Polyurethane Structural Composites: An Innovative Process Using In-Mold Decorating Films for Exterior Vehicle Parts.

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Abstract

The Woodbridge Group continues to progress with innovative composite technologies for high performance applications, encompassing its extensive expertise in the PU fields, as well as its growing experience in composites.

This paper presents a novel fabrication technology of PU Composites applicable for vehicles.

The novel technology is based on an open mould pouring process that allows the usage of relatively low cost tooling, low tonnage presses as well as a high level of component integration and process automation for the production of performance products. The process eliminates the need of in-mold or post-painting of the finished part, by integrating in the composite structure a high performance film as a decorative exterior layer, that provides a high quality surface resistant to environmental factors.

The new process allows the fabrication of relatively thin, lightweight, structural composite with flexural modulus in the range known in other technologies as Polyurethane Structural Reaction Injection Moulding (PU-SRIM) and Sheet Moulding Compound (SMC), with Coefficient of Linear Thermal Expansion (CLTE) compatible with the In-Mould Decorating (IMD) films. The specific gravity of the part, dependent on composition, is lower than for similar strength products manufactured via PU-SRIM or SMC. End-product performance easily matches or exceeds the requirements of general transportation or other similar applications.

Background

All current commercial composites offer a range of balanced product properties through a diversity of manufacturing technologies. However, independent of the fabrication method, the finished part needs a separate process step in order to achieve the optical surface quality required by the final application. Thus "surface painting" becomes part of the process, either at the time of moulding, like in In Mould Coating (IMC), or at the finishing stage, as in "post-painting". An additional difficulty may be presented by parts that need a built-in structural reinforcement causing an optical degrading, "read through" effect.

A short analysis of the most representative technologies for polyurethane based structural composite follows:

Structural Reaction Injection Molding (SRIM):

- A mature technology in which (pre-shaped) long fiber reinforcing structures pre-located in a mould are encompassed in a polyurethane (PU) nascent mass that is injected into the cavity.

- The liquid injection generated pressure in the closed mould assures the wetting of the fiber mass.
- Needs a relatively high clamping pressure and appropriately built strong mould
- The SRIM process is relatively fast but part surface quality remains questionable.
- A recent variant of SRIM provides, after the injection in a partly closed mould, a pressing effect that helps the wetting of large area reinforcements and assures subsequent surface quality improvements.
- SRIM is not yet compatible with automotive class-A- surface quality.

CompurTec™ / Baypreg™

- The wetting of fibers or other structural elements with the polyurethane precursors starts outside of the mould cavity.
- It is a two step process using special PU chemical systems (Bayer). The part is formed in a heated mould.
- It generates relatively low specific gravity composites within a specific range of mechanical properties.
- A polyurethane elastomer is generated that forms the outside surfaces of the finished part and provides different degrees of polymer penetration towards its core.
- Baypreg is not compatible with automotive class-A- surface quality.

StructureLite Excel™

- A technology developed by WFC that consists of pouring a polyurethane chemical system, in a completely open mould over a pre-located structural reinforcement.
- The bowl capacity assures the volume holding of the chemical system and once the mould is closed it controls its eventual expansion.
- A reinforced structure is generated with PU rigid foam as the encompassing and holding mass; PU elastomer systems may be used to improve the surface appearance and performance.
- The technology has some limitation with regard to the amount or type of structural reinforcing fibers that have to be wetted out by the generated foam.
- Not compatible with automotive class-A- surface quality.

The common problem with the presented technologies is their inability to create, in a one step process, a real structural part and to produce a high quality finish surface at the same time.

The Enhanced WFC Approach

The development work was oriented to extend the capability of WFC proprietary process. This novel process improves the product without negatively impacting our original process.

The technology is an open mould pour that produces thin, high Flexural Modulus PU composites characterized by:

- A substantially increased percentage weight of reinforcement.
- Compatibility with a large variety of reinforcing structures or fibers (polymeric/synthetic, natural or inorganic).
- In-mould, final optical quality, surface generation based on pre-located sheets of Thermoplastic, Thermosets / Polyurethane Elastomers or Metal.

