Injection Temperature Effects on the Properties of High Density Polyethylene Crates

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ABSTRACT:

This study was undertaken to provide more insight on the optimum injection temperature used for the production of PE crates, thereby saving time and money, and improving part quality. The work included processing trails of HDPE crates in an injection molding machine at five temperatures ranged from 220 to 300°C. Both Rheological and mechanical characterization was conducted in order to understand the effect of injection temperature on the properties of crates. Oven aging was also applied for (4 weeks) to evaluate the long-term thermal stability. The results revealed that producing the crates at a temperature range of (260-280 °C) gives the best rheological and mechanical result. The lowest drop in thermal stability has been observed for the crates produced at this temperature range.

KEYWORDS: Injection molding temperature, High density polyethylene; thermo-oxidative degradation, cross-linking.

تأثير درجة حرارة الحقن على خواص صناديق التعبئة المصنعة من مادة متعدد الاثلين العال الكثافة

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خلاصة

تم اجراء هذا البحث لغرض توفير معرفة لدرجة حرارة الحقن الامثل المستعملة لانتاج صناديق البولي اثلين، وبالتالي توفير الوقت والمال وتحسين نوعية المنتج.

تضمن العمل انتاج الصناديق باستعمال البولي اثلين عالي الكثافة بماكنة قولبة وحقن باستعمال خمس درجات حرارة تتراوح من 220 الى 300 درجة سلليزية .وتم قياس الخواص الميكانيكية وخواص السيولة لغرض فهم ودراسة تاثير درجات حرارة الحقن المختلفة على مواصفات الصناديق المختلفة. بالاضافة الى تعريض الصناديق الى عملية تقادم حراري في فرن ولمدة 4 اسابيع لتحديد الثبوتية الحرارية لها على المدى الطويل. افرزت النتائج ان انتاج الصناديق بالمدى 260- 280 درجة سلليزية تعطي احسن الخواص الميكانيكية وخواص السيولة ، وكذلك فان الصناديق المنتجة في هذا المدى ابدت اقل نسبة تدهور في الثبات الحراري عند فحص التقادم.

1. INTRODUCTION

Injection molding is a cost-effective way to produce complex, three dimensional shapes at high volumes (Pasquini, 2005). In the injection moulding process, the injected polymer flows through the sprue, runners and gate to the cavity. The melt flow in mold runners can be controlled by the processing conditions in order to obtain the molded parts with expected morphology, properties, shape, dimensions and surface (Bociaga et al, 2007). In the plastics industry, injection molding makes up approximately 32 wt. % of all plastic processing methods, second only to extrusion 36 wt. % (Rosato, 2000).

The quality of the surface finish, dimensional stability and mechanical properties are all determined by the microstructure, which can vary by orders of magnitude depending on processing conditions such as melt and mold temperatures, mold geometry, injection speed, packing and cooling hold times and pressures (Katti et al, 1982, Wenig et al, 1993 and Larpsuriyakul, 2007).

Optimum melt temperature is the key to successful molding because one basic requirement on an automatic injection molding process is that the molded parts must be ejected automatically without the need for secondary finishing operations (Cermak et al. 2006 and Vorgelegt, 2009). An exact control on thermal energy transmission to the injected polymeric material is important factor to prevent burning and chemical disintegration of polymer (Pickett 2001 and Beaumont et al, 2002).

High density polyethylene one of the most widely used commodity plastics, is used to produce a wide range of plastic containers. This is due to the advantageous properties of HDPE in various areas. Plastic crates used for bottle transportation is one of the major products manufactured from HDPE.

During processing, the combination of high temperature and shear forces can lead to complex events like chain scission, crosslinking and molecular enlargement which can either improve physical/mechanical properties or lead to degradation (Johnston et al, 1996 and Bernardo et al, 1996). Under most conditions due to thermo - oxidative degradation, chain branching and cross-linking predominates with HDPE, leads to an increase in molecular weight in a polymer, but under certain extreme conditions chain scission is more likely to occur (Vasile, 1993).

