Key criteria for composites

The experts of Hamburg-based KROENERT discuss in C2, how machinery manufacturers can support the requirements in the quality assurance of prepregs

The demand for fibre-reinforced products increases – mainly due to the high quality demands with a focal point in the aviation industry. The vision is to create a specification list, as it is available for metals, which makes it easy to find e-modules, tensions and stability. Similar material lists for composites, however, are not realistic due to the diverse variations of many different resin types and fibre qualities. Nonetheless, it is still possible to determine standardised processes for the manufacture of prepregs for composites. Machinery manufacturers can support standardisation with high-quality processes, in order to attain comparable and reproducible production steps – from the film manufacture to the process of fibre impregnation. There are many criteria within the process that have to be controlled and matched optimally to one another, in order to reach a good reproducibility.

When metallic materials are used, the information about the quality can be very exact. Depending on the metal, properties can be defined and categorised according to values such as tensile strength, modulus of elasticity, stretching, etc. The resilience against environmental influences can be defined easily as well. For instance, steel with a higher proportion of titanium is more resilient against organic solvents.

With the increasing usage of fibre-reinforced composites such as CFRP (carbon fibre-reinforced plastic), the demand for similar material descriptions for composites increases as well. One can describe a metallic composite with its elemental components such as iron, chrome, titanium, and others. It is almost impossible to also apply this process to composites as well, as the used fibre and resin qualities are too diverse. Moreover, there are different technologies for the production of a fibre-reinforced composite. The coating and impregnation processes have a high influence on the product quality. These processes, however, can be very well controlled with accurate coating and impregnation lines.

Spools with carbon fibres

Fibre-reinforcement – Qualities of the used fibres and materials

Usually, two different fibre qualities are used:

Synthetic fibres	Natural fibres
■ Carbon ■ Glass ■ Polyamide (Nylon) ■ Aramide (Kevlar) ■ Basalt ■ Highly-stable polyethylene (Dyneema) ■ Hybrid structures (mixture of glass / PA or PE)	■ Linen ■ Hemp ■ Sisal ■ Wool
An influence on the quality is possible, as the manufacturing process as well as the design of the synthetic fibres can be controlled	Low influence on the growth behaviour of natural fibres

Table 1: Fibre qualities

Unidirectional fibre orientation (UD tapes)	Multidirectional fibre orientation
Rovings with different K qualities (K determines the number of filaments, 1K = 1000 single filaments) Rovings are processed to a closed tape by means of spreading units	Bi-directional structures – woven fabrics Multidirectional structures ■ Laying structures ■ Warpknitted ■ Nonwovens ■ Combinations of different structures
Influence in the tape laying process in tension orientation	Low influence in the weaving process; Warpknitted partially oriented

Table 2: Material qualities

Matrix quality –resin qualities in usage

The variation of the resin qualities is large and constantly increases. The chemical industry permanently works on new formulations and reacts, for instance, to requests from the automotive and aviation industries concerning a quicker curing of thermosetting resins.

Thermoplastic materials	Thermosetting materials
■ Polyamide PA 6, 6.6 or 12 ■ Polyetheretherketone ■ Polyolefin PE or PP ■ Polycarbonate PC ■ Polytetrafluorethylene PTFE	■ Meltable epoxide resins ■ Solvent- or water-based epoxide resins ■ Polyester resins ■ Phenolic resins ■ Vinylester resins ■ Acryl or polyurethane resins
■ Temperature range 80-400°C ■ Viscosity range 1-1000 Pas (partially higher), depending on the chemical composition ■ Coating weight on both sides 10-300g/m² ■ Speed for film production 10-40m/min ■ Speed for impregnation 1-5m/min ■ Temperature accuracy +/-1K and constantly high pressure for the impregnation process	■ Temperature range up to 250°C, usual application temperature 70-120°C ■ Viscosity range 100-500Pas, depending on the chemical composition ■ Coating weight on both sides 10-300g/m² ■ Speed for film production 30-80m/min ■ Speed for impregnation 5-20m/min ■ Temperature accuracy +/-1K and constantly high pressure for the impregnation process

Process techniques for the manufacture of prepregs

Prepregs of high quality can be attained by a precisely running coating and impregnating line. Especially the following areas of the line have to be operated accurately and reproducibly:

- Temperature control of all heating and cooling aggregates for a controlled resin viscosity
- Concentric run of the coating rollers for a precise application of the film layers
- Concentric run of the calendar rollers for a precise pressing line during the impregnation process
- Tension control of the carrier paper in the entire line
- Process speed and speed management
- Adjustment of the drying temperature when using solvent-based resins

STEP 1 – Resin film coating

The first step in the production of a prepreg consists of applying a resin film precisely onto a carrier paper. Siliconized paper mainly serves as the carrier, but also siliconized and heat-resistant, as well as reusable polymer films are more and more often used in trial runs. The choice of the ideal coating technique for the resin film is made according to the viscosity and the required coating thickness of the resin. The application of the resin is usually conducted in the molten state. Coating stations are the performance centres of a coating machine. Different techniques are available.