- Additional characteristics provided by the specific reinforcing agents.
- Potential for automotive class-A surface in a one-step moulding process.

The process is schematically presented in Figure 1.

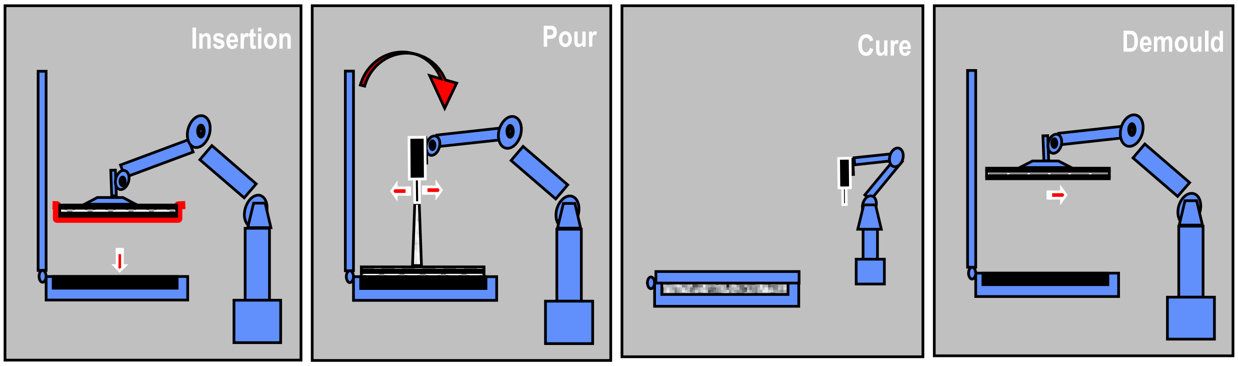

Figure: 1 Process Schematics

Several variations are possible, with the exterior skin being inserted (after thermoforming) or created inside the tool as an elastomer and/or in mould coating (IMC).

Figure: 2 Open Mould Pour

Materials Typically Used

Polymer Matrix

- Rigid PU Foam

Reinforcement

- Synthetic fibers
- Natural fibers

- Inorganic fibers (Fiberglass, Metal, Mineral)
- Any combination of the above.

A large variety of reinforcement materials and constructions were evaluated. Some results are presented in Table 1.

The evaluation was conducted using a flat plaque test tool fitted with different inserts for thickness variation. The reinforcement content was varied from 10% by wt. to 66% by wt. generating Flexural Modulus up to 10,000 MPa at Specific Gravity in the range of 0.25 to 1.45.

Thermal stability was evaluated as CLTE and Heat Deflection Temperature (HDT). The CLTE can be adjusted in a wide range, from values similar or lower than SMC or S-RIM (10-15 $x10^{-6}$ m/m°C) to values common for thermoplastic materials (50-80 $x10^{-6}$ m/m°C). HDT was measured in the range of 210-240°C.

Table 1: Various Composite Constructions

Sample	Thickness	Reinforcement		Specific Gravity	Flex. Modulus	Specific Modulus
	mm	Type	%		MPa	MPa
1	6.5	Bi-axial Stitched Fabric (0-90)	37%	0.84	3448	4104
2	6.5	Bi-axial Stitched Fabric (0-90)	51%	1.16	5915	5099
3 P	6.5	Bi-axial Stitched Fabric (0-90)	51%	1.04	7862	7560
5 P	6.5	Bi-axial Stitched Fabric (0-90)	62%	1.45	9960	6869
6	6.5	Random Continuous Filament Mat	25%	0.60	1861	3101
7	6.5	Random Continuous Filament Mat	55%	1.05	4771	4544
8	6.5	Random Continuous Filament Mat	66%	1.30	7267	5590
9	6.5	Woven Fabric	35%	0.76	3601	4738
10	6.5	Woven Fabric	51%	1.04	5923	5695
11	6.5	Woven Fabric	59%	1.30	7611	5855
12	6.5	FG / Paper Honeycomb	24%	0.73	3036	4159
13	6.5	FG / Al Honeycomb	25%	0.72	4597	6384
14	13 mm	FG - Various	19%	0.63	1517	2407
15	13 mm	FG - Various	34%	0.67	4137	6174
16	26.5 mm	FG - Various	10%	0.25	527	2109
17	26.5 mm	FG - Various	20%	0.34	689	2028
18	26.5 mm	FG / Paper Honeycomb	16%	0.46	1651	3588
19	26.5 mm	FG / Al Honeycomb	21%	0.33	1273	3857