Hinsken et al, (1991) showed that the presence of small amounts of dissolved O_2, always present in polyethylene exposed to air, causes scissioning under severe conditions. A study of the effect of processing conditions on the degradation of high density polyethylene was carried out by Dontula et al. (1993). At processing temperatures above 300°C, they found that the viscosity response of HDPE was complex with respect to extrusion conditions. Rideal and Padget (1976) also noted that melt temperatures over 290°C caused a decrease in melt viscosity.

Since the properties of plastic materials are affected by the processing conditions, it would be interesting to characterize them as a function of changing the injection temperature (Osswald et al, 2001 and Billingham, 2007).

The long-term thermal stability of polymers can be determined by means of oven aging tests at relatively elevated temperatures. This technique much more closely resembles conditions encountered by the plastics in use than other thermal analysis techniques (Gugumus 1985).

Scott (1990) mentioned that heat aging results in a gradual increase of the crystalline content. This could be correlated with an annealing effect, which leads to a molecular reorientation of the polymer crystals, and it is also accompanied by crystal growth.

Reducing the injection temperature saves energy and can reduce cycle times and so an understanding to the temperature dependence of melt viscosity is very useful. This study was undertaken to find the optimum melt temperature range in injection molding machines used for the production of PE crates used for bottle

transportation intended for outdoor use. The aim of this research is to focus on the processability through rheological properties, the mechanical properties and long term thermal stability of the crate material.

2. EXPERIMENTAL

2.1 Materials

HDPE pellets (injection molding grade) were supplied by a local plastic factory included in Zahfaraniah's Soft Drinks Company in Baghdad; with the following properties:

Melt flow index	15-20 g/10 minute
Softening point	125-133°C
Shore hardness	67-70 D
Tensile strength	30MPa
Elongation at break	>500%
Processing temperature	200-300°C

2.2Injection moulding: Injection moulding machine was used for polymer processing inside the same factory. The injection pressure and holding time were 120 MPa and 62 second, respectively. The average cooling time was 14 minutes; the rotational screw speed was 90 rpm.

The barrel temperature was raised from 220°C to reach 300°C in a constant interval. Crate production continued for one whole hour at each temperature, in order to reach the steady state and samples were taken (10 crates for each temperature) to be examined.

2.3 Oven Aging

For the determination of the long term thermal stability of the crate material, specimens of all different grades were subjected to accelerated aging in a circulating air oven, from Atlas Co. The oven temperature was set at 110 °C.

2.4 Characterization Methods:

The characterization of the samples can be classified into two main groups:

1-Rheological tests: These tests can indicate the changes that may happen to the chemical structure during the production and usage. They were tested by:

Melt flow index (MFI): The melt flow index, which is in essence a single point viscosity, is used to guide the selection of a resin for certain applications. (MFI) determination was carried out using a CEAST's Flow Test Apparatus; Model 3/80 in accordance with ASTM D 1238 procedures. An applied load of 2.16 kg load was used at a barrel temperature of 220°C with a die of internal diameter 2.095 mm. The basic principle employed in the melt flow index test is that of determining the rate of molten polymer through a closely defined extrusion plastometer.

Flow properties: were detected using a high pressure capillary rheometer, type Rheoscope 1000-CEAST; having a flat entry capillary tube with L/D ratio of 40. Flow properties were conducted at 190°C.

2-MECHANICAL TESTS:

The mechanical properties were specified by measuring the tensile and tensile impact properties.

Tensile properties: These provide a means to characterize the mechanical properties of a polymer in terms of modulus, strength and elongation to failure which in turn depend on the entanglement between molecules. Specimens for mechanical testing were cut out and then tested according ASTM D-638 for tensile properties. A Zwick testing machine was used to perform the tensile strength test at a crosshead speed of 50 mm/min, and each test was performed until tensile failure occurred. Elongation both at yield and break and were also measured (ASTM 1989).

Tensile impact: Impact tests measure the energy required for a sample to fail under different loading histories. This test was performed according to (ASTM D1822). A tensile-impact test with un-notched specimens is a uniaxial tensile test with a high deformation speed. The pendulum device has a working capacity of 7.5 J, at maximum falling angle (150°C). For the test, a specimen was fixed between a stationary clamp and a cross head. The pendulums hammer hit the cross head which is fixed to the specimen. In this way, the specimen is

deformed in the direction of its longitudinal axis until fracture occurs.

