

# New approaches to modifying the impact toughness of RTM components

Integrating thermoplastic laid scrims between the individual layers of carbon fibre fabrics can – with a suitable combination of materials – lead to a clear increase in impact resistance. Along with the improved impact toughness, the discrete laid scrims have further advantages when used with resin infusion processes.

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Fibre-reinforced lightweight structures are currently enjoying increasing popularity in many technical applications. For components manufactured in small and medium production runs of 1,000 to 20,000 parts per year, the resin transfer moulding (RTM) process is being increasingly used because of the high quality of the product and the cost efficiency of the process. Current examples are aircraft parts and the safety cells of the BMW i3 and i8 models as well as a variety of sports and leisure articles.

RTM is a production process for the manufacture of high-quality components in fibre-reinforced plastics that are capable of withstanding high stresses. It is a resin injection process in which the dry fibre structure is placed in a closed die and wet-

ted with a resin-hardener mixture which is then cured under high pressure and temperature (see Figure 1).

Epoxy resins are the most commonly used in the RTM process. They are particularly easy to use, show low shrinkage on cross-linking, and possess outstandingly good mechanical properties, such as for example their low tendency to creep. However, they exhibit a brittle fracture behaviour under impact loading. Given the growing use of the RTM process in the manufacture of fibre-reinforced structures, it is important to investigate the impact resistance of parts produced by this method and to take any necessary steps to modify the process so as to improve the impact toughness of such components.

## Damage mechanisms in fibre-reinforced structures

A clear distinction must be made between low-speed impacts such as those caused by a crash, bird strike or turbine blade shedding and high-speed impacts from shells and other projectiles, or from bomb fragments. The two types of impact lead to very different types of damage. This article is concerned with improving performance under low-speed impact.

There are three types of damage: fibre breaking, matrix cracking (intralaminar rupture between the fibres), and delamination between the layers of fibres. In practice, delamination is the most problematic because the damage is not readily discernible and its full extent can only be assessed by costly non-destructive testing (NDT) methods such as ultrasonic

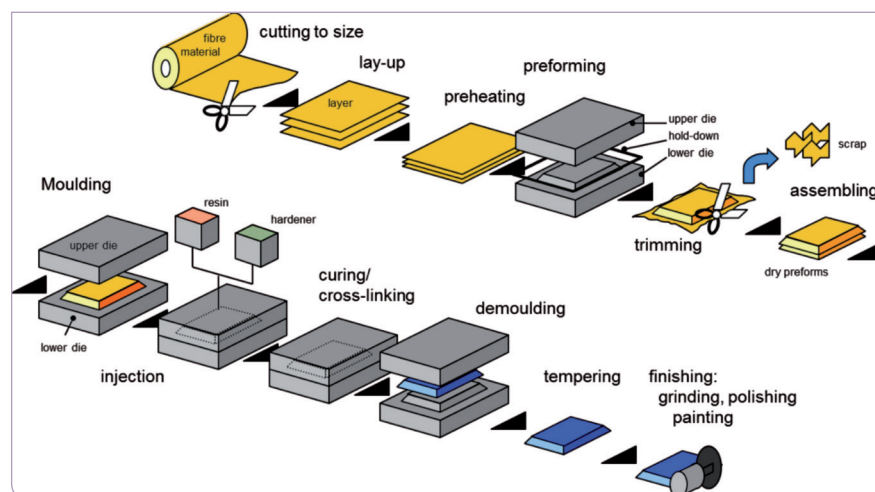


Fig. 1: Resin transfer moulding process

testing. Even from the mechanical point of view alone, delamination causes substantial weakening of the structure under compressive loading. A well-established procedure used in aircraft construction is the compression after impact (CAI) test according to AITM 1-0010.

The extent of the damage caused by a low-velocity impact to fibre-reinforced materials can be reduced by suitably designing the layer structure and by modifying the resin system used for this purpose. The energy absorption potential can be increased in a similar way.

### Conventional approaches to solving the problem

The fracture toughness of the resin system is usually modified using soft elastomers or else with hard filling materials such as silicates or nanoparticles. However, all of these measures increase the resin's viscosity so substantially that it can no longer be used in the RTM process. Furthermore, such additives are filtered by the fibre structure itself, causing an inhomogeneous distribution of the particles. On the other hand, using such additives in the production of prepregs presents few problems because in this case only one or at most a few fibre layers are soaked in the process of impregnation with the melted or dissolved matrix material.

