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The skin-core structure of injection-molded parts

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A highly oriented skin layer caused by flow-induced stresses from injection molding was visualized and quantified by x-ray nanotomography.

Polymer properties are well known to rely on their microstructure.[1,2] Thermal and flow stresses that develop during injection molding influence the microstructure of the molded component by introducing a layered structure and orientation.[3] In addition, material and process parameters such as viscosity, cooling rate, injection pressures, and their interdependency give rise to the uncertainty in predicting properties.

Development of the layered structure can be used to better engineer the process[4] and the final product. With industry lightweighting (i.e., less overall weight) and increased sophistication of mold geometries, it is necessary to quantify the extent of the layered structure. Different techniques are available to characterize the skin layer. For example, transparent polymers such as polyethylene terephthalate (PET) can be visualized using optical light (see Figure 1) and polarized light. However, with faster molding cycles and lower cooling times, there is a need for techniques that permit high-resolution measurements of the skin layer. We investigated x-ray imaging for this purpose.

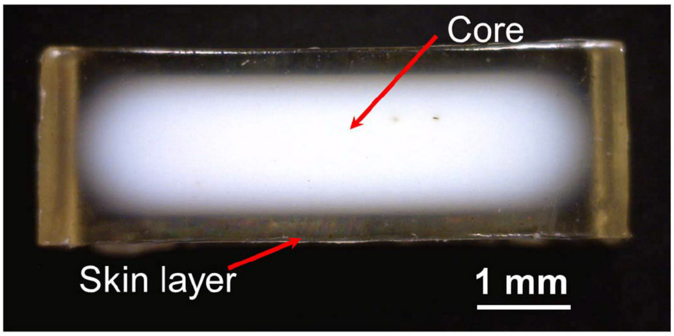

Figure 1. *Skin-core cross section of a polyethylene terephthalate bar.*

X-ray imaging of materials is based on the ratio of the transmitted to the absorbed beam intensities, making it a nondestructive technique. Progress in the field of x-ray optics has enabled imaging of low-absorbing materials such as polymers by employing phase contrast techniques. We previously showed that x-ray tomography is useful for product development.[5] However, imaging minor changes such as the formation of a skin layer in polymers is not easy because the difference in densities does not provide the required contrast.

To quantify the frozen (skin) layer under rapid cooling conditions, we used a molded PET tube (19mm outer diameter with a wall thickness of 1.5mm) with a secondary phase introduced during the injection-molding process. Graphene nanoplatelets (maximum lateral dimension 5μm), the secondary phase present in the PET matrix, aligns with the flow due to the stresses from injection molding. The composite sample we used was prepared at 2% nanoplatelet weight fraction on a 90-ton injection-molding system equipped with a chilled water circuit that allowed rapid cooling. X-ray nanotomography of the composite sample was performed with a spatial resolution of 150nm. In order to achieve this resolution, the x-ray beam was focused onto a small region (70μm) near the surface. Using the series of radiographs collected, we reconstructed tomographs (based on a parallel-beam filtered back-projection algorithm).

The radiograph shown in Figure 2(a), collected near the outer cast surface of the composite tube, shows that the technique is effective in providing contrast between the PET and nanoplatelets. Based on 3D visualization of the nanoplatelets inside the PET matrix—see Figure 2(b)—we ascertained their orientation along the injection flow direction near the surface. By calibrating the 3D reconstruction, the thickness of the frozen layer can be observed from the depth of the oriented nanoplatelets. The thickness of this layer was different on the inner and outer surfaces. From the outside surface, the thickness of the frozen layer was 8μm, whereas from the inner surface it was about 16μm. This shows that with the difference in the effective cooling rate (with change in the contact surface area), the frozen layer thickness changes. We also observed a layer with partial orientation of nanoplatelets underneath the fully oriented layer before their distribution becomes random. This indicates the presence of a secondary layer with limited influence from flow stresses.

