ONLINE MONITORING SYSTEM FOR THE TACK OF PREPREG SLIT TAPES USED IN AUTOMATED FIBER PLACEMENT

Benno Böckl[1], Christian Jetten[1], Klaus Heller[1], Christoph Ebel[1] and Klaus Drechsler[1]

[1]Chair of Carbon Composites, TUM Department of Mechanical Engineering,
Technical University of Munich, Boltzmannstr. 15, 85748 Garching, Germany
Email: boeckl@lcc.mw.tum.de, Web Page: http://www.lcc.mw.tum.de

Keywords: Tack, Prepreg, Online Monitoring, Automated Fiber Placement, Aging

Abstract

The tack of prepreg slit tapes is a crucial parameter for ensuring defect free lay-up of complex parts via Automated Fiber Placement. Therefore, exact knowledge of the tack during placement is essential. Different methods for measuring tack are known in literature. However, the existing methods are not applicable to online monitoring of prepreg tack during part production. A novel testing principle was developed measuring the transverse force generated by slit tape sliding over a probe. This allows for online monitoring of the tack. A test bench was designed for validating the principle. In addition, a first parametric study was carried out investigating the influence of compaction force, tape velocity and age of the material on the measured transverse force. Increasing transverse forces with increasing compaction forces and decreasing velocities were observed in the experiments. The aging of the material and therefore the loss of tack also led to decreasing transverse forces.

1. Introduction

Automated Fiber Placement (AFP) is one of the most commonly used manufacturing processes for the production of large scale composite structures in highly demanding aerospace applications. This process allows for the direct lay-up of prepreg slit tapes on complex tooling geometries. Due to the automated process, a high degree of quality and productivity can be achieved [1]. However, certain defects, e.g. positioning defects or bonding defects, can occur during placement. Previous studies showed that the lay-up quality strongly depends on the choice of process parameters, in particular compaction force, placement velocity and heater power [1–3]. A wrong choice of parameters can lead e.g. to bonding defects like bridging or insufficient adhesion between two plies or (even more likely) between first ply and tooling surface. The ideal set of parameters enabling high productivity and preventing placement defects at the same time is determined by the tack of the material. Therefore, exact knowledge of the current tack condition is crucial for ensuring a defect free lay-up.

Different methods for measuring the tack such as the peel test or the probe tack test have been developed in the past [4–6]. However, these testing methods merely allow for the assessment of the prepreg tack at a particular moment under controlled conditions in the laboratory. As tack is strongly dependent on temperature and material ageing, the results from tack measurements are not fully applicable to the production in a workshop environment. The assessment of the current tack condition of the slit tapes as they are being processed in an AFP machine is not yet possible.

A new testing method has been developed to eventually enable the determination of prepreg tack online during placement. A test bench using a novel measuring principle has been designed and first experiments for validating the concept have been carried out.

2. Experimental method

2.1. Measuring principle

With the known testing methods for prepreg tack such as the peel test or the probe tack test every specimen has to be measured in a separate experiment. Consequently, a continuous assessment of the material used for the production of parts is not feasible and online monitoring of prepreg tack is not possible. The approach in this paper is to measure the friction force generated by a sample that is moving relatively to the measuring device. A roller which is connected to a pneumatic actuator pushes the prepreg slit tape with a defined compaction force (F_c) against a cylindrical probe. As the tape passes through the system it slides over the probe generating a transverse force (F_t) on the probe. The probe is fixed to a 3-axis force transducer measuring the transverse force. In addition the compaction force exerted by the pneumatic cylinder can be measured simultaneously. A schematic representation of the measuring principle can be seen in Figure 1.

