NEW LONG FIBER REINFORCED PLASTICS: A SINGLE PELLET SOLUTION WITH ENHANCED PROPERTIES

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Abstract

Long fiber-reinforced (LFRT) thermoplastics are widely used in automotive and industrial markets, and are frequently used in metal replacement applications. Common automotive uses include front-end modules, instrument panel substrates, battery trays, sunroof beams, mirror brackets and fuel rails. The LFRT composites offer exceptional mechanical performance, high rigidity with outstanding strength and resistance to impact failures. More and more LFRT compounds are finding use in demanding structural applications and the industry is looking for added effects incorporated to these products such as a range of colors, UV resistance, flame retardancy and others. Currently these properties are incorporated using pellet blends of LFRT products with master-batches, which restrict the product design freedom.

We have developed a new technology that provides a “single pellet solution” to impart multiple effects in LFRT products, breaking the limitation of dry blending of colorants, additives, flame retardants or other properties. This paper reviews three distinct product families that deliver single pellet solutions with enhanced color consistency, robust non-brominated flame retardancy, superior UV and weathering resistance without compromising the balance between stiffness and impact offered by LFRT products. The enhancement in design freedom as seen in product properties, improvement in surface finish of molded parts utilizing a heat-cool process, and application development are discussed in detail.

General Introduction to Long Fiber Reinforced Plastics

Long fiber reinforced compounds in pellet form are typically manufactured via a melt pultrusion process where the continuous fiber tows are exposed to the resin melt [1,2,3,4,5]. The two commonly used pultrusion methods are - 1) a wire coating process which imparts minimal impregnation or wet-out of the individual fiber filaments and just provides a polymer coating or sheath around the fiber bundles. Such wire coating processes allow very high production rates and efficiencies. However the end pellets often create fiber bundles in the injection molded part leading to a poor surface appearance. 2) a melt impregnation process where the fiber bundles are separated via pins or other tension imparting devices in the pultrusion block in the presence of the polymer melt. This process allows very good wet out of the individual fibers and affords the opportunity to coat each individual fiber filament in the tow [6]. The end result of both these processes are pellets that generally vary in length from 8 mm to 25 mm. These pellets can then be used for secondary finishing operations such as injection or compression molding. To achieve a blemish free surface in the molded article, minimizing any un-impregnated fiber is critical, thus the melt impregnation process is preferred in such cases. The work described here utilized the melt impregnation process, which we have been using for few decades to make our Verton[*] LFRT products [11,12].

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[*] *Verton is a trademark of General Electric Company*

Figure 1 shows a schematic of the melt impregnation process utilized in the production of such thermoplastic composites. The glass fiber roving in the form of bobbins is fed into the impregnation block. The glass fiber is appropriately sized to be compatible with the polymer resin composition. Inside the block these filaments are separated via mechanical devices and are exposed to the polymer melt. The melt impregnated glass fiber strand then is pulled out of the block with the help of a conveyor belt and fed into the pelletizer. In the pelletizer the strand is chopped into desired pellet length.

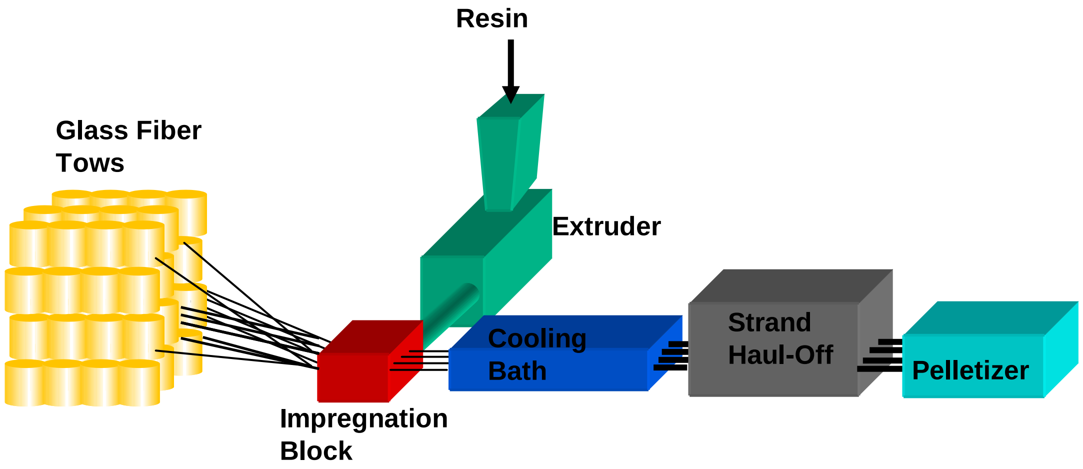

Figure 1: Schematic of a melt pultrusion process for manufacturing long fiber thermoplastic compounds

There have been several excellent reviews in literature [7,8,9,10] on the theoretical aspects that govern melt impregnation. Gaymans et. al have modeled the impregnation process by Darcy's law, which correlates the polymer melt viscosity (ν) through the individual filaments in the continuous glass fiber strand. K is the coefficient of permeability, η the polymer melt viscosity, dP the pressure drop over the penetration length L

$$\nu = \{K / \eta\} \{dP/dL\}$$

As is evident from the above equation the polymer viscosity is a key parameter towards the degree of impregnation. This necessitates process temperatures to be extremely high, generally in the order of 100 to 125°C higher than the melt temperature for semi-crystalline polymers. Furthermore, the residence times for the polymer resin melt is also substantial due to the volume of the impregnation block. All these factors lead to degradation of thermally sensitive components in the blends such as UV and heat stabilizers, color pigments and flame retardant additives. As a result effects such as weathering, color, flame retardancy are usually incorporated to LFRT as a pellet blend rather than a single-pellet during the melt impregnation pulltrusion process. We have modified the impregnation process utilizing a proprietary technique to impart these effects into directly into LFRT products to obtain single pellets as described below.

