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GMT based on Hybrid Nonwovens for Compression Molding of Deflection Sheaves in Elevator Applications

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ABSTRACT Deflection sheaves are a central component in rope dependent elevators. There is a large market demand for lightweight variants of deflection sheaves. In this field, products made of cast polyamide have become established. Another approach to manufacturing lightweight deflection sheaves is the compression molding of glass mat reinforced thermoplastics (GMT). Typically, market-standard GMTs have a polypropylene (PP) matrix. In practical tests, it was found that deflection sheaves made from PP-GMT lead to significant wear in the form of negative impressions of the rope`s surface in the grooves. Alternative sheaves made from GMT with a polyamide 6 (PA6) matrix do not show this wear. Since PA6-GMT is less common in the market and only available at high prices, a cost-efficient GMT was developed. This is made from hybrid nonwovens, consisting of a mixture of PA6 and glass fibres, which are consolidated by hot pressing. To analyse the suitability of this nonwoven-based GMT for molding deflection sheaves, an application-oriented material comparison with commercially available PA6-GMT was carried out. The focus was primarily on an analysis of the mechanical properties and flow characteristics. Based on the test results, fundamental suitability was confirmed, and suggestions for improving the material properties were derived.

KEYWORDS compression molding, deflection sheaves, elevator, glass mat reinforced thermoplastics, GMT, hybrid nonwoven, lightweight design, pulley

1. Introduction

In rope-dependent lifts, one of the primary components is the rope system, which includes the traction sheave, deflection sheaves, counterweight, and ropes. Deflection sheaves typically comprise several parts: the axle, axle housing, and bearings. According to current industry standards, deflection sheaves are primarily made from grey cast iron or cast polyamide (PA6 G). Cast iron sheaves are notably heavy, which poses challenges during assembly and maintenance in lifts. Transporting, handling, and installing these sheaves require more personnel, complex equipment, and significant time investment. Consequently, there is a substantial market demand for lightweight deflection sheaves. The objectives of lightweight design include reducing assembly effort, mounting times, and equipment needs, as well as improving safety and ergonomics during the mounting process. Additionally, the use of lightweight sheaves can extend the operating life of steel ropes [1]. To meet the demand for lightweight sheaves, alternatives made from cast polyamide have become established in the market.

To increase the properties of lightweight sheaves, especially regarding mechanical characteristics, creep under static load, and high temperature, fibre reinforcement is expedient. Within the framework of a cooperation between TU Chemnitz and AMB Oberlungwitz GmbH, lightweight sheaves with long glass fibre reinforcement were developed for this purpose. As a technological solution, compression molding was chosen—an established method for manufacturing lightweight components from glass mat reinforced thermoplastics (GMT). The scheme in Figure 1 shows the typical process chain for compression molding.

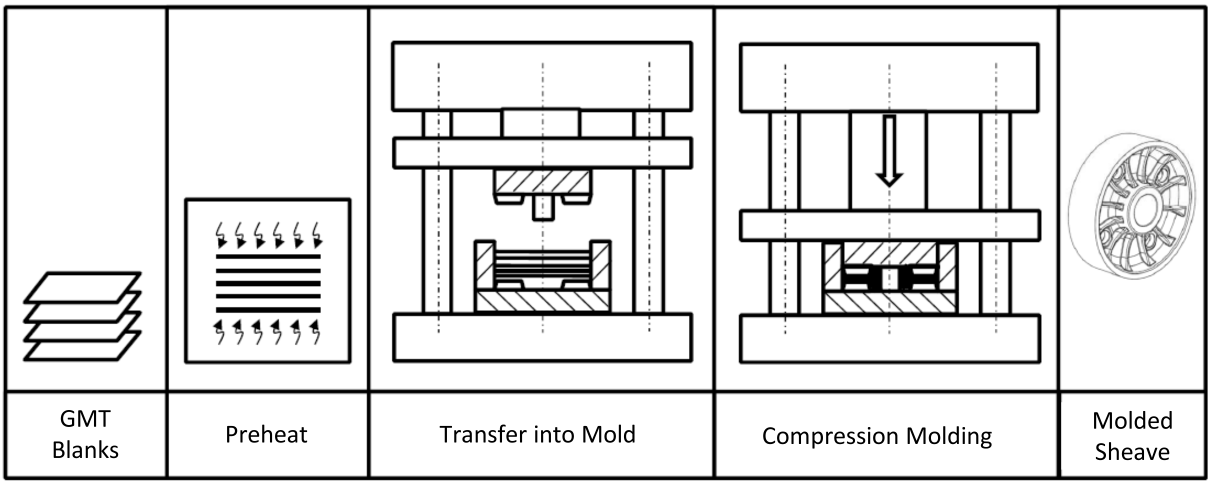

Figure 1: Compression Molding of Deflection Sheaves (ref. [2])

