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DISTRIBUTION OF MATERIAL IN AN INJECTION-MOLDED CONTAINER

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Abstract

The distribution of material (weight) in an injection-molded container was quantified by cutting the container precisely into segments. Molding conditions were varied, and different polypropylene grades were used. The material distribution remained nearly uniform when increasing the packing pressure. Increasing the packing time above a certain limit, however, mainly packed material close to the gate. The material distribution was also affected by material parameters such as melt flow rate and nucleation. The shrinkage and the compressive strength of the container were related to the material distribution.

1. Introduction

Materials for injection moulding are in a continuous development, in order to satisfy the market with regard to product properties and economy. Some important issues for polypropylene (PP) are a good balance between stiffness and impact strength, reduced warpage, improved clarity and enhanced flow properties.

In a previous study of products with long flow paths and relatively thin walls, it was found that the shrinkage of PP increased with increasing degree of nucleation. This posed a question about how modifications such as nucleation affect the material distribution along the flow path. The present publication presents measurements of material distributions, and discusses how these are affected by material parameters and molding conditions.

2. Experimental

Eight different PP grades were used in this study, see Table 1 for details. The molded product was a 10 liter container (bucket), with height 252 mm, bottom diameter 230 mm and top diameter 266 mm. The thickness was 1.4 mm at the bottom, with a gradual decrease towards 1.2 mm at the top. A hot runner was used, and the gate was at the center of the bottom. The containers were molded with a Netstal 1570/300-MP-Sycap machine, using a screw with L/D = 25. Molding conditions are shown in Table 2. Standard injection parameters (injection time 0.6 s and melt temperature 260°C) were used for all the trials in Figs. 1-8.

Table 1. PP materials used in this study (all produced by Borealis).

Grade	**Type**[a]	**MFR**[b]	**Nucleation**	**Impact strength**
BC245P	C	3.5	medium	high
BE170M	C	13	none	medium
BE375P	C	13	medium	medium
BE376P	C	13	strong	medium
RE220P	R	13	strong	low
HE125M	H	13	none	very low
BH345P	C	45	medium	medium
BJ355P	M	100	medium	low

[a] C = heterophasic copolymer, R = random copolymer, H = homopolymer, M = miniblock copolymer.

[b] Melt flow rate [g/10min] at 230°C with 2.16 kg load.

Table 2. Combinations of materials and molding conditions[a] discussed in this article.

PP grade	**Melt temp. [°C]**	**Inj. time [s]**	**Packing pressure**[b] **[MPa]**	**Packing time**[b] **[s]**
BE375P	220 - 260	0.6 - 1.2	35 - 55 - 75	0.5 - 1.5 - 3 - 5
BH345P	220[c]	0.6	35 - 55 - 75	0.5 - 1.5 - 5
BJ355P	220[c]	0.6	15 - 35 - 55	0.5 - 1.5 - 5
all other	260	0.6	35 - 55 - 75	0.5 - 1.5 - 5

[a] The cooling time (i.e. the time between releasing the packing pressure and ejecting the part) was 12 s in all the trials, in order to have the same screw residence time. A relatively high value was chosen in order to reduce variations in mold temperature, when varying the packing time. The total time with the mold open was also held constant. The mold temperatures were 5°C and 20°C for the moving and stationary halves, respectively.

[b] Containers were also molded with some intermediate packing pressures and packing times, but only the material distribution was assessed for these containers.

[c] This low melt temperature was used for the high-MFR materials in order to avoid overfilling.

The material distributions were analyzed by cutting the containers into five segments with roughly the same weight (see Fig. 1), using the following procedure: The container was placed upside down on the horizontal table of a drilling machine. A hole with diameter 10 mm was drilled through the bottom center. The container was fastened to the drilling table with a nut on a screw through this hole. A sharp knife was mounted on the table in a selected height, and with a free movement towards the container. Then the container was rotated in contact with the knife, leaving a circular track, but not cutting through the container wall. All containers were marked at the same height before the knife was moved vertically to the next position. Finally, the containers were cut along the four circular tracks, and the five segments were weighed.

Fig. 1. A photograph of the container after cutting it into five segments, in order to quantify the material distribution.