Material Preparation

Pultrusion Step

The long glass fiber compositions were made via thermoplastic pultrusion as described in the general introduction and Figure 1. The resin and additive compositions were blended using a slow speed blender, then fed into the throat of the twin screw extruder via a standard Brabender loss in weight feeder. The twin-screw extruder used was a Berstorff 40mm ZE40XUTX with 9 barrels and has a L/D ration of 44. This step was common for the single pellet color and single pellet weatherable compounds. In case of the single pellet flame retardant (FR) compounds the FR additive was introduced in the downstream port of the twin screw extruder via a heated liquid pump.

The polymer melt was fed into the pultrusion block through a short melt pipe. In the block the melt interacted with the continuous glass fiber strands via proprietary impregnation devices. Each experimental run consisted of 24 glass fiber strands being pulled through the pultrusion block at a production rate of 13 cm/s. These polymer impregnated fiber strands were then introduced into the pelletizer via a conveyor belt system. The strands were chopped into 12.5mm long pellets.

Injection Molding Step

The pultruded long fiber reinforced thermoplastic (LFRT) pellets were then molded using a 170T Cincinnati Milacron injection press. The injection molder had a general-purpose screw without any barrier flights or mixing elements & was fitted with a free flow screw tip. The nozzle and sprue sections were sized appropriate to preserving the glass fiber length in the LFRT compounds. ISO test specimens were molded from the LFRT compounds and Flexural (ISO 178), Tensile (ISO 527) and Notched Izod (ISO 180) properties were tested per the respective test standards [16].

Single Pellet Color (SPC) LFRTs

More and more OEMs are utilizing color and design to differentiate themselves from other competitors. LFRT compounds offer excellent benefits in terms of impact-stiffness balance and can be molded into intricate geometries using conventional injection molding processes. However, it has been difficult to achieve a consistent color performance (dE shift to color std.) and maintain mechanical properties in heavily pigmented formulations due to the restrictions imposed by the pultrusion process. Furthermore, most of the pigments (organic & inorganic) needed to obtain a broad color palette often have limitations from a thermal and shear standpoint and can degrade under the harsh processing conditions used in conventional pultrusion to achieve good wet-out of the reinforcing fiber. Thus, molded-in color LFRT compounds are routinely sold as a 2 pellet dry blend, where a natural LFRT pellet is dry blended with the color pigment master-batch pellet. We have been able to overcome these challenges with innovations in the pultrusion process and have observed excellent color consistency and mechanical property retention across a wide color palette in a single pellet version of the LFRT compound. This approach is applicable across the range of base resins ranging from the common semi-crystalline resins such as Polypropylenes (PP) & Polyamides (PA 6, PA 6/6, PPA etc.) to amorphous engineering resins like Polycarbonate (PC), Polycarbonate / Acrylonitrile-Styrene-Butadiene (PC/ABS) blends, Styrene-*co*-Acrylonitrile copolymer etc.

As an example, in the following is a comparison of a single pellet colored (SPC) 35% glass filled PA6 LFRT compound against a conventional 35% glass filled PA 6 LFRT two pellet dry blend system in a custom blue and yellow color. Figures 2, 3 & 4 show a comparison of the flexural, notched Izod and tensile properties for the two approaches. Both the SPC and two pellet versions were molded on the same injection molding machine using the same parameters and operator to minimize any variations due to processing. Further they were tested side by side on the same test equipment in the laboratory.

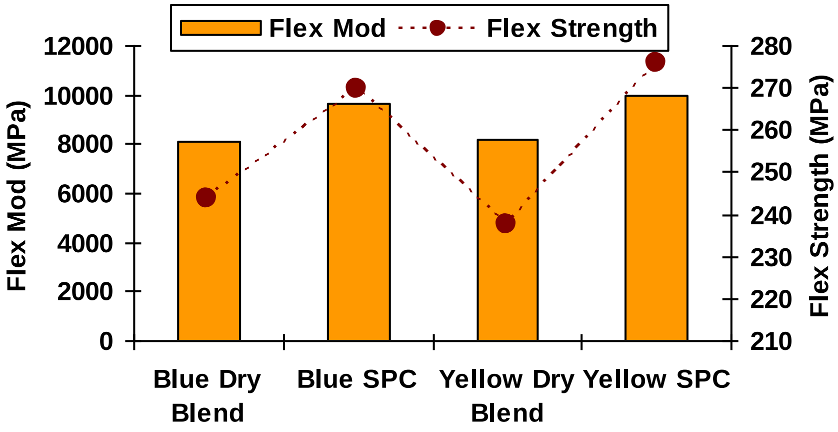

Figure 2: Comparison of flexural properties between conventional 2 pellet dry blend LFRT Vs. SPC LFRT

