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Using Unidirectional Glass Tapes to Improve Impact Performance of Thermoplastic Composites in Automotive Applications

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Abstract

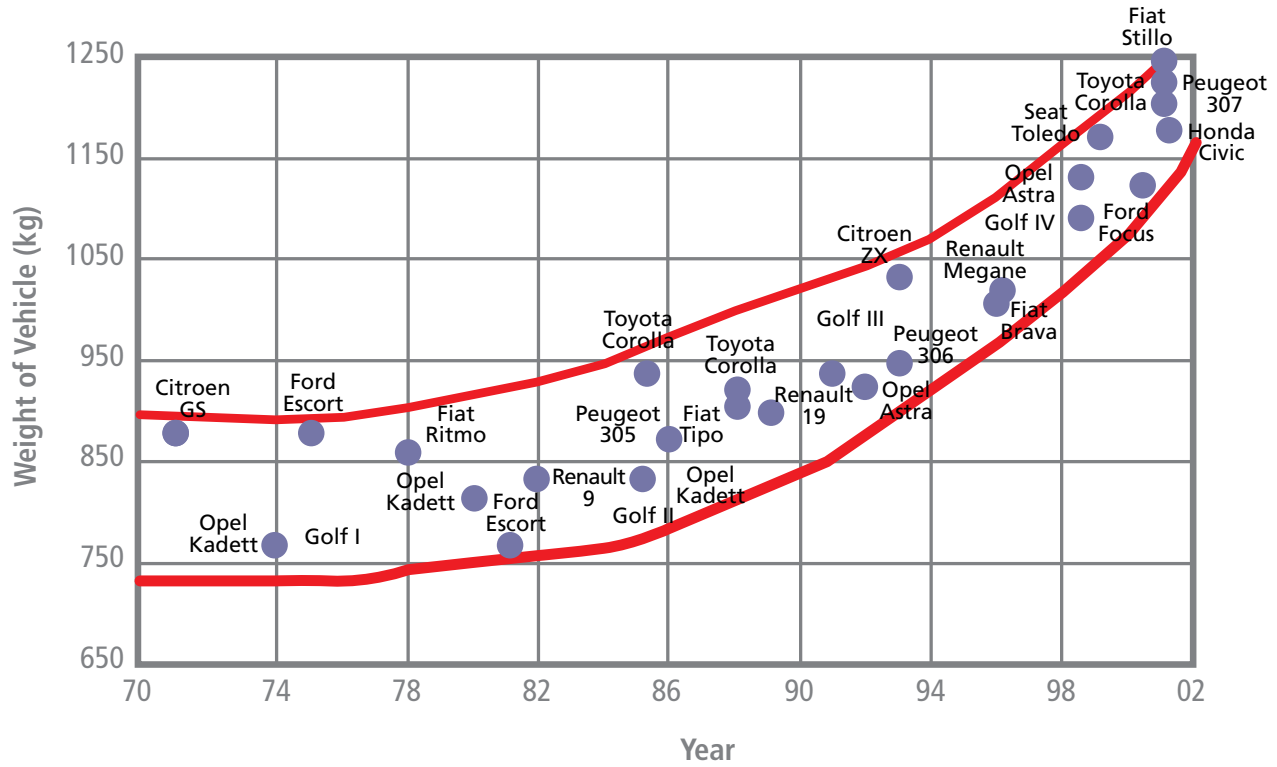
With strong pressures to reduce carbon emissions and improve fuel economy for passenger vehicles and commercial trucks in most geographies, interest in composites by transportation OEMs is growing. As a result, suppliers of composite materials are working to improve thermo-mechanical performance, increase processing speeds, reduce part mass and costs, enhance surface aesthetics with fewer post-mold operations and generally make it easier to position composites against high-strength steel and aluminum. To that end, a study conducted by organizations in Europe and North America last year looked at methods to increase stiffness/strength and impact resistance of thermoplastic composites by using continuous-strand, unidirectional-glass (UD) tapes to produce woven fabrics as well as laminates. Combinations of the tape fabrics and the tape laminates in various layup patterns were then used in conjunction with charges produced in the direct-long-fiber thermoplastic (D-LFT) inline compounding (ILC) process to compression mold both test plaques and later an actual automotive underbody-shield part to determine the extent to which impact performance could be improved.