P – IMD/Paint film exterior surface

Figure 3 shows the general dependence of the Flexural Modulus vs. the fiberglass content, while Figure 4 exemplifies the range of Flexural Modulus achieved with various constructions.

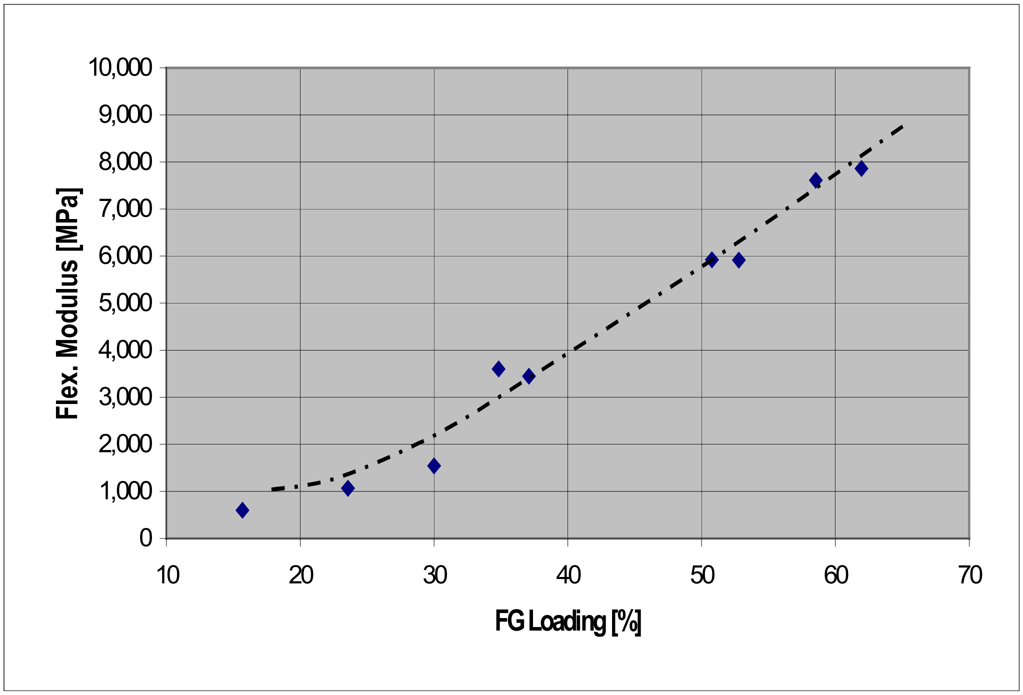

Figure 3: Flexural Modulus vs. % Reinforcement (6.5 mm flat panel)