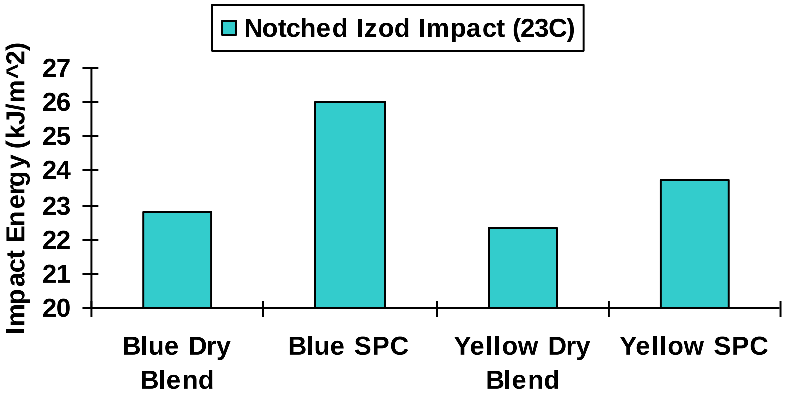

Figure 3: Comparison of room temperature notched Izod between 2 pellet dry blend LFRT Vs. SPC LFRT

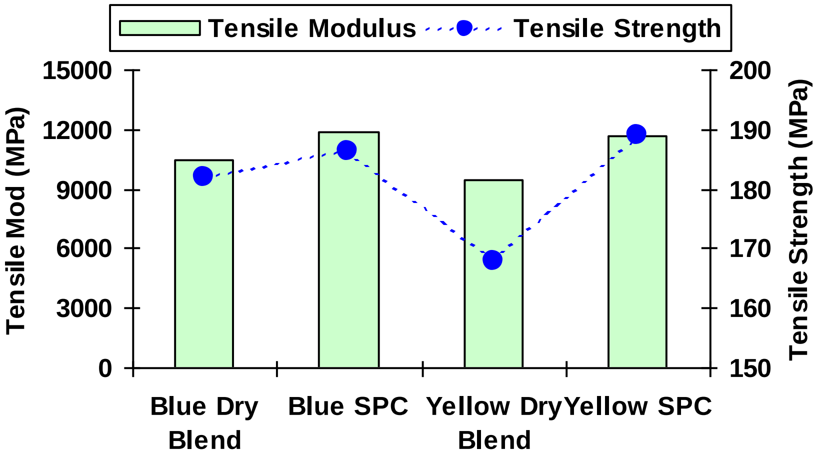

Figure 4: Comparison of tensile properties between conventional 2 pellet dry blend LFRT Vs. SPC LFRT

As is evidenced from the above data, there is a significant increase in all the mechanical properties of the SPC LFRT compounds as compared to the conventional two pellet dry blend LFRT compounds. This is due to a more uniform dispersion of the pigment particles in the SPC LFRT compounds. This is further borne out in the color consistency in molded articles. Plaques with a smooth and textured surface were molded from the two pellet dry blend LFRT and the SPC LFRT. Table 1 shows the dE shift between various measurement points on the individual plaques. Ten separate measurements were made on each surface. The dE shift for the SPC LFRT is significantly lower indicating that the color is more homogeneous across the molded surface.

Table 1. dE values measured on smooth and textured surfaces of plaques molded from conventional 2 pellet dry blend LFRT and the SPC LFRT

Blue Color	**Sample**	**dE***
Smooth	2 Pellet Dry Blend	0.138
	SPC LFRT	**0.037**
Textured	2 Pellet Dry Blend	0.13
	SPC LFRT	**0.048**
Yellow Color	**Sample**	**dE***
Smooth	2 Pellet Dry Blend	4.47
	SPC LFRT	**0.062**
Textured	2 Pellet Dry Blend	2.863
	SPC LFRT	**0.055**

Single Pellet Flame Retardant LFRTs

Applications in the consumer and business electronics (C & B E) markets often require Underwriters Laboratory (UL) certification for flame retardancy. Due to the potential harmful nature of halogenated flame retardant (FR) additives, legislations like the German Blue Angel, EU Eco-label were created several years ago that call for non halogenated (ecoFR) systems in engineering plastics. The C & B E market offers exciting and new opportunities for LFRTs, where their impact-strength-modulus balance makes them very attractive for metal replacement in structural components.

In this section we will present some new development in single pellet amorphous ecoFR LFRTs based on non-halogenated FR systems. Un-reinforced blends of Polycarbonate & Acrylonitrile Butadiene Styrene (PC/ABS) containing non-halogenated FR additives have been in existence since the 1980s. Such engineering plastics are widely used today in applications ranging from computer & television monitor casings to notebook computer covers. There is also a plethora of short fiber and particulate filler reinforced ecoFR PC/ABS compounds that are used in applications that call for medium stiffness (2000 MPa ~ 12,000 MPa) along with V0 flame performance in the UL94 tests. However these short fiber and particulate reinforced ecoFR PC/ABS compounds often have very poor impact performance that is critical to thin-wall applications in this market.

By marrying long glass reinforcement with a non-halogenated PC/ABS blend formulation in a single pellet version, we have attempted to overcome the shortfalls in the existing engineering plastics used in this application space. A broad formulation design space (Figure 5) was mapped using the tools from statistical design of experiments to create a blend space that ranges in long glass fiber loading from 10 to 60% by weight. A non-halogenated phosphate FR system was employed at various loading levels to optimize the balance between flame retardancy and thermal properties.

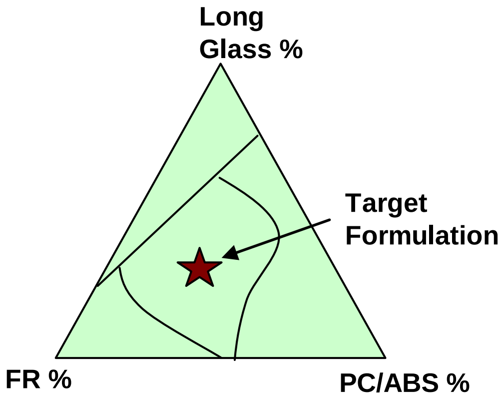

Figure 5. Schematic representation of statistical DOE approach adopted to optimize the target formulations for the single pellet ecoFR LFRT compositions

Taking such a design space approach permits the creation of mathematical equations called transfer functions that define the composition to achieve a specific property. On a broader level, these individual property transfer functions can be combined via optimization algorithms to determine the overall LFRT composition to meet all the property requirements for the final target application. Properties of 20, 30 & 40% long glass reinforced single pellet formulations of ecoFR PC/ABS are represented in Table 2.

