THE EFFECT OF INTERNAL COOLING ON BLOW MOLDED PRODUCTS

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Abstract: The article presented deals with the production of blow molding products where the cooling phase is one of the most important. The method of reducing the heat energy directly determines the production time and dictates product quality. One very efficient way to improve the cooling ability, and consequently to reduce production time, is to implement at this stage internal cooling systems. These systems make it possible to ensure savings 50% of the production time. This is an interesting result, but the next important question is how the intensive internal cooling influences product quality? The aim of this published research is therefore focused on finding an answer to the question posed. To achieve this target, theoretical research was used to create a series of experiments which measured and evaluated the microstructure, mechanical, visual behavior and also the stability of the shape of the product.

Keywords: internal cooling, blow molding process, microstructure, behavior of products, carbon dioxide

1 Introudction

Extrusion blow molding is the most commonly-used technology for the production of hollow parts (GARCIA-REJON, 1995). The process can be divided into three main steps: the formation of the parison, clamping and inflation of the parison, and the cooling and solidification of molten form. Of these 3 stages, definitely the cooling stage takes the longest. This is because the polymer materials have a low heat transfer coefficient (ROSAT, 2004). Consequently a number of improvements have been recorded. Internal cooling is one of the most efficient. The principle of internal cooling is based on the ability to increase heat reduction inside the parts of the product. These days there are several suitable solutions in use. The circulation of air is the easiest variant, which requires the lowest initial investment. On the other hand, the resultant increase in production efficiency is not as high as with the following cooling methods (HUNKAR, 1973). The use of deep-cooled air (-35°C) is clearly more efficient (STIPSITS, 1993). An even more efficient possibility is to connect to a cooling mixture system of pressurized air and water droplets. This system uses the Joule-Thomson effect to change water droplets into ice crystals (MICHAELI, 2007). Another method which uses an atomized medium to perform the cooling process is the injection of an inert gas such as carbon dioxide (-78°C) or nitrogen (-196°C). This cooling variant is by far the most efficient with a possible process improvement of up to 50% (JORG, 2006). The exact value depends on the volume of the product, its thickness, intricacy, injection setting, used gas, and so on. This is of great interest for producers who are continuously looking to speed up production. But the issue of product quality must not be forgotten. Although the quality is a very important part of blow molding production, there is not a lot of research recorded that deals with this topic. One of the most interesting studies was written by Professor Dilhan M. Kalyon et al.. They focused their research on investigating the influence of different heat transfer methods on the microstructure, the crystallinity and the birefringence of the blow-molded article (KALYON, 1983, 1991). In their study, the changes in the distribution of density, residual stress and molecular orientation were observed. S. B. Tan and P.R. Hornsby were part of another research group. This group explored the effects of cooling rate on the morphology, shrinkage, warpage and impact properties (TAN, 2011). Their results indicate that internal cooling could significantly influence the nature of the products. Hence experimental measurements were taken to explore the changes to the microstructure, the mechanical and visual properties and the shape stability of products by connecting a progressive internal cooling system to the common blow molding process.

2 Experiment

To investigate the influence of internal cooling on the quality of blown products, the liquid carbon dioxide injection system was chosen. This system has the biggest cooling effect due to the introduction of innovative internal cooling variants and therefore can produce the most obvious results. The cooling effect is evaluated on two products of different volume and wall thickness. They are a seven liter container with a 4mm average wall thickness and a 0,5 liter bottle with a wall thickness of 1,5mm (figure 1). The conclusions can be generally applied. The next important decision was the selection of test material. From the polymers used, polyolefin was selected. This is because polyolefin is by far the most common material in the production of hollow products. Two variants were selected. The first one is a common linear, high-density semi-crystal copolymer called PE-Liten BB 29 and the second one is a homopolymer, PP-Mosten EH 0.1. Production took place on 2 classic, single station, pneumatic, blow-molding machines: a GM 750 (0,5l product) and a GM 5000 (7l product) at the company G D K spol. s.r.o. The concept of the planned experimental measurements is shown in Table 1. In first part, the common blow molding process running at the maximum production limit was measured. The speed of production was restricted by the demolding temperature. Next, the carbon dioxide cooling system was connected to the common blowing process. The CO2 was injected for 50% of the total cooling time. The last part of the experiment was to assess the increase in productivity corresponding to the used period of CO2 loading. Thermographic pictures and test specimens were taken from each setting to additionally analyze the microstructure, mechanical and visual properties, and also the stability of the shape of the product. Several different areas of the form were selected to involvement differences across the product. The specific areas are shown in figure 1.

