

CARBON FIBRE/RRIM COMPOSITES FOR AUTOMOTIVE EXTERIOR APPLICATIONS

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Abstract

In the automotive industry's incessant drive towards higher performance, lightweight materials, there has been much interest in the area of carbon fibres (CF) as a potential filler solution for thermoset composite materials. RRIM (Reinforced Reaction Injection Moulded) composite materials have been successfully used in automotive exterior applications such as fascia, fenders, claddings and truck sides for over 25 years now, and have developed a reputation for offering durability, functional performance, design freedom, and paintability to the OEM. These RRIM composites have traditionally incorporated glass, wollastonite or mica as high performance fillers for these applications, which have a relatively high specific gravity of 2.5-2.9. The benefits that carbon fibre's high strength-to-weight ratio and lower density could bring to the RRIM polymeric network was the primary focus of this study.

This paper will explore the use of carbon fibres in RRIM polyurethane/polyurea composites as an opportunity to reduce weight, and will explore the characteristics of the resultant composite. The paper will provide an evaluation of the performance of the carbon fibres from a perspective of processability, mouldability, physical properties, paintability and functional part manufacture in the area of automotive exterior body panels, such as fenders or quarterpanels.

The study will touch upon the benefits that the developed carbon fibre composites can bring to the industry - such as light weight, a relatively high stiffness-to-weight ratio, a good balance of physical properties, and increased electrical conductivity for improvements in paint transfer efficiency and aesthetics. The study will also discuss some of the considerations that working with carbon fibres will likely entail such as higher raw materials cost, and processability limitations.

Background

Carbon fibre (CF) has become an important filler in today's high performance polymer composite solutions, and has seen applications in such areas as sporting goods, structural components, and the automotive industry. An investigation was undertaken to examine the potential benefits that carbon fibres could bring to RRIM composite materials for painted exterior automotive parts.

The RRIM process is well suited to the use of carbon fibre because it is produced as two-component low-viscosity thermoset reactants, which are reacted together in situ in a closed mould. The carbon fibre can be introduced into this process in a number of ways. It can be preloaded into the mould as a mat or a preform, it can be chopped from roving within a specially designed mixhead, or as was the focus of this study, it can be used as milled fibre. The milled fibres can be mixed in with the formulated polyol system and injected into a closed mould to react with the isocyanate prepolymer and form the polyurethane/polyurea composite.

In this study there were two main objectives:

- (1) To use carbon fibres in conjunction with Dow Automotive's **SPECTRIM**^{*} RRIM thermoset materials to successfully mould and meet the design, performance and aesthetic requirements for a plastic exterior body panel application. For this purpose a P20-grade steel RRIM tool was made using the computer generated (CAD) data for a current production rear quarterpanel fender. This tool was developed so that direct comparison and functional testing evaluations could be made with the current steel design.
- (2) To evaluate and characterize the potential benefits of using carbon fibres as a filler in a RRIM application. For this evaluation, physical properties and paint evaluations were conducted on parts made using a flat plaque tool, while functional, appearance and processability

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studies were completed using the fender tool.

Since the study was to be done on a fender application which could potentially be painted on-line at an OEM facility, it was decided that the polymer system chosen should be ELPO-capable. The "ELPO" process refers to the electrolytic phosphate corrosion resistant application to the steel body-in-white that is applied and then baked on at temperatures of up to 210 C.

Experimental Setup

Polymer Matrix

The polymer formulation used in the study was SPECTRIM* HH-400 polyol formulation and isocyanate from The Dow Chemical Company. This unique material has been shown to be able to withstand 400°F temperatures for up to 1 hour without degradation in polymer performance or paintability. Thus a panel moulded of this material could ride along with the steel of a car body through the traditional OEM ELPO-line and be treated almost in the same manner as a steel outer panel. The HH-400 material has been evaluated with both mica and wollastonite-based mineral filler options and shown to process very well.

