HOW CAN THE MACHINE ENGINEERING SUPPORT THE REQUESTS FOR HIGH QUALITY STANDARDIZED PREPREGS FOR COMPOSITES?

A. GLAWE[1], F. SCHAEFER[1]
[1]*KROENERT GmbH & Co KG, Schuetzenstrasse 105, 22761 Hamburg, Germany*
info@kroenert.de

Abstract: *The request for standard fiber reinforced products is increasing because of high quality demands from the aerospace industry. The vision is a specification list like existing for metals were e-module, tension and stability can be found very easily in tables. It is unrealistic to have similar material lists for composites because of the versatile variations between many different resin types and fiber qualities. But, at least, it will be possible to have standardized processes to produce the prepregs for composites. Machinery supplier can support the standardization with high quality processes to reach at least comparable processes for the production of composite materials. Each process step starts from the resin film production up to the fiber impregnation process. There are numerous criteria in the process which have to be well adjusted and monitored for a reproducible process.*

Keywords: *Prepreg, Coating, Impregnation, Lamination, Composite, Quality.*

1. Introduction

In case of using metallic materials it is possible to define the quality of a material very detailed. Depending on the metall consumption the features can be defined with the value of tensile strenght, e-module, elongation and so on. Also the density against environmental influences can be defined very easily. For instance steel with higher content on Titanium has a better resistivity against solvents.

With the increasing use of fibre reinforced composites the demand for similar material descriptions composites is increasing more and more. It is possible to describe a metal compound with the ingredients of elements like Iron, Chrome, Titanium and others. To do the same with composites is nearly impossible because of the large versatility of fibre qualities which can be used, resin qualities which can be used and the different technologies to produce a fibre reinforced compound. The coating and impregnation process is highly influencing the product quality as well in case of producing prepregs for fibre placement technologies. This quality can be defined with high precise coating and laminating machines.

1.1 Reinforcement quality - used fibre and fabric qualities

Generally two different fibre qualities are used.

Man made fibers	**Natural fibres**
• Carbon • Glass • Polyamide (Nylon®) • Aramid (Kevlar®) • Basalt • High stable Polyethylene (Dyneema®) • Hybrid Structures (Mixtures of Glass / PA or PE)	• Linen • Hemp • Sisal • Wool
Influence on quality partly possible because of the defined process in the chemical fibre design and process.	Less influence on the growing behaviour of natural fibres beside the plant quality and climatic conditions.

Table 1: Fibre quality

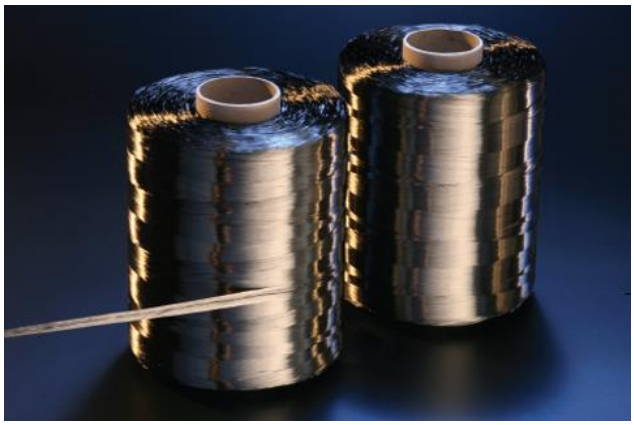
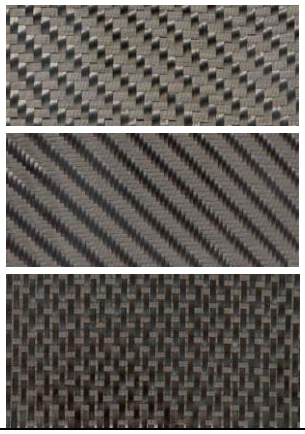
Unidirectional fibre orientation	**Multidirectioncal fibre orientation**
	
Rovings with different K qualities (Number of filaments 1 K = 1000 single filaments) Single Rovings are processed to a closed tape.	Bi-directional structures – woven fabric Multi-directional structures – laying structures – warp-knitted structures – non-woven – combinations of different structures
Influence with the tape laying process in tension orientation.	Lower influence with the weaving process, warp-knitted structures partly orientated according the later use.