Table2: Physical and mechanical properties of 20, 30 & 40 Wt %single pellet ecoFR PC/ABS LFRT formulations

Property	Test Method	Units	20% ecoFR PC/ABS LFRT	30% ecoFR PC/ABS LFRT	40% ecoFR PC/ABS LFRT
Density	ASTM D 792		1.36	1.44	1.51
ASH	ASTM D 5630	%	22	30	40
Flexural Modulus	ISO 178	MPa	7866	10092	12665
Flexural Strength	ISO 178	MPa	153	163	175
HDT 1.8MPa	ISO 75	°C	86	87	88
Notched Izod at 23°C	ISO 180	kJ/m^2	16	25	30
Tensile Modulus	Iso 527	MPa	8188	9000	10473
Tensile Stress @ Yield	Iso 527	MPa	104	113	120
Tensile Stress @ Break	Iso 527	MPa	104	113	120
Tensile Strain @ Yield	Iso 527	%	1.4	1.4	1.1
Tensile Strain @ Break	Iso 527	%	1.4	1.4	1.1
Flame Property		UL94	V0 @ 1.5mm	V0 @ 1.5mm	V0 @ 1.5mm
		UL94	V1 @ 1.0mm	V1 @ 1.0mm	V1 @ 1.0mm

The long glass single pellet compositions show an excellent balance of traditional LFRT properties in conjunction with flame resistance at thin wall thickness. Further, the impact performance is significantly better than available short fiber reinforced ecoFR PC/ABS products (Figure 6).

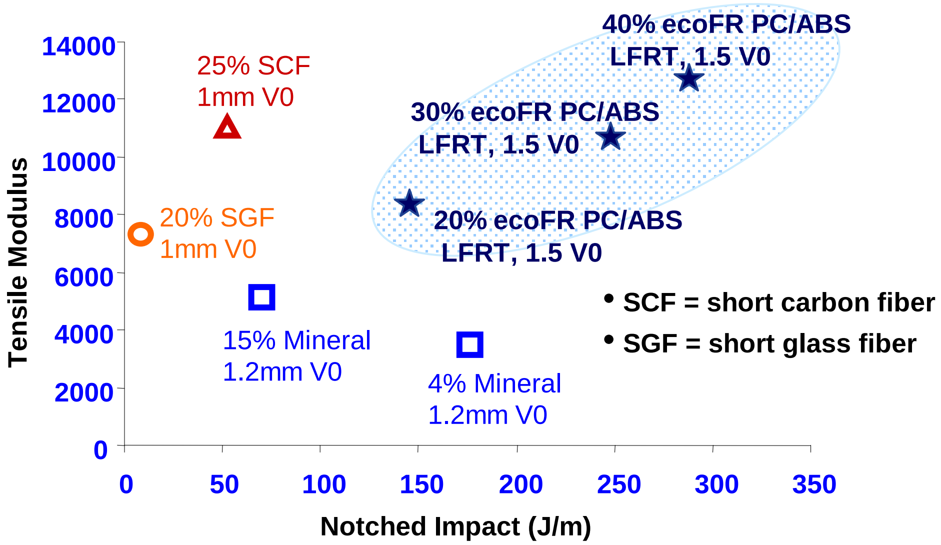

Figure 6: Modulus Vs Impact comparison of single pellet PC/ABS ecoFR LFRT compositions Vs. comparative short fiber and mineral reinforced PC/ABS ecoFR Products

Structural Weatherable LFRTs

Both automotive and industrial applications of LFRT products with superior UV resistance and high modulus LFRT are becoming increasingly popular due to their light weight and design flexibility [13,14]. These structural weatherable LFRT's fall into the category of technology called "Structural Aesthetics". "Structural Aesthetics" is a material solution that provides high modulus (> 7Gpa) with good surface finish (Figure 7). Good surface finish is categorized several ways: a high gloss surface for molded-in-color, weatherable applications using materials like Acrylonitrile-Styrene-Acrylonitrile terpolymer (ASA) or blends of ASA with Polycarbonate (PC/ASA) for auto exteriors, a smooth surface for painted applications using materials like Polyphenylene Oxide (PPO), Polyphynelene Oxide / Poly Amide blends (PPO/PA), Polycarbonate / Polybutyl terepthalate blends (PC/PBT), and others, or a very high gloss surface for applications requiring chrome plating using materials like Acrylonitrile-Butadiene-Styrene (ABS) and Polycarbonate / Acrylonitrile-Butadiene-Styrene blends (PC/ABS). Most of these "aesthetic" materials tend to be unfilled resins. Glass, mica, talc, carbon fibers and other fillers can be added to resins (PPO/PA, PA, PBT, PP, etc) to increase their strength and stiffness (modulus), however, surface quality tends to be sacrificed. Filled materials typically require lower gloss, or may require textures in the tool to allow for acceptable appearance. In addition to short glass fibers, long glass fibers can also be added to increase strength and stiffness above that of short glass filled materials. In comparison to the short glass reinforced materials the long glass reinforced thermoplastics (LFRT) do offer slightly better surface aesthetics due to the lower number of fiber ends at the surface. LFRTs generally exhibit a two part, core-skin morphology in injection molded articles. The long glass tends to orient in the direction of the flow (machine direction) in the skin while in the core the orientation is random. Despite having fewer fiber ends at the surface, the skin morphology hinders formation of a highly resin rich surface in conventional injection molding. Hence, achieving highly glossy surfaces is quite difficult in case of LFRTs and conventional injection molding practices. In the proceeding sections, we will describe a novel molding technique that addresses this challenge.

