A NEW HP-RTM MATERIAL TECHNOLOGY FOR AEROSPACE COMPOSITE PARTS: *WILL IT FLY?*

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Used widely across applications within industries such as aerospace, automotive and alternative energy, carbon-fiber reinforced polymer composites offer excellent mechanical properties, especially strength-to-weight and stiffness-to-weight ratios. While light-weighting is a notable advantage of composite parts, the production costs have historically been higher per kilogram than components designed using metals/alloys. This cost differential is, among other factors, due to long processing times and the complex, expensive autoclave curing equipment required for conventional prepreg technology, particularly for primary, and secondary structures, as well as future Urban Air Mobility applications in which high-rate composite manufacturing technology will be critical.

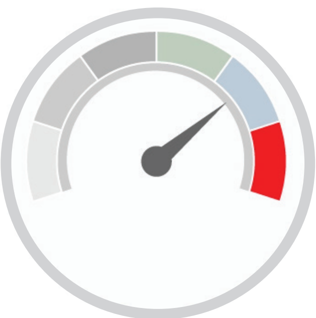
To facilitate broader use of composites, new material technology and processing techniques that enable lower-cost, higher-efficiency production as compared to prepreg methods have been developed. Liquid composite molding (LCM) using a resin transfer molding (RTM) technique has demonstrated many advantages over prepreg process. By definition, RTM is 'the injection of liquid resin with pressure or under vacuum into a prearranged reinforcement material or preform, which are contained in a close mold die'. The benefits of RTM include increased production output, lower-cost processing and more environmental consciousness than autoclaves' resource-intensive use. Though permeability and resin flow challenges with RTM and other LCM techniques have been recognized as potential drawbacks, Henkel has formulated a portfolio of matrix resins that help overcome these issues to deliver robust manufacturing combined with high mechanical and thermal performance, as well as excellent surface qualities.

In testing, Henkel's two-component materials LOCTITE RI 9501 AERO and LOCTITE RI 9502 AERO exhibited the following characteristics, which resulted in improved process flexibility, and reduced 'on tool' time for higher rate manufacturing:

Optimized resin systems and a high degree of cure, with 'on tool' cure time of 10-20 minutes, followed by freestanding post cure (reducing tooling downtime) of 60-240 minutes, depending on glass transition (Tg) requirement. Resin rheology with flow characteristics and viscosity stability enabling thorough preform impregnation, maintaining properties for the time required to ensure complete mold filling.

Excellent mechanical properties including tensile modulus, compression modulus, Tg, and hot/wet Tg. Composite properties consistent with aerospace secondary structure requirements, and excellent surface quality.

These characteristics, combined with advances in 3D woven preform architecture and porosity, ideal processing conditions, mold design and part geometry considerations, were able to produce test components that meet the challenging mechanical standards for aerospace secondary structures, while significantly reducing processing time. However, continued efforts to accelerate aerospace sector production speeds are warranted, as applications expand and build rates increase.



THE PRESSURE'S ON: EVEN FASTER RTM

Much of the current challenges with HP-RTM adoption within the aerospace industry have been resin-related. For the resins to align with HP-RTM equipment and processes, the viscosity must be low enough (< 200cP) to allow good flow within the mixing unit, with rapid and even distribution within the fiber preform. Due to safety critical applications many resin systems used in aerospace prioritize mechanical properties, employing toughening agents added to the formulations. These toughening agents, however, can have a detrimental effect on resin rheology, increasing viscosity, resulting in poor compatibility with HP-RTM processing. Presented in this work is a modified resin system that effectively addresses these formulation characteristics, in combination with compatible fiber and optimized process parameters, offering a viable substitute for conventional prepreg techniques and conventional RTM.

Leveraging extensive expertise in resin and carbon fiber technology, with equipment and manufacturing know-how, Henkel, Teijin, Krauss Maffei and Advanced Manufacturing Research Center (AMRC) at The University of Sheffield collaborated on a project to study these low viscosity resin systems and their capabilities within a high-pressure resin transfer molding (HP-RTM) process to evaluate the viability of accelerated production rates of complex composite parts for aerospace secondary structures.

PUTTING THE RESIN TO THE TEST

AMRC's facility has a customized HP-RTM system manufactured for the academic research institute by Krauss Maffei. (Figures 1 & 2) The flow of resin and hardener is controlled using up to four mixing heads that facilitate fast injection of material into complex parts. Resin and hardener are stored in tanks and fed into the system through heated hoses and then into the mixing heads. Stability of the materials within the tank, through the hoses and inside the heads is critical to in-mold performance and finished part integrity. A 1,000-ton press (Figure 3) located at AMRC was used for the HP-RTM analysis to close the tooling and resist injection forces within the tool cavity. The technology design of the self-cleaning mixing heads to control pressure and resin weight is critically important, as the flow of the resin and hardener into the tool must be balanced. Non-crimp carbon fiber fabric with 12K fiber was supplied by Teijin and used in this evaluation.