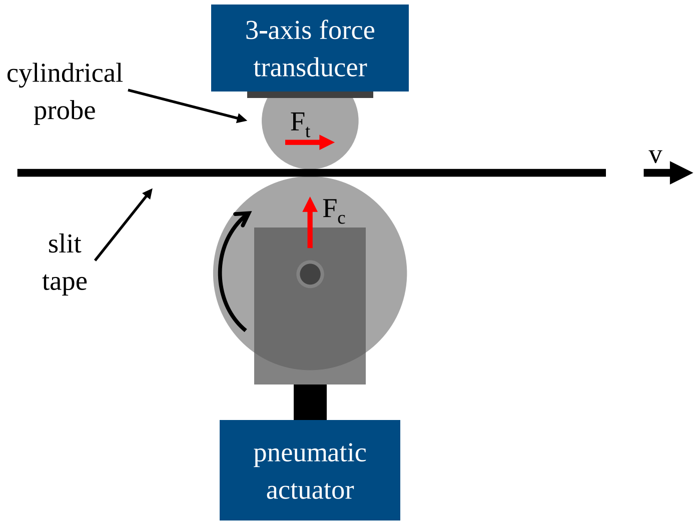

Figure 1. Schematic representation of the measuring principle.

The transverse force generated by the slit tape on the cylindrical probe is clearly dependent on the tack of the prepreg but also on the compaction force with which the tape is pushed against the probe. Since prepreg shows visco-elastic behavior also the relative velocity between probe and slit tape might have influence on the measured transverse force [7,8].

2.2. Testing setup

A test bench was designed in order to conduct experiments for validating the measuring principle. The setup consists of a 3-axis force transducer by ME-Messsysteme GmbH [9]. Since pretrials, conducted with an early development stage of the test bench, showed that maximum transverse forces can be expected to be below 25 N a force transducer with a nominal force of 50 N was chosen. The cylindrical probe connected to the sensor was made from stainless steel with a diameter of 15 mm. The compaction force was generated by a pneumatic actuator with a maximum extension force of 86 N by Airtec Pneumatic GmbH [10]. The force was transferred to the tape via a cylindrical roller with a diameter of 40 mm made from stainless steel which was mounted rotatable to the pneumatic actuator. In order to ensure defined velocity a stepper motor with a step angle of 1.8° and a maximum torque of

0.5 Nm by Nanotec Electronic GmbH & Co. KG was used to pull the tape through the measuring system [11]. The complete setup of the test bench is shown in Figure 2.