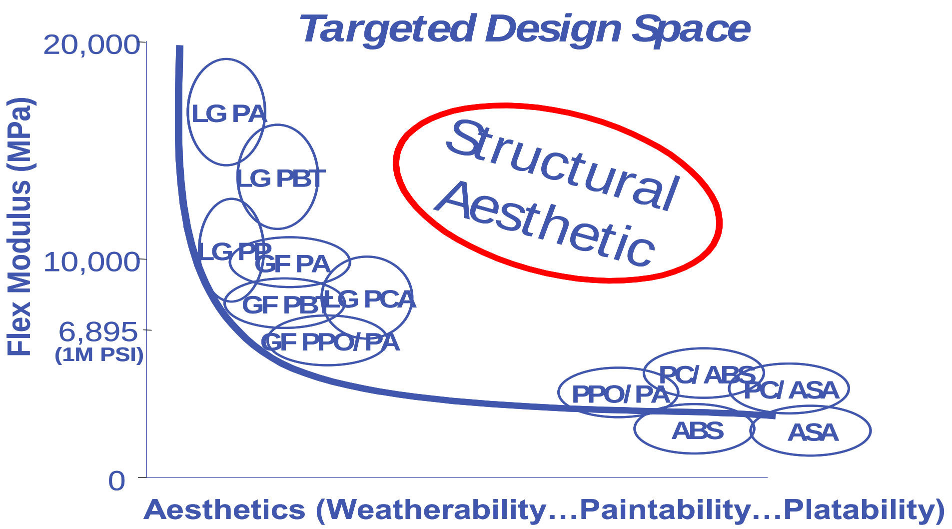

Figure 7: Structural Aesthetics looks to achieve high modulus materials with a high quality surface

Along with high gloss molded in color capability, weatherability or more accurately resistance to UV radiation is a key facet in some of the external components in the automotive and heavy truck industry. An increasing trend at present is that more and more components are being translated to structural engineering thermoplastics for weight & design advantages. Typical short & long glass filled engineering thermoplastics such as PP and PA often cannot offer very good retention of surface gloss and color upon UV exposure.

In this section we will describe some new amorphous LFRT developments that involve the use of Acrylonitrile-Styrene-Acrylonitrile (ASA) terpolymers. In the past such materials have not been suitable for pultrusion processes due to their high viscosity which limits the effective impregnation one can achieve. We have taken a fundamental approach of tailoring the composition of such materials and fine-tuning the blend viscosity to optimize the impregnation. Again, following a statistical design route we have mapped the entire formulation space covering long glass fiber loadings from 10 to 60% by weight. Unique saturated acrylic impact modifiers have been added to the blends to further boost the impact properties of these LFRTs. The glass fiber roving used was similar to the one employed in the single pellet color and ecoFR LFRT formulations described earlier. A proprietary additive package consisting of heat stabilizers & UV stabilizers was included in the blends.

The mechanical and physical properties of 20, 30 and 40% by weight glass reinforced weatherable ASA LFRT are shown in table 3. These formulations show a very good balance of traditional LFRT properties such as impact – stiffness along with low coefficients of linear thermal expansion (CLTE) which is an indication of dimensional stability when these materials are injection molded into the target applications.

Table3: Physical and mechanical properties of 20, 30 & 40 Wt % ASA LFRT formulations. Formulations were molded via conventional injection molding into ISO and ASTM test specimens & later tested after conditioning.

Property	**Test Method**	**Units**	**20% ASA LFRT**	**30% ASA LFRT**	**40% ASA LFRT**
Density	ASTM D 792		1.27	1.35	1.44
ASH	ASTM D 5630	%	21.5	28.6	41.7
CLTE	ASTM E 831				
Flow Direction		µm/(m-°C)	28.8	35.1	n.a.
X-Flow Direction		µm/(m-°C)	50.1	67.9	n.a.
Flexural Modulus	ISO 178	MPa	7795	9629	12125
Flexural Strength	ISO 178	MPa	181	172	213
Tensile Modulus	Iso 527	MPa	8264	9900	13694
Tensile Stress @ Yield	Iso 527	MPa	129	116	150
Tensile Stress @ Break	Iso 527	MPa	129	116	150
Tensile Strain @ Yield	Iso 527	%	1.8	1.3	1.3
Tensile Strain @ Break	Iso 527	%	1.8	1.3	1.3
HDT 1.8MPa	ISO 75	°C	93	93	96
Notched Izod @ 23°C	ISO 180	kJ/m^2	18	21	21
Notched Izod @ -40°C	ISO 180	kJ/m^2	19	23	22
MA Impact @ 23°C	ASTM D3763				
Energy to Max Load		J	5.4	5.7	n.a.
Total Energy		J	11.3	14.1	n.a.
MA Impact @ -40°C	ASTM D3763				
Energy to Max Load		J	5.8	5.9	n.a.
Total Energy		J	11.9	14.5	n.a.

