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High Pressure and Two-Sided Mold Surface Solutions

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Manufacturing Science Division

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ABSTRACT

This project provided surface solutions for highly loaded precision tooling relevant to the automotive industry. Previous development work in coatings for Big Area Additive Manufacturing (BAAM) has produced commercialized coatings for low temperature Acrylonitrile Butadiene Styrene (ABS) tools (TD Coat RT) as well as a soft coating for high temperature applications (TD Seal HT). The team developed these coatings and commercialized them during a prior Manufacturing Demonstration Facility (MDF) technical collaboration (NFE-15-05793). During the prior collaboration, commercialization testing was successfully performed by the Boeing and NAVAIR and resulted in an Awards for Composites Excellence (ACE), award at CAMX – The Composites and Advanced Materials Expo 2016. While this work was clearly successful, gaps in the technology were identified, that prevent widespread adoption of large-scale additive manufacturing in high pressure tooling applications prevalent in the automotive industry.

In this project we focused on development of surface solutions for two-sided, compression molding tooling printed on a large-scale polymer AM system in an arbitrary build orientation. We have printed a single cavity extrusion compression molding mold using Polyphenylene sulfide/carbon fiber (PPS/CF) materials, 50% by weight CF samples. These processes are commonly used by Original Equipment Manufacturers (OEM) and Tier 1 suppliers for high volume automotive applications. Several OEMs have identified the need for such technology, indicating significant time and monetary savings could be possible if commercially available surface solutions for high pressure Additive Manufacturing (AM) tooling existed.

LIST OF FIGURES

1. OBJECTIVES

The objectives of this project are to develop:

1. Understanding of the technical requirements for high pressure/elevated temperature composite molding operations. Properties of interest include thermal conductivity, heat deflection performance, creep, surface hardness, etc.
2. Formulation and test high pressure/elevated temperature stable coatings for the two-sided tool printed in arbitrary orientation.
3. Formulation and test coatings to developed substrates targeted at the high pressure/high temperature tooling markets.

2. COMPRESSION MOLDING TECHNOLOGY DESCRIPTION

In this work, we evaluate the use of the Additive Manufacturing (AM) molds for extrusion compression molding (ECM) process, in which long fiber thermoplastic (LFT) materials (i.e., fibers with aspect ratio ~ > 100) are used to fabricate complex, cost- effective and short cycle time composite components, see Figure 1. The retention of fiber length is the main attraction of ECM as a low shear force involved in the extrusion process when compared to injection molding processes [1]. This manufacturing process combined with the use of LFTs has gained a great deal of attention from the automotive industry, mass transit, marine and other unconventional applications.

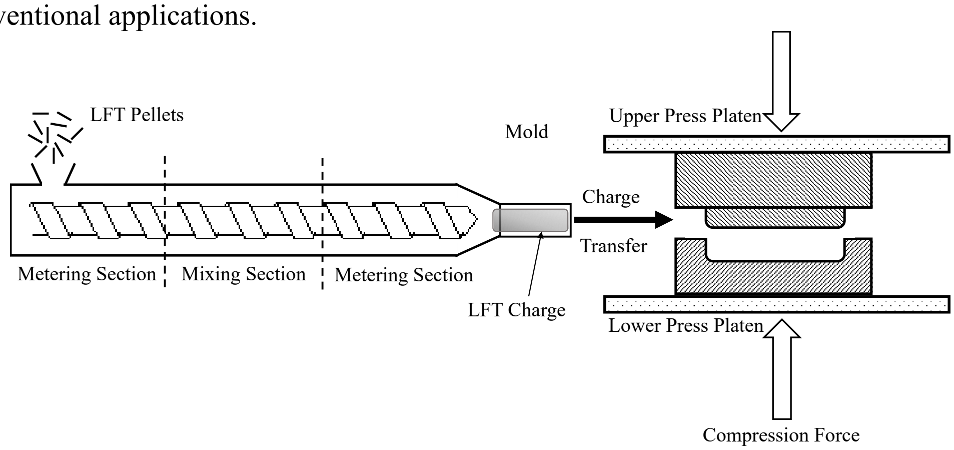


Figure 1: Schematic for extrusion compression molding (ECM) process [1]

3. AM TOOLING

Utilizing AM technology for tooling applications can significantly reduce cycle time, improve product time to market penetration, and provide cost savings. In this work we have printed a single cavity two-sided mold (17 inches x 10.5 inches) using Polyphenylene sulfide/carbon fiber (PPS/CF) materials, 50% by weight. The mold was printed using the Big Area Additive Manufacturing (BAAM) machine at the Manufacturing Demonstration Facility (MDF)/ORNL. The processing conditions for the AM tooling are listed in Table 1.

