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The effect of changing injection temperature on some mechanical and morphological properties for polypropylene material (PP)

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Abstract
This is a study of a medical injection factory-Babylon carried out in order to achieve proper mechanical and morphological properties, PP has been injection molded by using cold runner injection molding machine with temperature variation (198, 200, 203……220^0C) for ten samples. The physical and mechanical properties of PP product were examined. It has been found that the Shore hardness decreases linearly with injection molding temperature increasing. The tensile strength has a similar behavior to the hardness. However, it has been found that the MIF (Melt Index Flow) rates increases with the increase of injection molding temperature. The density of PP has been found for both virgin PP and the samples, it has been found that the density decreases with increasing operation temperature. FTIR (Fourier Transmission Infrared) spectra were taken for both samples with high and low operation temperature. Besides the SEM (Scanning Electronic Microscopy) test shows the difference in the morphology of the product surface and the PP product at high and low operation temperature. Moreover, for all these properties, the PP product exhibits good mechanical properties (hardness, tensile strength, density) for the samples produced at temperature lower than 207^0C. While the physical properties such as MIF improved with injection temperature increasing, additionally, the SEM images show that the sample produced in low temperature have surface damage.

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1. Introduction

Polypropylene (PP) polymer is very well-known polymer which has been widely used and studied. It is a thermoplastic polymer which produces, by using partial polymerization for the propylene, very long polymer chains (Charles, 2006). Polypropylene has excellent physical and mechanical properties when used at room temperature (Jones, 2008). The most common production process for such a polymer is injection molding process, which is considered one of the most important processing procedures for thermoplastic materials, based on the ability of thermoplastic materials to soften due to heat, and solidify due to cooling, (Mnas and Salil, 2007). To produce thermoplastic materials it is necessary to heat it till reaching the liquid state, and then force the melt to fill the mold cavity where it will solidify by cooling (Strong, 2000).

The injection molding process is a popular manufacturing process because of its ability to recycle byproducts such as runners, sprues, and gates. Moreover, the injection molding process is a fully automatic process that needs a small amount of surface finishing. The cold runner injection molding machines are similar to any other injection molding machines except for the fact that they do not contain heaters around the mold that is why they are called "cold runner" (Crawford, 1987; Crawford, 1998). It has been found that pressure and temperature of injection molding would affect severely the polymer viscosity (H. Li, 1998). PP possesses relatively high melting point, low density, high tensile modulus and it is relatively low-priced compared to other thermoplastics (Ariff et al., 2012). Commercial PP consists of generally linear molecular structure, thus, it can provide low melt strength. It also exhibits no strain hardening behavior in the melted stage. This suggests that PP is suitable for injection molding, blow molding and extrusion processing techniques (Rahim, 2011). Recycled polypropylene has less micro hardness besides low elastic deformation as compared to virgin polypropylene produced by using injection molding for each of them (Aurrekoetxeaa and others, 2003). Tensile strength increases linearly with fiber content for the PP-composites manufactured by using injection molding (Ota et al., 2005).

2. Material used

Polypropylene (PP) polymer was used, with type of (PP J 801). It has many applications, for instance in medicine. The Melt index Flow (MIF) for this material is between (20-25g/10min). The PP used in the research was not a 100% pure but was mixed with byproducts such as runners, sprues, and gates resulting from the production operation with range of (50% PP + 50% Recycled PP), the MIF for the PP granule was tested and it was 24.9g/10min.

Fig. 1. The pure (virgin) PP, recycled PP

3. Experimental method

Before beginning the production, the MIF for PP granule was calculated so that the range of temperature could be acknowledged, and it was (24.9g/10min). A weighted amount of (50% PP + 50% recycled PP) was placed in the hopper of injection molding machine, at the beginning of the operation about 7 cycles of PP products were produced to ensure the production operation stability and then select the samples for a further test. The machine parameters were constant secondary time (0.6 sec) and constant secondary pressure (50 bar) and the temperature was changed (198, 200, 203……….220^{0}C). The samples were manufactured using cold runner injection mold type JMI/SPI-150, Korea.

Table 1. The parameters of the injection molding process

No. of samples	Time (sec)	Temp. ⁰C	Pressure (bar)
1	0.6	220	50
2	0.6	217	50
3	0.6	215	50
4	0.6	213	50
5	0.6	210	50
6	0.6	207	50
7	0.6	205	50
8	0.6	203	50
9	0.6	200	50
10	0.6	198	50

The tensile test was performed with a tensile test instrument with type of (WDW/ 5E, China), with a load amount of (5 kN) and velocity of (10mm/min), and the samples standard was (ASTM-D1708) for all the samples.