Drivers for Composites Growth in Automotive

From the 1970s through the 2000s, mass of the average European compact-car increased 400 kg, or almost 50% (Figure 1[1]) thanks mainly to the addition of various electronic systems, passenger convenience, and safety equipment. North American vehicles gained even more weight and size over the same time period owing to readily available and inexpensive petroleum, and the twin desire for greater luxury and more power. The high-fuel prices of the mid-to-late 2000s significantly increased consumer demand for alternative-powertrain vehicles, and automakers scrambled to design and produce more hybrid-electric, battery-electric, and even fuel-cell vehicles. Unfortunately, the energy-storage systems commonly used for these platforms tend to increase vehicle mass an average of 100-300 kg, effectively limiting driving range. A further challenge owing to more demanding fuel-economy as well as greenhouse-gas emissions standards pending or already in place in North America, Europe, and Asia means automakers must get weight out of vehicles quickly. These trends have created market conditions that favor great interest in polymer composites as a means to reduce mass and increase a vehicle's overall energy efficiency.

While carbon fiber-reinforced plastics (CFRP) regularly receive attention in the automotive industry for their high-tech glamour and lightweight stiffness and strength, current technology constraints in cycle times, fiber availability, and costs continue to price these materials out of reach for most applications on all but the most exclusive performance and prestige vehicles. With all automakers looking for practical ways to reduce component mass while also managing costs, there is great interest in ways to increase performance of readily available, workhorse composites like glass-reinforced polypropylene (GR-PP), which is light, cost effective, damage tolerant, offers a good balance of mechanical properties, and has a long history of use on semi-structural and select structural components. The key to broadening the use of such materials on passenger vehicles is to increase stiffness and strength, and that is best accomplished by an increase in retained fiber length and fiber-volume fraction (FVF) as well as by using the fibers in a more intelligent manner (where they can do the most good) – all of which are well-known in the industry to improve mechanical performance of composites.

Figure 1 • Vehicle weight increase (in kg) for typical European compact-class cars from 1970 through 2002 (Source: EU-Super Light Car [1]).



Development of Tailored D-LFT Composites

In the late 1990s and early 2000s, an interesting collision of two competing technologies occurred that has led to development of a fairly new form of glass-reinforced (GR)-PP composite: tailored D-LFT.

Significant mechanical performance can be achieved from traditional continuous-fiber, randomly oriented glass-mat thermoplastics (GMT). Mechanicals can be further boosted with the addition of various types of fabric weaves, which are easy to add to the stack of "blanks" laid into the tool. However, the relatively high cost of these semi-finished advanced GMT products, and the inherent challenges of filling complex geometry (e.g., tall ribs) with continuous-glass reinforcements using sheet-form GMT composites has led first to use of a chopped discontinuous (rather than continuous) glass mat (which traded stiffness/strength for better flow into complex geometries). A still later development was the use of lofted forms of GMT (commonly called lightweight reinforced thermoplastics or LWRT), which allowed density to be varied across the part simply by compressing certain sections deeper than others to selectively boost stiffness without changing tooling or adding mass.

On the other hand, there has long been an ongoing effort on the part of producers of injection-molded thermoplastics to increase retained fiber length and FVFs to boost mechanical performance in these materials so OEMs could take advantage of the benefits of this materials/process combination – rapid cycling times, excellent surface finish, unmatched part complexity, and low cost in high volumes – in more demanding semi-structural and fully structural applications. This work led initially to development of longer pellets of precompounded resin and reinforcement (pelletized LFT), and later (when feed-throat restrictions in the injection molding system were reached) to development of the inline compounding (ILC) process, where resin is compounded with additives on-the-fly at press side and joined with continuous-strand reinforcement just prior to producing a charge or log of material that is then placed manually or automatically into an injection or compression molding press.