Table 1: Processing conditions for AM tooling

Nozzle Diameter (inches)	Maximum Travel Speed (inch/Sec)	Layer Hight (inches)	Screw Speed (RPM)	Bead Spacing (inches)	Temperature Profile (ºF)
0.2	11	0.1	205	0.225	581,610,620, 630,640

4. AM TOOLING PREPARATION AND COATING

Figure 2 shows a flow chart for AM tooling preparation, coating, and testing. After the tool was printed, it was machined to final desired dimensions. Note: we added 0.1 inch extra stock material for machining. The tool was then coated using TruDesign special coateimg for filling any macro or micro voids resulted either by the AM or machining processes, as seen in Figure 3. The tool then was coated with high temperature TruDesign coat, sanded to achieve a smooth surface, and then a thermal shock resistance gelcoat as seen in Figure 4.

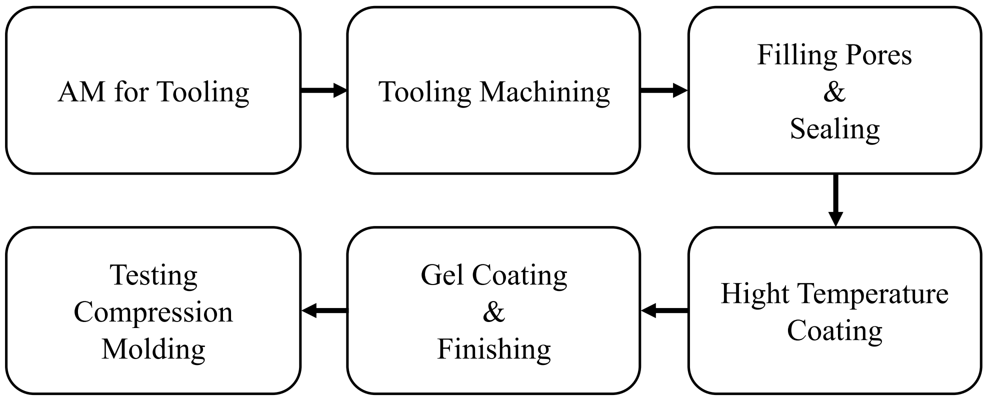
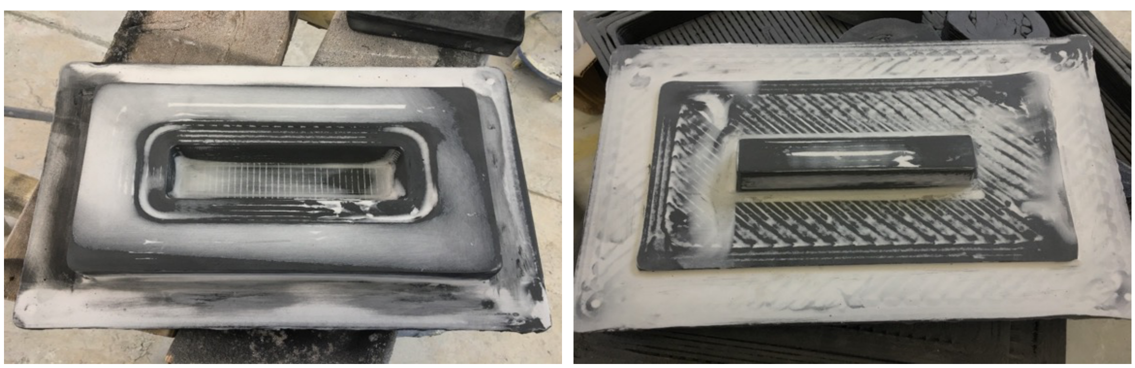


Figure 2: Flow chart for AM tooling preparation, coating, and testing



(a) (b)

Figure 3:AM tool after applying special coat for filling macro or micro voids; a) Female side, and b) Male side

(a) (b)

Figure 4: AM tool after applying special high temperature TruDesign coat, and thermal shock resistance gelcoat; a) Female side, and b) Male side

5. TESTING AND OBSERVATION

The AM tool was mounted to a compression press (Beckwood 100-ton capacity), as seen in Figure 5. LFT (i.e., 0.5 inches in length) Glass fiber (GF) / Poly- propylene (PP) with 40 % by weight glass fiber content (Provided by Celanese Corporation) was used. The GF/PP pellets were fed to a single screw extruder to produce a viscous charge. The extrusion temperature was 385 F, 400 F, 420 F, 420 F for Zone1, Zone 2, Zone 3, Zone 4 respectively. The charge size was 6 inch in length. The charge was transferred to a closed cavity AM mold mounted in the press. We have evaluated several molding tonnages ranging from 2 Ton, 5 Ton, and 10 Ton. A dwell time of 60 sec was set before the composite plates were demolded. The mold was used to fabricate 15-20 composite parts.