With the procedure outlined above, differences in the height of the container (due to shrinkage) would mainly influence the measured material distribution via the bottom segment. However, considering our data set, there is no general correlation between height shrinkage and weight fraction in the bottom. Hence, the effect of container height seems to be small compared to the other effects considered.

The shrinkage relative to the mold dimensions was measured for the height of the container, as well as the top and bottom circumferences. The compressive strength of the containers (maximum axial force prior to collapse) was measured in a Zwick 1464 universal testing machine, using a compression speed of 1 mm/min.

All measurements were done at least three weeks after molding. Three parallel measurements were made for all combinations of material and molding parameters. The weight of three “parallel” segments typically varied by 0.2 g (~0.4%). This is partly due to errors in the cutting, and partly due to shot-to-shot variations.

3. Results and discussion

3.1 Total weight

The total weight of the container increased with increasing packing pressure and packing time. The latter effect was small at long packing times. The weight difference between containers with high and low degree of packing, i.e. 75 MPa for 5 s and 35 MPa for 0.5 s, varied with material parameters, injection time and melt temperature. The largest weight difference (316 g – 276 g = 40 g) was observed for BH345P, which had the highest MFR among those materials that were packed with 75 MPa. The smallest difference (299 g – 275 g = 24 g) was measured for BC245P (lowest MFR).

The container weight increased with increasing degree of nucleation: Containers of the highly nucleated BE376P were typically 2-3 grams heavier than those of the unnucleated BE170M. This nucleation effect increased with increasing degree of packing. Hence, the difference in weight between high and low degree of packing also increased with the degree of nucleation. A comparison between the two unnucleated materials with equal MFR, HE125M (homopolymer) and BE170M (heterophasic copolymer), showed a slight difference. Containers produced with the homopolymer were typically 1 g lighter, but the weight difference between high and low degree of packing was somewhat larger with this material.

3.2 Material distribution

A typical example of the effect of packing pressure on the material distribution is shown in Fig. 2. The weights of the five segments increased by almost the same amount when increasing the packing pressure. There was, however, a slight tendency for relatively higher packing close to the gate (bottom) at the highest pressures. The effect of packing time is shown in Fig. 3. Above a certain packing time, only segments near the gate gained further weight. This is well illustrated by plotting the weight fractions as in Fig. 4. The first ring above the bottom is the “transition zone”, above which the weight fraction decreased with increasing packing time.