Efforts of GMT manufacturers to improve moldability at the cost of stiffness/strength, and of injection molding resin suppliers to increase stiffness/strength at the cost of molding complexity led to development of D-LFT materials for compression molding. This direct-LFT material/

process combination offers higher impact strength than conventional and pelletized LFT injection materials at lower cost and greater formulation flexibility (since it gives molders the opportunity to custom-compound compound at the press). However, the longer glass in D-LFT material does necessitate moving the process out of injection and into compression molding, owing to restrictions in the feed throat. This leads to a tradeoff, since compression molding cannot produce parts of the same level of complexity as injection. Fibers going into a compression-molding tool can be as long as 40-50 mm (vs. 13 mm for pelletized LFT for injection molding), which provides the improved impact properties. Efforts to help boost mechanical properties further on conventional D-LFT compounds led to the development of the hybrid "*tailored*" D-LFT process, which mixes discontinuous and continuous forms of reinforcement.

Like conventional D-LFT, the tailored process uses ILC techniques to compound, reinforce, and produce a charge of material at press-side. And like advanced GMT types, the process also enables additional layers of continuous-glass-reinforced fabric and/or laminate prepreg (heated in a nearby infrared [IR] oven to ensure good fusion with the D-LFT) to be laid up with the discontinuous-glass charge in the tool prior to molding. Use of such UD-glass products can boost FVFs from standard 20-30% to as much as 50-60% in localized areas of the part [3]. This makes it possible to selectively increase thermal stability, creep, and mechanical performance of tailored D-LFT parts at lower cost than purchasing advanced forms of GMT or opting for higher temperature resin matrices, while still providing the benefits of discontinuous reinforcement where moldability in complex geometry such as ribs is important.

Although the tailored D-LFT process was developed for the automotive industry in Europe, to date it has not been widely used for commercial parts production, particularly by suppliers outside of Europe and outside of the automotive market segment. However, the current interest in composites and the need to reduce component mass in the auto industry provided an excellent opportunity for four companies to work on a joint study to evaluate how the tailored D-LFT process might be used to boost the mechanical properties (and in particular the impact strength) of D-LFT composites. Results of that work are described and presented in this paper.

TECHNIQUES TO BOOST MECHANICALS OF D-LFT COMPOSITES

In 2011, Ticona Engineering Polymers[1], Oxeon AB[2], Fiberforge[3], and Fraunhofer Institute for Chemical Technology (Fraunhofer ICT)[4] decided to work together on a joint study to evaluate techniques to boost the mechanical properties of D-LFT composites with a PP matrix. The approach was to use the tailored D-LFT process and two forms of UD-glass reinforcement, which were produced from continuous-strand, UD-glass tapes produced by Ticona and subsequently formed into a plain-weave tape woven fabric by Oxeon or into a UD tailored blank/laminate by Fiberforge. Use of UD-glass tapes are already well recognized in the composites industry for boosting stiffness/strength of composite materials. Ticona's glass tapes in higher temperature matrices are already used in the commercial aviation market for a variety of thermoplastic components. Hence these tapes provided a logical starting point for the study. Oxeon is an experienced converter of spread-tow reinforcements (UD tapes and 0/90 & $+\alpha/-\beta$ fabrics) from a range of different materials, utilizing their novel Spread Tow- and Tape Weaving technologies, and thus was the perfect partner to produce woven fabrics based on the UD-glass tapes. Fiberforge has patented a process for converting preimpregnated thermoplastic tapes like those produced by Ticona into UD laminates with tailored fiber orientation (called Tailored Blanks, but hereafter referred to as tape laminates), which are used to boost the mechanical performance of thermoplastic composites. And Fraunhofer ICT is a fully equipped R&D center with significant expertise in the field of polymer composites. In fact, Fraunhofer ICT, in conjunction with Dieffenbacher GmbH Maschinen- und Anlagenbau[5] helped co-develop the D- LFT process in the early 2000s and then helped develop the tailored D-LFT process in the mid-2000s.

Study Overview

The main study consisted of two distinct phases.

In the first phase, pure D-LFT charge, pure tape-based fabrics, pure tape-based laminates, and then various hybrid combinations of 2 or 3 materials in different layups were laid up in a simple 400 x 400 mm flat test plaque tool and compression molded. After demolding, a number of standard test specimens were waterjet cut from each plaque and were subjected to *EN ISO 6603-2 "Determination of Multiaxial Impact Behavior of Rigid Plastics – Part 2: Instrumented Puncture Test"* [12]. The generous size of the test plaque allowed enough samples (6 total) to be cut from a single plaque to do all the testing planned while reserving 1 of the 6 as a control. The simple geometry

[1] Florence, KY, USA and Sulzbach, Germany
[2] Borås, Sweden
[3] Glenwood Springs, CO, USA
[4] Pfinztal, Germany
[5] Eppingen, Germany

allowed for very rapid evaluation of numerous combinations of materials and layup patterns so researchers could quickly evaluate results and determine the best-performing candidates.