The main focus of the project was to evaluate the performance of carbon fibers (CF) as a reinforcing agent for RRIM composites, and several sources of carbon fibres were contacted to determine an appropriate supply of milled fibres. A standard grade of milled carbon fibre was chosen to be evaluated in this study. This particular commercially available grade of carbon fibre material was manufactured from polyacrylonitrile (PAN), and had a carbon content of 95%. The CF that was used had no sizing or coupling agent coatings. The product was of a fibrous geometry having a nominal 7.2 micron diameter with a 150 micron length, and a density of 1.81 g/cc. This size is a bit larger than high aspect ratio wollastonite particles typically used in RRIM today, which are acicular in shape, having a nominal 5 micron diameter and a length under 50 micron. However, this particle size is approximately equivalent to the dimensions of coarser wollastonite or glass fibres that have also been used in the industry for many years. It was anticipated that the high aspect, or L/D (Length to Diameter) ratio of the carbon fibre could lead to dimensional or flatness concerns in a body panel application, as has been observed when incorporating wollastonite into body panel composites. Therefore the experimental scope of the project included the evaluation of mixed filler

combinations with mica, a more isotropic filler, which has been shown to improve the dimensional capability of other RRIM applications. This also allowed for the evaluation of the effect that lower levels of carbon fibres could have in the polymer. The mica chosen for this experiment was also an industry standard, that being a 30 - 50 micron diameter flake that is used in automotive exterior panels today with RRIM chemistry.

Tooling and Equipment

The primary tool, or mould, used in this study to evaluate processability and composite part functionality was a rear quarterpanel fender. It was manufactured using CAD data to match the geometry of a current model rear quarterpanel production part, which is supplied to an OEM in steel. The developmental RRIM tool incorporated some attachment flanges and holes but certainly not as many as could have been included if the part were to be optimized for a RRIM design. Therefore to fit the part onto the vehicle later some attachment brackets had to be added as a secondary operation. The part itself was obviously designed with steel in mind for the application. The RRIM part was made at a target constant wallstock of 3.0mm. This rear quarterpanel was a simple geometry, however, it included the gas filling opening.

The tool was relatively small for a RIM body panel application, both in terms of size and weight (under 2 kg), and it could be envisioned that this program be run as a dual cavity process, with both the left-hand and right hand moulds in the same tool.

The tool had but one core function - that being a stroking core, and was entirely made of P-20 steel. The tool was gated at the end of the part where the part blended into the rear taillight. This gating location had the advantage of aligning any filler used along the length of the part and would minimize any distortion caused by fillers along this axis. The tool had the provision for another gate entering into the centre of the part into the wheel-well area. This gate location had the advantage of minimizing the flow length for the material, and having a less critical gate trim edge, but could potentially lead to the most filler-alignment induced distortion. This gate was installed for future investigation of these phenomena, but the part filled out so easily, that this gate location was not investigated as part of this study.

The tool was cut with a 0.75% shrinkage allowance in all directions. This is not ideal for anisotropic, fibrous

fillers, as the direction perpendicular to the flow will shrink much more than in the direction of flow, but made for a simple tool construction. Measurements of substrate thickness in locations across the part indicate that it was a relatively constant wallstock thickness and varied from 2.9 mm to 3.3 mm thick. The nominal thickness was 3.0 mm.

In addition to the part moulding, flat plaque tooling was used to develop panels for physical property test purposes. The plaque tool that was used was end-gated, and produces a part with dimensions of approximately 1.5 x 1m x 3.0mm thick.

Results

The trials began using the RIM polymer with the 7x150 micron milled PAN-based carbon fibre at a 10% by weight loading. The filler material blended into the polyol relatively easily and the end polymer viscosity appeared to be similar to that of a 10% (w/w) loading of wollastonite. The fibres were coarser to handle than the normal mineral fillers used in RRIM, which was understandable given the larger carbon fibre size.