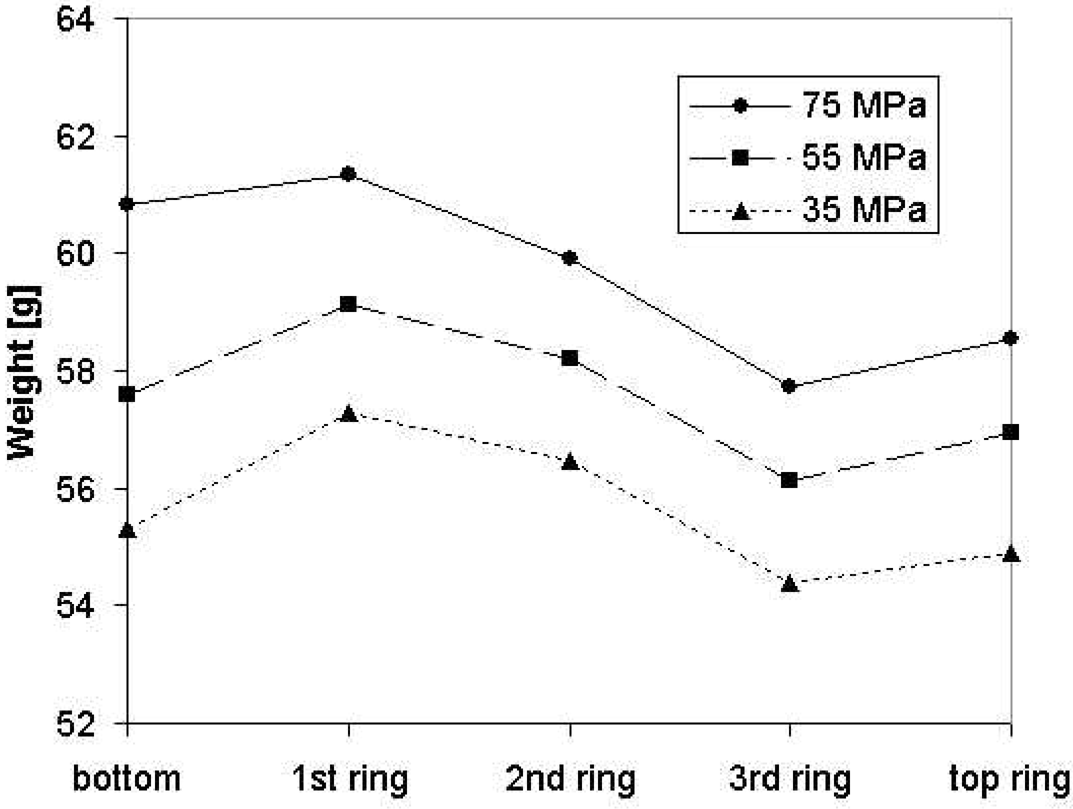

Fig. 2. Material distributions for different packing pressures. Data for BE375P with packing time 1.5 s.

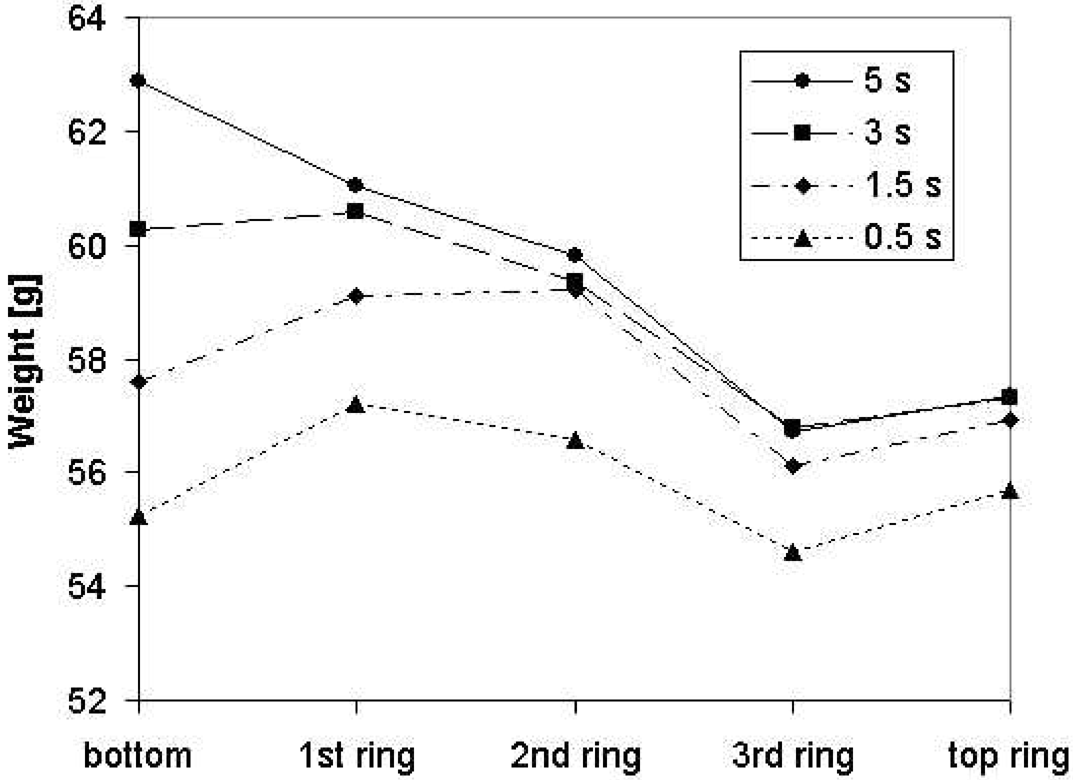

Fig. 3. Material distributions for different packing times. Data for BE375P with packing pressure 55 MPa.