As part of the first phase of testing, with the hybrid-material plaques, to reduce influence of sample prep on the results obtained samples for impact testing were cut from both the pure D-LFT as well as tape-fabric or tape-laminate side of the plaque.

In the second phase of the study, researchers used the knowledge they gained from molding the various combinations of pure and hybrid materials in the plaque tool to come up with a specific combination of all three materials that they felt would work in a more complex part – an approximately 1,100 x 800 mm automotive engine noise shield (generously loaned to study participants by Minda Schenk Plastic Solutions[6]). This was an excellent application to assess the commercial viability of tailored D-LFT since it was a real production automotive tool. It was a more demanding design to fill than the flat test plaques because it had segments of tall, thin ribs and other design features that UD-glass products would have a hard time penetrating. The tool did offer researchers a couple of challenges, although these turned out to be relatively easy to overcome. First, since it was designed to mold standard D-LFT, it was not equipped with clamps/fixtures that could be used to hold tape fabrics or tape laminates in place and prevent their movement during forming. This necessitated precutting the UD-tape-based products to end-shape dimensions and manually positioning them inside the cavity prior to press closure. Although problems were anticipated, the manual placement method worked well. In addition, since this was a real production tool meant for continuous operation, there were no heating lines installed, so no way to heat the tool other than to keep molding hot material. During the time when the hybrid parts were produced and molded, the tool was kept warm (≈40-45°C) by molding pure D-LFT parts, which exit the ILC process at close to 200°C. Since the goal of the engine-shield molding trial was to evaluate if the tailored D-LFT process was fast enough for commercial automotive production, no further testing was done on the hybrid shield parts.

Material Inputs

The base D-LFT material used in the study was inline compounded using resin (PP-C711-70 RNA) supplied by Dow Chemical, an additives package (Priex[7] 20078 coupling agent for improved impact performance and AddVance 453 stabilizer) supplied by Addcomp Holland BV; and glass fiber (JM 490 2400 tex glass) supplied by Johns Manville. For the plaque tool, glass loading for the D-LFT charge was 30 wt-%, which is the most common automotive loading level for D-LFT materials. However, owing to the complexity of the engine shield tool, a glass loading level of 20 wt-% was used to enhance fill.

A ZSE-60 GI500 32D inline compounding system was used in combination with a ZSG-75 HP300 mixing extruder (both from Leistritz Extrusionstechnik GmbH[8]) and a dosing unit from Brabender[9] GmbH & Co. KG[10]. The ILC system was supplied by Dieffenbacher and coupled to the company's 36,000-kN Compress Plus DCP-G 3600/3200 AS hydraulic compression press equipped with parallel leveling control[11].

For the UD-glass based products, the starting preimpregnated tapes (Celstran[12] CFR-TP PP-GF70 with 70 wt-% glass supplied by Ticona) were 0.25 mm thick, and were supplied slit to various widths depending on what was being done with them.

In turn, Oxeon used the tapes to produce plain-weave TeXtreme[13] fabrics that were 0.50 mm thick per layer in either a 0°/90° = (0/90) or a ± 45° configuration = (±45). These fabrics were supplied unconsolidated.

Ticona's tapes were also used by Fiberforge to produce Tailored Blank/tape laminates. Laminates destined for flat plaque molding trials were laid up in several different patterns: a 0°/90° configuration = (0/90) in a single preconsolidated sheet whose final thickness was 0.5, 1.0, 1.5, or 2.0 mm; or a quasi-isotropic configuration = $(0,90,+45,-45)_s$ where "s" represents number of layers of laminate symmetry. For the engine-shield molding trials, Fiberforge made both generic laminates for manual cut-out as well as Tailored Blanks (consolidated laminates with geometry cut to match tool geometry, thereby reducing scrap) to show the enhanced design options possible with tailored products.

