Improving impact performance in D-LFT composites via UD-tape based fabrics & tailored laminates

A study was conducted on inline compounded direct-long-fiber thermoplastic (D-LFT) composites to evaluate methods to increase energy absorption of glass-reinforced polypropylene in an impact scenario through addition of unidirectional (UD) tape-based fabrics and tailored laminates. Results indicate such hybrid structures may open new opportunities for thermoplastic composites produced in the tailored D-LFT process for a variety of market segments.

Improving Impact Properties of D-LFT Composites

Recognising the benefits of tailored D-LFT for any industry desiring to improve the mechnical performance of thermoplastic composites, this study set out to investigate the impact performance of D-LFT composites. With this in mind, the study evaluated the impact performance in the following areas:

1. Evaluate the effects on impact properties of using UD-glass tape-based products (which are currently not used in the taileredD-LFT fabrication and tailored laminate process) in the tailored D-LFT process; and
2. Check that tailored D-LFT is a viable process for designing structural components of complex parts. Ticona Engineering Polymers supplied PP-imregnated UD glass-reinforced tapes that Owen AB, with expertise in producing two formenrments (based on test tapes instead of parts), used to produce woven fabrics. Fibreforce also used the described tapes to produce Tailored Blank Plate laminea using its patented process for converting preimpregnated thermoplastic tapes. In turn, Fraunhofer Institute for Chemical Technology – a fully equipped RD center with significant experience in the field of polymer composites – compounded PP-based D-LFT material and used various combinations of the D-LFT charge, tape, fabrics, and tailored laminates in different layup configurations and thicknesses to compression mold test plaques and later an actual automobile part.

Study Overview

A 2-part study was conducted. First, different combinations of pure D-LFT, pure tape fabrics, and pure tailored laminates in various thicknesses, plus a number of Hybrid combinations were laid up in a simple, flat plaque test (400 x 400 mm) and compression molded. Twenty material and layup combinations were successfully produced and the most representative are shown in Table 1 (pure D-LFT, pure tape laminate, pure tape fabric and a number of hybrid configurations). One plaque was produced for each combination, and then 5 standard test coupons were removed from each plaque. For further processing, these plaques were used to allow researchers to test out sufficient coupons to inspect samples on both D-LFT side as well as the UD-tape side. Each plaque was then used to produce its own resin consolidated forms of the semi-finished products. The difference in dwell time and temperature was an effect of thickness.

Results, Observations & Suggestions

Flat Plate Testing – What impact Results Improved?

With the addition of UD-glass fabric, the study should significantly increase not only stiffness/strength but also impact properties, and impact results confirmed this. This study shows that pure D-LFT and combinations of UD-glass fabric and pure tape laminates yielded maximum energy at failure force (base bar) and total energy values that were approximately 3 times those measured from the baseline/control pure D-LFT material regardless of thickness. This shows the benefits of greater tailored fiber length and higher fiber content on improving mechanical properties in composites. It should be noted that while Figure 3 is useful for noting qualitative trends, it cannot be used to pull quantitative values from sample measured at different thicknesses, since both Boeing’s module and the second moment of area (and therefore coupon bending during impact) are strongly influenced by nominal thickness.

Table 1: Select materials/layup/orientation/thickness for Part 1 flat plate test plaque

<table>
<thead>
<tr>
<th>Material/Panel Type</th>
<th>Thickness (mm)</th>
</tr>
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<tbody>
<tr>
<td>Pure D-LFT</td>
<td>2.0</td>
</tr>
<tr>
<td>Pure UD-tape fabric</td>
<td>1.0</td>
</tr>
<tr>
<td>Pure UD-laminate</td>
<td>1.0</td>
</tr>
<tr>
<td>Hybrid V10</td>
<td>2.0</td>
</tr>
<tr>
<td>Hybrid V8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Figure 4: Energy at maximum force and total energy for pure D-LFT (2.0 x 2.5 x 0.5 D-LFT thickness) vs pure tape laminates and pure tape fabrics (both 2.0 x 2.0 thickness) showing the improvement in performance with use of UD-glass reinforcements.

Interesting results were also seen on hybrid samples containing tape fabric and/or hybrid laminate plus D-LFT. As previously noted, hybrid samples were tested by impact the D-LFT side as well as the tape fabric and/or laminate side from each hybrid test plaque, representative results of which are shown in Figure 1. As with Figure 3, the red bars represent total energy absorbed and the blue bars represent maximum force. For each set of samples (D-LFT side vs. tape fabric or/and tailored laminate sides), trends indicate that energy at maximum force is always lower on the D-LFT side than on the tape fabric or/and tailored laminate side, while the reverse is true for total energy absorbed. Researchers theorise that because the D-LFT side is less than 0.5 mm thick, defined by a lower modulus, this is reflected in a lower total energy as well as in the laminate and/or tape fabric side, which also have higher fibers per unit or larger gaps, that is, they result in higher maximum force and energy at maximum force. The reverse is true for the stiffer/stronger tape or/and laminate side, which requires more energy to break (higher energy at maximum force). As the D-LFT side breaks, it is the UD-glass side into tension, so when that impact breaks through the D-LFT side to hit the UD-glass side, there is less kinetic energy left to break the UD-glass in the sample (higher total energy absorbed). All impacted samples broke in the test.

Engine Shield Production – What Process Fast Enough for Commercial Production?

Since compounding, heating, and molding cells were located in close proximity, multiple steps could be completed simultaneously, giving a very flexible molding cycle for the engine shield of 10 sec, which makes the process compatible for medium to high production volumes. Typical cycle times in commercial thermoplastic compression molding operations range from 30 sec for thinner, smaller parts to 90 sec for thicker, larger parts, with a 30 sec cycle time being the target range. However, it should be noted that this was done in a non-optimized process and that it was the preheating operation that was the limiting step in the process sequence, not the D-LFT compression molding step, if the ILC is capable of producing D-LFT compound at a rate of 5 kg/hr. Researchers feel that with further work (e.g. staged compression, Laguna breaking, etc.), the results may be improved. The test part and a tool equipped with clamps would, in the future, be possible to drop the effective cycle time significantly lower than 10 sec, which would make the tailored D-LFT faster and even more cost-effective as an alternative materials/process combination.

The study demonstrated the benefit of a hybrid molding process like tailored D-LFT that allows a number of parameters (e.g. cost, weight, moldability, and higher mechanicals where needed) to be balanced and hence it can provide manufacturers with the best cost/performance ratio for a given application.

Michael Ruby & Daniel Grauer, Ticona Engineering Polymers
Benjamin Hands & Frank Henning, Fraunhofer Institute for Chemical Technology
Andreas Martsman, Oxeon AB
Simon T. Jespersen, Fibreforce

michael.ruby@ticona.com