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# Perspectives of web based composites from RCF material

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**Abstract**. "Web Based Composites" consisting of nonwoven fabric made from recycled carbon fibres (rCF) have excellent economic and ecologic perspectives to find a place in industrial product design for cost-effective lightweight solutions in composites. However, the processing conditions of rCF are challenging and the industry is not yet aware of the full potential of the mechanical properties as well as the cost structure. The goal of the project "CaRinA" is to provide reliable material cards for the industry with crucial information on the mechanical properties to encourage the application of rCF nonwovens. Therefore a complete investigation of the parameters and boundary conditions of the production process to the final part is performed. Within the project CaRinA the ITA Augsburg is focused on understanding, explaining and enhancing the nonwoven process using an industrial sized nonwoven line from the company Dilo Systems GmbH, Eberbach, Germany. Nonwoven lines have i.e. over 40 parameters that influence the product quality. The most influential factors are determined using statistical experimental design to understand the relations and effects on the nonwoven and the composite properties. The approach of the ITA is explained in detail.

## 1. Introduction

Carbon fibres are expensive and energy consuming in manufacturing. With increasing quantities (> 9,000 components/year) even in small batches, material costs of the production of CFRP components have a disproportionately high impact on the unit costs (over 57% in the RTM process) compared to forming, semi-finished and finishing costs [1]. Against this background, the reduction of material costs is an essential lever for reducing component prices. Fibre composite approaches are in strong competition with other lightweight materials (ultra-high-strength steels, aluminium, magnesium, etc.). Nevertheless, they often only have a single life cycle and - unlike the other material classes - are not or only to a very small extent recycled. Even low-priced raw materials such as paper or glass have a significantly higher recycling rate. Other established construction materials, such as aluminium or steel, are several generations ahead of cost intensive carbon fibres in this regard.

### *1.1. State of the art for carbon fibre recycling*

Considering the strong growth of the material class of carbon fibres, it is crucial to provide a suitable recycling strategy through a closed product life cycle in order to be able to compete with other materials and to exploit the full potential for lightweight construction economically and ecologically. The individual sub-steps for the realization of a complete recycling route are currently the subject of many research and development activities. Key advances have already been successfully demonstrated. The first important sub-process is the fibre-matrix separation for the treatment of matrix-containing waste streams. Currently various chemical methods (hydrogenation, solvolysis) and thermal processes

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(pyrolysis, partial oxidation, fluidized bed processes) are investigated. A variant of the partial oxidation is now implemented as the only method on an industrial scale by the project partner ELG Carbon Fibre Ltd., Birmingham, United Kingdom. In addition to matrix-containing waste, large amounts of dry fibre waste are produced in today's CF processes at cut rates of up to 40%. Further processing of the recycled carbon fibres is particularly suitable for the production of nonwovens due to the short nature of the fibres after the recycling process [2-7]. The established processes in this area are the carding process, the airlay and wet-laid process, which each differ considerably in processing parameters and nonwoven properties.

The wet-laid technique is based strongly on the classic paper production. In principle, the mostly shorter fibres are dispersed in water and continuously rinsed on a sieve. Due to the similarity with the processing of cellulose fibres, there are only minor adaptations of the process technology for the processing of carbon fibres.

In the field of dry web formation, the airlaid and carding processes are characterized by high productivity in the production of textile surfaces. For the price-oriented carbon fibre market this offers the advantage of low process costs. In addition, the nonwoven properties can be precisely developed for the respective applications.

### *1.2. Nonwoven production and challenges with the carding process*

The main advantages of the nonwoven process besides the lowest level of production costs for the manufacturing of a textile fabric is the high level of universality of the achievable properties. The drapeability, the variation of thickness, the chance to vary isotropy and structure of the material and the chance to blend with all fibres with limited fibre length (natural and synthetic origin) are designable properties for a nonwoven semi-finished product.

In order to be able to process recycled carbon fibres successfully on a nonwoven line adjustments in terms of the opening, the air flow and the storage have to be made to reduce fibre damage and to increase the nonwoven quality. Due to the very compact and economical process, the carding process combines several transformation processes to produce a homogeneous, textile surface from fibres without any need of yarn formation. The opening and parallelizing process of the fibres is conducted between steel toothed rollers. The steel teeth are called (saw tooth) wires. The process enables the production of highly oriented nonwovens.

Nonwoven lines can be divided in three main process steps: fibre preparation, web formation and web bonding. The most important and universal line concept is based on the web formation principle of a roller card (Figure 1), which converts a mat of fibre tufts into a uniform web. A roller card manufactured by the company Dilo System GmbH, Eberbach, Germany, is installed at the facilities of the ITA in Augsburg and used for research purposes in the project CaRinA.

Particular attention is paid to the improvement of the doffing roller system, which is realized with a so-called hacker. Hackers are currently used on most of the carbon fibre roller cards for web doffing. The hacker allows a stable process with relatively short cleaning times of the doffer roller, but causes little hooks of the fibres during the web doffing leading to a worse orientation. In addition, the production speed is limited by the mechanical limits of the oscillating hacker. A roller based web doffing, commonly used in other nonwoven processes allows for higher production speeds and the possibility to influence the orientation and structure of the nonwoven fabric via the parameters warp and compression.