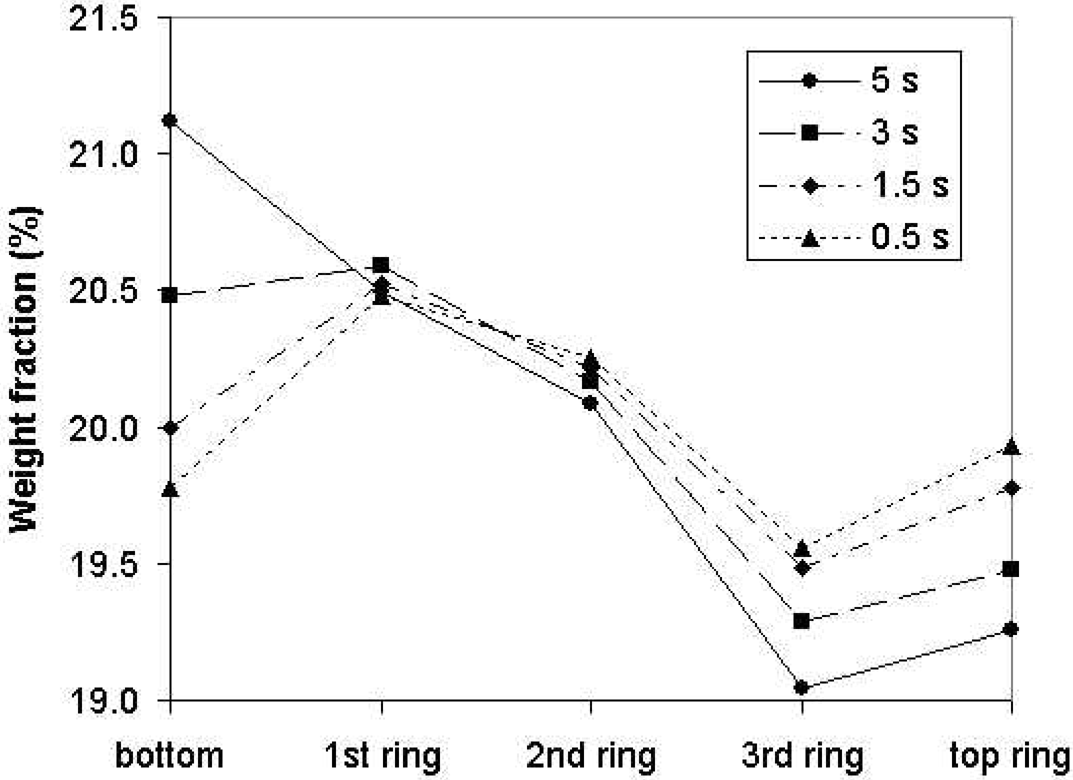

Fig. 4. As Fig. 3, but the weights are normalized by the total weight of the container.

BE375P was molded with two different injection times and melt temperatures. At low degrees of packing, low temperature or slow injection reduced the weight fraction in the top ring, while the weight fractions of the three segments closest to the gate increased. The effects were small, but significant. When the degree of packing was high, a reversed effect was observed: Slow injection, in particular, lead to a reduced fraction in the bottom segment, while increased fractions were measured in the first and second rings.

The material distribution tended to shift towards the gate when reducing the MFR, as shown in Fig. 5. Nucleation seemed to give the opposite effect, see Fig. 6. Regarding the type of PP, the homopolymer HE125M deviated somewhat from the other materials with the same MFR (with or without nucleation): A higher weight fraction in the first ring, and a lower fraction in the top, was obtained with the homopolymer.

A change in material or injection parameters may result in two competing effects. A higher melt temperature, for instance, will make it easier to transport material to the end of the flow path. However, the effective degree of packing will be lower.

