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Increasing the efficiency of plate to plate hot embossing

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A new method for plate to plate hot embossing has been developed, greatly decreasing the cycle time required for the process.

In the early 1970s, Urich and co-workers made the initial steps toward plate to plate (P2P) microscale hot embossing, a process in which microscale features are pressed into materials between two plates at high temperature.[1] In 1995, Chou and co-workers extended the hot embossing process to the nanoscale.[2] The strength of the fabrication method is its reproducibility; it is used in applications that include microneedle, microfluidic chip, and diffuser plate production.[2–4] However, the long cycle times required has meant that hot embossing technology has not been widely adopted. Indeed, conventional P2P hot embossing involves heating and cooling the mold plates during each press, and the entire process takes at least 10min (see Figure 1).[5–7] Here, we show how the cycle time can be reduced to greatly increase the efficiency of the process.

The conventional P2P hot embossing process involves five steps: the polymer substrate is placed in the mold, the mold and substrate are heated under pressure, the press is held to emboss the substrate, the mold and substrate are cooled, and the embossed polymer is removed from the mold (demolding): see Figure 1. In our new plate to plate transition-spanning isothermal hot embossing (P2P TSI HE) method, the mold plates are held at a constant high temperature.[8] The P2P TSI HE process does not require the embossing mold to be heated and cooled during each cycle and as a result cycle times are reduced to <10% of those of the conventional process.

In our process, the mold temperature is carefully chosen to ensure the polymer substrate is deformable enough to easily fill the cavities of the mold. This mold temperature is different for amorphous and semi-crystalline polymers. For amorphous polymers, such as poly(methyl methacrylate) (PMMA), the mold temperature should be near the glass transition temperature (T_g), the temperature at which an amorphous material changes from a hard 'glassy' state to a rubber-like state. For semi-crystalline polymers, such as polypropylene (PP), the mold temperature should be set above the thermal distortion temperature of the material.

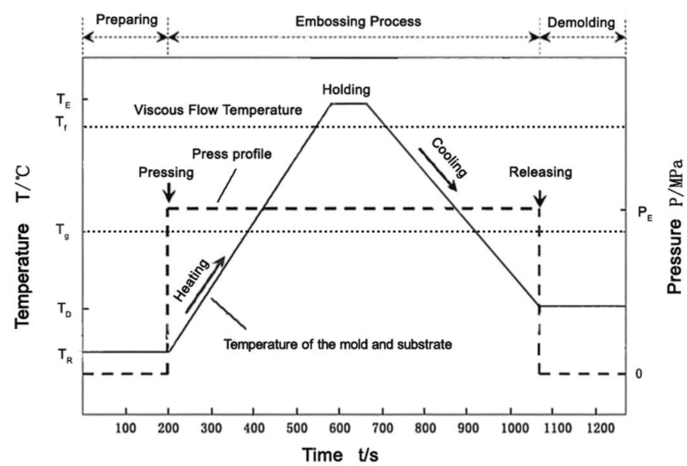

Figure 1. *The conventional plate to plate hot embossing process. T_R: Room temperature. T_D: Demolding temperature. T_g: Glass transition temperature. T_f: Viscous flow temperature. T_E: Embossing temperature. P_E: Embossing pressure.*

We use conventional hot embossing equipment for P2P TSI HE, but a considerably different temperature profile (see Figure 2). To emboss amorphous polymers using P2P TSI HE, two options are available. First, the process can be performed without preheating the substrate and using a mold temperature equal to or above its T_g: see Figure 2(a). This option might be particularly suitable for thin polymer substrates, in which the substrate is sufficiently heated by the mold in a few seconds. Alternatively, the substrate can be preheated above its T_g and then cooled slightly to a mold temperature equal to or below its T_g: see Figure 2(b).

We tested our P2P TSI HE method by embossing microscale V-shaped indentations onto PMMA substrates. We used 1mm thick PMMA sheets, constant mold temperatures between 100 and 107°C, an embossing pressure of 10MPa, and cycle times of 20–60s (2.2–6.6% of the cycle time used for the conventional P2P hot embossing process). Cross sections of PMMA samples embossed at 105°C (the T_g for PMMA) with or without preheating—shown in

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Figure 3—demonstrate that P2P TSI HE produces microscale V-shaped indentations with regular spacing and depth. These indentations closely resemble the embossing mold and the result is reproducible. The similarity of the products obtained with or without preheating the substrate is likely a result of the thickness of the PMMA samples used.