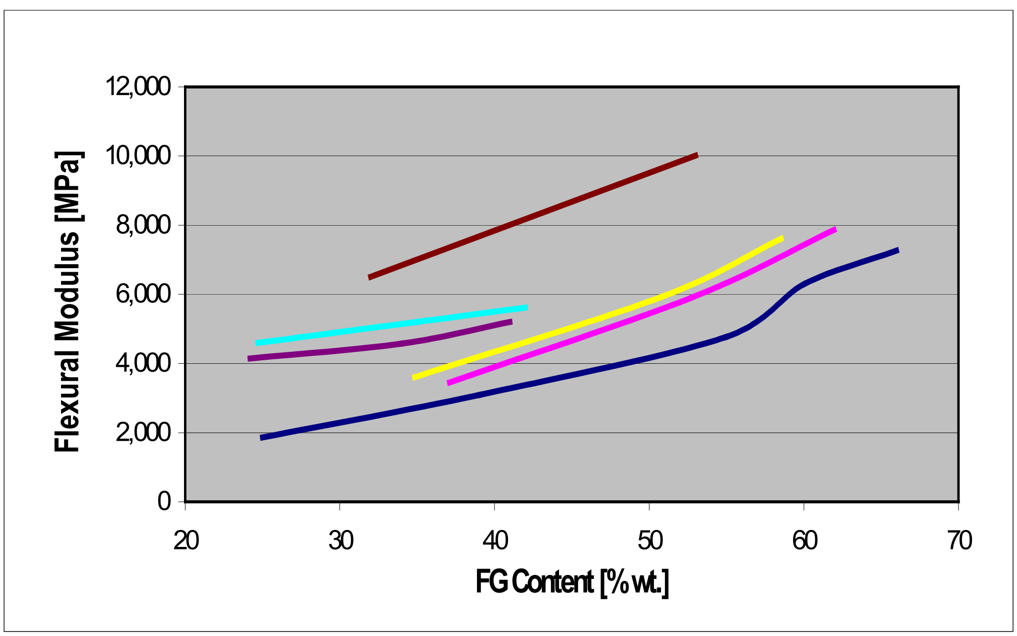

Figure 4: Effect of Composite construction on Flexural Modulus
Random CFM, Bi-axial stitched 0-90º, Woven , Random CFM with Al honeycomb, Random CFM with paper honeycomb, Bi-axial with Al honeycomb

Quality Surface through:

- In Mold Coating - PU (IMC)
- PU Elastomer application
- Thermoplastic sheets
- Thermoset sheets
- Metal foil
- IMD films, for a class-A surface quality

The developed technology allows the incorporation of various materials to create the part exterior surface.

IMD films were investigated in the current technology as an alternative to create high quality finished surfaces for automotive or non-automotive applications.

Preliminary experiments were conducted in the plaque tool to evaluate adhesion, mechanical properties and thermal/dimensional stability. In the next step, a tool with an appropriate finish was used to experiment with various IMD films and core constructions. A simple tool geometry allowed using the IMD film without prior thermoforming.

The surface quality was evaluated through gloss measurements using Gardner Micro-TRI-gloss meter at 60^o angle. The initial gloss of various commercially available films used is presented in Figure 5. The films differed in type, backing, thickness and color.