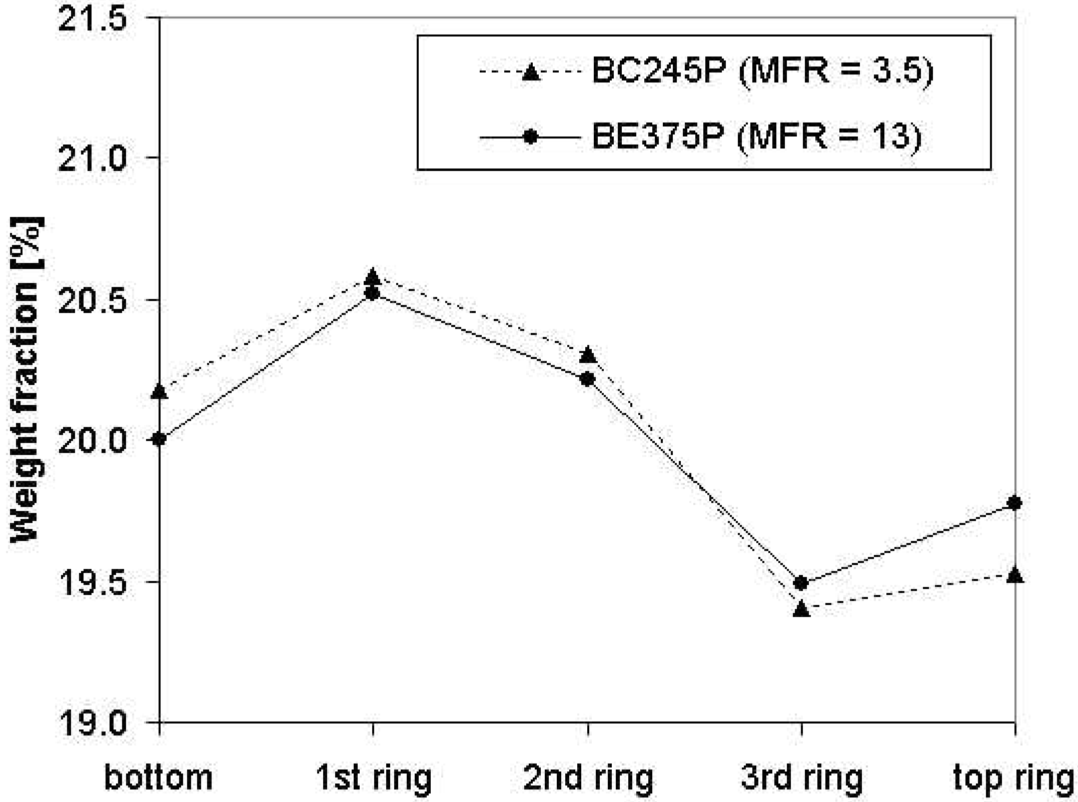

Fig. 5. Material distributions for different MFR values. The packing pressure and time were 55 MPa and 1.5 s, respectively.