Pure and Hybrid Layup Configurations

To quickly determine the effect of using UD-tape products to alter the mechanical properties of the base D-LFT material, for the first phase of testing, 21 different pure material and hybrid material configurations were attempted and 20 were successfully produced in the flat plaque tool.

[6] Esslingen, Germany
[7] Priex and AddVance are registered trademarks of Addcomp Holland BV.
[8] Nuremberg, Germany
[9] Brabender is a registered trademark of Brabender GmbH & Co. KG.
[10] Duisburg, Germany
[11] The latter feature is particularly important to guarantee global accurate thickness in parts when molding materials like D-LFT. Even if a charge is placed off center in the tool, the press will compensate (by pushing deeper into another section of the charge) so that final part thickness will be uniform across the part. Given the speed at which compression presses typically operate, especially with short cycle-time thermoplastics, the presses are required to have extremely accurate and responsive parallel leveling control.
[12] Celstran is a registered trademark of Ticona Engineering Polymers
[13] TeXtreme is a registered trademark of Oxeon AB.

The 11 most representative configurations are shown in Table I below. A single plaque was produced for each configuration, and then test coupons were removed and subjected to instrumented puncture impact testing as noted previously. The ability to produce a large number of test combinations quickly and then evaluate their performance helped researchers understand the combinations that yielded the best results.

Based on what was learned in the flat plaque molding trials, for the second phase of the study with the engine-noise shield, researchers selected a new hybrid materials combination that they felt would work best in this tool. Since this tool was larger and more complex, researchers wanted to understand how the various materials moved/flowed in the tool, especially since it was not equipped with clamps/fixtures and researchers were still concerned the UD-tape products might move significantly during the molding process. To evaluate material movement, Ticona supplied precolored UD tapes as well as a color masterbatch for the D-LFT material. Coloration was used as follows: the D-LFT charge was blue; the tape fabric was black; and the tape laminate was yellow, as shown in Figures 2a, 2b, and 2c and 3a and 3b and also in the color-coded rows in Table I (rows in green represent hybrid materials combinations).

Oven Preheating Parameters

In both studies, to ensure good adhesion between the D-LFT charge and the tape fabrics or tape laminates, the latter UD-glass forms were preheated in an IR oven just prior to being placed in either the plaque tool or the engine shield tool. Heating time was dependent on the thickness of each material, but generally ranged from 30 to 140 sec for materials used in the plaque tool and 60 sec for materials used in the engine shield tool. The fabric/laminate materials were always placed in the tool first and then covered with the D-LFT charge.

Because Oxeon's tape fabrics were produced in single layers, to create multilayer layups for the plaque molding, researchers needed a method to heat the plies to create a multiple-layer blank that could subsequently be placed in the tool. The method they used was that several sheets were placed next to each other in the IR oven, the PP matrix was heated close to its melting point of 200°C, individual plies quickly but gently stacked on top of each other (without any additional pressure) to produce blanks of the required thickness, and then equally quickly they were moved to the nearby tool for molding. Since only single ply (0/90) fabrics were used in the shield molding, this extra stacking step was eliminated.

Molding Parameters

The smaller plaque tool was molded at ≈3,200 kN pressure. During molding, dwell time in the plaque tool was about 45 sec at with a tool temperature of 75°C. Because many of the parts molded in this tool were 3.0 mm thick, the 45 sec dwell time was selected to ensure the part reached the proper temperature prior to demolding. For thinner layups, a shorter dwell time could have been selected, but researchers wanted to keep molding conditions uniform so they left thinner plaques in for 45 sec as well.

In the second part of the study, tool dwell time was actually shorter (at 30 sec) for the larger shield part because the tool was colder (≈40-45°C), allowing the part to freeze off more quickly so it could be demolded faster. Here, molding pressure was 12,000 kN. Section thickness

Table 1 • Representative types of materials and layup combinations used to mold flat test plaques (n/a = not applicable for this sample)