### A new approach for modifying the fracture toughness of epoxy resins

The novelty of this approach consists in integrating the additives for improving fracture toughness not into the resin, but into the semi-fabricated textile material. This has two advantages: not only can a low-viscosity unmodified resin system be used, but also building the modifier into the textile structure automatically ensures its uniform distribution in the component; and these cancel the main disadvantages of resin modification. In practice, a thermoplastic polyamide 12 yarn from EMS Chemie AG in the form of a separate multiaxial laid scrim is introduced in-between the individual fibre layers (Figure 2). This toughens the resin-rich interlaminar layer, significantly reducing the extent of delamination and hence of the invisible damage caused by the impact loading. In addition, the viscoelastic behaviour of the thermoplastic material reduces crack propagation and so further reduces the extent of the damage. It is precisely the discrete spacing of the thermoplastic that diverts

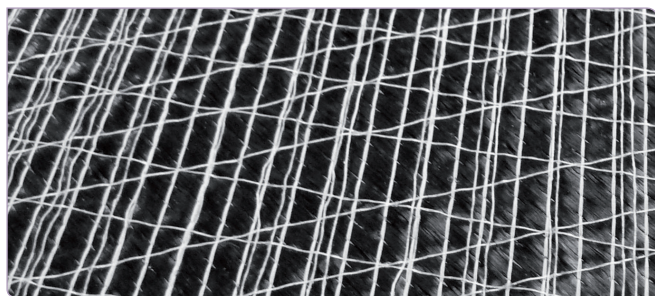


Fig. 2: The non-crimp carbon fabric with the thermoplastic lattice

the cracking, thus serving as a stopper.

Besides improving fracture toughness, this new approach using discrete thermoplastic laid scrims has four additional advantages for the process and for the resulting properties of the finished component:

- The thermoplastic yarn can be applied even in the preforming process, as a binding agent. During the pre-warming of the semi-finished textile, the thermoplastic yarn becomes sticky, helping to shape the preform: on the one hand it helps stabilise the shape, while on the other it helps debulking for aircraft applications.
- Flow testing has demonstrated that the in-plane permeability, taken as a measure of the semi-fabricated fabric's wettability, can be boosted by as much as 300%, the thermoplastic semi-finished textile acting as a flow media. The impregnation behaviour can also be decisively improved in the direction of the thickness, which is vital for the special compression RTM process, for vacuum assisted processing (VAP) (Airbus, EADS) as well as for resin transfer infusion (RTI) (Bombardier Aerospace), bringing considerable process advantages in the production of thick-walled structural parts.
- The electrical conductivity of the fibre-reinforced component in the direction of the thickness is not impaired – as it is with non-woven fabrics (e.g. fleece) – thanks to the discrete form of the laid scrim.
- The thermoplastic yarn can also serve as a carrier for other additives with the object of adding further properties to the component.

### Results of experimental investigations

All the test samples were produced using RTI (resin transfer infusion), a process in which the preform is saturated with epoxy resin by infusion and then cured in an autoclave. A quasi-isotropic layup was chosen  $[0/+45/-45/90]_2S$ , consisting of sixteen layers of carbon fibre (298 g/m<sup>2</sup>) with the polyamide 12 laid scrim (10 g/m<sup>2</sup>) laid progressively between the consecutive fibre layers. The resins Hexflow RTM6 from Hexcel and Cycom 890 from Cytec were used as matrix.

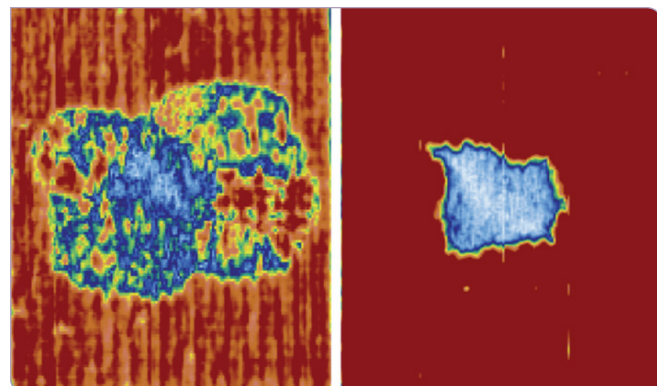


Fig. 3: The damaged surface area after impact testing without (left) and with (right) thermoplastic lattice

