MICROHARDNESS STUDY ACROSS THE WELD LINE IN DOUBLY INJECTION MOULDED GLASSY POLYMERS

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The use of microhardness (H) to characterize the changes in microstructure , molecular orientation and micromechanical properties of injection moulded polymer materials has been the object of increasing interest (1-4). In addition, it is known that process variables induce important changes in the microstructure and properties of the moulded material (5,6). Hardness variations often occur in the surface and across the thickness of the moulded samples. As a result , the mechanical properties can be controlled by processing variables such as melt and mould temperature, injection pressure, etc (2). Furthermore, it is known that microhardness can detect microstructural changes in glassy polymers, offering information about ageing effects below the glass transition temperature (T_g) and conformational changes and local molecular rearrangements above T_g (7-10).

Earlier studies (11) have shown that microhardness may give a useful information about the correlation between processing parameters near and at the weld line or knit line, i.e. the region where separated melt fronts reunite. In practice it occurs in injection moulding, i.e. after a flow obstacle or in case of multiple gating for melt streams of same material or in case of two component injection moulding for melt streams of different polymer materials (12). The aim of the present note is to extend the above studies to the microhardness investigation of two glassy polymers (PC and PS) processed using a two-component injection moulding system. Specifically, we wish to examine the H-value across the weld line arising when the two opposite flow fronts are filling the cavity of the mould.

Polycarbonate (PC) (Makrolon 3200, Bayer) with $T_g=148^\circ\text{C}$ and high molecular weight polystyrene (PS-168 N BASF) ($T_g=100^\circ\text{C}$) samples were used in this study. The mouldings were prepared in the form of ASTM tensile bars (gauge length 170 mm, thickness 4 mm and width 10 mm) using a two-component injection moulding machine in which both melt streams (of same material, though differently colored) can be controlled independently. The bars were moulded using for PC a melt temperature $T_m=270^\circ\text{C}$ and a mould temperature $T_w=80^\circ\text{C}$, respectively. The injection pressure for both melt fronts was 170 bar speed of the melt front was 200 m/s. In case of PS values of $T_m=230^\circ\text{C}$ and $T_w= 50^\circ\text{C}$ were used. The speed of the melt front and the injection pressure here were 0.2 m/s and 110 bar, respectively.

Microhardness was measured across the boundary at the surface of each one of the mouldings using a microindentation tester with a Vickers square based pyramidal diamond indenter. The hardness value (in MPa) was derived from the residual projected diagonal impression using, $H=kP/d^2$, where P is the applied force in N, k is a geometrical constant equal to 1.854, and d is the length of the projected indentation diagonal in m. A load of $P=0.25$ N and a loading cycle of 6 seconds were used. Special care was taken to make indentations whose diagonals were parallel and perpendicular to the injection direction (z).

Figure 1 illustrates the variation of H on the surfaces of the moulding along the injection direction, z , for the PC and PS samples respectively. We denote the position of the boundary plane as $z=0$. Results clearly show first the gradual decrease of H for both PC and PS samples along the z direction, till a minimum value at $z=0$ is reached. Then one observes a further increase of H when indenting away from $z=0$. It is noteworthy the symmetry of the hardness profile about $z=0$ in both cases. The weld line zone containing the H changes is defined in the PC case within a 1mm region. For the PS sample however, the boundary region seems to be somewhat narrower.

Most interesting is to note the large hardness difference found between H measured away from the weld line and H measured at $z=0$ ($H_{\min}$). For PC this difference is of about 20 MPa ($\approx 14\%$) while for PS is larger than 50 MPa ($\approx 30\%$).

Figure 2 illustrates a similar plot of H along the injection direction z for the PC and PS samples containing a pigment for better visualization of flow front. We find here again the $H_{\min}$ value exactly defining the weld line. It is to be noted the arising asymmetry of H values, between the sample side containing the pigment (left side) and the side without pigment (right-hand side). For both polymers we observe higher H -values on the side containing the pigment. This evidences the hardening effect of the pigment within the polymer.

In addition, an anisometry of the indentation shape is also observed. In the mouldings containing the pigment, the H values perpendicular to the injection direction (plotted in Fig.2) are always smaller (about 10 MPa) than the H values parallel to this direction (not represented). This result suggests the occurrence of a molecular orientation of the material along the injection direction, z , which contributes, after removal of the indenter, to an instant elastic recovery of the sample.

Although in all mouldings the hardness is minimum at the boundary plane, the variation of dH/dz within the weld line zone depends very markedly on the polymer used. One may think that the depth of the weld line region, defined by the H -decreasing values near $z=0$, could depend on the $\Delta T = T_g - T_w$ value and on the molecular weight of each polymer. Since ΔT is relatively small in case of the PS moulding ($\Delta T = 50^\circ\text{C}$), here the two polymer fronts coming from opposite sides may reach the $z=0$ plane when they are already partly cooled. In this case molecular diffusion and entanglement formation is probably not so well developed. Therefore, we find a large H depression at $z=0$. On the other hand, if the mouldings have a larger ΔT value (for PC $\Delta T = 68^\circ\text{C}$) when the two polymer fronts meet they may find themselves in the molten state and chain diffusion and entanglement formation is facilitated so that the depth of hardness decrease in the weld line becomes smaller.

In conclusion, microhardness is shown to be an adequate technique which can accurately define the region across the weld line in injection moulded parts and can furnish information about the local degree of molecular orientation within the welding boundary.

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Legend to Figures

Fig. 1. Microhardness measured at the surface of the moulding along the injection direction (z) for PC and PS samples. Arrows denote the direction of the two opposing flow fronts.

Fig. 2. Comparison of microhardness values measured along the injection direction for PC and PS samples containing a pigment (left) and without pigment (right).

Fig. 1

Fig. 3