3. RESULTS AND DISCUSSION

Flow of the plastic in the mold is quite important to ensure adequate fill to avoid short shots as well as voids. **Fig. 1** shows the melt flow index of HDPE crates as a function of injection temperature. From this figure it is clear that there is a decrease in MFI from 16.813 at 220°C to 15.351 at 260°C. That decrease means that the viscosity of resins is high, because there is an inverse proportional relation between and viscosity. Since the melt flow index indicates the alterations in molecular mass of the polymer, this behavior can be attributed of being this temperature range was not high enough for injection, so the melt do not flow easily. While, with processing temperatures above 260 °C there was an increase in MFI. The same observation was noted by Rideal and Padget, (1976).

Because processing conditions cover a wide range of shear rates, tests that can simulate both temperature and shear rate conditions like capillary rheometer are more useful in predicting flow properties. The influence of injection temperature on the PE crates viscosity melt was studied by rheological tools.

By noticing **table 1** and **Fig.2** that demonstrate the viscosity of crates produced at different temperatures, it can be seen that there were no changes in viscosity with processing temperature at low shear rates. While, at high shear rates showed a slight increase in its shear viscosity. It may be concluded that the variation in injection temperature at this range of temperature did not affect the molecular structure of HDPE crates (Pickett J.E., 2001).

The effect of injection temperature on crates mechanical properties was also obtained. For tensile strength at yield it can be seen in **Fig.3** that there was an obvious increase when raising the injection temperature from 220°C to reach a maximum value, to be 29.6 MPa at 260°C. After that, there was a pronounced decrease to reach 28.9 MPa at 300°C. This may be due to chain scissioning occurring with processing temperatures above 260°C.

Fig.4 demonstrates the elastic modulus of crates with injection temperatures increasing from 220 to 300°C. It is well known that this modulus is an important design parameter used for computing crates elastic deflections. It was noticed that practically the maximum yield modulus was obtained at 280°C, where it reached 38.6 MPa at this temperature. Since the magnitude of the modulus is a measure of the resistance to separation of adjacent atoms, it can be concluded from that this processing temperature the interatomic bonding forces are high.

The experimental results for elongation at yield are shown in **Fig. 5**. It can be seen that the maximum point for elongation at yield was reached at 260°C followed by a slightly decrease to reach 81% at 300°C.

Elongation at break of HDPE crates at various injection temperatures is shown in **Fig. 6.** It was noticed that there was a gradual increase followed by an obvious decrease at 300°C. This may be due to the entanglement between molecules.

Fig. 7 shows the impact resistance of the crates produced at different injection temperature. It is important to mention, that all data, at different injection temperatures, indicated the same trend. it can be seen that there was an increase by 26.5% with increasing injection temperatures from 220 to 300°C.

Oven aging was applied to study thermo-oxidation effects on HDPE bottle crates produced at 5 different temperatures.

After aging the crates injected at different temperatures, a remarkable improvement of the tensile strength at yield was observed, especially after the second week of heat aging, caused probably by the crystallinity increasing. On the other hand, the crosslinking increased during further aging, yielding a decrease in the tensile strength.

For the crates produced at 260, 280, 300°C the tensile strength was lower than the new ones by 10, 3, and 7%, respectively, as shown in **Fig. 8**. This means that the crates produced at 280°C showed the best durability and stability

towards heat effect, because tensile tests measure the bulk property of the material that results from crystallinity, lamella thickness and crystal size [Suwanprateeb, 2004].

Fig. 9 illustrates the effect of heat aging on the elastic modulus for the crates injected at five temperatures. This modulus may be thought of as stiffness, or a material's resistance to elastic deformation. It can be noticed that there is a trend of a small decrease after four weeks of heat exposure. For the crates produced at 260, 280, 300°C the elastic modulus was lower than the not exposed crates by 15, 12, and 20%, respectively. This can be again correlated to thermo-oxidative effects, occurring during heat aging leading to crosslinking phenomena between the polymer chains. Luzuriaga et al. (2006) observed a crystallinity increase in oven-aged HDPE plates and indicate that scission prevails over cross-linking.