A 10% loading was chosen as a starting point because there was no history of the amount of viscosity that would be built as the filler was introduced to the polyol, and thus no guidelines as to how well the material would mix. Based on the specific gravity difference between the carbon fibre and the wollastonite (1.8 versus 2.9), this type of weight loading of carbon fibre in the final polymer would be volumetrically equivalent to about a 16% loading of wollastonite in the final polymer.

The parts ran easily and the process was subjectively rated as being very comparable to running RRIM material with wollastonite filler. The surface looked very glossy and smooth (and black, obviously). It was expected that the surface might look a little rougher because of the larger particle size, but that did not appear to be the case. The material nucleated very easily, reaching its setpoint in 15 minutes, and held the nucleation well throughout the trial. The parts were more flexible than those made with other fillers. This made demoulding very easy. The parts looked very good and the release from the cavity was very good. The part weight was about 10% lighter than parts made with wollastonite control materials.

The loading of CF was then increased to 15% by weight in the final polymer. This, too, blended reasonably well into the polyol side, but the resultant

slurry was noticeably thixotropic. Some minor processing concerns were seen on the quarterpanel tool, but the material ran well on the plaque tool, indicating that there is likely a smaller processing operating window as the level of CF in the final polymer increases. This was further proven when the level was attempted to be raised to 20% by weight in the final polymer, which required a filler loading of 36% by weight in the polyol formulation slurry. The material proved too thick to be able to be process at normal operating temperatures.

The parts were post-cured at 190 C (375 F) for 1 hour and all of the parts exhibited some slight wrinkling and distortion during the process. This is typical of rod-like fillers because of the polymer shrinkage and thermal expansion (CLTE) differences between the parallel and perpendicular directions, but seemed a little more exaggerated than is typically seen with wollastonite fibres.

As a result, it was decided to run the CF in combination with mica, which is a more isotropic filler. An important requirement of body panel materials/parts is that they be able to meet the tight gap tolerances required for automotive applications. The ability to do this requires that the shrink and CLTE values throughout the part are the same (isotropic), or alternatively, that they are predictable and known. Modeling of the tool can be done based on knowledge of the flow profile of the material through the part, and appropriate tooling corrections can be made so that the part has the proper dimensions when mounted to the car. The modeling of the RRIM process is difficult, and, in any event, the ability of a tool shop to cut several different scale factors across the part surface is limited and costly. Therefore it is in the best interest of design for fit-and-finish that the filler or filler combination used have a high degree of isotropy. The downside to this practice is that, currently, fibrous fillers are generally easier to process and provide superior reinforcement and impact properties than the isotropic flake or sphere-like fillers. It has been found that some balance can be achieved by blending the two types of fillers together so that the directional problems associated with the fibrous fillers are minimized, and yet some of the physical property and processability advantages remain.

Since the carbon fibre has a relatively large aspect ratio (Length / Diameter of approximately 21:1) it was expected that there would be large difference both dimensionally and property-wise between the parallel and perpendicular directions. This fact lead to the

consideration of a mixed filler approach, using both mica and carbon fibre in the moulds.

From a processability standpoint, lower levels of CF filler such as 5-10% behaved very similarly to how wollastonite materials would in the composite application.

Polymeric Shrink

A study on the post-moulding shrinkage of the polymer was done by measuring the distance along scribe lines in the postcured parts and comparing those results against the length of the scribe lines measured in the cold tool at room temperature. Three readings were taken: 1) along the length of the part going from front to back in car position (C-D), 2) in the up-down direction from the bottom of the “leg” up towards the gas cap hole (A-B), and 3) diagonally from the bottom corner of the leg to the middle of the part (E-F).

The shrink results are shown in Table 1 and show the anisotropic nature of the filler.

The plaque tool was installed and middle two materials were run in addition to the fender parts: HH-400 with 15% carbon fibre, and HH-400 with 10% mica / 10% carbon fibre. The following are the shrink numbers that were obtained are shown in Table II. The first set of numbers indicate the shrink of the polymer taken 24 hours after moulding and before being post-cured at 375°F for 1 hour. The second number is the shrinkage value obtained from the part after postcuring. The plaque tool has 4 notches located in the shape of a rectangle for measurement: AB and CD are measurements parallel to the flow, while AC and CD are perpendicular.