To determine the UV performance of these formulations a 30% ASA LFRT sample was submitted for accelerated Xenon-Arc weathering per the SAE J 1960 test protocol [15]. It is difficult to replicate an outdoor exposure in the Xenon Arc chamber, however it is a good estimate of how a material will behave to UV exposure and offers the benefit of providing timely data [17]. In parallel, we are in the process of submitting the sample for outdoor exposure in Florida per the SAE J 1976 protocol [15]. Those forthcoming results will be covered in a future paper.

For the SAE J 1960 weathering, 50mm by 75mm color chip plaques were molded on a conventional Cincinnati Milacron Magna T85 injection molding machine. The test plaques were then submitted for weathering under the SAE J 1960 specifications [18] as shown in table 4.

Table4: Details of the SAE J 1960 Accelerated Weathering conducted on the ASA LFRT samples.

SAE J 1960 Test Details	
Instrument	Ci65A
Inner Filter	Quartz
Outer Filter	Boro
Wavelength cut off (nm)	270
Irrad. (W/m2 @ 340 nm)	0.55
Air Temp (°C)	~ 50
Black Panel Temp (°C)	70
Rel Humidity (%)	50
Light (Min)	100*
Light/mist (Min)	20*
Dark (Min)	60*

**Each cycle consists of 40 mins. light / 20 mins. light+mist / 60 mins. light / 60 mins. Dark*

The molded sample plaques were then inserted in the Xenon-Arc chamber and one plaque each was pulled at the 1250 kJ and 2500 kJ intervals. Upon removal, the color shift for each plaque was tested at three separate locations on the exposed surface & the L,a,b values recorded. Figure 8 shows the dE shift values for the individual exposure intervals for ASA LFRT samples as measured by a Gretag Macbeth spectrophotometer. An un-reinforced ASA samples was included in the study as a control & for comparison purposes.

An obvious but important fact is that the amount of dE shift is highly dependant on the color pigment package. In case of the ‘black’ colored ASA LFRT sample the total dE shift after 2500 kJ is only 0.75 while for the ‘light gray’ ASA LFRT sample the shift at the same interval is 2.6. The ‘black’ color pigment formulation comprises fully of carbon black which is a well known UV absorber & acts to protect the base polymer matrix in the sample from degrading under the UV exposure. Meanwhile, the ‘Light gray’ color pigment formulation contains a very small amount of the carbon black absorber. The un-reinforced ASA sample shows a dE shift that is normal for ASA resin. All the ASA LFRT samples show slightly higher dE shift as compared to the un-reinforced control because of the presence of glass fiber at the surface which becomes visible once the top most resin layers are lost due to UV degradation. However, from prior studies we have observed that in case of the ASA LFRT this loss is significantly lower than other LFRT composites. All polymers are affected to varying degrees by UV radiation, so the challenge then becomes on controlling the rate of the degradation. A processing approach to this is to increase the resin rich surface layer in the molded article made from highly reinforced thermoplastics. This can be accomplished using novel injection molding processes such as Heat / Cool molding. In the next section this technique is described followed by some results that show remarkable improvements in the surface gloss due to a thicker resin rich surface layer.

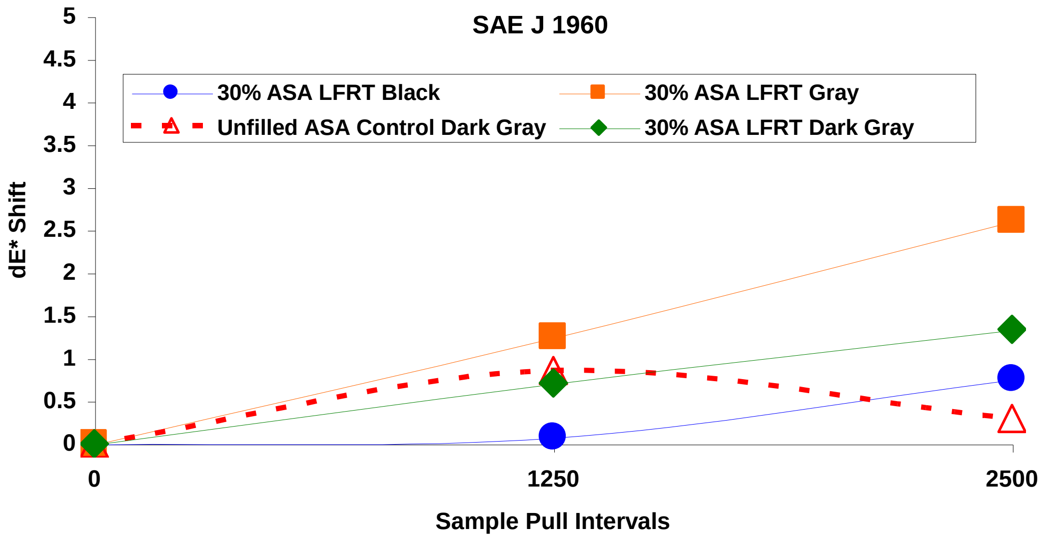

Figure 8: dE shift in color to the initial plaque for the ASA LFRT materials after SAE J 1960 weathering. An un-reinforced ASA sample was included as a control.

Heat / Cool Molding – An avenue towards improving the surface aesthetics of LFRT materials.

The objective of the program described here is to develop a solution for high modulus materials that can ultimately be molded-in-color, painted, and chrome plated all from a single injection-molding tool. This is done by combining materials, processing, tooling and secondary operations (Figure 9). This program focuses on long glass engineering thermoplastics (long glass ASA resin and long glass PC/ABS resin) molded using a Heat and Cool injection molding process, in an injection mold with conformal cooling, and then painted and/or chrome plated. The process, tooling and secondary operations are described below.