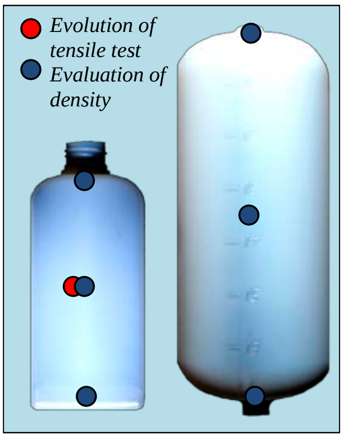


Fig. 1 Examined products

Tab.1 Process parameters of the experiment

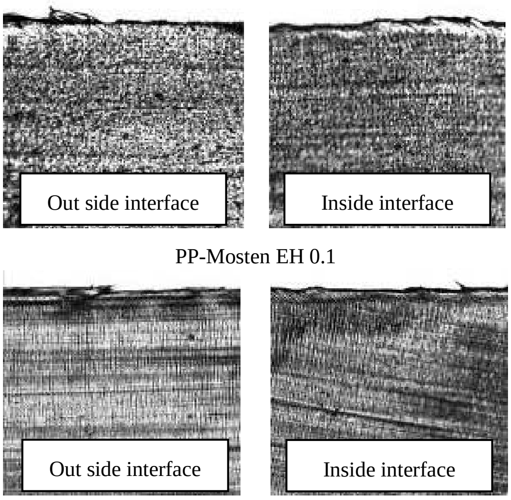
Products	Melt temperature	Cooling temperature of mold	Critical cycle time of blow molding setting	Cooling time of blow mold cooling system	Machine time	Time of injection of liquid CO2	Increase of efficiency (evaluated form max. temperature)	Increase of productivity
0,5l	190 °C	5°C	22s	16s	4s	8s	43%	45%
7l	190 °C	5°C	95s	80s	10s	40s	17%	21%

3 Results and discussion

The morphology and consequently also the material properties of the polymer are strongly affected by the thermal-kinetic conditions during the process of solidification. This is because the initial temperature and intensity of cooling determine the number, size and distribution of spherolites, which determine the mechanical, visual and other properties of the semi-crystal polymer (KREBS, 2006). The thermal reduction phase of the cooling process is therefore of enormous important. Blow molding production is a complicated non-isothermal, cyclic process with two cooling interfaces. These are the interface between the polymer and the mold and the interface between the air and the polymer (ROSAT, 2004). If they are compared it is evident that their cooling ability is not the same. The inflated parison touches the cold wall of the mold, initiating the intensive heat transfer (500 W/m2 K). On the other side of cooling interface, the heat transfer between the still air and the polymer (free convection) is very low (20 Wm2 K). These differences in cooling rates could cause the non-uniform structure throughout the wall thickness, as well as changes of density, molecular orientation, birefringence, shrinkage or even warpage (KALYON, 1983, 1991, TAN, 2011).

3.1 Structure

The microstructure of the polymer is composed of deposited (crystals) and amorphous fragments. Their rate is specified as percentage of crystalline. The quantity of fragments created is mainly influenced by the ability of the material to crystallize, but the thermal-kinetic conditions also have a considerable impact (KREBS, 2006). For example, if slower cooling is applied, it gives the spherolites more time to grow than with faster cooling and the result is the creation of fewer, but bigger spherolites. Conversely, using more intensive cooling causes the creation of more, but smaller spherolites (KREBS, 2006). For blow molding process, this means that by intensively cooling the effective interface, polymer/ mold, a large number of small spherolites should be created. Low heat transfer of the effective interface, air/ polymer, gives the spherolites enough time to grow to larger sizes. The difference in morphology increases with increasing product thickness and a faster cooling rate of the mold (external cooling system). How does this influence the connection to a progressive internal cooling method? From the theoretical statement introduced above, it can be assumed that the spherolites would be smaller and the structure more uniform. The influence of the different cooling rates at both interfaces on the microstructure across the product was observed using polarization microscopy. The results, which are shown in figure 2, showed that no structural changes were noted. This result was found for all tested samples of both of the examined materials. The explanation could be found through experimentation of the cooling settings. Water at five degrees centigrade is circulated in the mold, which is the lowest recommend temperature to produce the product without causing rejection (through the effect of sweating). If a higher cooling temperature or a thicker product were tested, the results could be different.