This data shows that the CF is able to reduce the amount of shrink substantially in the direction of flow, but does not have a significant effect on shrink perpendicular to flow. As a comparison point, it would be expected that HH-400 with 15% high aspect ratio wollastonite filler would shrink by about 0.6% in the parallel direction. The data also illustrates the anisotropic nature of the fibre in that it provides little resistance to polymer shrink when oriented in the perpendicular direction.

Molding Test Plaques

The plaque tool used for this study had two pressure transducers on the core (non-show) surface of the mould, which were used to determine the internal

pressure that the polymer generates through mould filling and polymerization. The first probe is located 6” from the gate along the centre axis of the part. The second probe is located 0.3 metres from the end of the plaque (approximately 1.3 metres from the gate) along that same centre axis. Figure 1 shows the pressure profile that the 15% CF material generated.

The peak pressure was approximately 200psig, while the residual pressure was about 50psig, according to the transducer located at the gate area. In order to keep the tool closed, and to minimize the amount of flash emanating from the parting lines of the tool, it is necessary for the tonnage of the press to overcome the pressure generated by the injection of the material into the mould. The pressure inside the mould climbs as the material fills the tool and starts to pack out. This pressure build-up is related to fluid dynamics, and the flow of the material into the mould. Thus this pressure is affected by material viscosity, density, flow rate, part thickness, flow regime, etc. After the injection is complete and material flow into the mould ceases, the pressure drops off quickly, and continues to decrease throughout the mould cycle as the polymer shrinks. At the end of the tool, the pressure increase due to flow is minimal, and the reduced packing is responsible for the delta in the internal pressures of the material. In this case note that there are offsets (the pressure should start at 0 psig at time=0) in the end transducer to better show the two pressure readings.

The physical property data that was tested on the plaques are shown in Table III. The marked difference between properties parallel and perpendicular to flow again illustrates the anisotropic nature of the carbon fibre filler.

CONDUCTIVITY

A potentially interesting aspect of carbon fibre fillers is the hypothesis that through their incorporation into a composite material, the polymer may become more electronically conductive. By definition increasing the conductivity of the polymer improves the ability of the polymer to dissipate an accumulated electronic charge improves. This is an important property in electrostatic painting applications, whereby increasingly conductive materials show improvements in paint transfer efficiency, and enhanced aesthetics through both more consistent paint coverage and increased paint wrap to areas that otherwise could not be reached by the paint spray. In the automotive industry many paint lines are fitted with electrostatically charged paint lines utilizing robotic applicators. This type of application has improved paint quality as charged paint particles will travel to ground through the path of least

resistance, which in a well-designed paint line will be the component to be coated. This works very well as long as the part to be painted dissipates the charge to ground and retains a neutral charge. Thus for metals like steel, which has a high electronic conductivity, this is the preferred method of painting. On relatively non-conductive plastics however, what happens is that the charge imparted to the paint particle may not be transferred to ground as quickly as the paint is being deposited on the part. This allows an accumulated charge to build up on the surface of the part. This charge is the same as the paint particles that are emanating from the paint nozzle. Since like charges repel, some paint particles do not go to the surface of the part, resulting in a loss of transfer efficiency.

The product literature from CF suppliers states that the percolation level for milled carbon fibres in a polyethylene thermoplastic matrix is around 12% by weight. "Percolation" in this case describes the level of filler necessary to form a matrix of CF that can transfer electrons effectively through the composite. This mechanism allows for an exponential jump in the conductivity of the material, and the minimum amount of filler required to reach this critical stage is an important determinant in the creation of a new composite. There has been no reported data on what this level would be with RRIM materials.