As can be seen in **Fig. 10**, oven-aging has a negative effect on elongation at yield. This deterioration may be caused by the changes in the polymer molecular weight due to chain scission and thus molecular weight reduction.

On the other hand, oven aged samples prepared for testing the changes in elongation at break with increasing the oven-aging period failed after approximately three weeks. This may be a consequence of the chain breaking in the backbone of polymer matrix.

This is in agreement with literature findings, where it was reported that the failure of the mechanical properties of polyethylene in the course of heat aging is associated with crack formation on the surface and subsequent crack propagation (Zweifel, 1998). Mendes et al (2003) indicated that oxidative degradation causes significant reduction of molecular weight which is reflected in a drop of around 50% in impact resistance and elongation at break.

Fig. 11 presents the effect of heat aging on the tensile impact strength of the crates produced in different injection temperatures. Annealing may be the explanation for the tensile impact strength improvement at the very early stages of the aging procedure. On the other hand, as aging further increases, the tensile impact strength starts to decrease rapidly, owing to thermo-oxidative degradation occurring in the polymer chains, resulting brittleness (Bociaga E., Jaruga T., 2007).

This result coincides with (Incarnato et al, 1999) who noticed that aging PE improves the tensile impact strength of the polymer whilst other properties such as tensile strength and elongation at break, all decrease. Luzuriaga et al. (2006) stated that crystallinity increase also contributed to a drop in original impact strength HDPE plates prepared from oven-aged granules.

4. CONCLUSIONS:

The results of the study produced the following main conclusions:

From comparing the properties of the crates produced at 5 injection temperatures it can be concluded that at the temperature 280°C the elastic modulus and elongation at break, was the best. While those produced at 260°C showed best melt flow index, tensile strength, elongation at yield and tensile impact.

The maximum yield modulus for crates was obtained at 280°C, denoting that the interatomic bonding forces are high at this injection temperature.

From the flow curves of crates at different injection temperature, it may be concluded that the variation in injection temperature in this range do not affect the molecular structure of HDPE, at low shear rates.

Oven-aging has a negative effect on tensile strength, elastic modulus and elongation both at yield and break caused by the influence of changes in the polymer molecular weight due to chain scission. From another hand impact strength improved at early stages of the aging followed by rapid decreasing.

During oven aging, it was noticed that the crates produced at 280°C showed the least variance of deterioration in mechanical properties, which means it have best durability and stability towards heat effect.

The properties of HDPE crates after 4 weeks of thermal aging was generally worse than those with no heat exposure,

particularly the elongation at break, possibly due to thermo-oxidative degradation occurring in the polymer chains.

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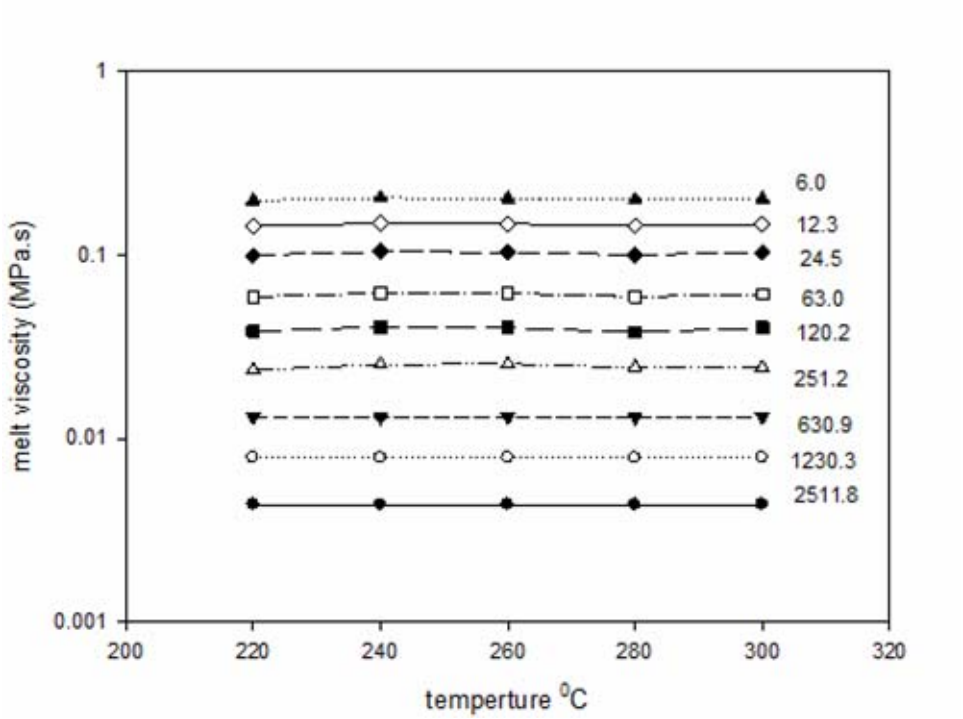