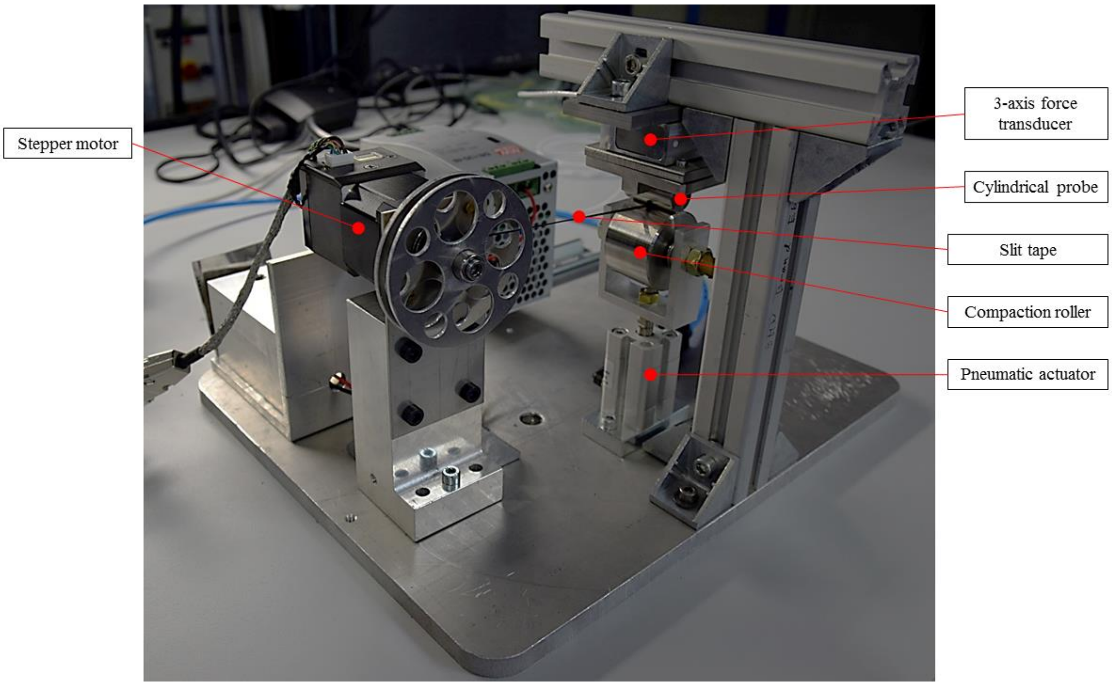

Figure 2. Test bench.

2.3. Material

Tests have been carried out with HexPly 8552 IM7 slit tape with a width of 1/8 inch [12]. Samples of the same batch have been tested at different states of aging. The aging of the material took place at controlled conditions at room temperature, i.e. 20°C, 35% rH. Experiments were also conducted at room temperature with samples that have been unfrozen for a period of 1, 3, 5, 7, 10 and 15 days. For every state of aging 4 different levels of compaction force and tape velocity have been investigated in separate measuring series. The tested settings are summarized in Table 1 (note that setting 3 and setting 6 are identical in order to verify constant testing conditions). Every experiment was repeated 3 times.

Table 1. Investigated levels of velocity and compaction force.

Setting N°	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
v [mm/s]	20	100	200	500	200	200	200	200
F_c [N]	14.3	14.3	14.3	14.3	6.7	14.3	23.5	33.6

3. Results and Discussion

The transverse force generated on the probe by the moving tape was measured in the experiments. Due to the tack of the material a stick-slip movement of the material alongside the probe was observed. This leads to a certain level of noise that can be seen in the measurement results of the transverse force (see Figure 3). In order to obtain a single value for the transverse force for every experiment the mean value of the measurement curve was computed. The mean values were then used to evaluate the behavior of the prepreg slit tape depending on velocity, compaction force and state of aging.

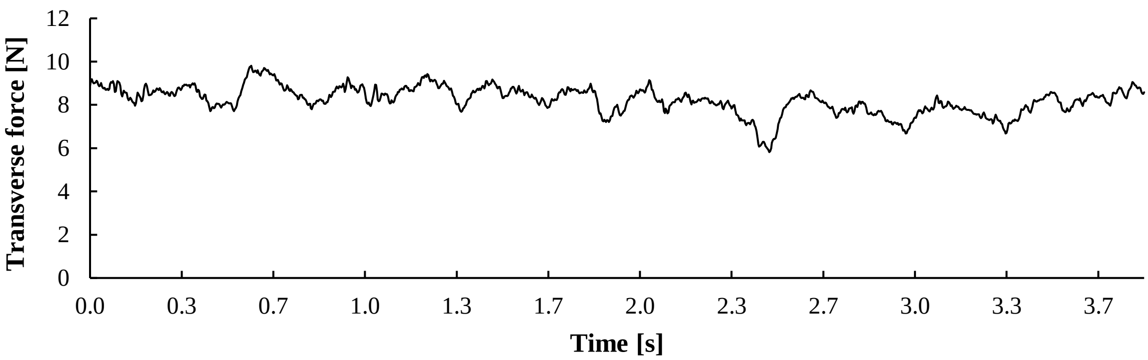

Figure 3. Transverse force measurement for one experiment (v=20 mm/s, F_c=14.3 N, material 15 days unfrozen).

The experiments showed a linear correlation between measured transverse force and compaction force. The measured transverse force as a function of the compaction force is shown in Figure 4.

Previous studies showed that the prepreg tack has to be considered a visco-elastic property [7,8]. Therefore, a dependency of the transverse force on the sliding velocity over the probe was expected. This was clearly shown in the experiments. A decrease of the transverse force with increasing tape velocity was observed (see Figure 5).