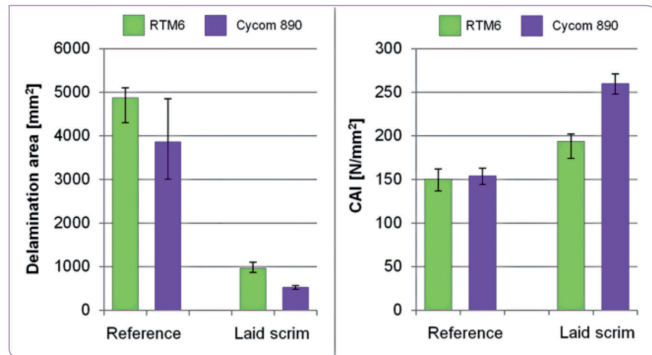


Fig. 4: The left hand side shows the effect of PA12 addition on delamination for the two resin systems, while the right-hand side shows how PA12 affected compressive strength after impact (CAI)

Samples cut out of the laminates to 100 x 150 x 4 mm were struck in a drop weight impact tester according to the CAI standard, in the centre and normal to the surface, with an absorbed energy of 30 Joules. After the depth of penetration had been determined, the samples were subjected to ultrasonic testing, the degree of delamination being assessed by the half-value method (Figure 3). The samples were then mounted on end in a standardised jig and subjected to increasing vertical pressure until failure in order to evaluate the residual compressive strength after impact.

Figure 4 shows the striking reduction in the delaminated area: the thermoplastic laid scrim leads to a reduction of up to 80%, independently of the resin system. The residual compressive strength shows a similar improvement: with RTM6, the thermoplastic laid scrim provides a 28% increase, while with Cycom 890 the increase is even greater at 69%.

The effect of the addition of polyamide 12 on the epoxy resin's glass transition temperature ( $T_g$ ) was investigated by differential scanning calorimetry. This showed that for Cycom 890 with 20% PA12 by weight, the  $T_g$  fell by 3% to 204°C, while for RTM6 there was no change at all, the  $T_g$  remaining at 218°C. The results of testing for interlaminar shear strength after impact (ILSS) are not so favourable. In this case, the samples show a clear reduction in shear strength, ranging from 20% (RTM6) to 45% (Cycom 890) at an elevated temperature of 120°C.

### Conclusions and findings

The experimental results demonstrate in the most striking way that the thermoplastic laid scrim significantly reduces the extent of the damage to the fibre-reinforced samples. This laid scrim, initially a semi-finished textile, is transformed into an integral part of the resin during the RTM process, increasing the fracture toughness of the otherwise brittle resin matrix.

Optimal linking of the copolyamide with the epoxy matrix is a decisive factor, and this takes place only when the thermoplastic melts during the cross-linking of the thermosetting matrix. It follows therefore that the melting temperature of the yarn must

be lower than the curing temperature of the epoxy matrix. If the yarn does not completely melt, then the improvement in impact toughness falls off sharply. Since the cross-linking temperature of the RTM systems approved for aircraft applications is around 180°C, thermoplastics with a relatively high melting point are used, which scarcely affect the glass transition temperature ( $T_g$ ) of the cured epoxy matrix.

In the case of isothermal processing at lower temperatures, which is more typical of resin systems for automotive applications, it is more difficult to secure the required increase in impact toughness, and this is the object of current research.

### Further outlook

Despite these outstanding results, there is still much to be done before thermoplastic laid scrims are commonly used in the manufacture of structural parts for aircraft. The biggest obstacle is to get the new material system officially approved. However, it is an advantage in this regard that, up to now, few resin systems suitable for the RTM process have been accepted and approved for use in aircraft, which limits the number of possible material combinations that will require such acceptance and approval. From the standpoint of textile technology, integrating thermoplastic yarn in a carbon fibre fabric presents no great challenge. The thermoplastic laid scrim structure can either be prefabricated (for instance by BAFATEX Bellingroth GmbH & Co. KG Germany) and paid off from the roll into the fabric, or else the thermoplastic can be spooled off as yarn and integrated directly as the fabric itself is being produced.

As mentioned in the introduction, epoxy resins are typically used in the RTM process. However, various raw material manufacturers recently begun to propose injectable polyurethane resin systems. A special feature of a matrix of this material is – among others – its high fracture toughness, due to the specific interactions between the polyurethane molecules, which also result in the chemical cross-linking. This means that innovative resin systems themselves are opening up new ways of producing impact-resistant fibre-reinforced components. How far and with what benefits can these systems in turn be modified by integrating thermoplastics remains to be seen. ■

### Main features

Integrating a thermoplastic laid scrim of polyamide 12 into the interlaminar layers of carbon fibre fabrics has the following advantages:

- Outstandingly good impact toughness of the epoxy matrix
- Binding effect in preforming and debulking
- Improved permeability during resin infusion
- No reduction in electrical conductivity
- Possibility of integrating other additives into the resin matrix

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