Fig. 1 Melt flow index of HDPE crates as a function of injection temperatures.

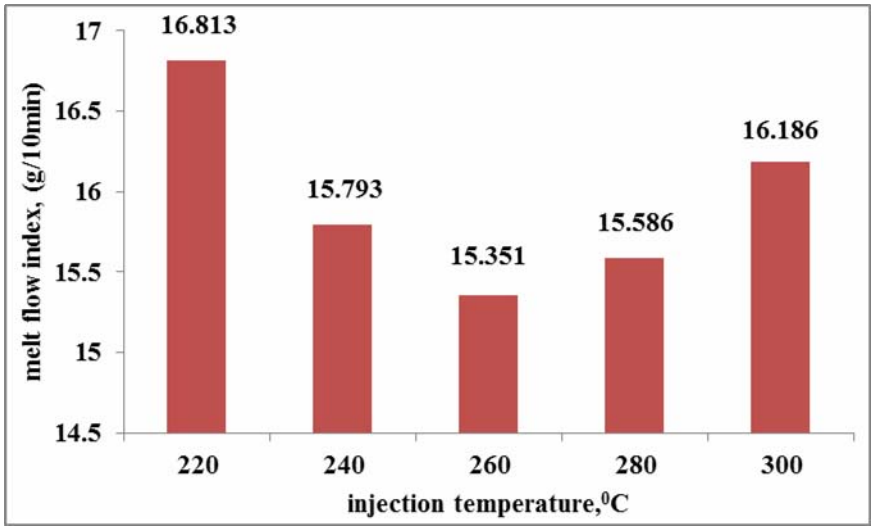

Fig. 2 Melt viscosity of HDPE crates at various injection temperatures and shear rates.

Table 1 Viscosity of crates produced at different injection temperatures and shear rates.

Shear rate(1/s)	220°C	240°C	260°C	280°C	300°C
6.02	0.00436	0.00436	0.00436	0.00436	0.00436
12.3	0.00784	0.0079	0.0079	0.0079	0.0079
24.54	0.01309	0.0131	0.0131	0.0131	0.0131
63.09	0.0236	0.0253	0.0255	0.0244	0.0244
120.22	0.0384	0.0406	0.0402	0.0379	0.0401
251.19	0.0593	0.0619	0.0619	0.0593	0.06108
630.96	0.0999	0.1042	0.1035	0.1003	0.1029
1230.27	0.1439	0.1492	0.1484	0.1444	0.1475
2511.89	0.1982	0.2051	0.2032	0.1995	0.2033