Figure 6 shows the GF/PP molded part using the AM tooling. The image shows flash material (extra material) squeezed out of the cavity due to the lack of shear edges in the tool. This resulted in increase in gap between male and female mold (tolerance) during the molding process.

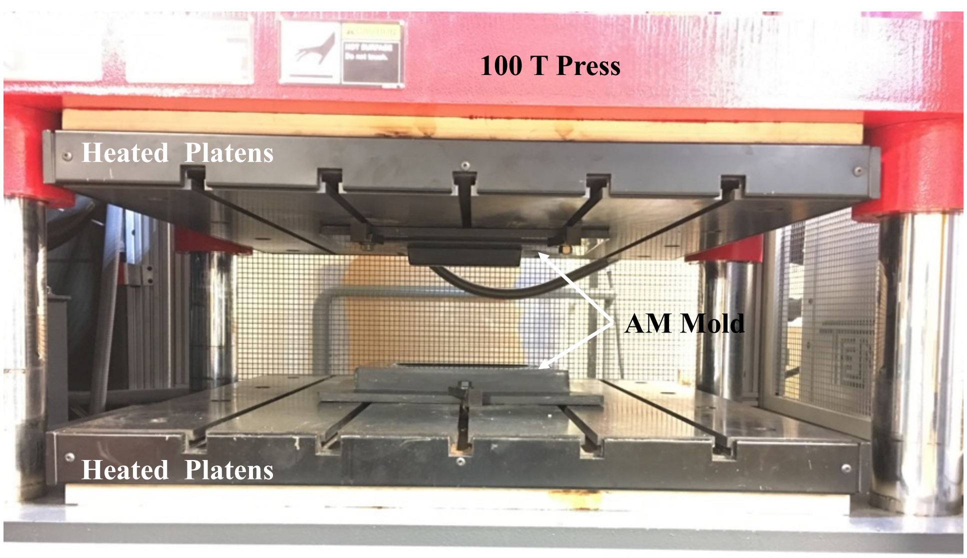


Figure 5: Compression molding setup

Figure 6: GF/PP molded part using the AM tooling. The image shows flash material (extra material) squeezed out of the cavity due to the lack of shear edges in the tool

After molding 15-20 parts we have noticed that the tool was retaining heat (around 145 F) after each run. It needs to be noted that the molten hot charge (~ 400F) and low cycle time resulted in the heat buildup as the tool is not heated. The difference between the tooling temperature and the molding plastic is high and resulted in a small surface crack (~ 1.5 inches) as can be seen in Figure 7.

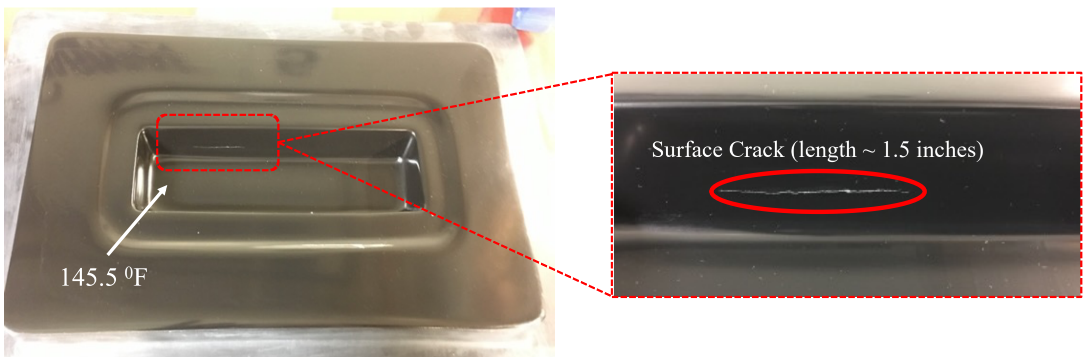


Figure 7: AM tool with relatively small surface crack after15-20 parts molded under compression molding

Even though that a thermal shock resistance gelcoat was used, it was observed that this coat was cracked and there is a need for development for a specialized gel coat that can withstand the large thermal profile of the tool. Also, a need for embedded heating system such as cartridge heater, or heating fluid channels is needed to control this thermal gradient.

6. CONCLUSIONS

The technology of high pressure two sided additively manufactured tooling is in its early stages of development. Fundamental issues of toolpath induced anisotropy, porosity and low thermal conductivity limit wide spread application of this technology. Under this CRADA, tool surface solutions were investigated with parts being successfully molded.

7. REFERENCES

1. Haibin Ning, N.L., Ahmed Arabi Hassen, Krishan Chawla, Mohamed Selim, Selvum Pillay, *A review of Long fibre thermoplastic (LFT) composites.* International Materials Reviews, 2020. **65**(3): p. 164-188.