Name of Combination	Materials	Nominal Wall (mm)	No. of Plies/ Layers	Fiber Orientation of Each Ply (°)
V1	Pure Tape Fabric	2.0	4	(0/90)
V2	Pure Tape Laminate	2.0	1	$(0/90)2_s$
V3	Pure D-LFT	2.0	n/a	D-LFT
V4	Pure D-LFT	2.5	n/a	D-LFT
V5	Pure D-LFT	3.0	n/a	D-LFT
V6	Hybrid of Tape Fabric + D-LFT	0.5 + 2.5	1	(0/90) + D-LFT
V7	Hybrid of Tape Laminate + D-LFT	0.5 +2.5	1	(0/90) + D-LFT
V8	Hybrid of Tape Fabric + D-LFT	1.0 + 2.0	2	2 x (0/90) + D-LFT
V9	Hybrid of Tape Laminate + D-LFT	1.0 + 2.0	1	$(0/90)_s$ + D-LFT
V10	Hybrid of Tape Fabric + Tape Laminate + D-LFT	2 x 0.5 + 2.0	1 + 1	(0/90) + (0/90) + D-LFT
V11	Hybrid of Tape Laminate + Tape Fabric + D-LFT	2 x 0.5 + 2.0	1 + 1	(0/90) + (0/90) + D-LFT

Materials used in the shield molding trial were colored to see how they moved in the tool.

Figure 2a • Tape fabric (black)

Figure 2b • Tailored blank (yellow)

Figure 2c • D-LFT (blue)

How various materials looked on molded shield part.

Figure 3a • Front-side facing the road

Figure 3b • Back-side faced the underside of the vehicle

was approximately 2.5 mm within the part. Since the compounding, oven heating, and molding cells were adjacent, it was possible to simultaneously heat fabrics or laminates and compound D-LFT while parts were being molded. In the case of the engine shield, that yielded an effective cycle time of ≈70 sec, which would be fast enough to keep pace with typical automotive production volumes even with this non-optimized manual sequence.

Flat Plaque Impact Test Parameters

Once flat test plaques were molded and samples were removed, instrumented puncture tests were conducted. As previously noted, increasing impact strength of the base D-LFT material was a significant goal of the study and is the focus of this paper. A CEAST Fractovis testing machine equipped with a Type C clamping device (40 mm inner diameter) and a 20 mm hemispherical-shaped impactor was used to hit samples at a speed of 4.4 m/sec at room temperature (23°C). In the pure material testing phase, samples were cut as 60 mm wide coupons. In the case of very-thin samples, which were either tape fabrics or tape laminates alone (without the additional pure D-LFT), the 60 mm coupons proved so thin that they pulled out of the clamping device during testing. Realizing there was a problem, researchers referred to a standard (*ISO 7765-2 for Film & Sheeting: Determination of Impact Resistance by Free-Falling Dart Method – Part 2: Instrumented Puncture Test*) for testing foils (skin/foam laminates) and saw that an 80 mm sample was allowed in order to increase the clamped surface area of the specimen. For subsequent impact tests of the thinnest pure fabric or laminate, wider 80 mm coupons were cut and tested successfully for the pure fabric and pure laminate samples.

Results & Next Steps

PHASE 1: Flat Plaque Impact Testing – Pure Material Combinations

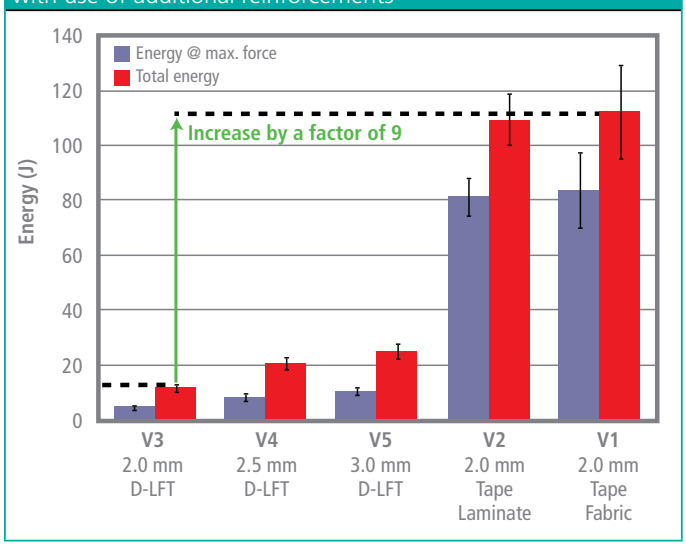
Impact testing of the pure D-LFT (at 2.0, 2.5, and 3.0 mm thickness), pure tape laminates (at 2.0 mm thickness), and pure tape fabrics (at 2.0 mm thickness) showed dramatic improvements in both impact energy at maximum force (blue bars) and total energy (red bars) for the UD-glass products (Figure 4). Results for both tape fabrics and tape laminates were similar and showed roughly 9x higher values in total energy vs. those for straight D-LFT (control) materials without additional reinforcements – once again underscoring the benefits that longer reinforcement and higher FVFs have on stiffness/strength and toughness properties. It should be noted that this graph is useful for noting general (qualitative) trends but should not be used to obtain absolute (quantitative) values on samples of different thicknesses. This is because Young's modulus varies with wall thickness (which is dependent on the ratio of D-LFT to UD-tape materials used in each plaque) and the second moment of inertia also is strongly dependent on wall thickness.