Table 2: Fabric quality

1.2 Matrix quality – used resin qualities

The variation of resin qualities is huge and continuously increasing. The chemical industry is working constant on new resin qualities as well as is reacting on demands from the automotive and aerospace industry for faster curing duroplastic resin qualities.

Thermoplastic materials (hotmelt)	**Duroplastic materials (thermo setting materials)**
• Polyamide PA 6, 6.6 or 12 • Polyether ether ketone PEEK • Polyolefin PE or PP • Polycarbonate PC • Polytetrafluroethylene PTFE	• Solvent or water based epoxy resins • Polyester resins • Phenolic resins • Vinyl ester resins • Acrylate or Polyurethane resins • 1- or 2-K curing products
• Temperature range – 250 °C, usual application temperature 60 – 120 °C • Viscosity range 1 – 200 Pas depending on chemistry • Coating weight both sides 10 – 300 g/m² • Average speed for film production 50 – 80 m/min • Average speed for impregnation 5 – 20 m/min • Temperature accuracy +/- 1 K	• Temperature range 80 – 400 °C • Viscosity range 100 – 500 Pas depending on chemistry • Coating weight both sides 10 – 300 g/m² • Average speed for film production 50 – 80 m/min • Average speed for impregnation 1 – 5 m/min • Temperature accuracy +/- 1 K and constant high pressure for impregnation process

Table 2: Matrix qualities

2. Process technology for the prepreg production

Machinery suppliers are requested to produce high quality coating and laminating machines for the impregnation of fibres for semi-finished fibre-reinforced composites. With the machine it is possible to define the prepreg quality with respect to:

- Precise temperature adjustment of all heated and cooled equipment for a controlled resin viscosity,
- Precise coating roller concentric run-out for precise layer application,
- Precise calendar roller concentric run-out for precise pressure during the impregnation process,
- Precise tension steering of substrate through the whole handling during the fibre impregnation process,
- Precise process speed and speed control and
- Precise drying temperature adjustment in case of using curable resins.

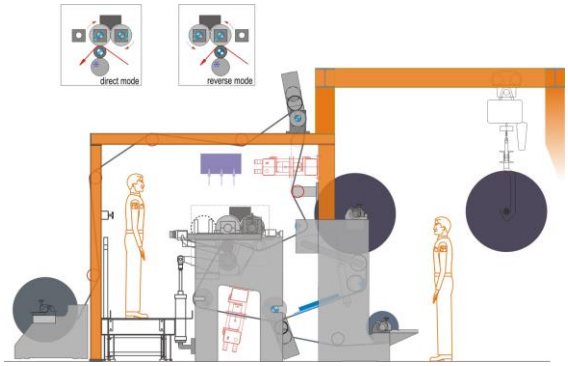
2.1 Coating plant design and impregnation technology

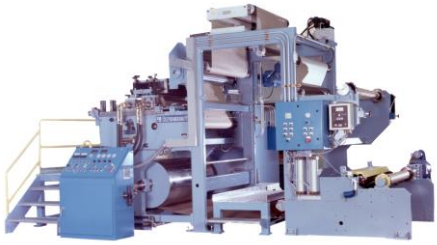
Different process technologies are possible to produce pre-impregnated semi-finished fiber reinforced products:

1) Tape and resin production and lamination / impregnation with two different production lines.
2) Combination of resin application and lamination/impregnation in one production line with two coating systems for simultaneous production of the top and bottom resin layer.
3) Direct coating / impregnation with water based and solvent based matrix materials.