Commonly available GMTs have a polypropylene matrix with random glass fibre reinforcement with a fibre length of approximately 50 mm. These fibres typically are present as randomly oriented fibres. This allows the fibres to flow with the matrix during the pressing process as the mold is filled. Additionally, the laminates exhibit quasi-isotropic properties. The long fiber reinforcement in GMT enables high mechanical properties to be achieved. Regarding the application for a deflection sheave, the ability to achieve high wall thicknesses is also very advantageous. Thus, raw parts with machining allowances can be produced, which can be machined by turning to application-specific final dimensions. This allows, for example, the use of different types of bearings or the variation in the number and geometry of the rope grooves.

The developed prototypes included sheaves with outer diameter of 410 mm designed to accommodate six ropes with a diameter of 10 mm (see Figure 2). Regarding load capacity, very good results were already achieved with GMT made from PP and a 50 wt% glass fibre reinforcement. Axial loads of up to 160 kN were demonstrated in tensile tests, which means a two-fold safety margin considering the required axial load of 80 kN.

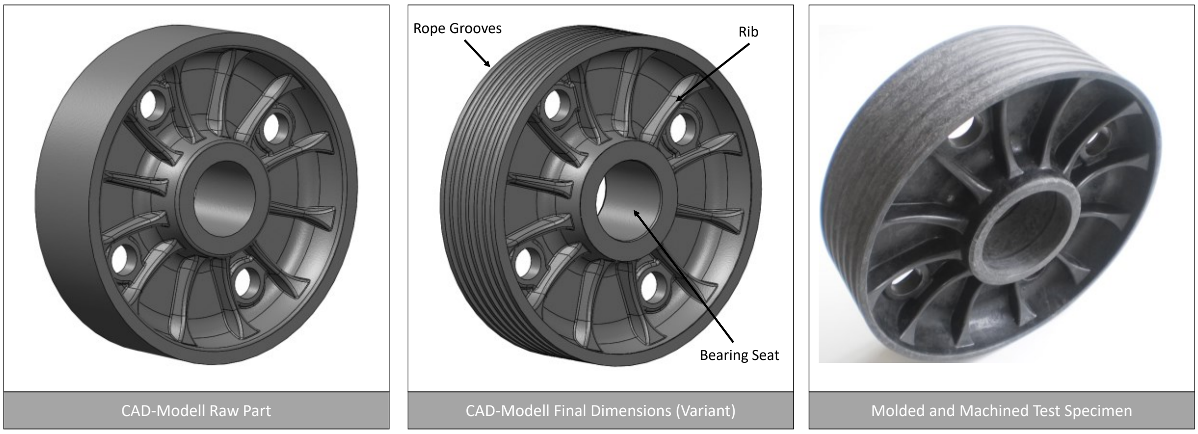

Figure 2: Prototype of a Deflection Sheave as CAD and molded test specimen (ref. [3])

Furthermore practical duration tests were conducted in a test elevator. It became evident that significant wear in the form of negative impressions of the rope`s surface in the grooves occurred after a short period when using PP-GMT with 50 wt% of glass fibres. The same test was conducted with sheaves made from PA6-GMT with 32 wt% glass fibre reinforcement. In this case, no negative impressions of the rope`s surface were observed. As a result, a PA6-based GMT was defined as suitable for the application. The GMT, hereinafter referred to as Reference GMT, was sourced from a common market manufacturer.

A challenge is, that GMT with a PA6 matrix is relatively rarely processed in industry and therefore has limited demand. Consequently, high prices are noted for this material. For this reason, investigations were carried out to find an alternative cost effective material for manufacturing of the deflection sheaves. In cooperation with the Cetex Institut gGmbH a cost effective GMT made of hybrid nonwovens was developed (hereinafter the material is referred to as CetexTUC GMT) with the aim to compare with the properties of the Reference GMT. The hybrid nonwoven consists of PA6 fibres mixed with 32 wt% glass fibres and is consolidated by hot pressing. Figure 3 shows the manufacturing of common GMT and the manufacturing of GMT based on hybrid nonwovens.