In summary, we developed a new hot embossing method (P2P TSI HE) that greatly decreases the cycle time required for the process. This efficient method produces good results using PMMA substrates <10% of the time required for conventional hot embossing. These results show that P2P TSI HE has the potential to be used in a wide range of microscale and nanoscale applications. Our future work in this area will involve adapting the process for semi-crystalline polymers such as PP. We will also investigate application of vacuum to remove air from the mold cavities prior to molding, to fabricate different microscale and nanoscale shapes (such as cuboids and hemispheres). In addition, we will investigate the mechanism of deformation and the morphology changes that occur in polymer substrates during P2P TSI HE.

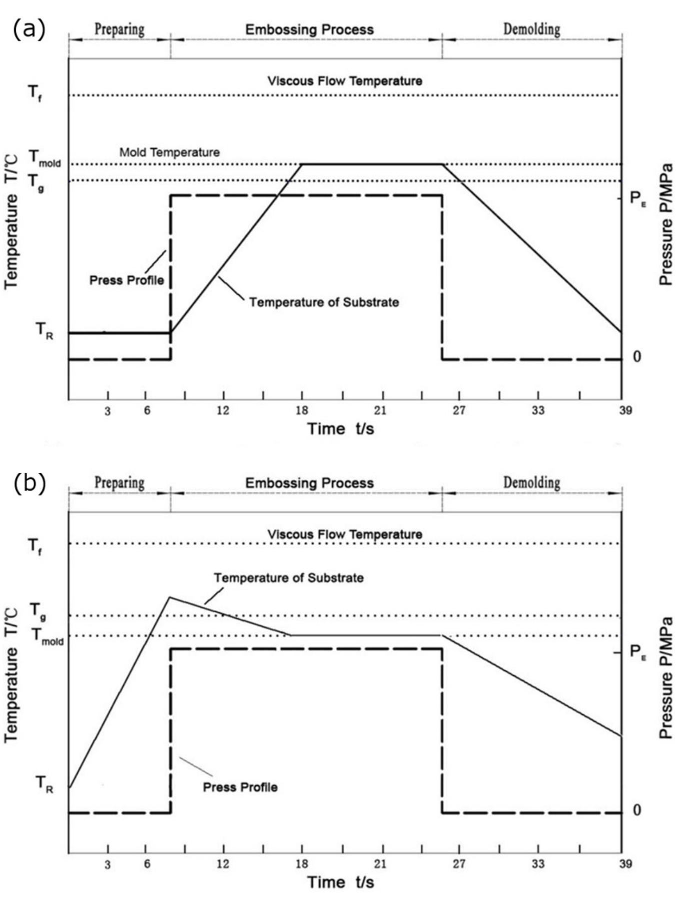

Figure 2. *The new plate to plate transition-spanning isothermal hot embossing (P2P TSI HE) process for amorphous polymers. (a) The substrate is not preheated and the mold temperature (T_{mold}) is higher than T_g. (b) The substrate is preheated and T_{mold} is lower than T_g.*

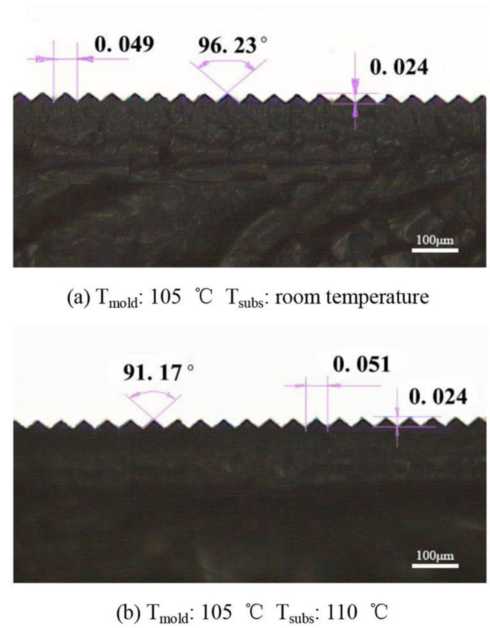

Figure 3. *Confocal microscopy images of cross sections of poly(methyl methacrylate) samples embossed with microscale V-shaped indentations using P2P TSI HE (a) without substrate preheating and (b) with substrate preheating. T_{subs}: Substrate temperature.*

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