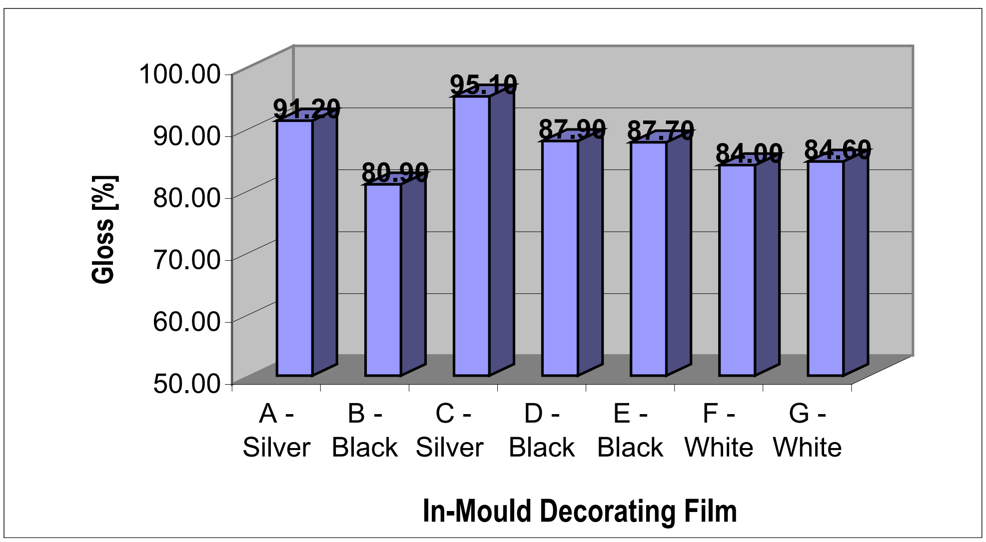

Figure 5: In-Mould Decorating Films – Virgin Film Gloss Measurements

The IMD films have a multi-layer construction generally consisting of: a top clear layer, colored layer and a base layer. The chemical nature of each layer varies depending on supplier and application. The material used in our experiments were on a PC or ABS base, the colored and top layer being PMMA or a fluoropolymer.

The films were used to produce finished parts in a proper tool, then evaluated for surface quality visually and through gloss measurements. The parts were tested for change in surface quality during thermal cycling. Each cycle consisted of exposing the sample for: 2 hrs. @ 85 ± 2^{o}C, cooling down to room temperature for 2 hrs. followed by exposure to –20^{o}C for 2 hrs. and recovery at room temperature for 2 hrs.

Gloss measurements were made using a Gardner Micro-TRI-gloss meter at a 60° angle, only after the sample had recovered at room temperature for 2 hrs. Results of the gloss measurements during thermal cycling are presented in Figure 6. No significant change in the gloss or the surface visual quality versus the virgin film was observed.

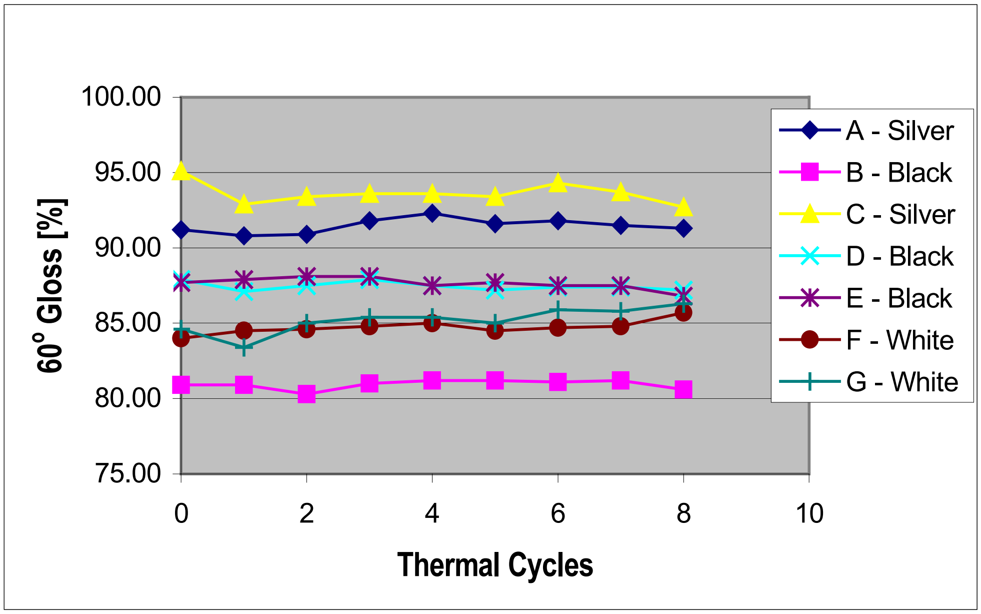

Figure 6: Moulded Parts with IMD/Paint Films

Thermal Cycling - Gloss Measurements

At this stage no Long-Wave/ Short-Wave (LW/SW) measurements were done to completely characterize the DOI (Distinctiveness of Image). The work will continue with this step and results will be presented under a separate cover.

Figures 7and 8 shows some moulded parts with IMD / Paint film exterior surface.