Industrial production lines based on nonwoven processes are available and first applications are known from research institutes but still only a few industrial lines are employed. Several research projects are addressing the topic of processing conditions [8, 9].

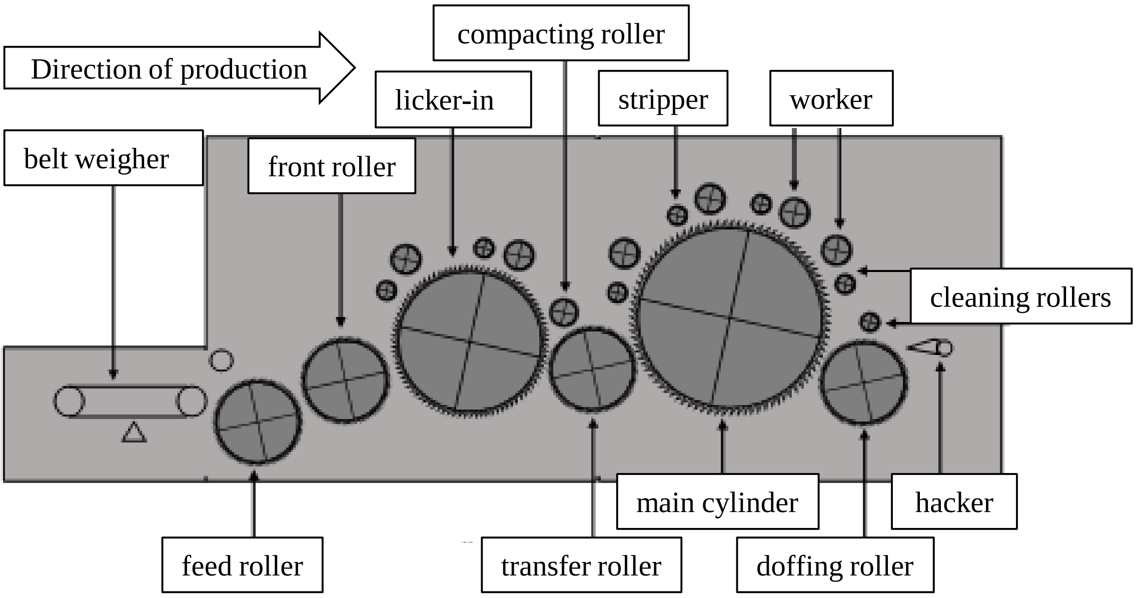


**Figure 1.** Schematics of a roller card.

## 2. Joint Project CaRinA and goals thereof

The aim of the project CaRinA is to meet the strong demand of the industry for a clear and easily accessible cost-specific performance spectrum for rCF nonwovens. Including all industrially relevant parameters, the nonwovens will be characterized by a comprehensive property profile for unambiguous traceability. Thus providing the required comparability both within the family of rCF nonwovens and in competition with other material classes. Furthermore the results allow for the first time to create a data model covering the entire process chain for the production of rCF products.

In order to achieve the set goals, the partners will produce, process and characterize several different nonwovens. The collected data is correlated with the process parameters and stored in a database to provide a complete data set of each individual material. In addition to processing parameters the data set will include thermal and mechanical characteristics of the respective materials as well as the history of the recycled and mixed fibres.

## 3. Work priorities of ITA

The focus of the ITA in the project is to gain knowledge about the processing parameters of the roller card and their respective interactions concerning the influence on the nonwoven and composite properties. For this purpose, the following investigations or developments are carried out by the ITA:

- Investigation of the processability of dry and pyrolysed secondary carbon fibres in the roller card process
- Improvement of fibre preparation, especially with the aim of a uniform mixing and gentle opening of the fibres
- Investigations of the influence and the improvement of the web bonding process "needling"
- Development of a roller based web doffing system for carbon fibres and the investigation of the influence on important nonwoven properties
- Investigation of different methods of application of thermoplastic matrices to rCF nonwovens
    - Investigation of powder spreading technology
    - Development, design and investigation of the incorporation of TP nonwovens in rCF nonwovens - Stacking
- Examination of various fibre blends and processing behaviour

- Investigation of the effects of modified PET fibres on the processability and nonwoven as well as composite properties

### *3.1. Approach for the investigation of opening, web formation and web bonding*

The aim is to find the most influential factors beneath the more than 40 relevant parameters a roller card has to offer. The focus of the investigation is on the opening and mixing, the web formation and web bonding. Nine key factors are determined by an assessment of a panel of experts and then efficiently screened for their impact on four quality characteristics using a screening experiment design following a Plackett-Burman design [12].

