OPTIMIZED BAST FIBER REINFORCED POLYPROPYLENE FOR AUTOMOTIVE APPLICATIONS

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Abstract

Natural fiber reinforced polymer composites (NFRPC) are of high interest for the automotive industry since they provide advantageous properties at extremely low density and low costs. Currently, a main problem of NFRPC applications is insecurity concerning the mechanical properties. As every OEM characterizes his parts and components within its own test specifications in accordance to generally valid testing norms, it is not easy to compare the results of mechanical characterization of the OEMs among themselves and Tier-1 suppliers. This is based on the difference of the testing methods or rather testing parameters leading to not comparable testing results, e.g. regarding threepoint bending. It is unclear in which way the characterization itself has an influence on the outcome and also the insights on the influence of the processing conditions on the mechanical properties are not sufficient.
This paper deals both with the influence of the processing conditions on the mechanical properties and with the mechanical characterization of NFRPC with an area weight of 1700 g/m². Test parts are manufactured with thermoforming process while variying calibration time and calibration temperature. It was found that both calibration process, including time and temperature, and testing norm have a slight influence on the mechanical properties of the NFRPC-based automotive parts.

1. Introduction

Steadily increasing environmental demands and the growing awareness of mankind to the self-made climate effects, topics like environmental friendliness, sustainability and carbon footprint gain importance. This is one reason why the replacement of mineral- and crude-oil based materials by bio based and renewable resources is discussed in many industries. A common target is to replace fossil raw materials by renewable materials, preferably without any loss of mechanical properties and economic benefits. Natural fiber reinforced polymer composites (NFRPC) are a good example: Since decades, NFRPC have been applied in the European automotive industry, due to their environmental and economic benefits, e.g. the low energy consumption during production. As reinforcement fibers normally flax, hemp and kenaf are used. As matrix, due to cost-effectiveness and mechanical properties polypropylene is used. Usually, NCF-products for automotive interior parts are processed by thermoforming process and used as semi-structural parts like door panels, stiffening parts, backrest coverings etc. [1], [2], see Figure 1. The specific mechanical properties of NFRPC are at least as high as the properties of glass fiber reinforced composites (GFC) [3], but do not reach their level completely. Based on their extremely low density and the low cost, they provide advantage over GFC-parts in automotive interior applications. For those applications normally natural nonwoven fiber mats

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with an area weight between 1200 g/m² and 2000 g/m² are used. The composite part normally shows a density between 0.85 and 0.95 g/cm³ and is processed via thermoforming process.

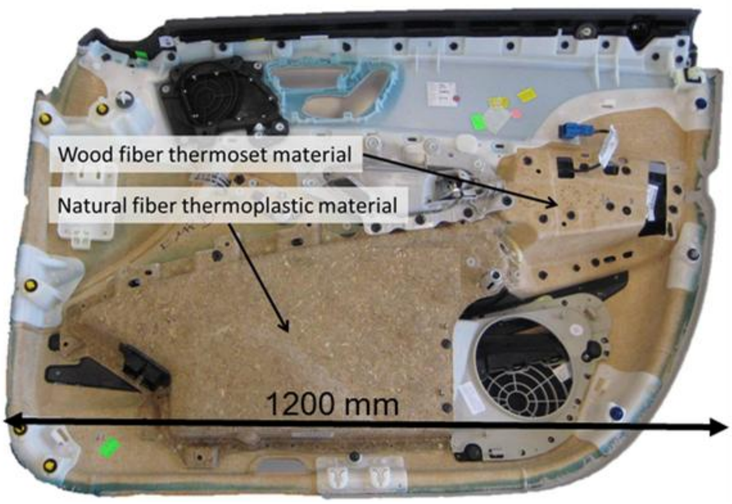

Figure 1: Example for NFRPC application in automotive industry **-** Interior door panel