The current work shows that phase contrast x-ray nanotomography with submicron resolution is valuable in assessing solidification of injection-molded parts, including composites. Based on our measurements, 25μm is the minimum feature thickness that can be injected

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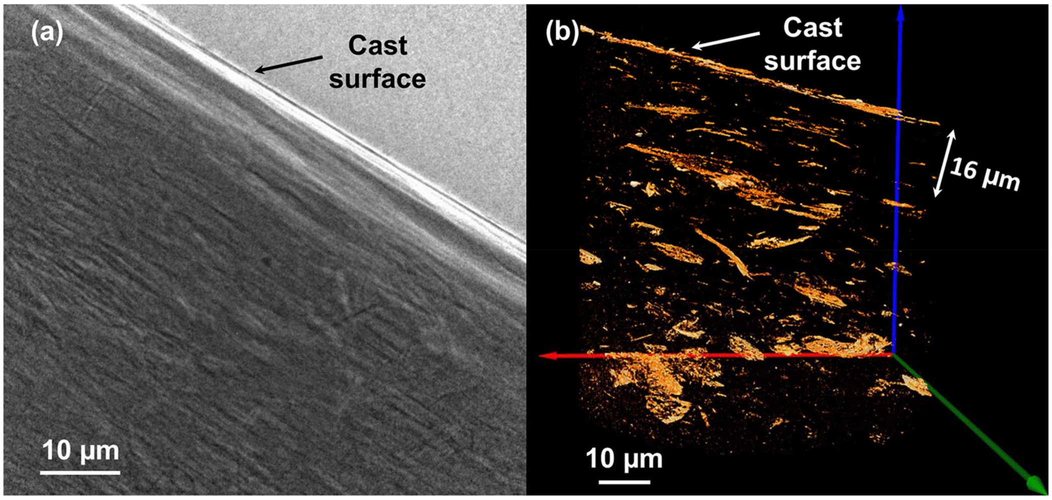

Figure 2. *(a) Radiograph from the outer edge of the molded tube. (b) 3D visualization of nanoplatelets aligned near the inner surface (flow direction indicated by green arrow).*

on a similar-scale polymer component. This shows how much scope remains for improving future injection-molded components. PET-graphene composites are part of patent-pending work at Oklahoma State University. In the future, we plan on analyzing thin-wall (<1mm) moldings to understand the formation of the skin layer as a function of mold wall thickness.

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Sudheer Bandla is a PhD candidate working in the field of polymer nanocomposites. He received his MS in mechanical and aerospace engineering from OSU, specializing in polymers. His research experience involves processing and characterization of polymers and polymer composites, and x-ray imaging and diffraction of materials.

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References

1. S. Bandla, M. Allahkarami, and J. C. Hanan, *Thermal crystallinity and mechanical behavior of polyethylene terephthalate*, in H. J. Qi, B. Antoun, R. Hall, H. Lu, A. Arzoumanidis, M. Silberstein, *et al.* (eds.), **Challenges in Mechanics of Time-Dependent Materials**, pp. 141–146, Springer Int'l Publishing, 2015. doi:10.1007/978-3-319-06980-7_17
2. S. Bandla, M. Allahkarami, and J. C. Hanan, *Out-of-plane orientation and crystallinity of biaxially stretched polyethylene terephthalate*, **Powder Diffract. 29** (2), pp. 123–126, 2014. doi:10.1017/S0885715614000190
3. H. Mavridis, A. N. Hrymak, and J. Vlachopoulos, *The effect of fountain flow on molecular orientation in injection molding*, **J. Rheol. 32**, pp. 639–663, 1988. doi:10.1122/1.549984
4. Y. Hioe, K.-C. Chang, M. G. Villarreal, and J. M. Castro, *Predicting the cycle time in injection molding as a function of the frozen layer thickness*, **Proc. SPE ANTEC**, pp. 2501–2505, 2009.
5. S. Bandla and J. C. Hanan, *Use of x-ray tomography for efficient package design*, **Proc. SPE ANTEC**, pp. 2248–2251, 2012.