RRIM polymers typically have a room temperature conductivity on the order of 1×10^{-14} S/cm (S stands for Siemen, where $1 \text{ S} = 1 \text{ mho} = 1 \text{ reciprocal ohm}$). In the past Dow has analyzed the conductivity of the carbon fibre-filled materials and found them to be under the limit of detection of specific instrumentation, which was 1×10^{-8} S/cm. Dow's experience is that substrate materials need to have a conductivity higher than 1×10^{-6} S/cm in thermoplastics for there to be significant electrostatic paint transfer efficiency improvements. Thus these materials were not classified as "conductive" from a thermoplastic standpoint.

It has been shown, however, that in RRIM applications, there are paint transfer efficiencies to be gained if the static decay time is less than 0.1 sec, and the conductivity can be increased to the order of 10^{-12} S/cm. Therefore the conductivity tests were re-run using more sensitive equipment at higher potentials, and the results are shown Table IV. All testing was done at room temperature at 45% humidity. The surface resistivity was calculated using 100V of input voltage. The testing was done on the quarterpanel parts, so there was some variability, and the results were perhaps slightly higher than could be anticipated with perfectly flat panels. The base polymer resin in

all of these instances was SPECTRIM* HH-400.

To test conductivity and its effect upon transfer efficiency, a simple experiment was set up in which a 4" x 12" panel of each material was hung in the spray booth. The panels were supported by a 6" backing of aluminum onto which each panel was clipped, so that the upper half of the panel would have metal backing, and the lower 6" would be hanging free. The parts were sprayed with PPG Performance White basecoat in a single pass across all 6 materials and a steel control using an electrostatic bell. It was noticed that in all cases but the steel control and one formulation, there was very little wrap and very little paint coverage in the unsupported lower section of the panels. The 15% CF formulation had an even coverage of paint across its entire surface and had significant paint wrap to the edge of the part and around the backside. The difference in paint coverage between the 10% CF and 15% CF formulations was dramatic. This would seem to indicate that the 12% loading for the carbon fibres reported as the percolation limit for polyethylene would be approximately applicable for RRIM polymers as well. RRIM polymer has a higher specific gravity than polyethylene, so this value may have to be higher to obtain the same volume percentage loading. However the result is not too surprising as the percolation mechanism basically relies on a matrix of continuous contact between the conductive carbon fibres being established in the polymer.

Carbon Fibre and Electron Transfer Agent Technology

The Dow Chemical Company has a patented technology on the use of special electron transfer agents in RRIM polymers to improve the conductivity of such composites. Much research work and field validation has been done in this area to demonstrate the effectiveness of this technology. There have been problems with implementation of the technology due to the difficulty in the quantification of the benefit that conductive technology could bring to the customer. Customers have been finding ways around the conductive issue in painting plastics for years, and have a hard time measuring the actual transfer efficiency of their systems, thus they could not rationalize the additional cost of incorporating the technology.

Nevertheless it was of interest to determine whether the patented technology would have any combinatorial attributes with the carbon fibres, and be able to produce a much more conductive polymer composite. The results of conductivity testing done on plaques of various formulations are listed in Table V. The data is

presented for both a low humidity scenario and a mid-range humidity environment.

This data shows that both carbon fibres and the patented electron chain transfer (ECT) agents do have the capability to make the RRIM substrate conductive. It would appear that the ECT mechanism is more effective than the carbon fibres, however the highest purity most electronically conductive grade of PAN carbon fibres were not used in this study and could improve upon the conductive performance. This higher carbon content grade of fibre does not yield the best physical strength properties in composite applications so it was not studied at this time.

The effect on conductivity of the both the carbon fibres and the ECT would appear to be additive, and do not appear capable to get the composite down to low resistivities that would approach metals. Attempts to model the data were not very successful presumably because the surface resistivity is an exponential function, however, even so it is clear that carbon fibres and the ETC agents have a distinct and independent effect on the conductivity of the polymer.