The state of the art thermoforming processes includes a calibration step, whereby the NFRPC-material is heated up to 220°C, while it is compacted with a preasure of 1 N/mm². After calibration, which takes normally at about 40-60 s, the NFRPC-material is quickliy transferred to the shaping die, where it is formed to final geometry. The aim of this study is a variation of the calibration time and calibration temperature to improve the mechanical properties of the NFRPC-material. Calibration preasure is kept constant for the testing series. Subsequently, the influence of different testing norms regarding mechanical properties is investigated on the basis of threepoint bending tests. This is based on the fact that most of the OEM characterizes his parts and components within its own test specifications. These specifications are in accordance with the generally valid testing norms but have differences in some specific testing conditions such as part geometry or testing velocity. So it is not easily possible to compare the results of mechanical characterization among the OEM themselves.

2. NFRPC-materials for automotive applications

The material used within this work is a needled natural fiber mat with an area weight of 1700 g/m². As reinforcement fibers a mix of flax, hemp and kenaf is used as also Polypropylen as matrix material (NFPP). These materials are utilized as standard for interior parts in the automotive industry.

In a preceding process step, raw fibers are gained from the flax, hemp and kenaf plants. These fibers are processed by a carding machine to a fibrous web, where the fibers are orientated along the production direction. In this process step, the natural fibers are mixed with the polypropylene fibers in an appropriate mixing ratio of 50:50 in terms of weight. The fiber mat that results herein is laid up by a compensating stacker to the desired area weight.

In a last process step, the fiber mat passes a needle machine where the fibers are interlocked, force-fitted and subsequently processed by a calibration and thermoforming process to the required part geometry. Therefore, temperatures between 180 °C and 230 °C as also cycle times of at about one minute are used.

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3. Methods and processes

3.1. Sample manufacturing: Thermoforming process

The processing of NFRPC-material is done by thermoforming process which includes several process steps, see Figure 2. In the first processing step, the NFRPC-material is calibrated. Within this calibration process the NFRPC-material is heated up to a temperature which is higher than the melting temperature of polypropylene, whereby it is simultaneously compacted with a pressure of 1 N/mm² to a thickness of 2 till 3 mm, depending on the thickness of the end part. The thickness can be adjusted by spacers in the press and is dependent on the area weight of the specific NFPP-material. For automotive applications, the materials are calibrated at temperatures between 180°C and 220°C. After the material is calibrated, it is transferred into the press, where it is formed to the final part geometry. Optionally, the trimmed material can be concealed with a covering foil between calibration and press process. After the NCF-material is formed and cooled down, it is removed from the press and trimmed to end geometry.
The processing, including calibration, lasts at about 30 to 60 seconds. The density of this pars is normalls in the range of ~ 0.85 to 0.95 g/cm³.

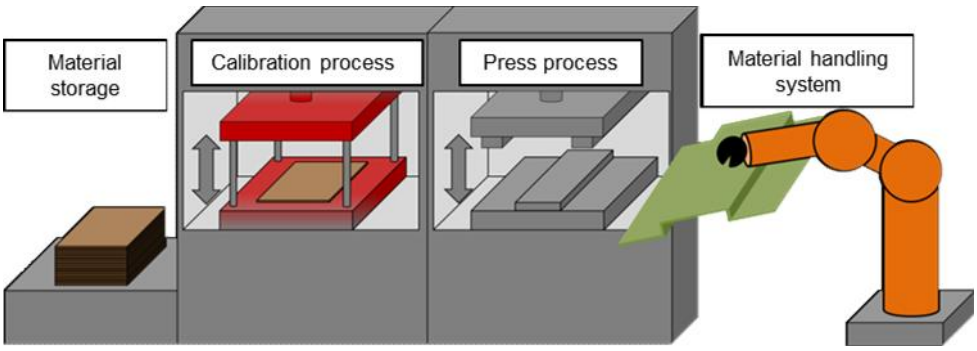

Figure 2: Process chain for NFRPC-automotive components [4]

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3.2. Process variation: Variation of calibration cycle

Within the calibration process the NFRPC-material is heated up by the calibration press over the melting temperature of the polypropylene. If there is residual moisture in the NFRPC-material, the press is shortly opened for a degassing of water vapour, see Figure 3.