To investigate the suitability of the developed CetexTUC GMT for the production of sheaves, a material comparison with the Reference GMT was conducted. With regard to the application for compression molding of deflection sheaves, an analysis of the mechanical properties and flow characteristics was carried out.

Regarding mechanical properties, the tensile strength is of primary interest. Special attention is also given to the directional properties. For the production of rotationally symmetrical components, such as sheaves, a high degree of isotropy is particularly important.

In terms of flow characteristics, the flow ability of the material is crucial. The preheated GMT blanks should completely fill the mold through the flow process. Both, the matrix and the fibres are expected to flow during this process. Fibre-matrix segregations, which can lead to component inhomogeneities, should be minimised.

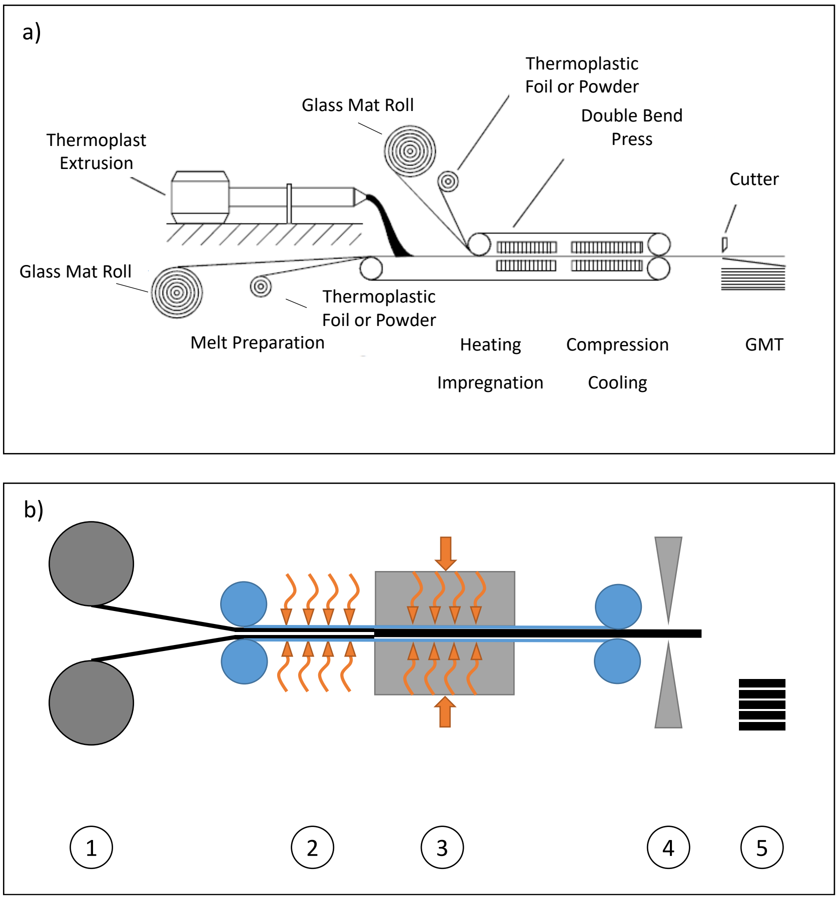

Figure 3: a) Scheme of Manufacturing of GMT with melt impregnation [4], b) Scheme for processing hybrid nonwovens to the CetexTUC GMT, 1 = hybrid nonwoven roll, 2 = heating, 3 = double bend press, 4 = cutter, 6 = GMT

2. Methods

2.1. Tensile Testing

Tensile tests were conducted according to DIN 527-2. All samples were conditioned to saturation before the tensile test. Samples were cut from the laminate both in the machine direction (MD) and in the cross direction (CD) using water jet cutting.

Additionally, laminated plates with a 0°|90° layer construction were molded on a hydraulic press from the laminate. For this purpose, pre-dried laminate was heated in a contact heating station at T = 260 C° for a duration of t = 240 s. Subsequently, the transfer to a plate mold with dimensions of 500 mm x 500 mm took place. The preheated laminates were stacked in cross layers. The press force was F = 300 kN.

2.2. Flow Properties

To characterize the flow behavior, so-called press rheometers are suitable. Experimental setups are described in [4], [5] and [6]. The experimental setups essentially involve a mold with a rectangular surface geometry. GMT blanks are placed unilaterally in this tool, so that only a part of the mold surface is covered. During pressing, the GMT begins to flow. The maximum flow path can be measured on the molded sample. The experimental setup (see Figure 4) was designed in accordance with [6]. A press mold with a base area of 200 mm x 200 mm was used, which was integrated into a hydraulic press. GMT blanks with dimensions of 200 mm x 50 mm were placed unilaterally in this tool, providing a theoretical flow zone of 150 mm. Preheating was performed using a contact heating station.

