26.875	650	0.524	13.100	700	2.059	51.475
1100	0.851	26.593	750	0.510	12.750	800	2.228	55.700
1200	0.811	25.343	850	0.424	10.600	900	2.556	63.900

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 SUBSEQUENT
PRESSURE

recorded at the subsequent pressure of 750 bar and 850 bar, and it is 93.906 N/mm².

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 subsequent pressure by injection of PC+ABS from 500 bar to 900 bar leads to a decrease in hardness from 85.912 N/mm² to 85.210 N/mm². It can be observed that by increasing the subsequent pressure in injection of HDPE, it leads to a slight increase in hardness, and in the case of PMMA and PC+ABS blend, an increase in the subsequent pressure leads to a decrease in hardness. 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_{iw}) were obtained (table 4).

In the case of HDPE, an increase in the subsequent pressure from 800 bar to 1200 bar leads to a decrease in the shock resistance from 33.906 kJ/m² to 25.343 kJ/m². In the case of PMMA, an increase in the subsequent pressure from 450 bar to 850 bar leads to a decrease in the shock resistance from 13.925 kJ/m² to 10.600 kJ/m². In the case of PC+ABS, an increase in the subsequent pressure from 500 bar to 700 bar leads to a decrease in the shock resistance from 68.675 kJ/m² to 51.475 kJ/m². 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).

Materials					
HDPE CABELEC XS6114		PMMA PLEXIGLAS 8N CRYSTAL		PC+ABS CYCOLOY RESIN XCY620	
Subsequent pressure [bar]	F [N]	Subsequent pressure [bar]	F [N]	Subsequent pressure [bar]	F [N]
800	748	450	2396	500	2016
900	760	550	2248	600	2016
1000	760	650	1864	700	2032
1100	784	750	1850	800	2038
1200	784	850	1837	900	2040

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 SUBSEQUENT
PRESSURE

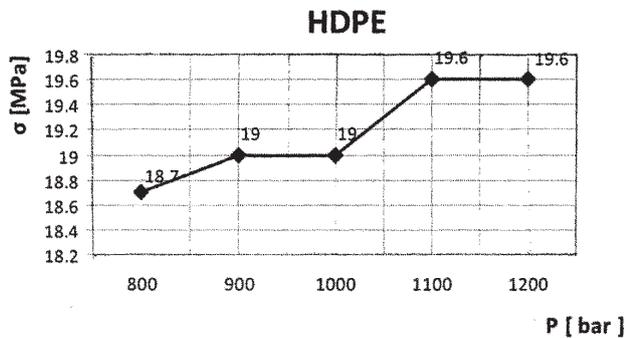


Fig. 9. HDPE tensile strength at break variation (σ) depending on the subsequent pressure

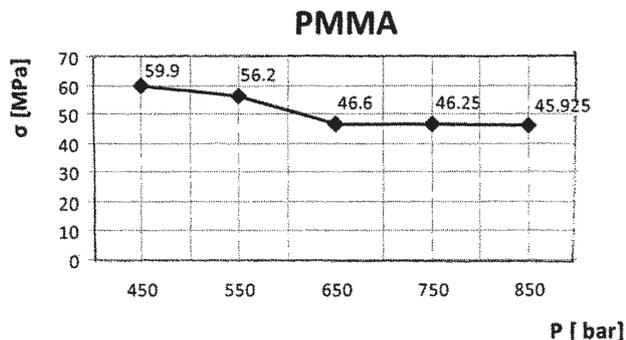


Fig. 10. PMMA tensile strength at break variation (σ) depending on the subsequent pressure

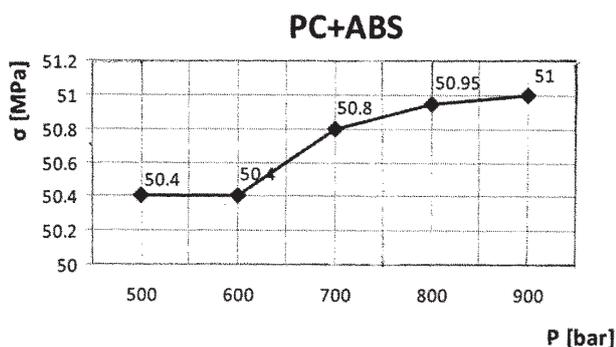


Fig. 11. PC+ABS tensile strength at break variation (σ) depending on the subsequent pressure

In the case of HDPE, an increase in the subsequent pressure from 800 bar to 1200 bar leads to an increase in the tensile strength needed to break the sample from 748 N to 784 N. It is the same for PC+ABS. An increase in the subsequent pressure from 500 bar to 900 bar leads to an increase in the tensile strength needed to break the sample from 2016 N to 2040 N. In the case of PMMA, an increase in the subsequent pressure from 450 bar to 850 bar leads to a decrease in the tensile strength needed to break the sample from 2396 N to 1837 N.

Graphic representations of tensile strength at break variation (σ) depending on the subsequent pressure 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 subsequent pressure, we can conclude that the increase of subsequent pressure in case of HDPE and PC+ABS leads to an increase of tensile strength at break, whereas in the case of PMMA, an increase in the subsequent pressure leads to a decrease of tensile strength at 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 subsequent pressure and by injection. The HDPE samples were obtained at the following subsequent pressure: 800 bar, 900 bar, 1000 bar, 1100 bar, and 1200 bar. The PMMA samples were obtained at the following subsequent pressure: 450 bar, 550 bar, 650 bar, 750 bar, and 850 bar, and PC+ABS samples were obtained at the following subsequent pressure: 500 bar, 600 bar, 700 bar, 800 bar, and 900 bar. 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 subsequent pressure by injection leads to slight increase of hardness in the case of HDPE, whereas in the cases of PMMA and PC+ABS blend, an increase in the subsequent pressure leads to a decrease 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 that the shock resistance decreases along with the increase in the subsequent pressure in the case of HDPE and PMMA. In the case of PC+ABS, the increase of the subsequent pressure from 500 bar to 700 bar leads to the decrease of shock resistance from 68.675 kJ/m² to 51.475 kJ/m². Further increase of the subsequent pressure up to 900 bar leads to the increase of shock resistance up to 63.900 kJ/m². 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 subsequent pressure. An increase in the subsequent pressure in the case of HDPE and PC+ABS blend leads to an increase in the resistance of tensile strength at break, whereas in the case of PMMA, an increase in the subsequent pressure leads to the decrease of the resistance of tensile strength at break.

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