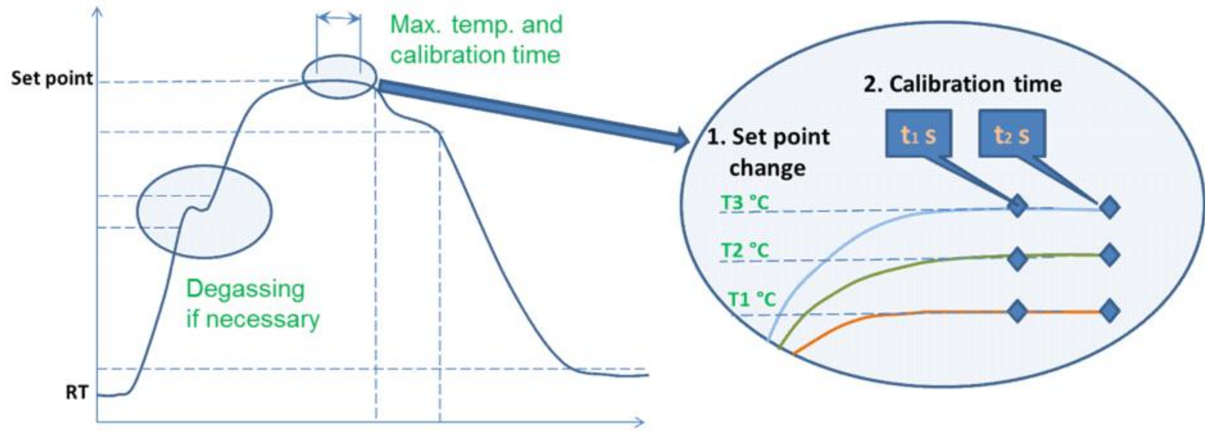

Figure 3: Variation of calibration cycle

After degassing, the material is heated up to the set point which is between 180°C and 220°C. As soon as the inner core of the NFPP-material is heated up to the set point temperature, the calibration time starts. Within this study there was a change of calibration time (t1, t2, t3) and calibration temperature (T1, T2, T3) to see the influence of those parameters, see Table 1, to achievable mechanical properties. If the calibration temperature is too low, the reinforcement fibers will not properly be impregnated, if the temperature is too high, the reinforcement fibers will thermally degrade. So it is very important to obtain a temperature which is high enough for a good impregnation of the fibers but without harming the natural fibers themselves.

Table 1. Variation of calibration parameters

Calibration time / Calibration temperature	*“short” t1 [s]*	*“middle” t2 [s]*	*“long” t3 [s]*
“high” T3 [°C]	T3, t1	T3, t2	T3, t3
“medium” T2 [°C]	T2, t1	T2, t2	T2, t3
“low” T1 [°C]	T1, t1	T1, t2	T1, t3

3.3. Testing of mechanical properties: Three point bending test

Bending properties were measured according to the different testing norms, which are commonly used by the OEMs. Therefore, they are measured on a Zwick universal testing machine according to DIN EN ISO 14125, DIN EN ISO 178 and DIN EN ISO 310 [5-7] whereby the size of the specimen, the distance between the bearings and the testing speed were changed. Table 2 shows the most important differences between the different testing norms.

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Table 2. Overview of bending parameters

Testing parameters	Sample width *(mm)*	Sample thickness *(mm)*	Sample length *(mm)*	Span (mm)	Begin flexural modulus (%)	End flexural modulus (%)	Testing speed (mm/min)	Pre load (N)
DIN EN ISO 14125	15	2	80	32	0.05	0.25	5	5
DIN EN ISO 178	25	2	80	32	0.05	0.25	5	5
DIN EN ISO 310	50	2	80	40	0.05	0.25	20	5

The most important mechanical value of the bending test is the flexural modulus. This value is calculated by maximum force (F_m), deflection at maximum force (f), distance between the spacers (l) and the geometry of the sample (b x h) which is applicated to the sample and can be calculated as:

$$E[MPa] = \frac{F_m * l^3}{4 * b * h^3 * f} \quad (1)$$

For every variation of calibration parameters, which are shown in Table 1, test series for the different testing norms, see Table 2, were made. Therefore, seven specimen were tested for each testing series.