The hardness test was carried out using (Shor D) hardness instrument, the device type was (TH 210, China), and the samples standard was (ASTM-D2240) for all the samples.

The MIF granule was performed with the samples by using a crusher to get a small granules, Fig. 8. The samples were subjected to melt index flow test using MIF instrument (SHI JIA ZHUANG ZHONG SHI, China), with a temperature (230^{0}C) and load of (2.16 Kg) according to the standard ASTM D 1238 (ISO 1033), ~~a~~ three weights for ten seconds were taken to get the average and to know the MIF for the samples. The density for the virgin PP and the samples were tested using density instrument tester (GP-1205, China). To find the change in the structure of PP after and before manufacturing, FTIR test was carried out using Infrared Spectroscopy tester (Shimatzu, Japan). Finally, Scanning Electron Microscope (SEM) images were studied for the sample that have the highest and lowest injection molding operation temperature to compare to get a clear idea of the temperature effect, two images were taken with (500 and 10000kx). This test took place in Islamic Republic of Iran using Scanning Electron microscope instrument (Brno, the Czech Republic).

4. Results and discussion

Fig. 2 shows that in the case of the Stress – Strain behavior for PP samples with temperature variation for the samples with singular arrangement that were taken from the sheets of Stress – Strain curves in tensile test, all the values have similar behavior.

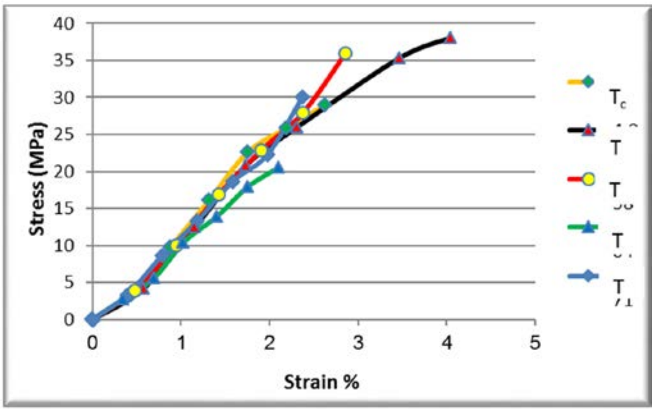


Fig. 2. The Stress – Strain behavior for PP samples with temperature variation

Fig. 3 shows the tensile strength change with temperature, it can be seen that the tensile strength decreases with an increase of temperature where the lowest tensile strength is (20 MPa) at temperature (220^{0}C). It is the result of high operation temperature on the polypropylene melt which causes lowering the density leading to decrease viscosity and the increase of flow rate. All this is caused by cracking of polymer chains thermal degradation resulting in a decrease of plasticity and increase of brittleness and, finally, causing a drop in mechanical properties. Moreover, Fig. 3 shows that the tensile strength is (38 MPa) at temperature (198^{0}C), which takes place at this temperature because of the low operation temperature that prevents the melt from reaching the degradation state which leads to decreasing the mechanical properties, including the tensile strength. It can be observed that neither high temperature nor low temperature is good for the operation, therefore, the best operation temperature is the one which occurs between these temperatures. These results comply with the results presented by (Senol and Pasa, 2005; Tao C., 1999; Zhou, Mallick, 2005).

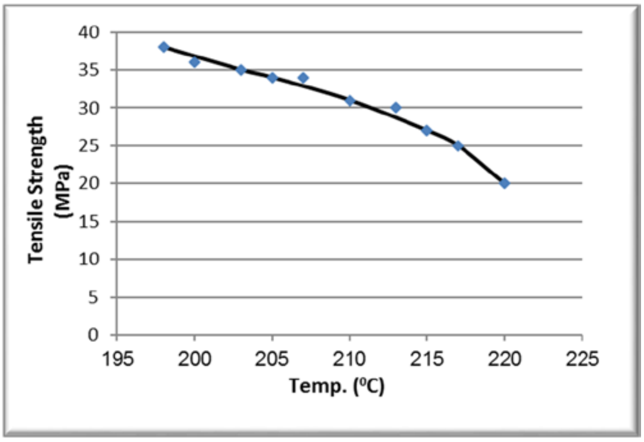


Fig. 3. The tensile strength change with temperature variation

Fig. 4 shows the hardness change with temperature, the hardness decrease with temperature increasing, hardness reach its lowest value (68.18) at (220^{0}C). It happens because of decreasing in nucleation rates which leads to increasing in grain size and reduction in connection between them, and finally causes formation of many internal defects leading to a decrease of hardness with the increase of temperature. Moreover, according to the same Fig. it can be noticed that the hardness reaches (70.35) at temperature (198^{0}C), which results from the low operation temperature which increases the melt viscosity and nucleation rates that leads to increasing density and decreasing the internal defects that make the hardness increase. These results are in agreement with results of (Bahrololoom and Younesi, 2009; Senol and Pasa, 2005).