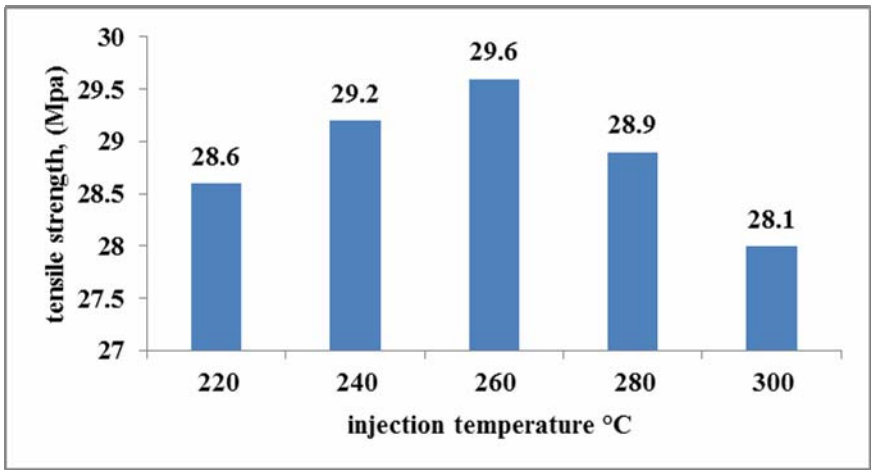

Fig. 3 Tensile strength of HDPE crates as a function of injection temperatures.

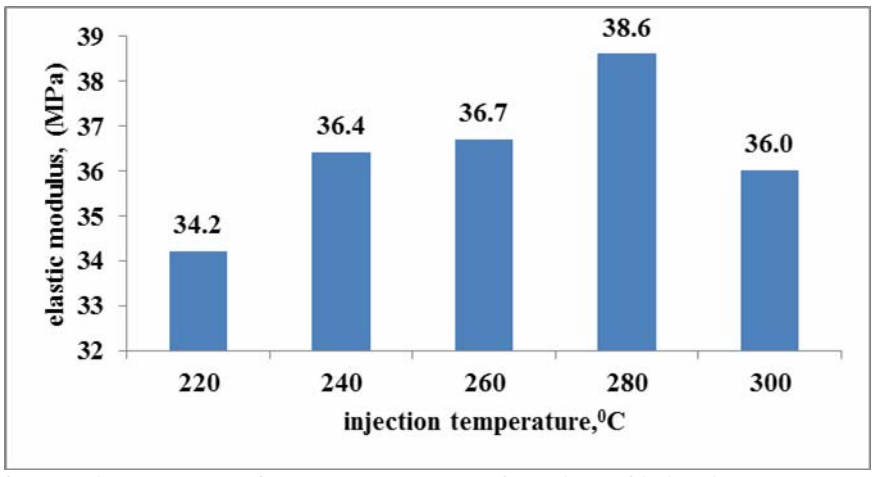

Fig. 4 Elastic modulus of HDPE crates as a function of injection temperatures.

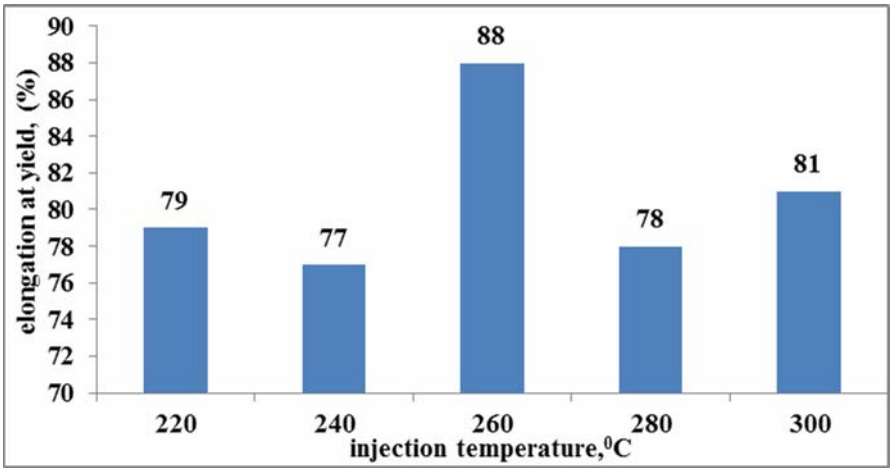

Fig. 5 Elongation at yield of HDPE crates as a function of injection temperatures.