4. Results

4.1. Results of mechanical properties: Bending stiffness

The test series with different calibration temperatures and different calibration times showed that there is a slight influence of the processing conditions. The selection of the testing norm has a big influence to the flexural modulus and also for the maximal force of the single test series.
The increase of flexural modulus, based on optimized processing conditions (calibration time and temperature), is at about 30 %, regarding the values for T1,t1 (reference 1960 MPa) and T2,t2 (optimum 2550 MPa). This shows that a longer calibration time at a higher calibration temperature leads to better mechanical properties.
The results showed a big influence of different testing norms (DIN EN ISO 14125, 178 and 310) to specimen which were processed at same process conditions. The influence of the norms showed an average growth between 43 % and 57 % resulting in a continuous increase of flexural modulus in dependence on the width of the testing specimen, based on the appropriate testing norm. As the flexural modulus is independent from the geometry of the specimen, the growth of modulus with simultaneous growth of the width could be explained with the longer fibers in the samples. In average DIN EN ISO 14125 showed the lowest values for flexural modulus, DIN EN ISO 310 showed the highest results. The results of DIN EN ISO 178 are in between. All the results show an almost equal deviation and prove the difficulty of the comparison of the results from different norms.

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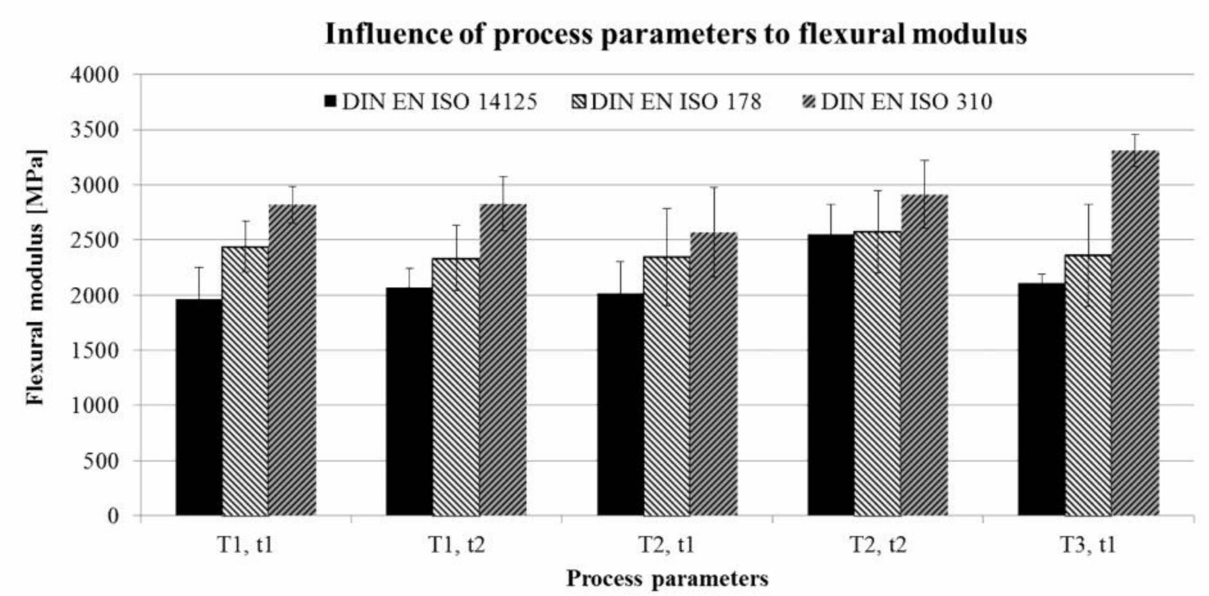

Figure 4. Influence of process parameters to flexural modulus

4.1. Results of mechanical properties: Bending stiffness

Referring to the maximum forces which can be applicated to the specimen, the test series showed almost no influence of the calibration time and temperature. The influence of the different testing norms, which distinguish mostly in the width of the samples, is clearly visible. The test series also showed that the deviation between DIN EN ISO 14125 and DIN EN ISO 178 is at about 62 % and between DIN EN ISO 14125 and DIN EN ISO 310 up till 175 %. This is based on the different width of the samples. If the forces are normed to the force of the width of 15 mm, there is almost no influence recognisable.

