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# Investigating rapid heat cycle molding

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*New molding technology affects the mechanical properties of fiber-reinforced polymer materials.*

The performance and low cost of materials containing long glass fibers (LGFs) have made them increasingly attractive in recent years for applications such as seat shells, instrument panel supports, door modules, and technical parts in a car's engine bay. The length distribution and orientation of the fibers are crucial microstructural parameters affecting the mechanical properties.[1] Stiffness and strength are especially related to the lengths of the fibers, which break during processing.[2–4] Many researchers have previously investigated, either experimentally or numerically, the effects of injection-molding processing conditions on fiber degradation and orientation.[5–7] As a result, shear stress has been identified as the main factor influencing fiber orientation and breakage.[8, 9]

At the same time, rapid heat cycle molding (RHCM) has begun to be used to enhance the surface appearance of molded parts.[10, 11] Increasing the mold temperature produces a smoother surface on fiber-reinforced molded parts. We have studied the effects of RHCM on the mechanical properties of thermoplastic fiber-reinforced injection-molded parts and used x-ray micro-computed tomography (CT) to analyze fiber orientation.

In experiments, we employed a hydraulic Battenfeld 1100kN injection-molding machine and a Variotherm system. Conventional cooling channels in the moving plate were replaced by specially designed circuits behind the cavity wall. The molded sample was a standard EN ISO 527-2 type 1A tensile test specimen.[12] All specimens were made of commercial polypropylene (Celstran) containing 30% long glass fibers with an initial fiber length of 10mm. We first studied the effect of mold temperature, sample thickness, and injection velocity on the fiber orientation tensor, which represents the fiber distribution across the sample thickness. Table 1 summarizes the temperature, thickness, and velocity conditions we investigated. We used a Nikon Metrology MCT225 system for measurements (see Figure 1)[13, 14] and calculated the fiber orientation distribution (FOD) with specialist software.[13]

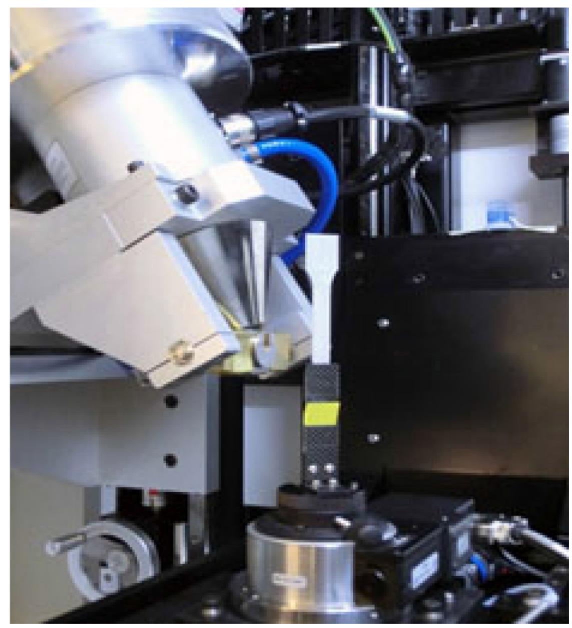

***Figure 1.*** *The molded sample fixed inside the computed tomography (CT) cabinet.*

***Table 1.*** *Factor levels*

| | | |
|---|---|---|
| **Mold temperature [°C]** | 60 | 120 |
| **Injection rate [mm/s]** | 10 | 100 |
| **Sample thickness [mm]** | 1 | 4 |

We plotted FOD averages for 4mm-thick specimens as a function of the position across the thickness: see Figures 2 and 3 for the influence of the mold temperature on fiber orientation at injection speeds of 10 and 100mm/s, respectively. The blue and red curves represent the detected FOD for mold temperatures of 60 and 120°C, respectively. Comparing these FODs reveals no significant variation, and we conclude that the injection speed and the mold temperature do not affect the fiber orientation.

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Tensile strength tests were carried out at a deformation rate of 5mm/s according to the ISO R527 standard.[15] For each combination of process parameters considered, we conducted three tests. Our results show that mold temperature, injection rate, and sample thickness all influence the ultimate tensile strength (UTS) of the samples (see Figure 4). We obtained better mechanical properties with thicker samples or by reducing either the injection speed or mold temperature. The interaction plots in Figure 5 show that increasing the injection speed reduces the influence of the thickness, but raising the mold temperature, while reducing the UTS overall, makes the effect of increasing either the injection velocity or the thickness more positive, i.e., the slopes of the plots become steeper.