Pros and cons for a two-step process	**Pros and cons for a one-step process**
+ Resin film process and impregnation separate and independent. + No stop of one process if other one doesn't work. + With one coating line can be charged more than one impregnation line.	+ Resin film process and impregnation in one step – less heat stress for resin. + Melting of the resin only one time necessary.
– Resin film has to be melted again before lamination. – Higher volume of silicone paper or double side silicone paper necessary – Higher investment for two plants.	– Resin film production with lower speed and thereof longer staying time of the resin in the application system. – If one process is not working well the other one will be negatively influenced as well. – Higher investment for two coating units.
Ideal solution for production.	**Ideal solution for research and development.**

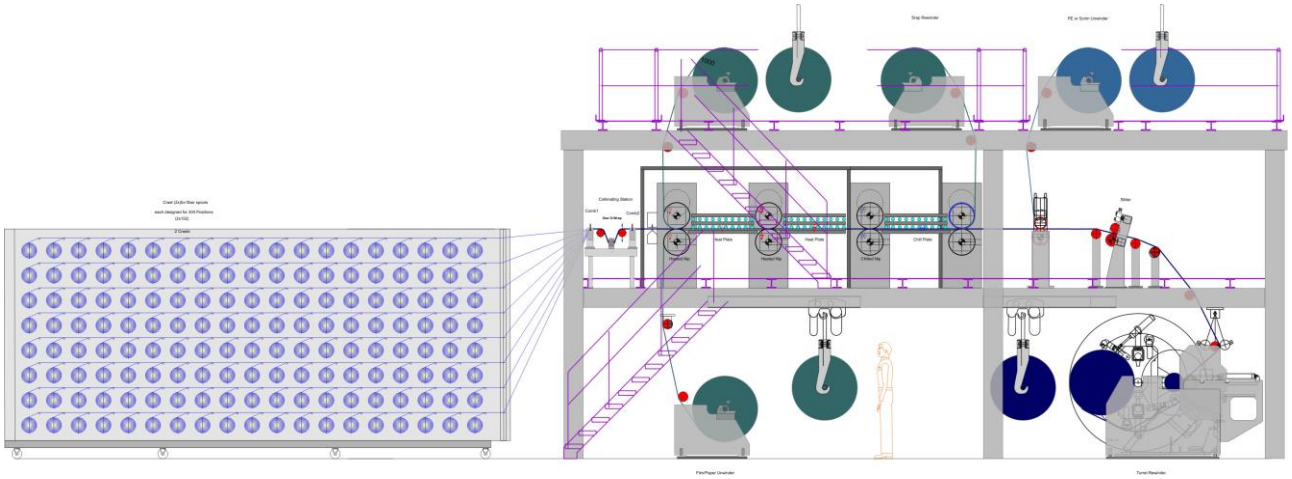
Table 3: Process step variations



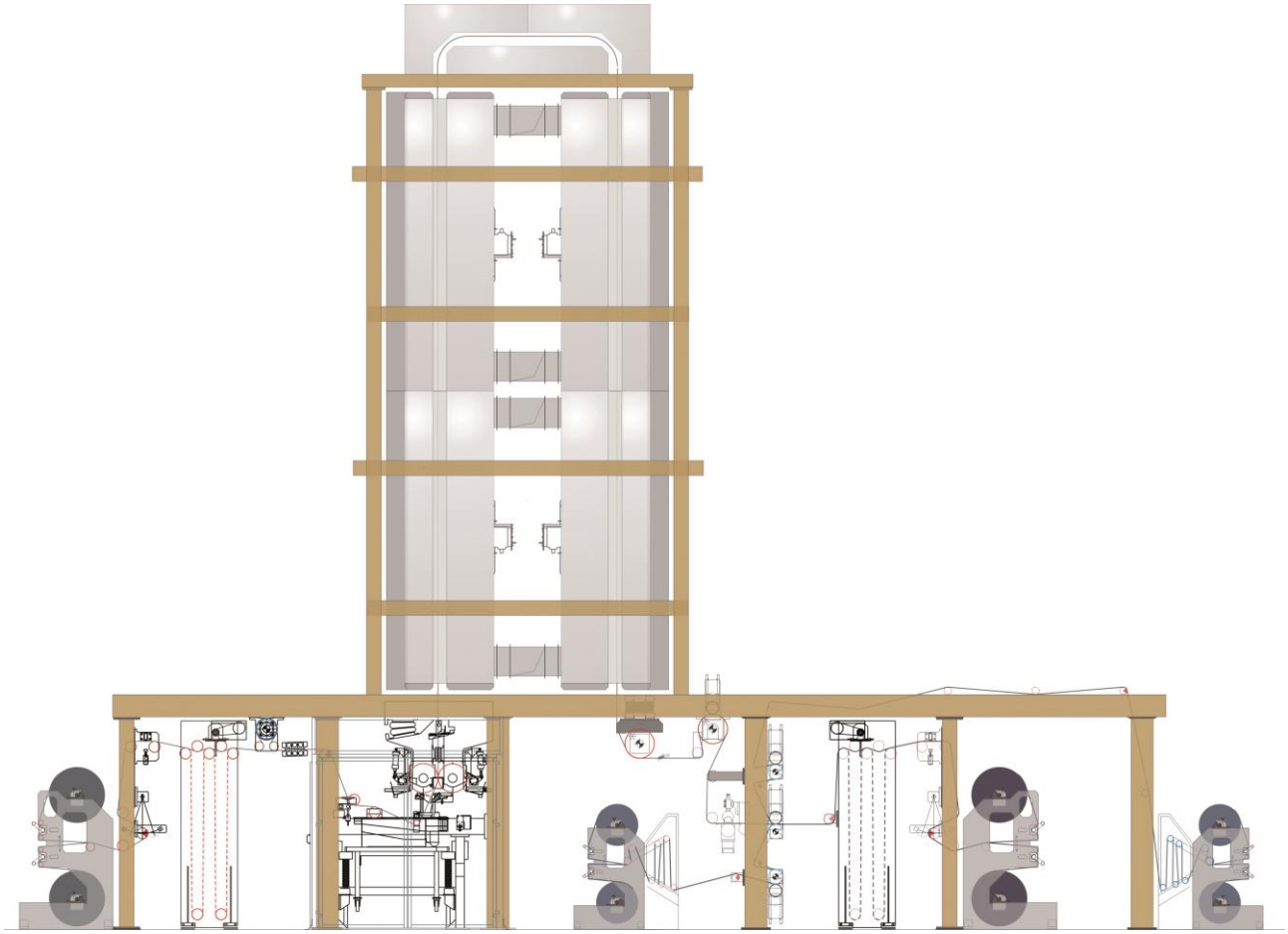


Picture 1: Step 1 - Resin film formation

The resin type is mainly defining the filming process. The resin has to be applied on a release liner with a defined quality. With precise coating technologies it is possible to apply very precise resin films with an accuracy of +/- 1 % in cross and length direction.



Picture 2a: Step 2 - Resin film transfer and fibre impregnation process



Picture 2b: Direct impregnation with solventbased resins and vertical dryer

For the transfer of the resin it is necessary to handle the fibers and fabrics with a perfect tension control as well as to control each tempered system carefully.

The impregnation line has to allow:

- Processing of all types of tapes/rovings in varying quality and with different resin contents,
- Controlled unwinding tension of spools and
- Optimized feeding of tapes/rovings.

Beside the optimal temperature distribution of each tempered device it is necessary to control the substrate tension through the whole guiding through all impregnation steps.