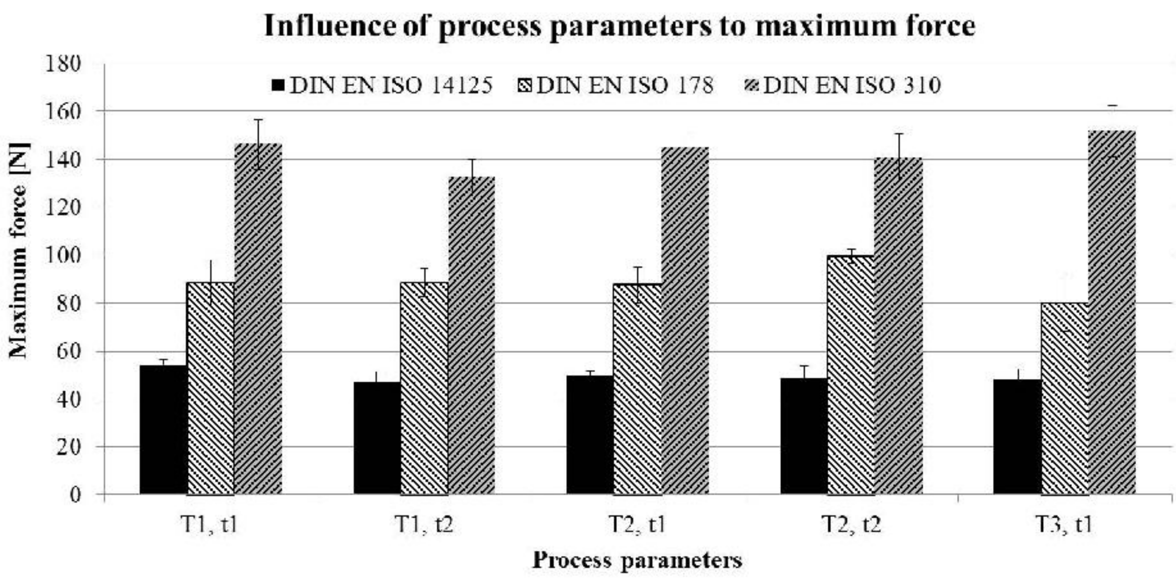

Figure 5. Influence of process parameters to maximum force

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5. Conclusions & Outlook

Within this work NFRPC-composites, based on a mix of flax, kenaf and polypropylene as matrix, were processed under different processing conditions. The process parameters calibration time and temperature were varied to see the influence regarding flexural modulus and maximum forces. Furthermore, different test standards were used to test samples, to see the influence of the testing norm regarding flexural modulus and maximum forces.
The test series showed that there is only a slight influence of the process parameters calibration time and calibration temperature to mechanical properties. The best mechanical properties were achieved with a middle calibration time and middle calibration temperature, see Table 1, which is based on the fact that the reinforcement fibers are well impregnated, but not weakened by thermal degradation. Regarding maximum forces, there is a big deviation from up to 300 % between the different testing norms. This is based on the specimen geometry, the maximum fiber length of the natural fibers, which are randomly orientated, is a possible explanation.
It could be demonstrated, that there is a large difference of the results of the mechanical properties, which were tested with the different testing norms in accordance to the OEMs. Based on this fact, a reliable comparison of the values is not easily possible. Hence, it is very important to indicate the norm at which the tests were done.
Further test series will be made to proof these results of the first test series and thereby create the possibility to transfer the values of the mechanical properties of a test standard to the other.

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