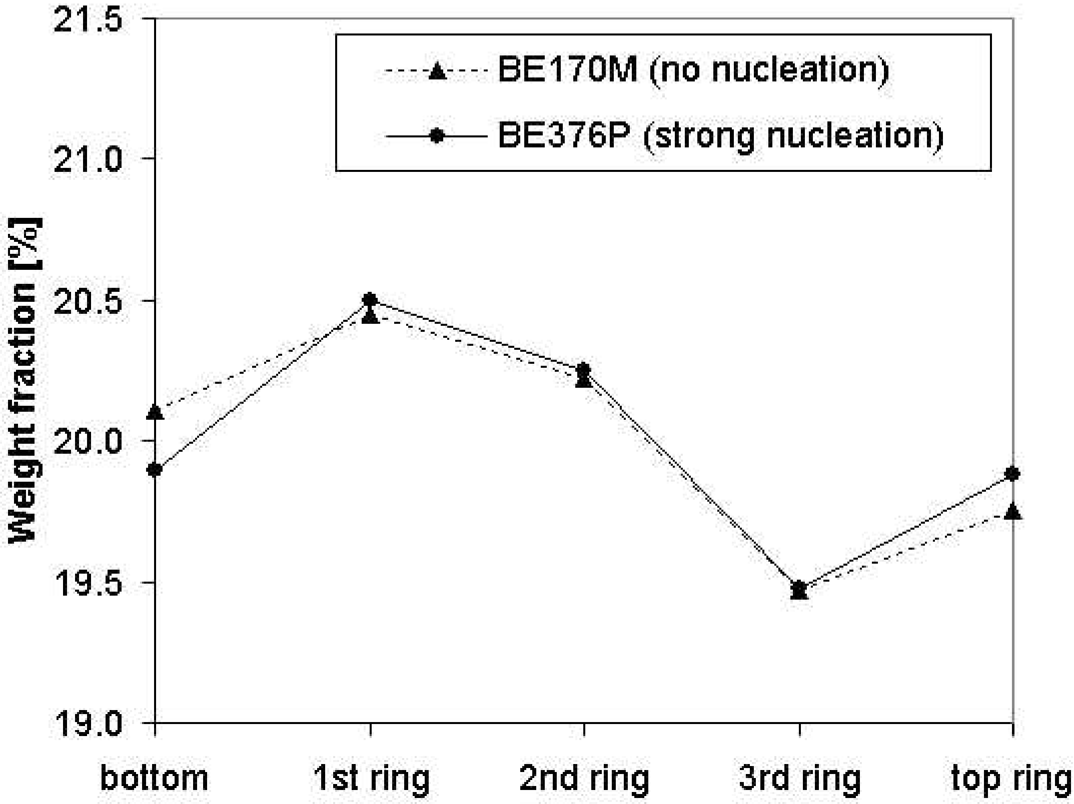

Fig. 6. Material distributions for different degrees of nucleation. The packing pressure and time were 55 MPa and 1.5 s, respectively.

3.3 Shrinkage

Typical shrinkage data as function of packing time are shown in Fig. 7. Note that an increase in packing time above ~2 s hardly reduced the shrinkage of the top circumference. This agrees with the material distributions reported above. Also note how the difference between the highest (top) and lowest (bottom) shrinkage increased with increasing packing time. Inhomogeneous shrinkage may lead to warpage.

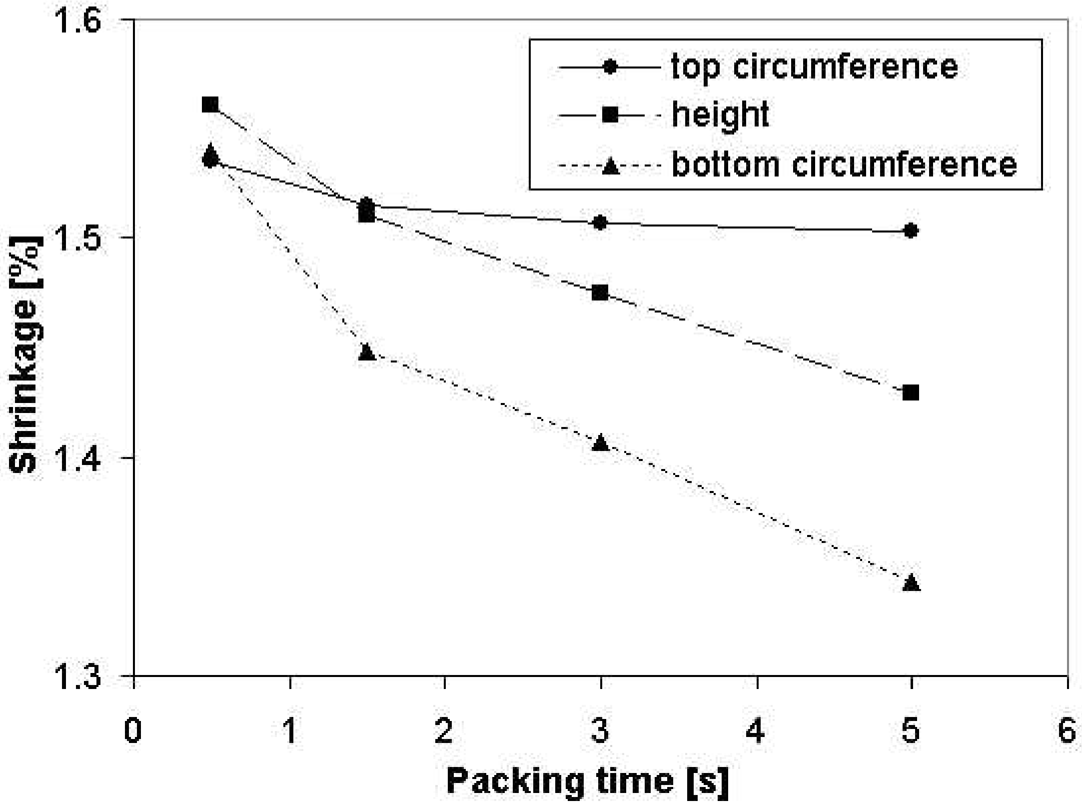

Fig. 7. Shrinkage of BE375P vs. packing time, with 55 MPa packing pressure.