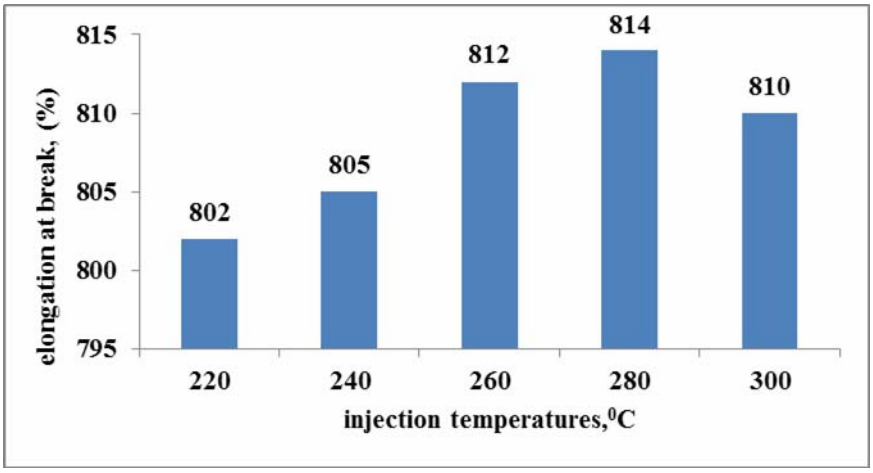

Fig. 6 Elongation at break of HDPE crates as a function of injection temperatures.

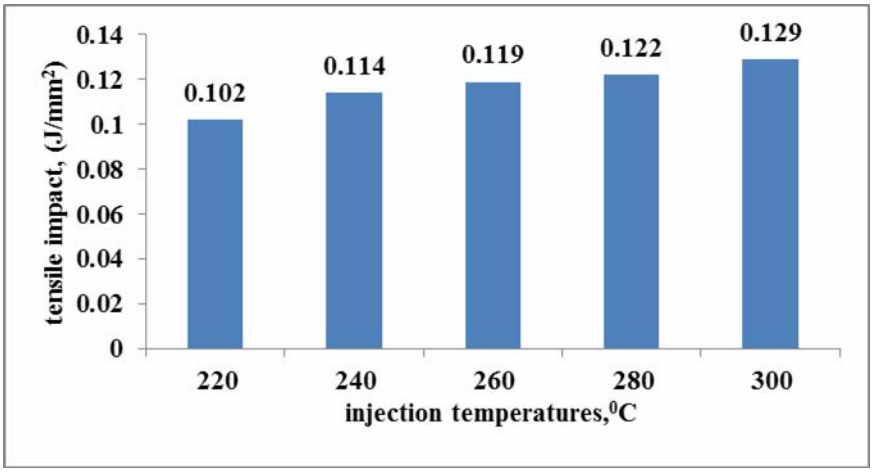

Fig. 7 Impact strength of HDPE crates as a function of injection temperatures.

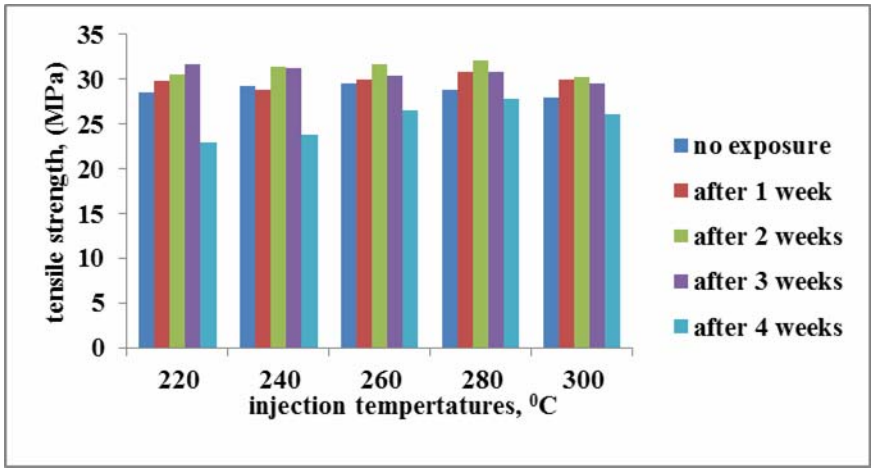

Fig. 8 Changes in crates tensile strength with increasing oven-aging exposure time at 110°C.