PE-Liten BB 29

Fig. 2 The distribution of microstructure

3.2 Density

As previously mentioned, the microstructure is defined. But, how was the percentage of crystals changed? The easiest test for crystalline changes is the determination of the density. The crystal fragments contain macro-molecules which are closer together than the macro-molecules in amorphous locations. Consequently these areas have a higher density (KREBS, 2006). The increase in density then clearly indicates an increase in the percentage of crystals. To explore the changes in density, and hence crystal percentage, three areas on each product were examined (figure 1). Different temperatures were recorded in these locations. This could cause different thermal-kinetic conditions and therefore different crystal percentages. The results which are showed in figure 3 confirmed this theory. Higher densities were recorded in locations with higher measured temperature. Connection to a liquid carbon dioxide injection system brings about an increase in cooling efficiency. The products were re-tested using a lower temperature and the test specimens reached lower density. But by increasing productivity the demolding temperature was increased and therefore the density was similar to the first experimental measurements. This discovery allows us to declare that increasing productivity does not change the percentage of crystals.

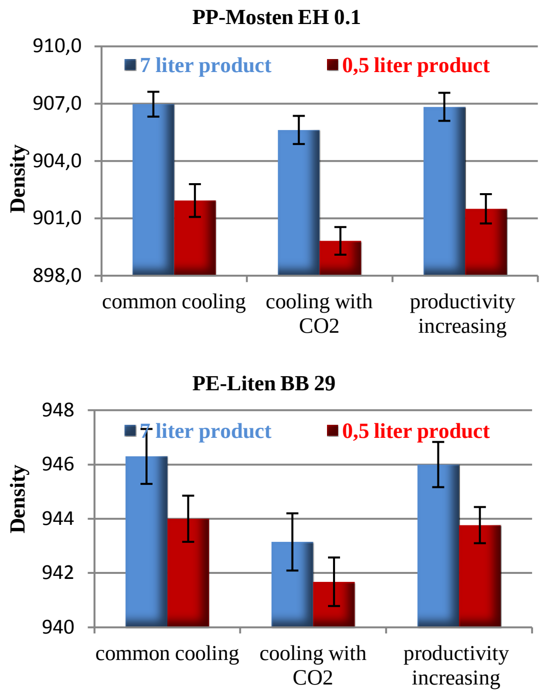


Fig. 3 Average values of measured density with standard deviation

3.3 Mechanical properties

For the evaluation of mechanical properties of semi-crystal polymers, it is necessary to know that crystal fragments have different mechanical properties from amorphous ones. Their closer ordering leads to higher adhesive forces. Consequently, the increasing percentage of crystals leads to increased strength, mechanical stiffness and hardness by several degrees of toughness. The amorphous segments are possible to imagine as joints about which the crystals can rotate by deformation. It contributes to improving toughness and elongation (KREBS, 2006).With respect to the results of density and the declared theory that, as the density (percentage of crystals) was changed by more intensive cooling, so the mechanical properties could be changed too. The tensile test didn´t confirmed this premise, as can be seen in the figure 4 and figure 5. The differences between the results are very small and could be with relation to reached values of standard deviations neglected.