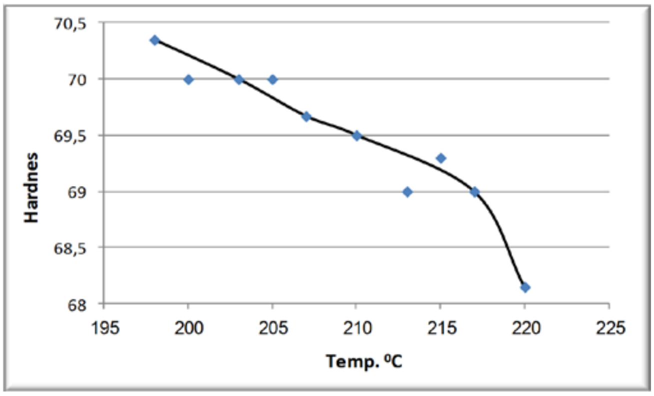


Fig. 4. The hardness change with temperature variation

Fig. 5 shows that the Melt Index Flow MIF changes with temperature. It can be clearly seen that the flow rate increases with temperature increase, which happens due to the increase of melt volume. The distance between polypropylene chains also increases, which leads to decreasing viscosity with increasing temperature. Finally, with increasing temperature, the flow also increases. Moreover, the same Fig. reveals that the flow decreases with temperature deceasing, which is caused by the alignment of chains together which increase viscosity and decrease flow rates. These results are in agreement with results of (H. Li, 1998; Ariff et al., 2012).

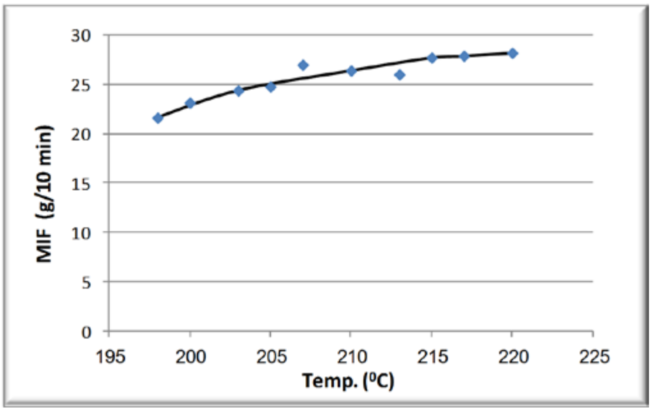


Fig. 5. The MIF change with temperature variation

Fig. 6 shows how the density changes with temperature. The density decreases with temperature increasing, the density (ρ) equals mass/volume where the mass decreases by increasing the distance between molecules resulting from the high temperature which caused decreasing viscosity of PP melt. As compared with the density of virgin PP which equals (0.8618 g/mm^3) it can be seen that the prepared sample density is much higher than the virgin PP density, which results from high temperature.

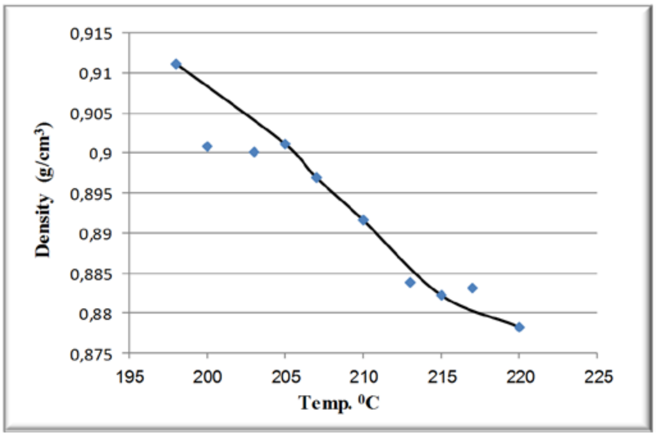


Fig. 6. The density change with temperature variation

Fig. 7 shows the FTIR spectra for low operation temperature PP. It can be noticed that the temperature did not affect the PP produced with low temperature as compared to virgin PP.

