Dynamic Fluid Compression Molding

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As part of its effort to produce lighter-weight vehicles, the automotive industry is seeking to incorporate more structural composite parts in new-generation designs. A key to cost-effectively mass-producing high-performance composite parts is the utilization of advanced resin systems and production processes.

Through several years of research, Huntsman recently introduced a rapid-cure ARALDITE® epoxy system formulated for use with a wet compression molding process known as Dynamic Fluid Compression Molding (DFCM). The process utilizes low-pressure injection, produces high-quality, void-free parts, reduces cycle times to as low as one minute and eliminates the need for post-curing. The resin system exhibits excellent flowability yielding parts with fiber volume contents of more than 65% and virtually no porosity even on deep-draw and highly contoured designs.

About Huntsman

With over 60 years' experience developing composite resin technologies for use in a variety of processes including compression molding and resin transfer molding, Huntsman is uniquely qualified to support automotive design engineers in their lightweighting efforts. Specifically, our chemists and research scientists have been working with automotive OEMs and their suppliers including BMW and Lamborghini to develop resin systems that support fast cycle times to cost-effectively produce composite parts with outstanding mechanical performance.

Introduction

Composite parts have been produced via processes such as resin transfer molding (RTM) for years. In RTM, liquid thermoset resins are injected under low pressure into a fiber reinforcement in a closed mold. Typical injection pressures limit injection speed producing part cycle times of greater than 15 minutes for small parts and several hours for large parts. High part complexity and function integration are possible, but the cycle time limits the process to low-volume production. (See Figure 1.)

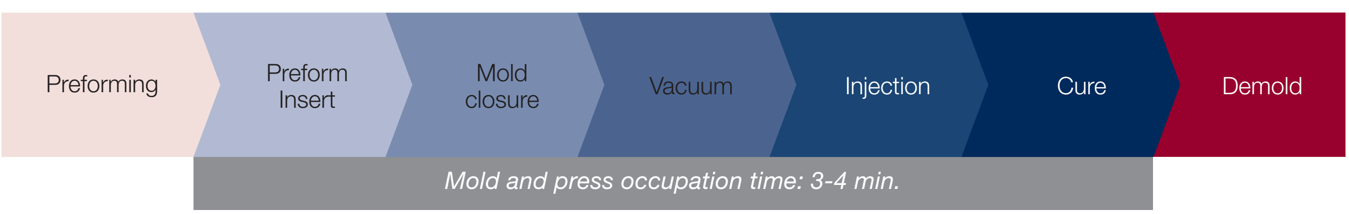
Figure 1. Resin Transfer Molding Process

When resin injection pressures are increased, as in high-pressure resin transfer molding (HP-RTM), cycle times for small composite parts are reduced to less than five minutes. For example, Huntsman's ARALDITE® LY 3585 epoxy resin/ARADUR® 3475 hardener produces high-quality structural composite parts with a complete HP-RTM cycle time of about 4 minutes. Process temperature is 239°F (115°C) with a one-minute injection time and two-minute curing time. Resulting carbon composite parts have a fiber volume content (FVC) of 50% with no voids. A more than 95% cure conversion makes post-curing unnecessary. (See Figure 2.)

The ability to further reduce HP-RTM cycle times has been a challenge for fabricators because of the long resin injection paths required for full fabric impregnation. Other disadvantages of HP-RTM have been the cost of vspecial high-pressure mixing/ dispensing equipment along with the required heavy molds and presses. Moreover, the process usually utilizes a preform in which layers of fiber reinforcement are bonded together using a binder in order to prevent movement during injection (fiber wash). Preform manufacture adds an additional step in the production process and often does not always completely eliminate fiber wash.

Figure 2. High Pressure Resin Transfer Molding Process

State-of-Art HP-RTM



A third process used for building composite parts, wet compression molding (WCM), is the fastest existing industrial scale composite molding process. In WCM, liquid resin, such as Huntsman's ARALDITE® LY 3585 epoxy resin/ARADUR® 3475 hardener, is applied to a fiber reinforcement. The wet composite is placed in an open mold and the mold is closed, pressing the resin into the fabric. Excess resin is used to push entrapped air to the sides of the part into special overflow channels. Since impregnation of the fibers is largely vertical (through-thickness), thermoset resin systems with shorter gel times (higher reactivity) can be used. Processing temperatures can also be increased to reduce cure time. A further advantage of WCM is that the through-thickness impregnation significantly reduces fiber wash, so a fiber preform may not be necessary. However, the method has a number of drawbacks including high laminate porosity, relatively high resin waste and the inability to build highly contoured or deep draw parts. (See Figure 3.)

Figure 3. Wet Compression Molding Process

Wet Compression Molding

New Dynamic Fluid Compression Molding with Fast-cure Epoxy

In an effort to minimize cycle times for cost-effective mass-production and, at the same time, produce high-quality, structural composite parts, Huntsman began investigating the use of a new process. Dynamic fluid compression molding in combination with a new fast-curing liquid epoxy, ARALDITE® LY 3031/ARADUR® LY 3032 resin system, demonstrates significant improvements over the traditional processes outlined above, including:

- Production cycle time of less than one minute
- Fiber volume content of greater than 65% without visible fiber wash or porosity
- Ability to produce complex three-dimensional geometries (including deep-draw parts)
- High (>95%) cure conversion rate with a 30-second cure time
- No post-cure
- No preforms for many projects
- Minimal equipment/tooling costs
- Composite parts with no voids and excellent mechanical characteristics

In the DFCM process, ARALDITE® LY 3031 liquid epoxy resin is mixed with ARADUR® LY 3032 hardener and injected under vacuum and via low pressure into the mold to wet-out reinforcing fabric. (See Figures 4 and 5.)