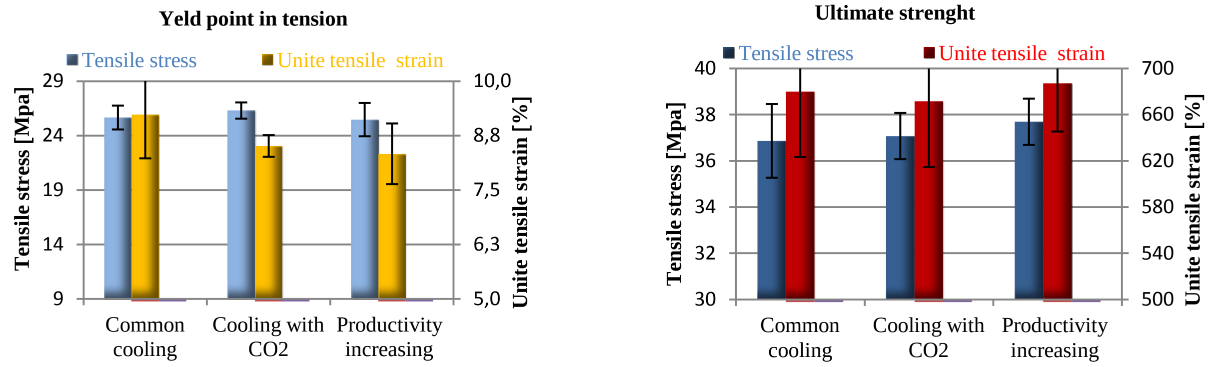


Fig. 4 Results of tensile test for PP-Mosten EH 0.1

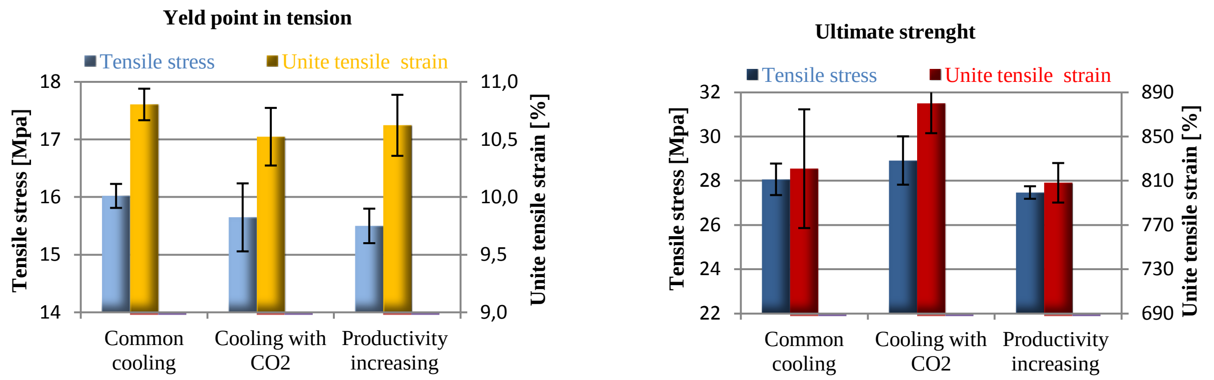


Fig. 5 Results of tensile test for PE-Liten BB29

3.4 Visual properties

The visual properties of semi-crystal polymers can be evaluated with the help of birefringence (KALYON, 1983). Professor Dilhan M. Kalyon proved in his publications that the distribution of birefringence is a function of the distance from the outer surface. "The rapid cooling rates at the interface polymer/ mold induce the retention of the orientation and generate high values of birefringence (especially at low initial parison temperature)" (KALYON, 1991). Conversely, the low heat transfer at the interface air/polymer causes a decrease in the orientation of the macromolecules and gives rise to negligible birefringence values. This means that the birefringence deceases from a maximum at the outer surface to a minimum at the inner surface (KALYON, 1983). The measured rate and distribution of birefringence for the experimentally created, cooling variant did not show any significant variations. This behavior corresponds with the earlier conclusion concerning the structure across the product.

3.5 Warpage

Warpage is directly related to residual stress which is built up by locally varying strain fields during solidification of the polymer. Non-uniform cooling therefore causes temperature variations, strain gradients and lead to an uneven residual stress, which induces a bending moment in the part. The bending moment leads to warpage of the part in order to balance the residual stress (TAN, 2011). It can be supposed that increasing the external cooling rate will increase the unbalanced residual stress. As a consequence, the induced bending moment and the part warpage also increase. On the other hand, increasing the cooling ability at the air/ polymer interface should decrease the potential warpage or distortion during molding because the thermal heat transfer is more uniform on both sides (TAN, 2011). Because the structure is uniform and no-residual stress was detected, warpage distortion is not an issue. Comparison of the shape stabilities of the products confirmed this association.

4 CONCLUSIONS

The aim of this article is to investigate the influence of an internal cooling method on the structure, the mechanical and visual properties and the stability of shape of semi-crystal products. Theoretical research states that differences in thermal conductivity at the polymer/ mold interface and the air/ polymer interface could lead to a non-uniform structure throughout the product regarding wall thickness, as well as changes of density, molecular orientation, birefringence, shrinkage and even warpage. Improving the cooling ability of inner surfaces should ensure more uniform structure and a decrease in potential warpage or distortion in the mold. Consequently the use of a progressive internal cooling method should have a positive effect. Experimental examination of the changes in heat transfer on the internal interface did not show any changes in the structure. This is probably because a very intense cooling setting of the mold was applied which caused fast and uniform cooling of the structure. The question is how the structure would look with thicker products or materials with higher thermal-kinetic requirements for crystallization. The crystal percentage decreased with the more intensive cooling setting. However, no differences were noted with increased productivity. Neither in the evaluation of shape stability of the product nor in its visual behavior and mechanical properties were any significant differences of tested variants observed. This allows us to state that using the liquid carbon dioxide injection system for 50% of the total cooling period brings about an increase in efficiency of 21% in a 7l container, and 45% in 0,5l container and it does not cause any structural, mechanical or visual changes, nor were there any product shape differences in either of the tested polyolefins (PP, PE).

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