**Table 1.** Factors that will be evaluated for screening by a panel of experts.

| Section of the nonwoven line | Fibre preparation | Web formation | Web bonding |
|---|---|---|---|
| Factors | Degree of opening | Specification of wires | Warp |
| | Roller speeds | Roller speeds | Needle density |
| | Application of avivage | Amount of worker rollers | Needle penetration |
| | Roller spacing | Roller spacing | Needle type |
| | Material flow | Web weight | Area weight |

A total of 12 plates is produced. The material combination tested consists of 40% pyrolysed carbon fibre and 60% PA6 fibres.

The quality features are:

The *regularity of the nonwoven area weight*, also called CV value. The CV value is the quotient of the standard deviation of an area weight measurement series (longitudinal, machine direction (MD) and transverse (cross directional (CD)) divided by the mean value of the respective measurement series.

The *intrinsic regularity of the nonwoven* (CV-I value) or the quality of the mixture of the carbon fibres within the nonwoven. For this purpose, the previously taken area weight samples are pyrolized, leaving the carbon fibre content remaining. Since the same test specimens are used this allows the measurement of the weight fraction of the carbon fibres. The determined CV-I value is the quotient of the standard deviation of the carbon fibre mass fraction of a measurement series (longitudinal (MD) and transverse (CD)) divided by the mean value of the respective measurement series. The CV-I value is a measure of the quality of mixing and distribution of carbon fibres within the nonwoven fabric.

The *flexural strength* and the *flexural modulus*, determined from mechanical bending tests in 0°, +/- 45° and 90° direction respectively to the machine direction of the nonwoven. The samples are tested in accordance with DIN EN ISO 14125 in a 4-point bending test.

The *orientation*, expressed in a polar diagram of the examined composites. The polar diagram is established from the mechanical characteristics of the four different angles, which each generated a data point. The polar diagram provides a more accurate orientation of the material than the typically in nonwoven industry employed MD/CD ratio. On the other hand the polar diagram allows to conclusions concerning the damage of the carbon fibres. Nonwovens with the same polar diagram orientation but reduced mechanical values will show those properties mainly due to a reduction of fibre length (Figure 2).

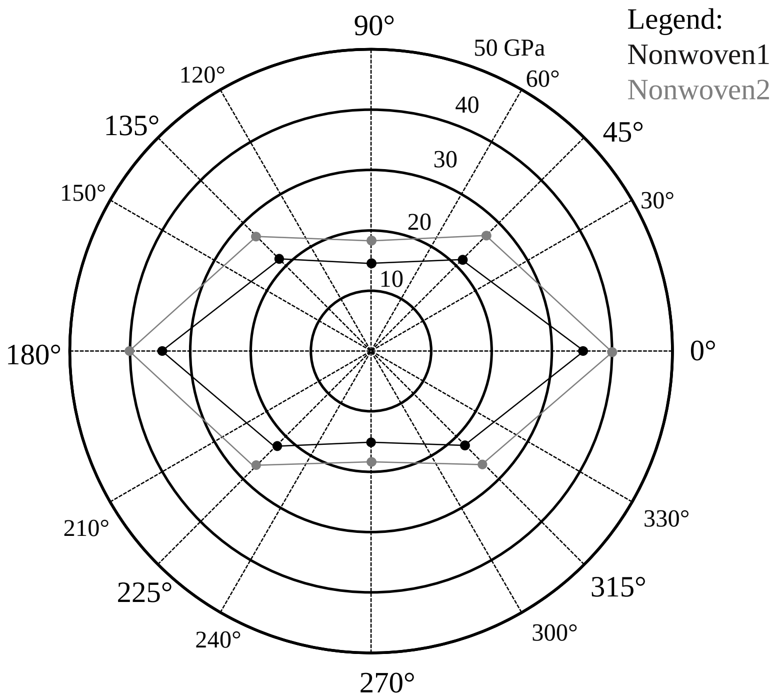


**Figure 2**. Schematic polar diagram of 2 nonwovens differing in fibre damage.

Based on the results of the screening experiments, the 2-4 most influential factors are determined. These factors are examined in a second statistical design plan for their exact relationship and interactions regarding the influence on the 4 quality characteristics. The procedure is the same as described for the screening experiments. The design is chosen from Central-Composite-Design, Box-Behnken-Design or Monte-Carlo-methods [12], enabling the detection of a cubic course of the factors influences. The results serve as a basis for the selection of the best operating point of the roller card for the production of nonwovens for material characterization and for further processing. Furthermore, at the end, the best degree of opening of the fibre mixtures and the settings for solidification are established.

## 4. Conclusion

Lightweight design is a key technology to enable the design and manufacturing of modern energy optimized cars especially for electro mobility. Although CFRP is the best available lightweight material available we have to face the challenge to reduce manufacturing costs and enable production scales of high volume production.

The combination of rCF and nonwoven processes shows high potential to contribute to solving this problem. The project CaRinA , which is presented in this lecture will help to understand the process key factors and create material cards which will help the rCF nonwoven industry as well as the parts manufacturer to apply this new technology in a much better way to use recycling materials for industrial purposes.

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