Figure 4. Dynamic Fluid Compression Molding Process

DFCM

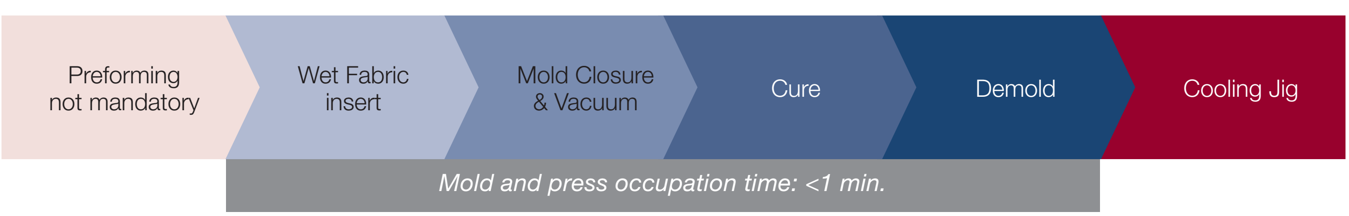
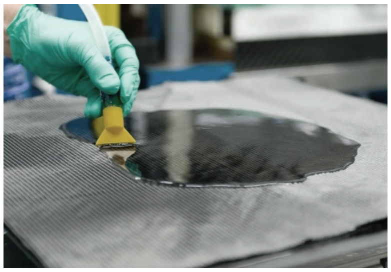
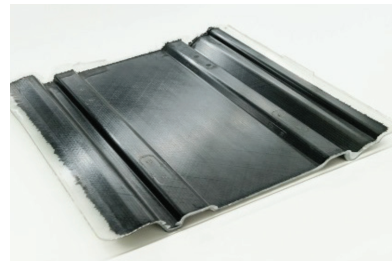


Figure 5. Photos of DFCM Production Process



Apply epoxy to fiber reinforcement

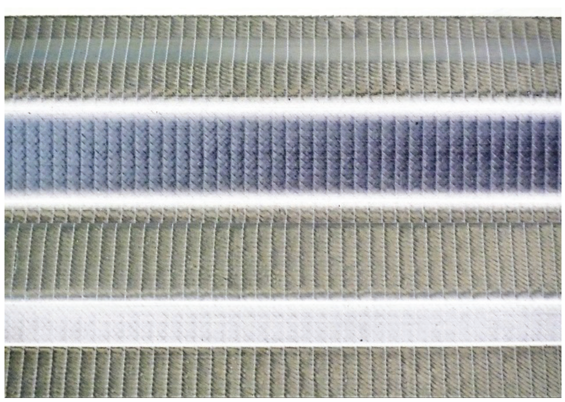
Install wet-out part in mold



Completed high-quality panel

Comprehensive testing was performed on the completed DFCM composite parts. When panels were subjected to micrographic studies, neither voids nor porosity were noted. Furthermore, results demonstrated that with the one-minute cycle time, it was possible to produce void-free composite parts with up to 67% FVC. It was also found that fiber displacement/misalignment during molding was minimal, even when a fiber preform was omitted, offering a significant advantage when compared to the HP-RTM process.

Figure 6. Fiber Alignment



Completed parts exhibited no fiber wash

Mechanical properties of DFCM molded ARALDITE® LY 3031 epoxy resin/ARADUR® LY 3032 hardener parts were also excellent and comparable to those built via HP-RTM. Glass transition temperatures were greater than 212°F (100°C) in all cases. Interlaminar shear strength values were consistently greater than 9,200 psi even when varying cure schedules were utilized. Charpy impact strength was in the 137–147 kJ/m^2 range. (See Table 1.)

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Table 1. Properties of ARALDITE® LY 3031/ARADUR® LY 3032 Epoxy With DFCM Process

Resin: ARALDITE® LY 3031		100 parts		
Hardener: ARADUR® 3032		21 parts		
Internal release agent		1.5 parts		
	Test Method	Unit	266ºF (130ºC) Cure	284ºF (140ºC) Cure
Cure (1)		seconds	45	30
DFCM cycle time (2)		seconds	75	60
Carbon fiber composite 0.08 in. (2mm) plate				
Vf	Calculated	%	57	57
Visual aspect			High surface quality / no visible defects	High surface quality / no visible defects
Cure conversion	ISO 11357-2	%	>98	>98
DSC Tg		ºF (ºC)	243 (117)	244 (118)
DMA Tg onset	ISO 6721-4	ºF (ºC)	219 (104)	219 (104)
Charpy impact resistance	ISO 179	kJ/m²	147	137
Interlaminar Shear Strength	ASTM D2344	psi (MPa)	9,282 (64)	9,427 (65)

(1) Cure time when press fully closed *(2) Total press occupation time including closure + opening*

Summary

The Dynamic Fluid Compression Molding process utilizing fast-curing ARALDITE® LY 3031 epoxy resin/ ARADUR® LY 3032 hardener produced high-quality composite parts quickly making the opportunity for mass-production a reality.

When compared with HP-RTM, the new process reduced press cycle times, using lower pressures to decrease required equipment investment costs. Moreover, parts were molded without a preform, yielding a >67% fiber content with virtually no voids or porosity, and exhibiting excellent mechanical properties.

Compared with WCM, the new DFCM-produced parts were of significantly higher quality with virtually no voids or porosity. The new methodology permits the fabrication of parts with deep draws and complex contours and, with lower required injection pressures, reduces investment costs. Resin and fiber waste is also minimized.

Initial testing by leading automakers indicates great promise for the new resin and DFCM process in providing for cost-effective production of composite parts in volume quantities.

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