In the study it should be noted that the highest carbon fibre content was 15% by weight in the final polymer. This limit was found due to the viscosity build in the polyol as the filler was added that made the material not able to be processed. It is possible that different types of surface treatments that could serve to lower the viscosity of the slurry as the CF in incorporated could lead to higher possible loading levels.

CONCLUSIONS

A few general conclusions can be made about the use of carbon fibres in RRIM at this point:

- (1) Carbon fibres have a lower specific gravity than mineral and glass fillers (1.8 versus 2.5 - 2.9), and the trials to date show that typical RRIM body panels can be made about 10% lighter by using carbon fibers.
- (2) The processability of carbon fibres is very similar to high-aspect ratio wollastonite, when the volume correction is made. The properties of a polymer would largely be expected to be based upon a VOLUME percentage, not a weight basis, therefore we would have to compare 15% CF with about 22% wollastonite. The polyol slurry becomes too viscous to process at loadings much above 15% by weight in the polymer (28.5% in the polyol slurry). Studies done at 20% by

weight in polymer (36% by weight in slurry) showed that the material could not be pumped.

- (3) The cost of carbon fibres currently (approximately \$6.50 - \$10.00 US/lb) will make the material cost of a body panel in the finished part about 30% more expensive at loadings of 15 - 20% by weight in the polymer. Typical engineered mineral fillers used in RRIM today cost under \$1.00 US/lb.
- (4) The physical properties of carbon-fibre filled RRIM materials are very similar to those achieved using conventional wollastonite fibres. No significant advantages or disadvantages were seen. The flex modulus appeared slightly higher and the elongations appeared somewhat lower for the carbon fibre composites than those typically seen.
- (5) There does appear to be some electronic conductivity advantages with the carbon fibre composites, which should lead to paint transfer efficiency improvements if the loading of carbon fibre is at 15% by weight. This value appears to be in agreement with the literature stating that the percolation limit for similar carbon fibres is about 12% (w/w) with thermoplastics. The advantages in conductivity have been shown through studies of charge dissipation and by paint wrap comparisons.
- (6) The studies have shown some additive effects between carbon fibres and Dow's existing conductive RIM ionic salt technology. The lowest conductivity achieved is on the order of 1.0×10^{-10} ohm.

COMMENTS and OBSERVATIONS

This study has explored many facets involved in the potential of carbon fibres for exterior automotive applications, and has shown that from a technical point of view, carbon fibres could readily replace fibrous fillers as a material option for RRIM applications. That being said, there are considerations that must be made before that step is taken. The following are just some general comments on advantages and disadvantages of using carbon fibres as a reinforcing filler in RRIM applications:

gain as had been hoped.