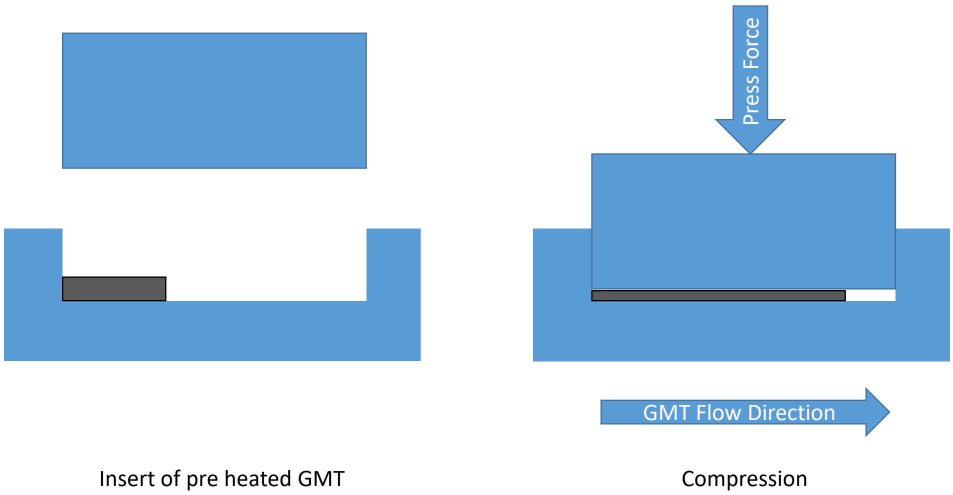

Figure 4: Test cavity for characterization of the flow properties in accordance to [6]

To assess the flow ability, the maximum flow path length is determined on the molded samples. Since the Reference GMT and the CetexTUC GMT have different laminate thicknesses, the flow path length was recalculated per 1 mm of laminate thickness. To characterize the flow ability of the fibres, rectangular samples were cut from the samples produced in the press rheometer using water jet cutting (see Figure 5). These rectangular samples were then analysed for fibre content through ashing.

Ashing was conducted according to DIN EN ISO 1172, Method A. The specimens were cleaned with ethanol and n-hexane and dried at 105°C for 1 hour in a vacuum. Ashing was performed at 625°C for two periods of 30 minutes each.

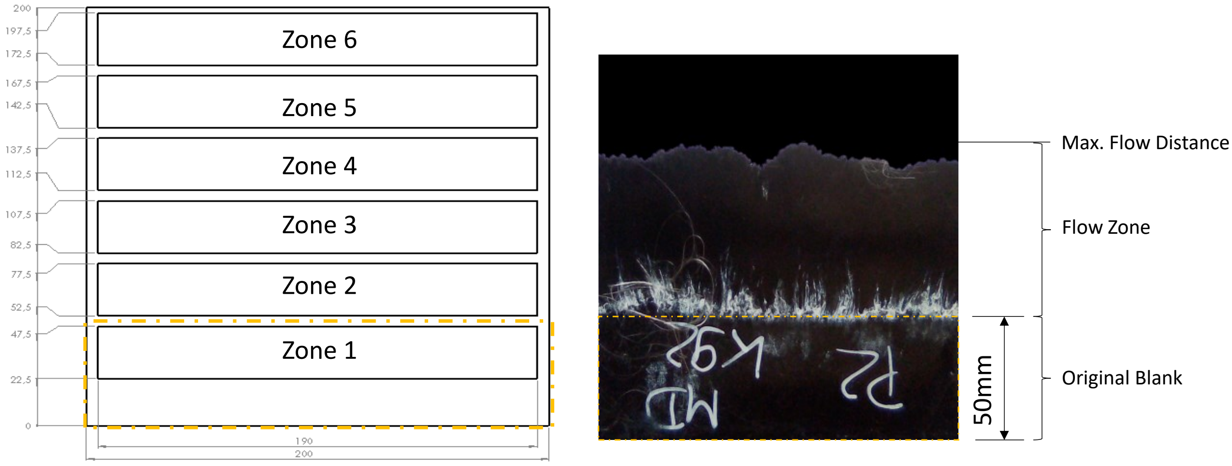

Figure 5: a) Scheme of the positions of rectangular samples for ashing (original blank dimension marked with yellow frame), b) Typical sample after flow testing

3. Results

3.1. Tensile Testing

Figure 6 shows the stress-strain diagrams for the CetexTUC GMT.