The trends for the three shrinkage measurements vs. packing pressure differed somewhat from those in Fig. 7. At a certain packing pressure (e.g. ~45 MPa for BE375P with 1.5 s packing time) the three shrinkage values were equal. With short packing times, the difference between the three shrinkages values were quite small, even for the highest packing pressure.

The shrinkages were affected by injection time and melt temperature, as studied with BE375P. The height shrinkage tended to increase when the melt temperature was reduced to 220°C, and when the injection time was increased to 1.2 s. The shrinkage of the bottom circumference, on the other hand, was reduced when increasing the injection time, and (for low degrees of packing) reducing the melt temperature. The shrinkage of the top circumference was also reduced by these parameter changes, when the degree of packing was low. At high degrees of packing, these effects on the top shrinkage were reversed (although small). The three combinations of injection time and melt temperature studied gave roughly the same variation between the three shrinkage entities.

The shrinkage of the height (parallel to the flow direction) tended to decrease with increasing MFR, especially when the degree of packing was high. The shrinkages of the top and bottom circumferences generally followed the opposite trend. In particular, the two materials with highest MFR differed from the rest by having lower shrinkage of the height, and higher shrinkage of the top and bottom circumferences. Hence, the anisotropy in shrinkage is probably larger with these materials. However, if only the top and bottom shrinkages are compared, the MFR effects were small. The material with the highest MFR (BJ355P) differed from the rest by giving higher shrinkage at the bottom than at the top at all packing conditions (the highest degree of packing for this material was 55MPa/5s, for which the top and bottom shrinkages were equal).

The shrinkage increased with the degree of nucleation. The variation in shrinkage from one position to another was lowest with medium nucleation, at low and medium degrees of packing. At the highest degree of packing, medium and strong nucleation performed equally well in reducing the shrinkage variation.

The homopolymer (HE125M) generally showed higher shrinkage than the copolymer with equal MFR and nucleation (BE170M). At a certain degree of packing with the homopolymer, the top shrinkage 'crossed' the bottom shrinkage (the former being highest at higher degrees of packing). At and above this intermediate degree of packing, the homopolymer had lower variation among the three shrinkage entities than the copolymer.

3.4 Compressive strength

The compressive strength generally increased with increasing degree of packing, see Fig. 8. However, for most materials the compressive strength leveled off or even decreased at long packing times. At high packing pressures, this negative effect of packing time disappeared when reducing the cooling time, i.e. the screw residence time. The negative effect remained at low packing pressures, and the position of the collapse moved towards the top (decreasing thickness) with increasing packing time (the point of maximum inflection was typically 60-70 mm from the top). Hence, in this case, the reduction in compressive strength was due to a change in collapse pattern/position (the initial compressive stiffness did not decrease with increasing packing time). These issues could be studied further by finite-element structural analysis coupled with simulations of the injection molding process.