BEST PARAMETERS

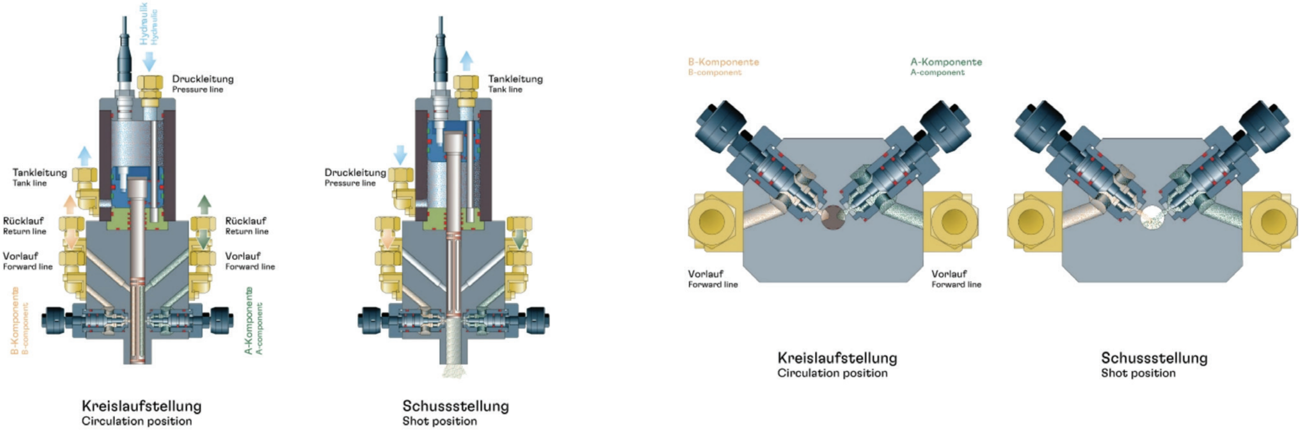
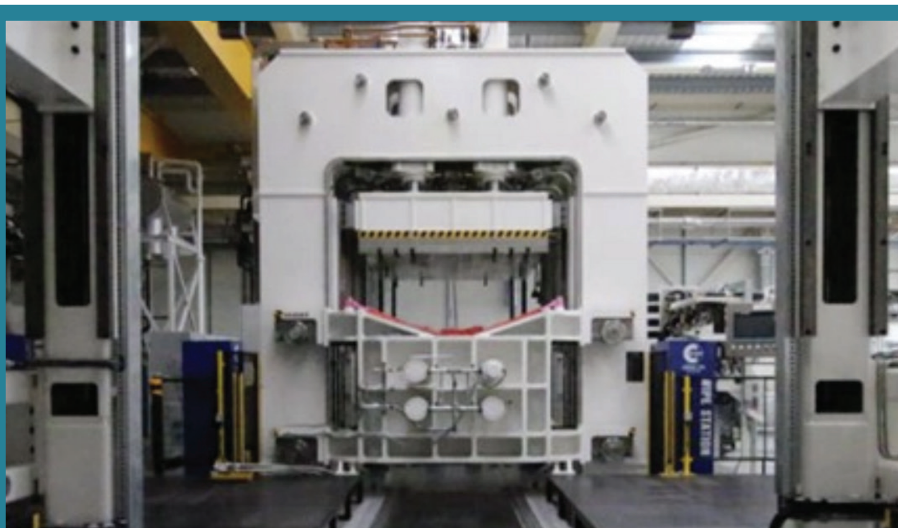


FIGURE 1 & 2:
Krauss Maffei mixing head: This Krauss Maffei impingement mixing process was used to mix the A and B components of the LOCTITE RI 9501 AERO infusion system.

To establish optimized press force, injection resin weights and flow rates, initial trials were conducted to confirm the best parameters. Ultimately, it was discovered that a resin flow rate of 20g/sec. (vs. the initial 45g/sec.) produced good results and allowed desired injection weights without creating pressures incompatible with the HP-RTM system or significantly affecting the total manufacturing time.

FIGURE 3:
Rhodes 10MN Press: 1000-ton hydraulic press used to close the HP-RTM tooling.