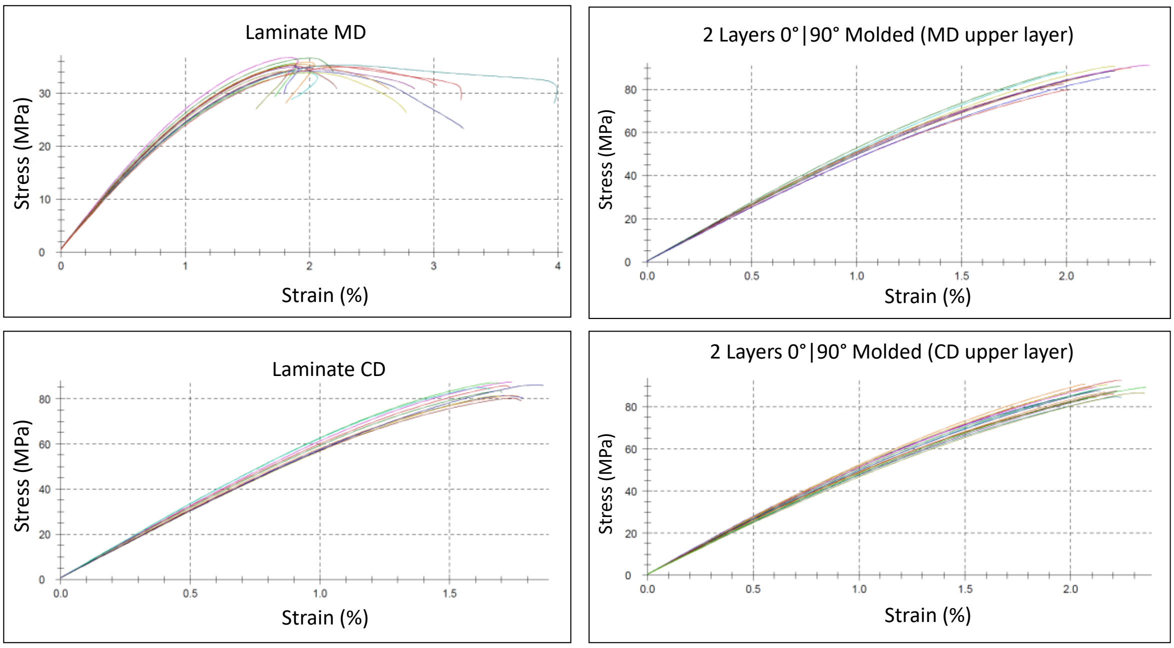

Figure 6: Stress-Strain Diagrams for the CetexTUC GMT as laminate and cross layer molded (MD = machine direction, CD = cross direction)

Figure 7 shows a comparison of the average tensile strength of the CetexTUC GMT in comparison with the tensile strength of the Reference GMT according to the data sheet.

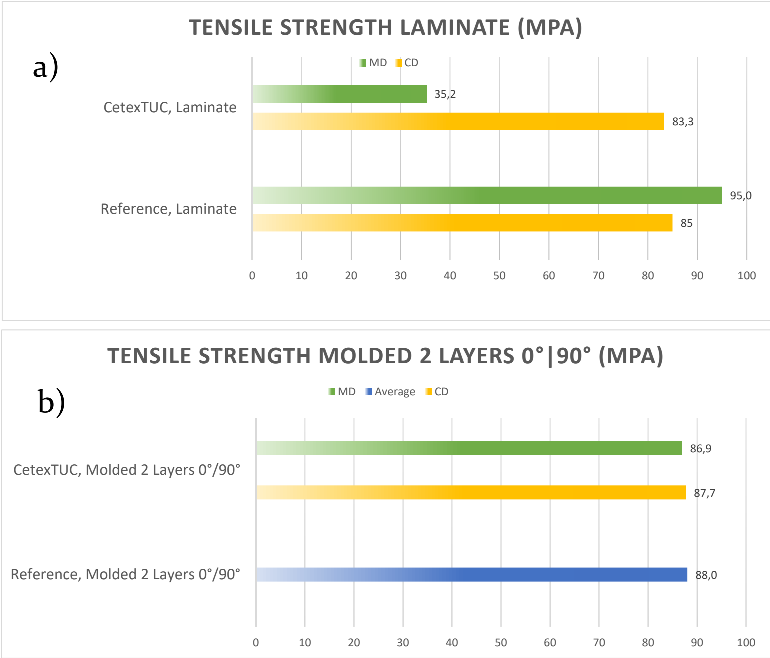

Figure 7: Comparison of Reference GMT and the CetexTUC GMT regarding the Tensile Strength, a) Tensile Strenght of the laminate, b) Tensile Strength of 2 layers 0°|90° molded (MD = machine direction, CD = cross direction)