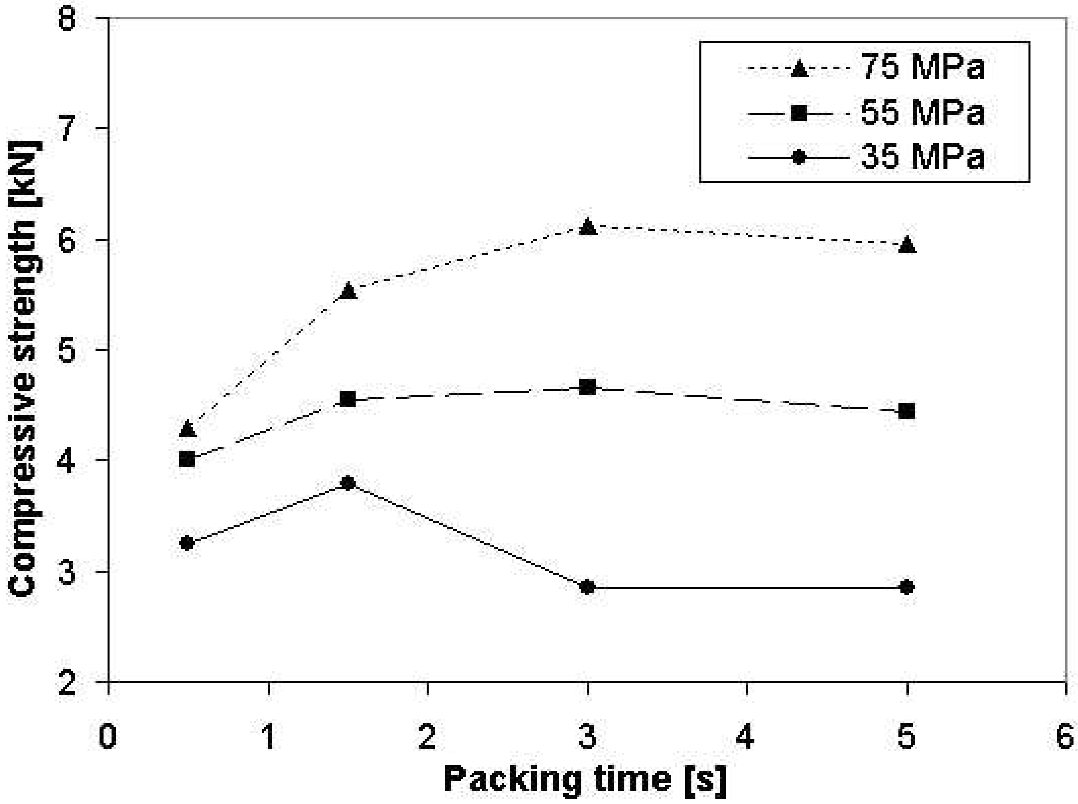

Fig. 8. Compressive strength of BE375P for different packing times and pressures.

The compressive strength is a strong function of MFR. The material with the highest MFR gave the highest compressive strengths. This was probably mainly due to higher stiffness, which is known to increase with increasing MFR. The material distribution was also favorable, but other materials gave higher total and top weights. The material with the lowest MFR gave the lowest maximum compressive strength. For this material the compressive strength was not much affected by packing pressure. Among the materials with MFR = 13, the highest compressive strengths were achieved with the strongly nucleated heterophasic copolymer and the homopolymer.

3.5 Interactions and correlations

The shrinkage and the mechanical properties of injection moulded products are determined by material parameters *per se* (e.g. type of nucleation and impact modification), and the interaction between material parameters and molding conditions. This interaction results in flow-induced local properties (including anisotropy), and a certain material distribution in the mold.

The correlation between the different measurements (total weight, segments weights, shrinkages and compressive strength) was investigated by calculating correlation coefficients (linear regression) for the data sets obtained at nine different packing conditions (three packing pressures and three packing times). This was done for all materials.

The correlations between total weight and height shrinkage, total weight and bottom shrinkage, and height and bottom shrinkage, are high for all materials (average $r^2 = -0.95$). The weight of the top segment is the entity which is highest correlated with the compressive strength (average $r^2 = 0.90$). The top weight is also highly correlated with the three shrinkage measures (average $r^2 = -0.90$).

The correlation coefficients are high for high-MFR materials, and vice versa. If the low-MFR material is omitted from the average, the correlation between top weight and compressive strength has an average coefficient of 0.94.

4. Conclusions

The properties of the container were affected by the material distribution, in particular the weight of the top ring at the end of the flow path. The material distribution was determined by molding conditions and material parameters. A high packing pressure was favorable for packing the top ring. On the other hand, increasing the packing time above a certain limit mainly packed material close to the gate. A high MFR and a high degree of nucleation were generally positive for the material distribution.

With a single-gated mold of this type, a high packing pressure will often be favorable. The material consumption can be reduced by preferentially packing the weakest part of the product. Furthermore, less material and more effective packing could reduce the cycle time. On the negative side, a larger machine may be required. Furthermore, tooling costs may be higher, and residual stresses in the product could become detrimental.

Acknowledgments

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