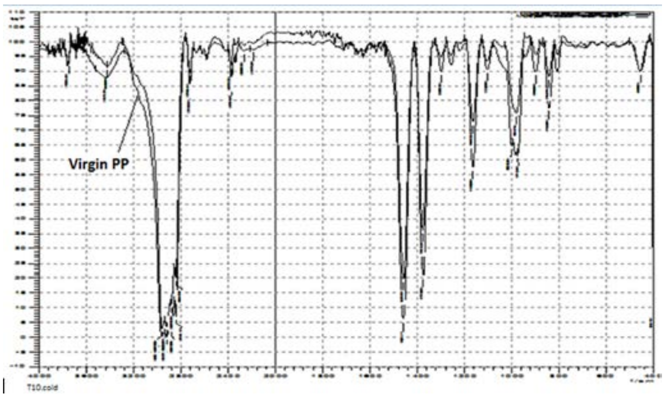


Fig. 7. The FTIR spectra for low operation temperature PP

Fig 8. shows the FTIR spectra for high operation temperature PP. It can be noticed that the only difference in intensity appeared, which is a sign of the lack of changes in chemical structure for the high temperature products.

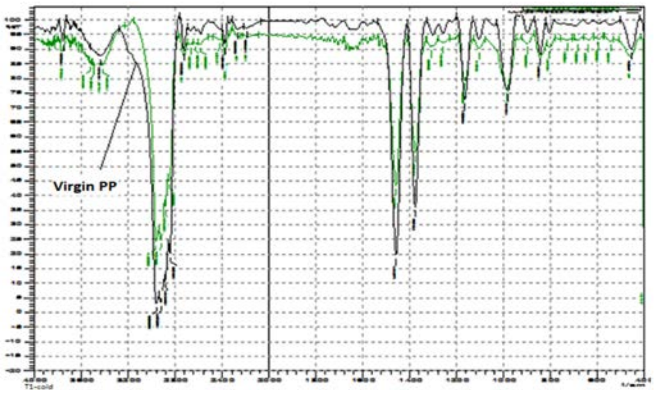
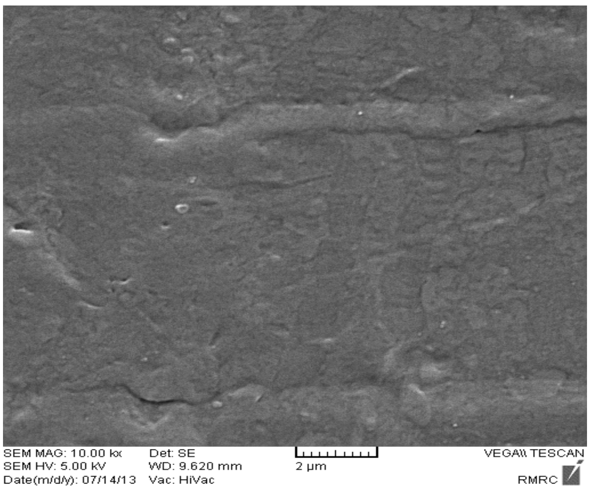


Fig. 8. The FTIR spectra for high operation temperature PP

Fig. 9 shows the SEM images for the lowest operation temperature and Fig. 10 shows the SEM images for the highest operation temperature. As it can be easily seen, the sample at high operation temperature has a better surface finishing in comparison to the images of low operation temperature. It results from high temperature increasing the flow and decreasing viscosity which, further, leads to better mold filling with good rates as compared to low temperature.