The tension depends on the substrate quality but also the position in the impregnation line during the impregnation process. The following experience is a guideline for handling the fibres and substrate from the unwinding, trough the impregnation process up to the rewinding of the impregnated prepreg:

- Tension for each roving bobbin winding station: 100 – 400 g
- Tension increase during spreading process: 5 N / 1 m width
- Release liner and foil: 10 – 1000 N
- Substrate tension unwind: 25 – 300 N
- Substrate tension finished product rewind: 300 – 3000 N

2.2 Coating technologies for precise resin film application

The first step to create a high quality prepreg is to coat a precise resin film on top of a release liner. The right coating technology will be chosen depending on the viscosity of the resin as well as the requested layer thickness. The application of resins in a melted state is the most typical technology.

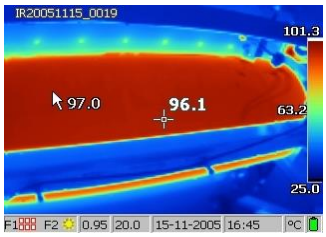
Coating stations are performance centers of a coating line. Different coating technologies are available. Mechanical precision with integrated, state-of-the art drive and controls can be achieved with accurate roller speeds. Securing highest precision in coatings and guaranteeing highest production quality are necessary for high quality prepreg products.

2.2.1 Direct or indirect roller application

The most important coating technology for resin film application is the roller application technology. The system can be used in direct or reverse mode as well as with a different number of rollers. The decision between direct and reverse mode is mainly influenced by the requested coating layer thickness and the resin viscosity.

Picture 3: Drawing and pictures of the roller application technology

By use of the roller application technology it is possible to cover a viscosity range up to 200 Pas For high viscosities it is necessary to adjust a high pressure between rollers or to use one roller in a knife mode without rotating. Thin layers can be applied by use of a three or four roller system.

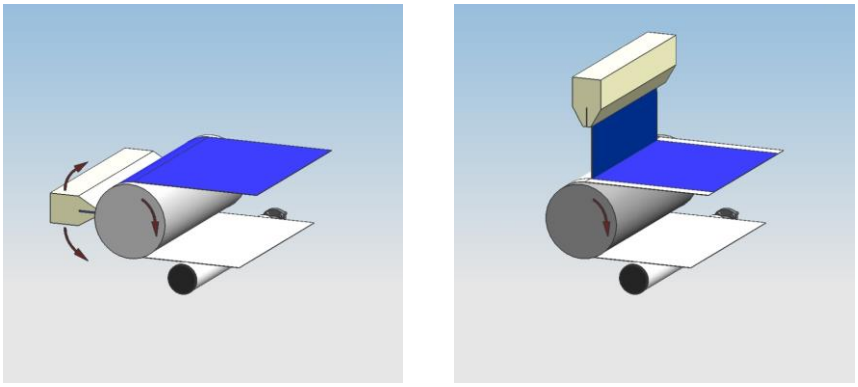


Picture 4: Temperature accuracy between coating roller

Temperatures up to 250 °C are reachable with precise heating equipment and an optimized heating fluid distribution. The requested temperature accuracy of +/-1 K can be reached. Coating weights between 10 – 300 g/m^2 can be applied depending of viscosity and coating technology.

2.2.2 Slot die and extrusion technology

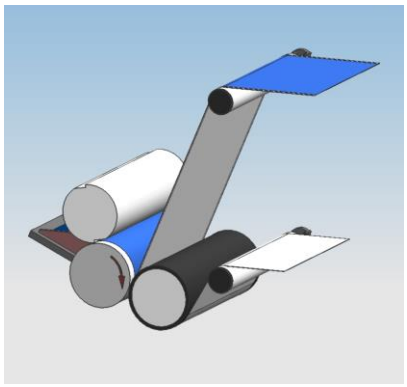
Viscosity range:	up to 500 Pas possible but only with extrusion pumps
Temperatures:	up to 400 °C, requested accuracy +/- 1 K
Coating weight:	10 – 400 g/m² depending on viscosity and technology



Picture 5: Slot die technology

2.2.3 Commabar technology with heated commabar

Viscosity range:	0,1 up to 300 Pas theoretical possible
Temperatures:	heatable roller as well as commabar requested accuracy +/- 1 K
Coating weight:	10 – 1000 g/m² depending on viscosity and technology
Accuracy:	very high - > non-bending commabar



Picture 6: Commabar technology

2.2.4 Request for the coating technology for high quality prepreg products

For high quality resin film layers it is necessary to have high precise coating equipment. Parallel it is necessary to define the release liner quality as well as the resin quality.