Advantages

- (1) **Conductivity** - The carbon fibres are electronically conductive - but that conductivity is dependent upon % loading, fibre orientation, and fibre length (the longer the better). The data from the carbon fibre supplier indicates that for 100 - 150 micron fibre length in polyethylene, about a 10-12 volume % loading is needed to reach the conductive asymptote, or point of decreasing benefit. In RRIM, conductivity improvements with the carbon fibre are similar to that seen with the patented ECT technology. Therefore it is possible that the molder could see some cost savings through paintability and/or flash reduction through static dissipation. That valuation of the technology has historically been a tough theory to prove at the customer and provide an attractive cost-benefit argument. Carbon fibres may have more potential in future initiatives, such as powder coating initiatives for plastics, as plastics are easily powder coated.
- (2) **Weight Savings** - A major claim to fame for carbon fibre is its ability to reduce the weight of the manufactured component in which it is used, but in reality the specific gravity of the fibre is 1.8. Replacing, say, high-aspect ratio wollastonite with a specific gravity of 2.9, with the carbon fibre will not appreciably lower the weight unless there is a high level of filler in the composite. The carbon fibre is a slightly better, more efficient reinforcing filler, and perhaps less filler could be used in the polyurethane/polyurea polymer (s.g. about 1.0) and weight could be saved in this manner as well. In the molding of actual parts, 10% weight reduction was achieved but little improvement in reinforcement was seen. This A 10% weight savings is desirable to the automotive industry, however this must be balanced against the cost differential of the CF-reinforced composite versus the traditional mineral-filled component.
- (3) **Stiffness**- The data would seem to indicate that the CF is a slightly better reinforcer than glass or wollastonite. Flexural modulus values should increase, helping improve the stiffness of body panel applications. The consequence of that increase on impact strength and ductile properties will have to be determined, however under functional validation methodology. The data shows only nominal gains - not as great a
- (4) **Availability** - The carbon fibre market is currently heavy in supply so product seems readily available, and there are active initiatives in the industry to continue to become more efficient and reduce the price further. Custom milling seems possible but is not offered currently. All carbon fibre suppliers seem to have about the same size fibre offerings, none that match the current preferred dimensions for a filler like wollastonite.
- (5) **Marketing** - "Carbon Fibre" or "Graphite" sounds much better than "filler" and does give the fibre some marketability. The reputation of these materials is well-known for yielding high performance goods - irrespective of the type of polymer that the filler is in. It is somewhat ironic that the average person wouldn't know what type of polymer is even used in a tennis racquet, bicycle, golf club or on the space shuttle, but they do know that the product is advertised as "carbon fibre" or "graphite". With this type of performance "branding" OEMs and customers might be willing to pay a little more just to be able just to be able to advertise their plastic panels as "space-age carbon fibre" or "high performance graphite". Carbon Fibre material certainly more recognizable right now to the average car buyer than "RRIM" and has a superior quality/performance connotation than "plastic".

Disadvantages

- (1) **Cost** - Milled carbon fibres are priced at approximately \$6.50 - \$10.00 US/lb depending on volume and grade. The CF industry is very interested in breaking into the automotive marketplace, so they would consider some aggressive pricing strategies but there would still be a significant cost increase over current fillers. Recent reports indicate that a ultimate goal in pricing would be to get down to \$5.00US/lb. Calculations show that in a typical body panel formulation, the part raw materials would cost 30 - 40% more with CF in place of high aspect ratio wollastonite. There has been some activity in producing pitch-based carbon fibres, which are targeted to be at a lower cost, but this technology is unproven.

- (2) **Anisotropy** - The aspect ratio (L/D or length/diameter) is around 20 for the material. Carbon fibre suppliers have said that custom products might be possible in the future if there are some glimmers of hope for higher volume opportunities based on trials with the stock items, but their stock product is 7 x 150 micron fibre length \pm 50 micron distribution length. This goes against current recommendations for body panel fillers, which have been focused on isotropic fillers, or with smaller size and aspect ratios for better surface quality and flatness. Incorporation of these fillers into body panel formulations will result in the fit and finish issues that have been endured in programs launched with anisotropic fillers.
- (3) **Fibre Length** – The mean fibre length of the carbon fiber at 150 microns is over twice the length of wollastonite and mica, so surface quality issues (DoI & Gloss) will have to be examined further, though the gloss and DoI studies showed results comparable to current filler technology.
- (4) **Surface Treatments** - This is an area which could be investigated. Currently most milled fibre materials are coated, or have a "sizing" agent on the fibre to prevent fraying and for ease of winding when making filaments. In this study, there were no recommendations for RIM materials, and uncoated fillers were trialed. The surface treatments available are not designed for enhancements in the RIM final polymer or process. However surface treatments have been engineered and developed in the mineral industry to add performance, reduce moisture uptake, enhance wettability, or reduce viscosity for the RIM process. There would have to be

some joint R&D work to evaluate different types of surface treatments to be evaluated against those type of characteristics and whether value can be created through this type of technology.