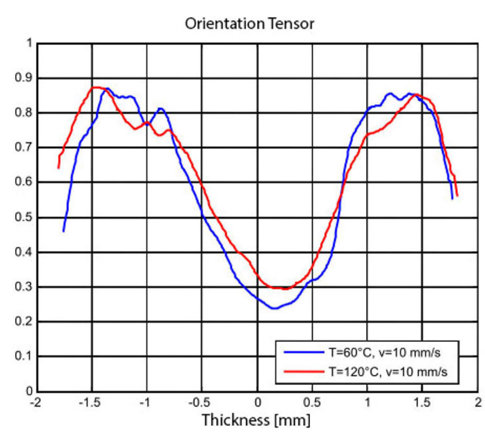


*Figure 2. Fiber orientation distribution (FOD) across the thickness of 4mm-thick (0 is at the center) samples molded at injection speed (v) of 10mm/s and temperature (T) of either 60 or 120°C.*

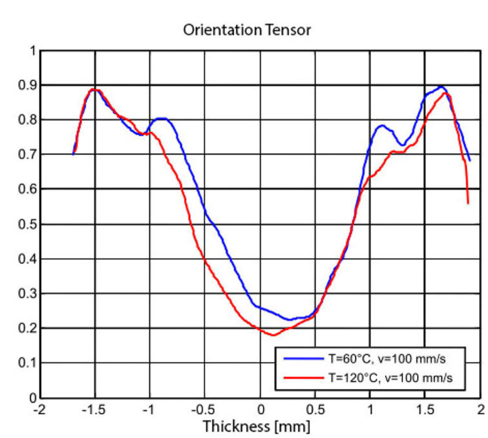


*Figure 3. FOD across the thickness of samples prepared at an injection speed of 100mm/s.*

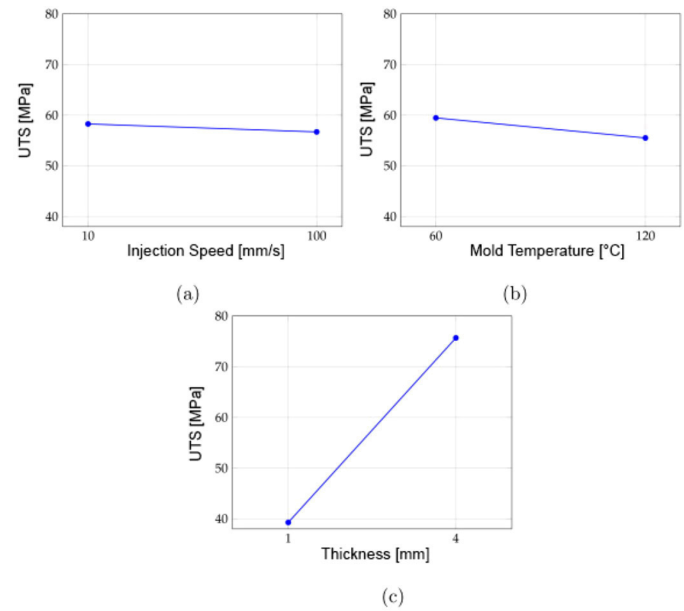


*Figure 4. Plots of the effect on ultimate tensile strength (UTS) of (a) injection speed, (b) mold temperature, and (c) thickness.*

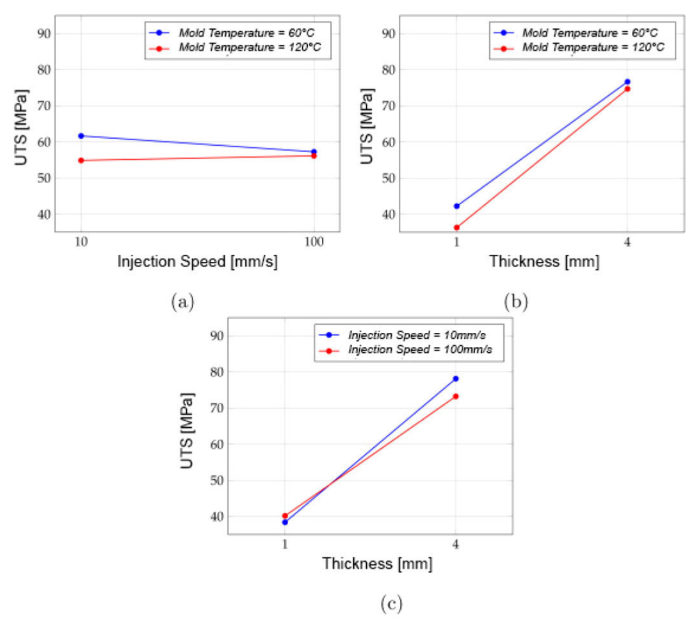


*Figure 5. Interaction plots of (a) injection speed and mold temperature, (b) thickness and mold temperature, and (c) injection speed and thickness.*

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To sum up, we carried out an experimental analysis to understand the effects of an RHCM technology on mechanical properties of thermoplastic fiber-reinforced injection-molded parts. RHCM technology negatively affects the mechanical properties. The results show that the mechanical properties are maximized by high part thickness, low mold temperature, and injection velocity. Conversely, the orientation analysis showed that the specimens' morphology is negligibly affected by a variation of the mold temperature. Therefore, the unexpected reduction in mechanical properties caused by a higher mold temperature seems not to be due to the different fiber orientation, at least concerning the qualitative analysis carried out. It is difficult to interpret the tensile test results considering that they are affected by fiber orientation, residual fiber length, material porosity, and morphology. However, since the mechanical resistance of the molded parts is directly correlated with fiber orientation and residual fiber length, we are now investigating further how these parameters are influenced by RHCM.

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Luca Crema is a doctoral student working on injection molding and in particular the aesthetic, morphological, and mechanical advantages of the RHCM process.

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