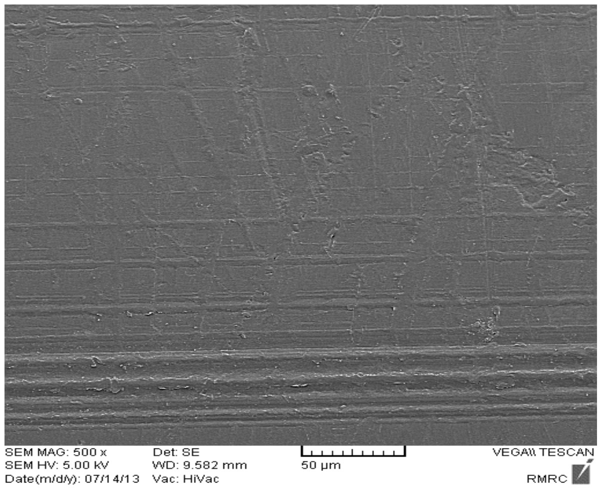


Fig. 9. The SEM images for the lowest operation temperature

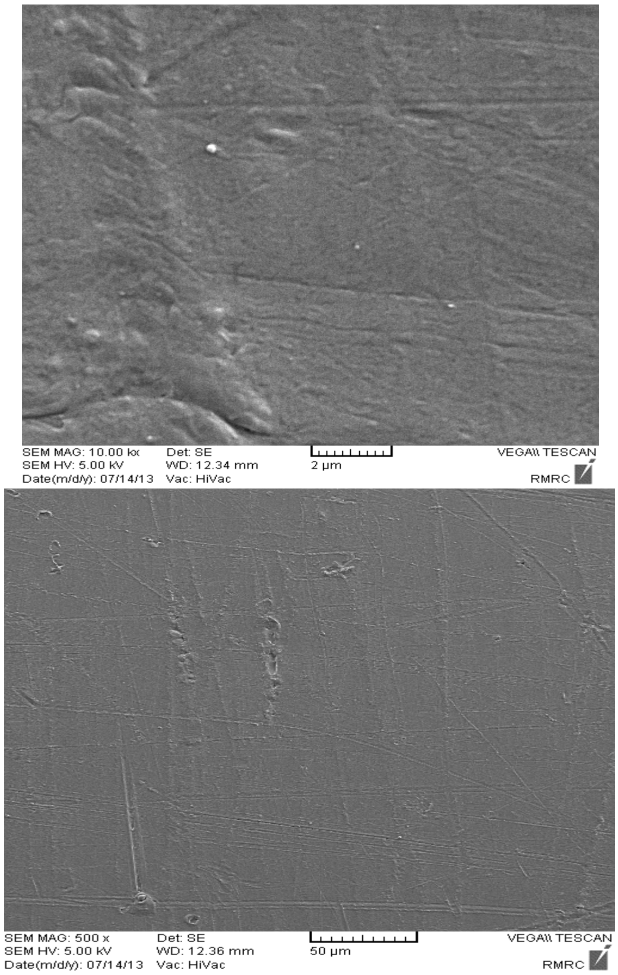


Fig. 10. The SEM images for the highest operation temperature

5. Summary and conclusion

This paper outlines experimental results from (Tensile, Shore hardness, MIF, density, FTIR, SEM) in different operation temperatures. Regarding the effects of injection temperature on the mechanical and morphological properties of polypropylene, the following conclusions could be drawn:

- The tensile strength as well as hardness decrease with operation temperature increasing, at temperature of (207^0C) it seems that it has curvature for both tests, this is good indicator for this operation temperature to be the best as compared to others.
- Melt index flow MIF increasing with operation temperature increasing at almost constant rate.
- The density decreases with operation temperature increasing, which is not good when high quality products are sought. When mechanical properties are taken into account, it can be seen that because of high operation temperature to both mechanical properties and density decrease.
- FTIR spectra do not show any changes in chemical structure, except for those occurring in high temperature which show small change in intensity.
- Finally, the SEM images show homogeneity in surface at high operation temperature as compare to SEM images at low operation temperature.

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改变注射温度对聚丙烯材料（PP）某些力学和形态特性的影响

關鍵詞

聚丙烯PP

注塑成型

聚合物的机械性能

摘要

这是一项医疗注射工厂 – 巴比伦为了获得适当的机械和形态特性而进行的研究，PP采用冷流道注塑机注塑成型，温度变化（198,200,203 ...... 2200C）样本。检查了PP产品的物理和机械性能。已经发现肖氏硬度随着注塑温度的升高而线性地减小。拉伸强度与硬度具有相似的行为。然而，已经发现MIF（熔体指数流）速率随着注塑温度的增加而增加。已发现原始PP和样品的PP密度，已发现密度随操作温度的升高而降低。对具有高和低操作温度的两个样品进行FTIR（傅里叶透射红外）光谱。除了SEM（扫描电子显微镜）测试外，在高和低操作温度下显示产品表面和PP产品的形态差异。此外，对于所有这些性能，PP产品在低于2070℃的温度下生产的样品表现出良好的机械性能（硬度，拉伸强度，密度）。虽然MIF等物理性能随着注射温度的升高而提高，但SEM图像显示低温下产生的样品有表面损伤。