CONTACT

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Tables & Figures

Table I: Fender Tool Polymeric Shrink (%) with SPECTRIM* HH-400

COMPOSITE FILLER	DIRECTION A-B	DIRECTION C-D	DIRECTION E-F
10% CF	0.69	0.54	0.65
15% CF	0.66	0.27	0.49
10% CF/10% Mica	0.69	0.46	0.59
5% CF/15% Mica	0.89	0.66	0.80

Table II: Plaque Tool Polymeric Shrink (%) with SPECTRIM* HH-400

COMPOSITE FILLER	POSTCURED @190 C/60 MIN	DIRECTION A-B	DIRECTION C-D	DIRECTION A-C	DIRECTION B-D
15% CF	No	0.19	0.11	1.09	0.85
15% CF	Yes	0.22	0.18	1.36	1.10
10% CF/10% Mica	No	0.21	0.18	0.90	0.71
10% CF/10% Mica	Yes	0.30	0.24	1.04	0.90
5% CF	Yes	0.67	0.68	1.50	1.50
10% CF	Yes	0.29	0.35	1.55	1.55
4% CF/15% Mica	Yes	0.46	0.46	0.94	0.94

Table III: Physical Properties of Selected CF/ HH-400 RIM Composites

PHYSICAL PROPERTY	TEST CONDITIONS (UNITS)	5% CF	10% CF	15% MICA/5% CF
Flexural Modulus	25C, para/perp, kpsi	150/84	250/105	243/160
Flexural Modulus	70C, para/perp, kpsi	120/67	195/87	196/130
Flexural Modulus	-30C, para/perp, kpsi	230/149	349/174	351/229
Tensile Strength	25C, para/perp, psi	4130/3970	5570/4200	4780/3950
Elongation	25C, para%	83	74	24
Heat Sag	121C, 150mm OH	1.5	1	0.8
Izod Impact	25C, para/perp, J/m	163	162	91
Izod Impact	-30C, para/perp, J/m	93	109	51
Multi-Axial Impact	25C, 2.2 m/s, J Total Energy	11.7	9.8	5.6
Multi-axial Impact	-30C, 2.2 m/s, J Total Energy	14.2	13.1	9.1

Table IV: Electronic Conductivity of Carbon Fibre/RIM Composites

COMPOSITE FILLER	SURFACE RESISTIVITY (OHM)	STATIC DECAY (+VE, S)	STATIC DECAY (-VE, S)
15% CF	4.1 E + 12	0.5	0.21
10% CF	9.1 E + 12	4.9	0.01
15% Mica / 5% CF	8.3 E + 13	60	60
10% CF/10% Mica	2.1 E+13	1.33	0.26
20% Mica	1.5 E + 14	9.55	7.41
10% Mica / 10% Wollastonite	2.1 E + 14	60	60

Table V: Surface Conductivity (@100V) of RRIM/CF Composites

MICA %	CARBON FIBRES %	ECT LEVEL (%)	HUMIDITY %	SURFACE RESISTIVITY X 10E10 OHM
10.33	7	17	45	3.2
10.33	7	17	12	34
10.33	7	33	45	2
10.33	7	33	12	26
10.33	7	50	45	1.5
10.33	7	50	12	20
15	4	17	45	3.8
15	4	17	12	46
15	4	33	45	2.7
15	4	33	12	20
15	4	50	45	1.7
15	4	50	12	19
19	1	17	45	4.2
19	1	17	12	52
19	1	33	45	3
19	1	33	12	29
19	1	50	45	1.9
19	1	50	12	23
0	12	0	50	560
0	12	0	12	840
0	12	8	50	9.6
0	12	8	12	28
0	12	80	50	4.3
0	12	80	12	14
0	12	100	50	1.6
0	12	100	12	6.2
0	15	100	50	1.1
0	15	100	12	8.8
0	15	0	45	410
0	10	0	45	910
15	5	0	45	8300
10	10	0	45	2100
20	0	0	45	15000
20	0	0	40	18000

Figure 1: In-Mould Pressure Plot of SPECTRIM* HH-400 with 15% CF. 3.5mm Wallstock