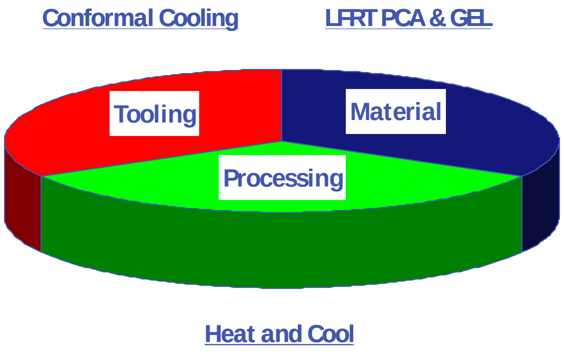

Figure 9: Structural Aesthetics is a combination of materials, tooling, and process technology

Processing

It is widely understood in the molding community that increasing tool surface temperature of an injection mold does several things: it improves the surface finish of the molded part; it reduces molded in stress; and it increases cycle time. Conversely, decreasing the tool surface temperature reduces the quality of the surface finish, increases molded in stresses, and decreases cycle time. To achieve improved aesthetics, Heat and Cool [19] process technology was used. In this process, pressurized, high temperature water is pumped through the cooling channels of the mold. The temperature of the water in this system reaches 200°C, and is pressurized to prevent the water from turning to steam. By contrast, typical “high temperatures” for ASA or PC/ASA materials range from 70-90°C and from 80-100°C for PC/ABS. SINGLE Temperiertechnik GmbH of Hochdorf /Germany supplied the control unit for this study. The control unit (which supplies both hot and cold water) and its operation are shown in Figure 10. Following heating of the tool, the plasticized resin is injected into the cavity. The control unit switches from the “hot side” to the “cold side”, flushing the hot water, and replacing it with cold water. Figure 11 shows a tool surface temperature profile using this process. In this case, the tool is heated to a peak temperature above the glass transition temperature (T_g) of the resin followed by a cooling cycle so that the part may be ejected from the tool with-out any distortion. Overall cycle time increases, and is addressed in the tooling section below.