Figure 7: Moulded Part with In-Mould Decorating / Paint Film Finish

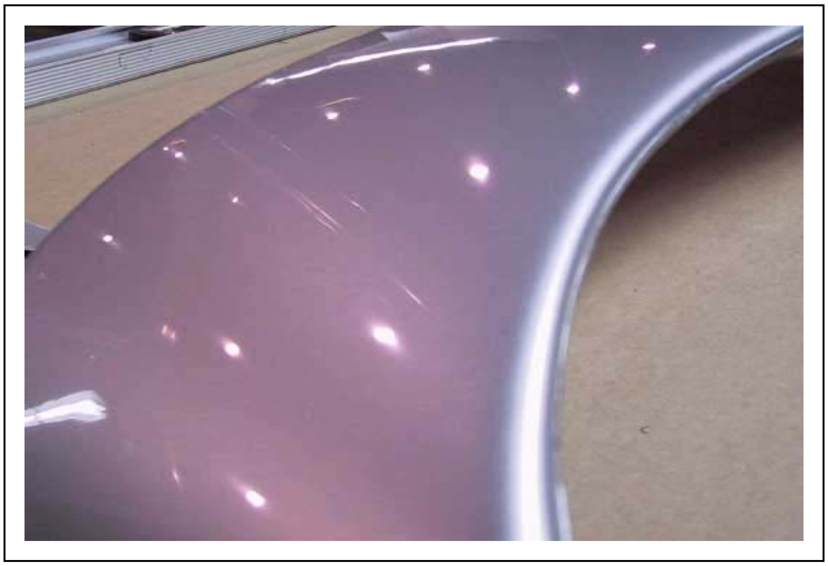

Figure 8: Moulded Part with In-Mould Decorating / Paint Film Finish

General Process Parameters:

- PU High Pressure Equipment ,
- L - Type PU Mix-Head,
- Throughput: 36 kg/min,
- Mould Temp. - 65 deg.C,
- Mould material - steel with embedded heating lines,
- Low to medium clamping force required,
- Demould Time 5-6 min.

Process characteristics:

- Open mold pour,
- One step process,
- The polyurethane composition delivered to the mould in one or several steps may be based on one or multiple PU systems that become mechanically and chemically bonded during the process.
- Variety of reinforcement materials; large range of % wt reinforcement content,
- Simple to complex core construction; the reinforcing core may be any of a large variety of adequate materials: synthetic, metal, glass, natural, or combinations thereof, in stratified or sandwich construction.
- Manual or fully automated process,
- Advanced component integration possibilities,
- Suitable for short production runs,
- Relatively low cost tooling.

Product characteristics:

- Wide range of specific strength,
- PU Elastomer skin integration possibility,
- UV stability through IMC or IMD,
- Color matching,
- Surface grain,
- Class-A surface potential,
- Good thermal stability,
- Excellent dimensional stability,
- Ductile type failure (construction dependent).

Potential Applications:

- Automotive
  - Roof top elements
  - Tonneau
  - Load floors
  - Decks, Spoilers
  - Running Boards
  - Floors
- General Transportation
- Agricultural Equipment
- Recreational and Sport Vehicles

General Conclusions

- A novel technology was developed, based on a fully open mould pouring process, using low cost tooling and carriers. Thus, the proprietary WFC Composite Process is extended to the manufacture of structural, thin cross-section composites while using a variety of reinforcing fibers (FG, polyamides, polyesters, metal, natural) imbedded in a PU matrix.
- This technology produces parts with properties that may prove them to be competitive to those manufactured through SRIM, SMC, Baypreg™ or other technologies,
- Different facing materials for enhanced surface and composite performance may be used: metal sheets, multi-layered plastic films or any natural surfacing materials.
- With specific films, class-A- optical surface quality is possible with heavily reinforced parts.
- By integrating in the composite structure a high performance film as a decorative exterior exposed layer, the process eliminates the need for in-mold or post-painting and provides a high quality surface resistant to environmental factors.
- The novel technology also allows for a high level of component integration and process automation in the production of performance products.
- The technology may be useful in the general mobility application areas.

Acknowledgements

The authors would like to thank Woodbridge Foam Corporation for the providing the means for this development and to the Brampton Composites Development Group for its continuous support that made this work possible.