3.2. Flow Properties

Table 1: Flow Distance shows the measured flow distances.

Table 1: Flow Distance (MD = machine direction, CD = cross direction)

Material	Thickness (mm)	Flow Distance (mm)	Flow Distance per 1mm thickness
Reference GMT CD	4,1	85	20,7
Reference GMT MD	4,1	92	22,4
CetexTUC GMT CD	6,3	136	21,6
CetexTUC GMT MD	6,3	135	21,4

Figure 8 shows a comparison of the fibre contents of the samples according to Figure 5.

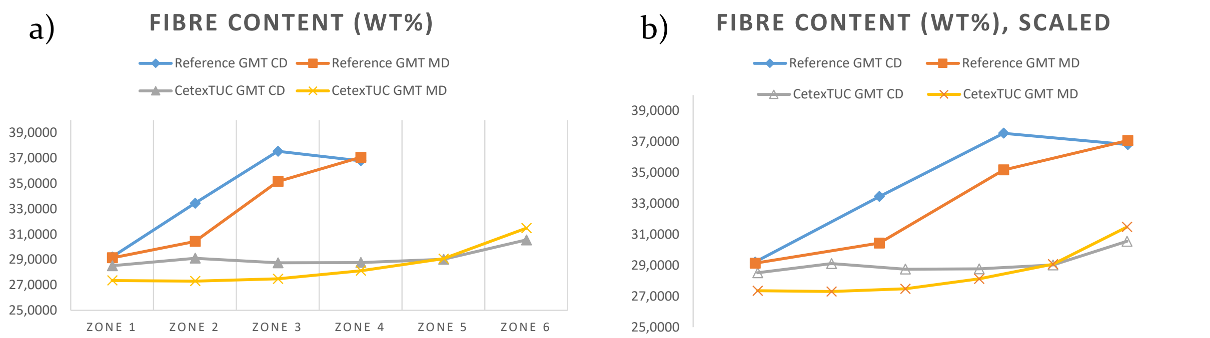

Figure 8: a) Fibre content measured in the different zones according to Figure 5, b) Scaled illustration of fibre content from zone 1 to max. flow distance (MD = machine direction, CD = cross direction)

4. Discussion

The tensile test values obtained for the CetexTUC GMT laminate show a significant discrepancy between the machine direction and the cross direction. Compared to the Reference GMT, this discrepancy is much more pronounced. For the application in a rotationally symmetrical component, isotropic material behaviour is important, as otherwise, property differences dependent on the rotational angle can occur, which could be disadvantageous in practical use. By specifically varying the layer orientation when inserting the preheated blanks into the press mold, largely isotropic properties can be achieved. However, due to the flexible state of the preheated materials, precise insertion is often only possible with low repeat accuracy. In the molded 0°|90° cross layer, this discrepancy is largely not observed anymore. The tensile strength of the cross layer samples is almost equivalent to the Reference GMT.

Regarding flow behaviour, the CetexTUC GMT is comparable to the Reference GMT. No disadvantages are expected concerning mold filling. Initial trials of compression molding the sheaves from CetexTUC GMT already showed sufficient mold filling. Concerning fibre matrix segregation, the CetexTUC GMT appears to be more advantageous. The segregation was less pronounced, which can be beneficial for homogeneous component properties, but it may also indicate a lower tendency of the glass fibres to flow. Further tests should investigate the fibre content in samples from different areas of the component to address this.

5. Conclusion

The test results indicate a fundamental suitability of the developed CetexTUC GMT for the production of deflection sheaves using the compression molding process. However, a significant drawback is the strong discrepancy in mechanical properties between the machine direction and the cross direction. Nevertheless, there is room for improvement in this area during GMT production. A key approach to solving this issue is the variation of the nonwoven structure. This should aim for greater homogeneity between the fibre content in the cross direction and the fibre content in the machine direction.

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