From the machinery side it is realistic to follow the quality parameters. Suitable features are depending on requirements as well as the layout of the coating station:

- high precision rollers with rolling contact bearings and minimal tolerances (< 2µm at 90°C),
- chromed or ceramic coated surfaces of coating/ metering rollers,
- bending compensation of coating/metering rollers: max. 2,5 µm deflection,
- precise temperature control of coating/metering rollers: +/- 1 K,
- accuracy in roller adjustment and positioning: +/- 1,5 µm (hydraulic),
- manual or automatic positioning of rollers,
- quick change over of backing roller (also sleeve possible),
- minimum gap: 40 µm at 90°C,
- antistatic coating of parts in contact with resin,
- accurate tension control of web and
- good accessibility of coating station.

2.3 Additional equipment for the impregnation process

With second step of the process, the impregnation step, the resin film has to be transferred to the fibers. In order to guarantee a perfect impregnation process it is necessary to guarantee the contact between heating tables and the laminated compound of paper / prepreg / paper or film and to guarantee a temperature accuracy of +/- 1 K.

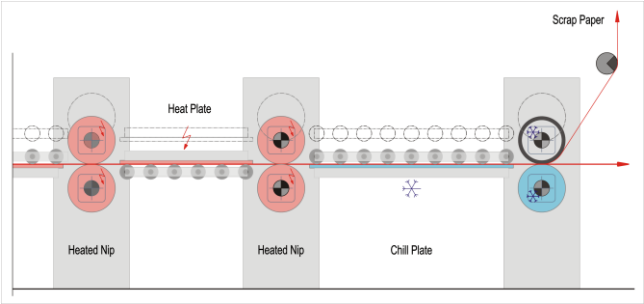
PTFE-coated heating tables or covered with changeable PTFE protective film to avoid adhering of the resin and to minimize the friction between the paper and the heating table.

Precise calendars with a high running precision are a basis for a defined impregnation process too.

Picture 7: Calendar, cooling and lamination technology

By covering all applications with 2 roller technique for lamination and delamination, tempering and cooling of plates and rollers an optimized impregnation process can be guaranteed. Additionally the following design parameters define the impregnation quality:

- High precision rollers with minimal tolerances of < 2µm,
- Bending compensation of rollers,
- Accuracy of roller adjustment +/- 1,5 µm (hydraulic),
- Consistent and reproducible nip settings (nip pressure and gap measurement) and
- Precise temperature control of rollers, heating and cooling plates of +/- 1 K.



Picture 8: Combination of calendars, heating tables and cooling technology during the impregnation process

The cooling process is necessary to cool down the fiber, resin, paper compound. For cooling of the heated web to a defined temperature precise cooling station with cooled steel roller and pressure roller are used. The requested temperature variation +/- 1 K can be reached and with the size and numbers of cooling rollers the cooling effect can be varied. Also air coolers or cooling plates can be used.

3. Summary

With high quality release papers, defined resins and carbon and glass fibres it is possible to define the material quality. With the coating and impregnation machines it is possible to define the process engineering parameters.

The current requested parameters can be more than fulfilled with existing and new developed technologies.

- Aspired resin content - 30 – 50 %, accuracy +/- 1 %
- variation of coating weight depending of substrate weight with an requested accuracy of:
  - 15 - 50 g/m² with +/- 2 g/m² and
  - 50 - 150 g/m² with +/- 3 g/m².
  -

Quality requests for UD-tape qualities from the aerospace industry are:

- no gap between single filaments wider than 0,76 mm and longer than 250 mm,
- highest accuracy and

- deep and constant impregnation.