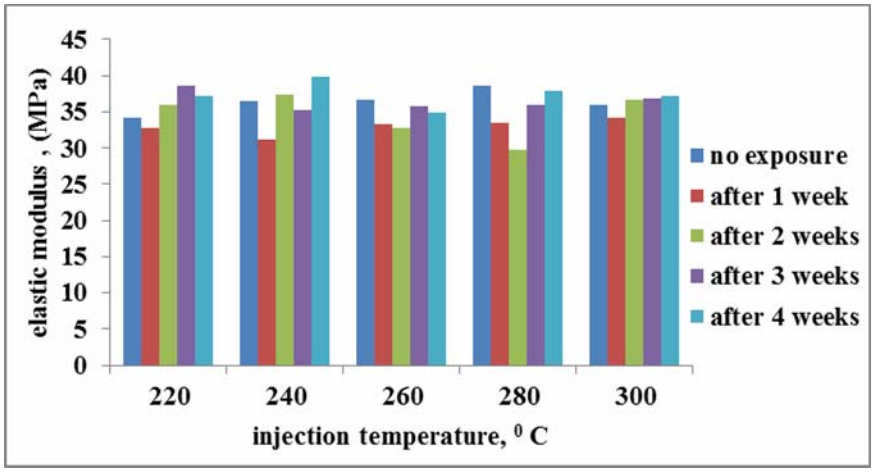

Fig. 9 Changes in crates elastic modulus with increasing oven-aging exposure time at 110°C.

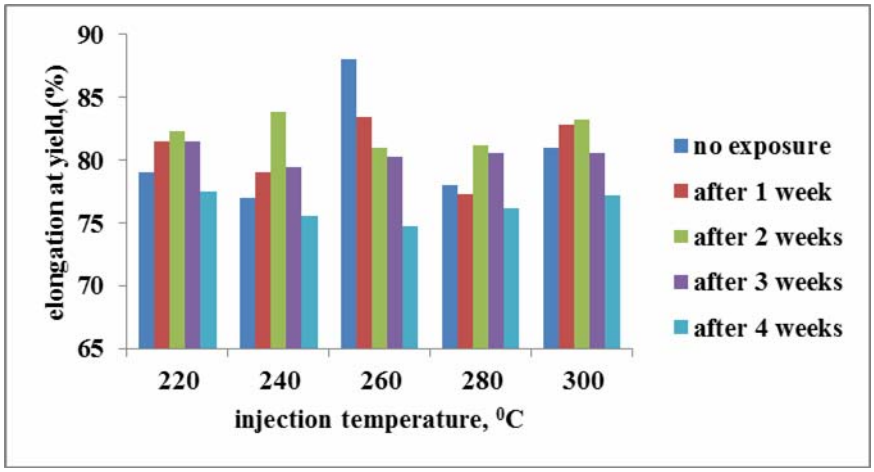

Fig. 10 Changes in crates elongation at yield with increasing oven-aging exposure time at 110°C.

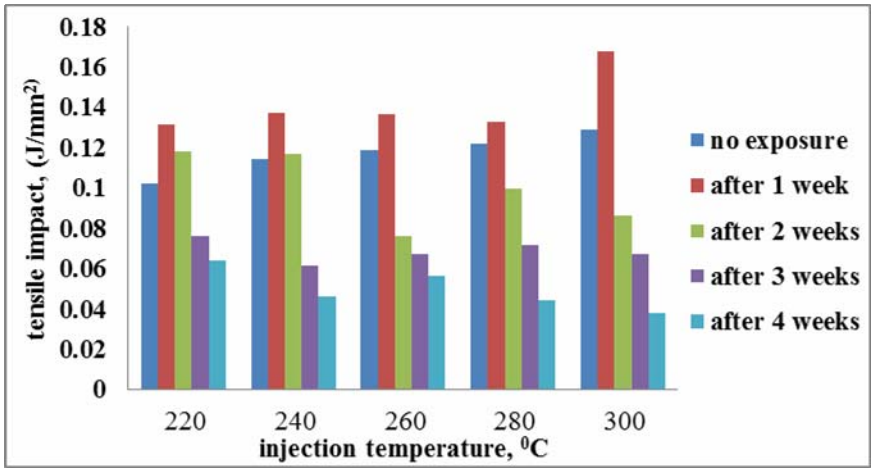

Fig. 11 Changes in crates impact strength with increasing oven-aging exposure time at 110°C.