STRONG PERFORMANCE

The Henkel resin's Tg and degree of cure were measured with DMA and DSC from samples following initial cure after demolding and post-cure before mechanical testing. The results are very encouraging:

Test panels, one of which is shown in Figure 4, demonstrated a 95% degree of cure or greater immediately following molding. This may allow the potential to perform rapid cures in the mold without requiring additional post-curing.

Henkel LOCTITE RI 9501 AERO's Tg also had little difference between initial and post-cure when used in HP-RTM processing.
While the results of this study indicated dry Tg values @ 175-185° C, which are slightly lower than conventional prepreg/autoclave results, this material has exhibited post-cure dry Tg values of 230° C and hot/wet Tg of >160° C using a standard infusion method, indicating its typical capability. The reduction in Tg is due to the binder compatibility issues with the Henkel infusion resin.

The lack of voiding observable in microscopy analysis, and the even distribution of resin and fiber, is encouraging. Tool vacuum played an integral role in this result through injection and cure.
In general, all mechanical properties tested such as tensile strength, open hole compression, open hole tension and short beam shear were comparable to the performance of conventional low-pressure RTM and prepreg.

STRONG PERFORMANCE

Overall, as evaluated within the parameters of the AMRC testing, this resin system shows excellent compatibility with the HP-RTM process and demonstrates its viability for producing aerospace secondary structure components consistent with the mechanical specification for in-flight integrity. In this work, cure temperatures of 140° C and up with ten-minute cure times produced poor-quality components. Therefore, based on the AMRC analysis demonstrating cure times of 120° C for 20 minutes with a 96% demolded state of cure, it is conceivable that the post-cure could be reduced or eliminated. Initial testing outlined in Table 1 exhibits very comparable combined loading compression results for no post cure vs. post cure. Once validated, the Henkel resin combined with Krauss Maffei HP-RTM equipment has the potential to accelerate aerospace carbon-fiber reinforced polymer composite parts production rates significantly compared to infusion and prepreg processes.

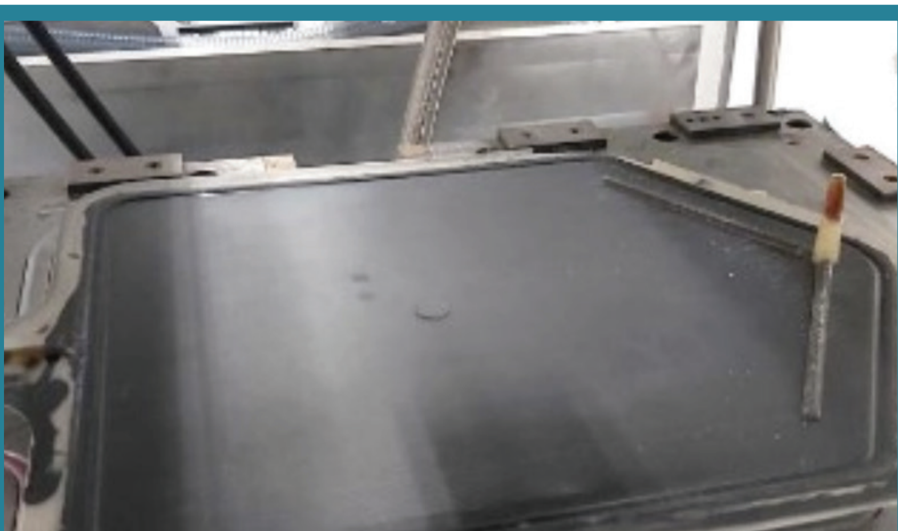
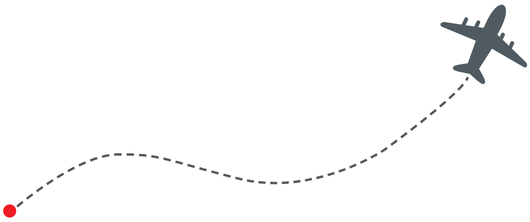


FIGURE 4:
Panel made from HP-RTM Process with AMRC and Henkel's LOCTITE RI 9501 AERO.

	% DEGREE CURE		COMBINED LOADING COMPRESSION (KSI/MPA)	
Panel ID	No Post Cure	Post Cure	No Post Cure	Post Cure
PF 23	96	97	59/407	67/459
PF 25	98	98	49/337	55/337
PF 29	92	100	67/464	67/461
PF 30	95	100	65/450	69/474

TABLE 1:
Degree of Cure and Combined Loading Compression (ASTM D6641).



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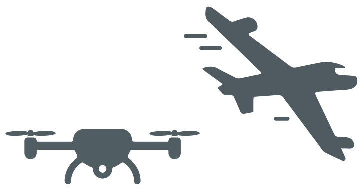

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