PHASE 1: Flat Plaque Impact Testing – Hybrid Material Combinations

The same tests were repeated for hybrid flat plaque samples as well. As previously noted, to better understand the influence of fiber orientation with these materials, coupons were cut so that each sample had a D-LFT side as well as a UD-tape side. Impact testing for the hybrid plaques was done on both the D-LFT and the UD tape and results were compared. This helped researchers better understand how real hybrid parts might respond in the end-use environment during a puncture-type impact event.

Figure 5 plots the pure D-LFT control materials against results from a number of the hybrid configurations (all at 3.0 mm thickness) from both the D-LFT and UD-tape (either tape fabric or tape laminate) side of the part. In all cases, the impacted side of a given sample was destroyed during the test. Not surprisingly, results were different for each side of a given hybrid pair of test samples. What's interesting here is the values for impact energy at maximum force (blue bars) and total energy absorbed (red bars) for samples from a given part from both the D-LFT and UD-tape sides of the part. Energy at maximum force (blue bars) is always lower on the D-LFT side of a sample than on the UD-tape side for each pair – whether tape fabric, tape laminate, or a combination of both were used. The reverse trend is observed for total energy absorbed

Figure 4 • Impact energy of pure D-LFT (at 2.0, 2.5, & 3.0 mm thickness) vs. pure tape laminates and pure tape fabrics (both at 2.0 mm thickness) showing a 9-fold increase in performance with use of additional reinforcements