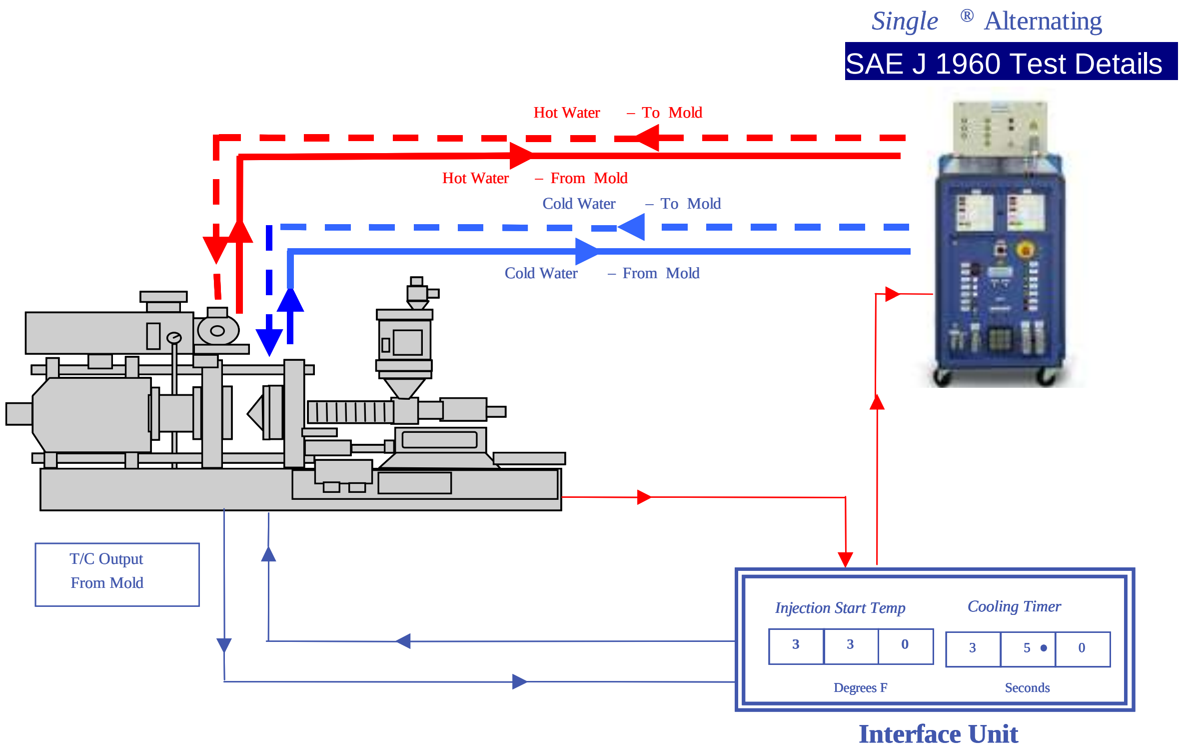

Figure 10: Heat & Cool Temperature Controller

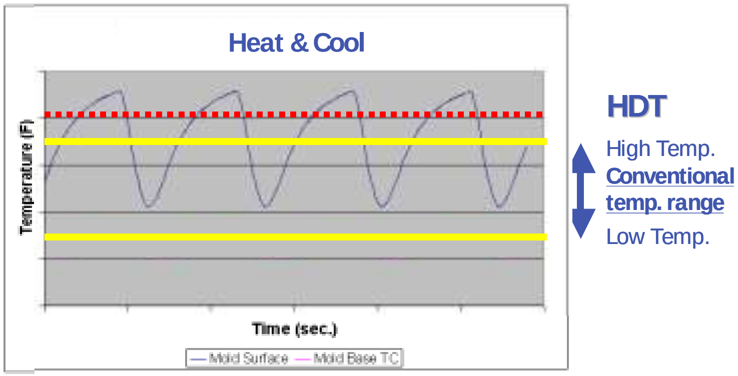

Figure 11: Mold surface temperature profile

Molded at elevated temperatures, the resin flows into the cavity under very low stress and replicates the tool surface very well. Figure 12 shows three parts molded with Heat and Cool process technology. The part shown in the top image represents a part molded with conventional tool temperatures (~ 85°C), and shows substantial amounts of surface glass. The image in the center was molded with a tool temperature above the Tg of the resin and the cavity was polished to a SPI B2 level. The part at the bottom of the image was also molded at a temperature above the T_g of the resin, and the tool was polished to an SPI A2 finish. The gloss levels achieved in this case exceed 90° gloss on a 60° degree gloss measurement using a BYK Gardner micro-TRI-gloss reflectometer (see Table 5). This compares to less than a 4.0 gloss with a tool polish level of SPI B2.

Figure 12: Molded part shown top to bottom: 20% ASA LFRT molded at conventional temperatures; 20% ASA LFRT molded with Heat and Cool in unpolished tool; 20% ASA LFRT molded with Heat and Cool in polished tool

Table 5: 60° Gloss readings on parts molded via the Heat / Cool process

	SPI B2 Tool Surface	SPI A2 Tool Surface
	3.8	90.6
	3.4	91.7
	4.0	90.3
	3.5	88.1
	3.3	91.1
Average	**3.6**	**90.4**

Tooling

Heat and Cool processing increases the overall cycle time of the part due to the fact that the tool steel itself is raised and lowered. Conformal cooling is used to minimize this effect. By designing the cooling/heating lines to conform to the part surface (Figure 13), it's possible to reduce the amount of time needed to cool the part. The cavity insert can also be cored out to minimize the amount of thermal mass that is heated and subsequently cooled. Finally, the cavity and the core inserts can be insulated from the mold retainer plates using ceramic, air, or other insulating materials. There are several methods to obtain conformal cooling channels, including, laminar plate steel tooling, lost-core casting, investment casting, etc. This program uses a laminar plate steel tool built by Fast4M in Troy, MI (Figure 14).

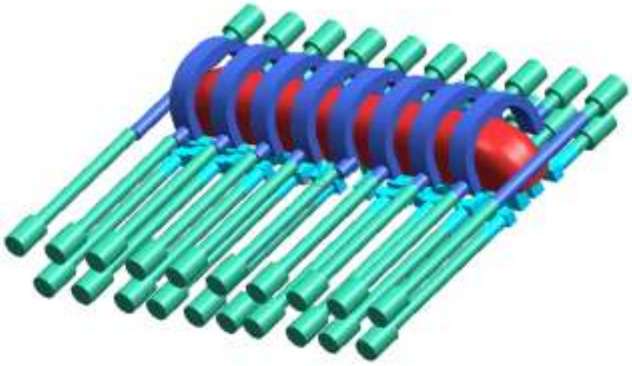

Figure 13: Section Tool showing cooling line layout

Figure 14: Cavity insert of Section Tool prior to polishing

Applications

Numerous applications exist in the automotive and non-automotive industry that could benefit from the technologies described here. Applications requiring high stiffness and good first surface aesthetics include roof racks, running boards, front grilles, door handles, step assists, and mirror brackets, to name just a few. The value to the customer is a one-tool solution for the molding of chrome plated, painted and molded-in-color appearances. A one-tool solution avoids the capital expense of multiple tools for multiple appearances. Paint elimination is also an advantage when molding parts in color. Part mass reduction can also be gained when removing metal components and integrating into a single injection molded article. Design flexibility is also an advantage if the current applications are limited to straight metal sections, like extruded aluminum or roll formed steel.

Conclusions

This study shows some new developments in the areas of LFRT materials with respect to color, flame retardancy and weatherability. In all three cases, we have shown new materials that can be successfully pultruded into LFRT compounds that maintain the inherent advantages of such materials (impact-stiffness-strength balance) & further add value.

- Single pellet color LFRT – A novel single pellet solution for custom colored LFRT materials offers better mechanical properties as compared to current two pellet dry blend LFRT materials. These single pellet materials show more uniform color across the molded articles due to the higher dispersion of the color pigment particles. This methodology can be applied across multiple engineering base resin systems. These single pellet LFRT materials can offer end-users higher flexibility in terms of color choices while maintaining superior structural properties
- Single pellet flame retardant LFRT – Single pellet LFRT compositions based on a non-halogenated (ecoFR) FR system were successfully developed. These compositions marry the advantages of a ecoFR PC/ABS base polymer blend with long glass fiber technology. Their FR performance and mechanical properties make them an ideal choice for structural applications in the consumer and business electronics markets

- Structural Weatharable LFRT – A new class of LFRT compositions based on ASA resins was introduced. These compositions exhibit excellent weatherability in accelerated Xenon-Arc testing. Along with very high stiffness and impact performance they also offer excellent dimensional stability as indicated by their CLTE (co-efficient of linear thermal expansion) results. By marrying these materials with innovative injection molding techniques such as Heat / Cool molding, on can achieve excellent surface aesthetics in parts which show good resistance to UV exposure
- Heat / Cool Molding – Use of this injection molding process has been demonstrated in case of the structural weatherable materials. Extremely high surface gloss values were measured on molded articles. Further, this technique can be utilized across the range of other LFRT materials to improve aesthetics in molded parts.

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