A comma blade coating unit

Direct or indirect roller application: The most important coating technology for the resin film application is the roller technology. The applicator roll coater can be used in both forward and reverse rotation, as well as with a different number of rollers. Thin layers are applied with a three- or four-roller system. The decision for forward or reverse rotation is mainly influenced by the thickness of the coating, the viscosity of the resin and its behaviour (e.g. shear force under mechanical influence of the material or surface structure).

With the roller application technique, a viscosity range up to 1000Pas can be covered. At high viscosities or resins with demanding transferability, the direct or indirect comma blade technology is an option.

With the fitting thermal oil heating, temperatures up to 250°C are attainable. A temperature accuracy of +/-1K in cross

direction of the rollers can be reached. Coating weights between 10-500g/m² are possible, depending on the viscosity and coating technique.

Slot die and extrusion technology: For longer production runs, coating with slot dies is an option. Viscosities above 500Pas can be applied by means of dies and extrusion pumps. Compared to roller application technologies, higher temperatures up to 400°C are possible. The coating weight usually ranges between 12 and 400g/m², depending on the viscosity.

Comma blade technology: The viscosity range lies between one and 2000Pas. The required temperatures are provided by heating rollers or comma blades. The required accuracy ranges at +/-1K; the coating weight varies between 10-1000g/m², depending on the viscosity and technology. The coating accuracy is very high at the bend-proof comma blades.

With the ideal coating technologies and depending on the resin, films can be applied with an accuracy of +/-1% in cross- and machine direction.

Overall requirements for film lines: The properties are dependent from the specific requirements and the layout of the coating station. The following aspects sum up the most important parameters:

- High-precision rollers with matching bearings and minimal tolerances (<2µm at 90°C)
- Chromed or ceramic-coated surfaces of the coating/dosing rollers
- Deflection compensation of the coating/dosing rollers with max. 2.5µm deflection
- Exact temperature control of the coating/dosing rollers: +/-1K
- Accuracy of the roller adjustment and positioning: +/-1.5µm (hydraulic)
- Manual or automatic positioning of the rollers
- Quick changeover of the counter-pressure roller (sleeves possible)
- Minimal gap: 40µm at 90°C
- Anti-stick coating of the components that are in contact with the resin
- Exact tension control of the web
- Good accessibility of the coating station

An example for a roller application unit

Controlled plate cooling

STEP 2: The impregnation process

In this process, the coated resin film is transferred evenly onto the fibres or fabrics from the carrier paper under the influence of temperature and pressure from above and below. The prepregs – the pre-impregnated fibres or fabrics – are produced. The impregnation process must take place with an exact control of the web tension and the heated or cooled components.

Moreover, the impregnation line has to enable the following:

- Processing of a multitude of tapes/rovings in different qualities and with different resin contents
- Controlled unwinding tension of the spools
- Optimised feeding of the tapes/rovings

The applicable tension depends on the individual process steps. The following values are rough guidelines:

- Tension per roving spool: 100-400g
- Tension increase at the spreading process: 5N/1m width
- Removal of the carrier paper: 10-1000N
- Unwinder carrier paper: 25-300N
- Rewinding of the finished product: 300-3000N

Additional components for the impregnation process: In order to guarantee an even impregnation process, a defined contact between the heating tables and the laminated prepreg has to be ensured. PTFE-coated heating tables or heating tables with exchangeable PTFE protective film are necessary in order to avoid the adhesion of the resin and minimise the friction between the carrier paper and the heating table.

Precision calendar rollers with high concentricity are the basis for a defined impregnation process. The following design parameters count for the calendar rollers:

- High-precision rollers with minimal tolerances of <2µm
- Deflection compensation of the rollers
- Accuracy of the roller adjustment +/-1.5µm (hydraulic)
- Even and reproducible nip adjustments (pressure and gap measurement)
- Exact temperature control of the rollers, heating and cooling plates: +/-1K

The cooling process is necessary, in order to cool down the composite made of fibres and resin and then be able to remove the carrier paper. In this process, steel rollers and cooling plates with pressure rolls are used. The precision of the cooling can be influenced by the size and number of the cooling rollers and plates. Air coolers can be used as well.

Summary

By using carrier papers, resins, carbon and glass fibres with a defined high quality, the quality of the prepreg can be determined. With coating and impregnating lines, the process-technological parameters can be defined.

In the following lines, the currently demanded specifications are enumerated:

- Desired resin content: 30-50%, accuracy +/-1%
- Accuracy of the coating weight:
  - 15-50g/m² with +/- 2g/m²
  - 50-150g/m² with +/- 3g/m²

The requirements for UD tape qualities to be used in aviation are:

- No gap between single filaments wider than 0.76mm and longer than 250mm
- Highest accuracy
- Deep and continuous impregnation

With high-precision coating and impregnation lines and the suitable carrier papers and resins, these specifications can be met. ■