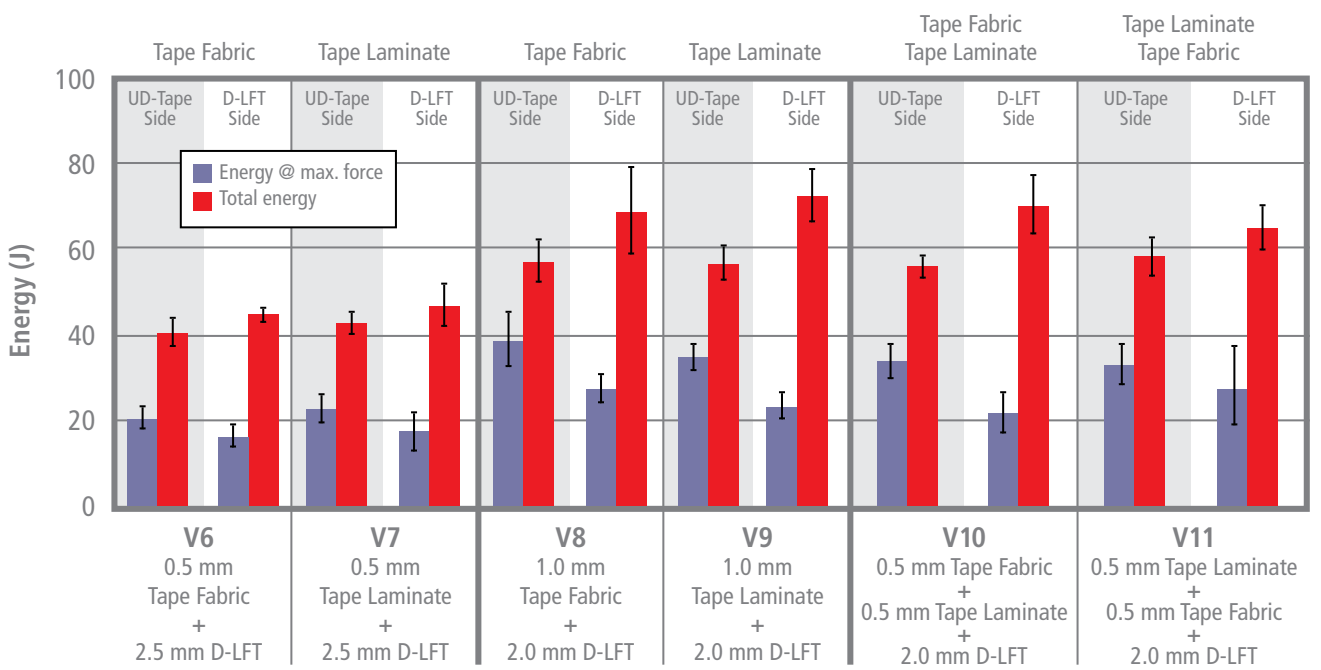


(red bars) for each pair of samples. Researchers believe that because the UD-tape side of each sample is stiffer and stronger, more energy is required to initially damage that side of the part (higher energy at maximum force) vs. the D-LFT side. On the other hand, because the D-LFT side of the part is not as stiff, it breaks more easily and sooner during impact testing, absorbing less initial energy (lower energy at maximum force) during testing while simultaneously putting the UD fibers on the reverse side into tension (higher total energy), so when they are finally impacted (as the D-LFT side fails), less kinetic energy is left in the impactor.

PHASE 2: Engine-Shield Molding Demonstration

Since the goal of the engine-shield molding trial was to evaluate whether the UD-tape products could successfully be used in the tailored D-LFT process in a cycle time that would be realistic for a commercial automotive part production, no further testing of these molded parts took place. While the effective cycle time for the shield parts was 70 sec with a non-optimized manual transfer of preheated UD-tape products, it is still well within the range of acceptable cycle times for thermoplastic composites and is vastly faster than similar performing thermoset composite offsets. The actual tool dwell time was just 30 sec, which is good even by thermoplastic composites standards. Since the limiting process step was preheating the UD-tape products, researchers are confident that with a staged oven, an automated materials handling setup, and a tool equipped with clamps/fixtures to hold UD-tape products, that total cycle times could be driven lower.

Figure 5 • Summary of impact performance of both impacted sides of the hybrid configuration with respect to UD-tape (tape fabrics, tape laminates, or both) and D-LFT side of part.



Summary and Next Steps

Both phases of the study reiterated results seen in numerous other studies that longer fibers and more fibers increase stiffness/strength and impact resistance (toughness) of parts. The study also showed the benefits of a hybrid molding process like tailored D-LFT. Although pure tape fabrics and pure tape laminates provide better ultimate performance at a given wall thickness, these materials are more costly to use per unit weight than pure D-LFT and can pose filling challenges for parts with complex geometry such as thin ribs if used alone. They are best suited for selectively adding performance locally where needed.

Similarly, while the discontinuous glass (in significantly lower FVFs) in the pure D-LFT lacks the stiffness/strength and impact performance of the UD-glass products, it offers better flow properties to fill a complex part geometry like was present in the engine-shield tool. By using a hybrid approach like tailored D-LFT, the best features of one material compensates for the weaknesses of the other material and vice versa with a result that should improve durability and length of service life for thermoplastic composite parts. This, in turn, can be used to either improve performance of a given compression molded D-LFT part at comparable wall thickness and only a modest weight increase vs. a pure D-LFT part, or it can be used to provide comparable performance with less material at thinner walls.

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13. *Hangs, B., M. Reif, S. Jespersen, & F. Henning, "Verbesserung der Impacteigenschaften Langfaserverstärkter Thermoplaste durch deren Kombination mit UD-Tapes," 18. Nationales Symposium der SAMPE Deutschland e.V., 29.02. – 01.03.2012, Karlsruhe, Germany.*

14. *Grauer, D., B. Hangs, M. Reif, A. Martsman, & S.J. Jespersen, "Improving Mechanical Performance of Automotive Underbody Shield with Unidirectional Tapes in Compression-Molded Direct-Long-Fiber Thermoplastics," SAMPE Journal, May/June 2012, Vol. 48, No. 2, pp. 7-13, 2012, (Covina, CA).*

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