For reasons of legibility, error bars are only displayed for results of one day old samples in Figure 4 and Figure 5. The standard deviation reached within the other experiments was similar.

Nearly all tested settings for compaction force and velocity showed a reduction of transverse force with increasing out-time. This is an indication of the loss of tack of the prepreg over time. Consequently, a correlation between the tack and the transverse force was shown, enabling the determination of the current tack state of the material with the aid of the transverse force measurement. However, two outliers were recorded. For a compaction force of 14.3 N, slit tape samples with an out-time of 7 days showed the same transverse force as 1 day old samples (highlighted with red circle in Figure 4). For a velocity of 200 mm/s, the samples that have aged for 1 day showed a substantially lower transverse force than 3 or 5 day old samples (highlighted with red circle in Figure 5). The reasons for these outliers cannot be explained yet.

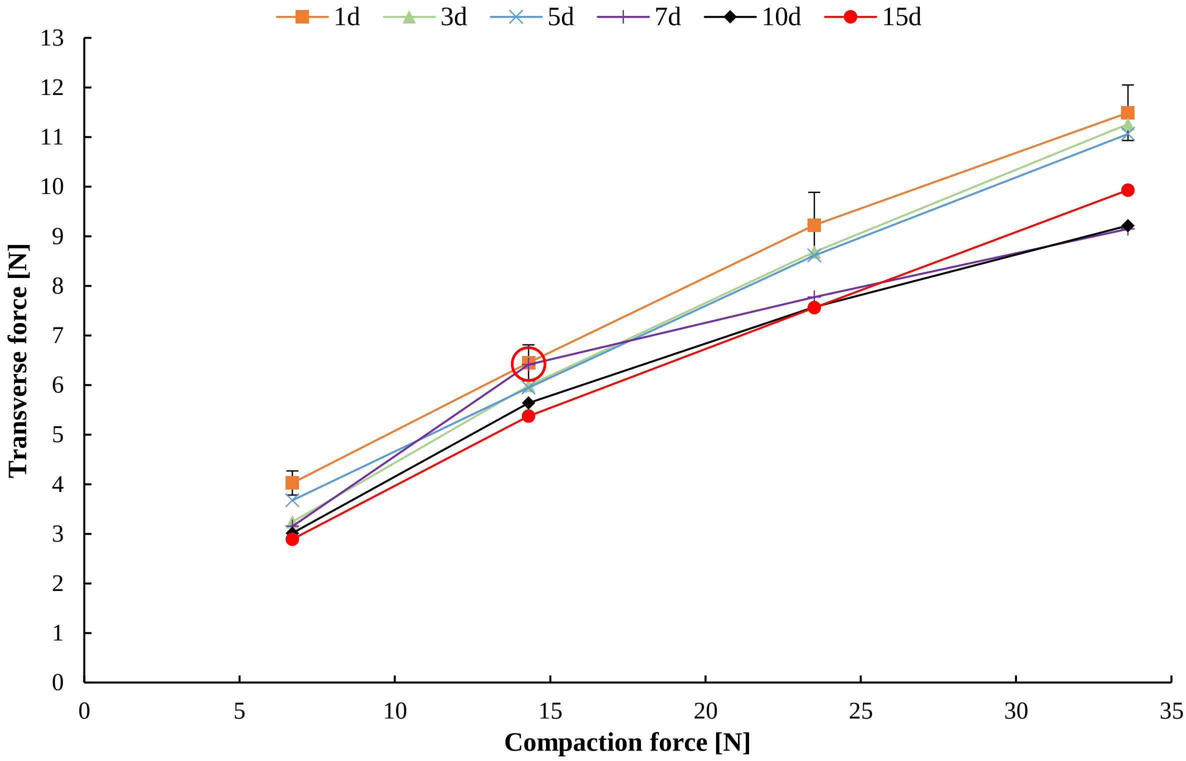

Figure 4. Transverse force as function of compaction force for different states of aging (v=200 mm/s). Outlier highlighted with red circle.

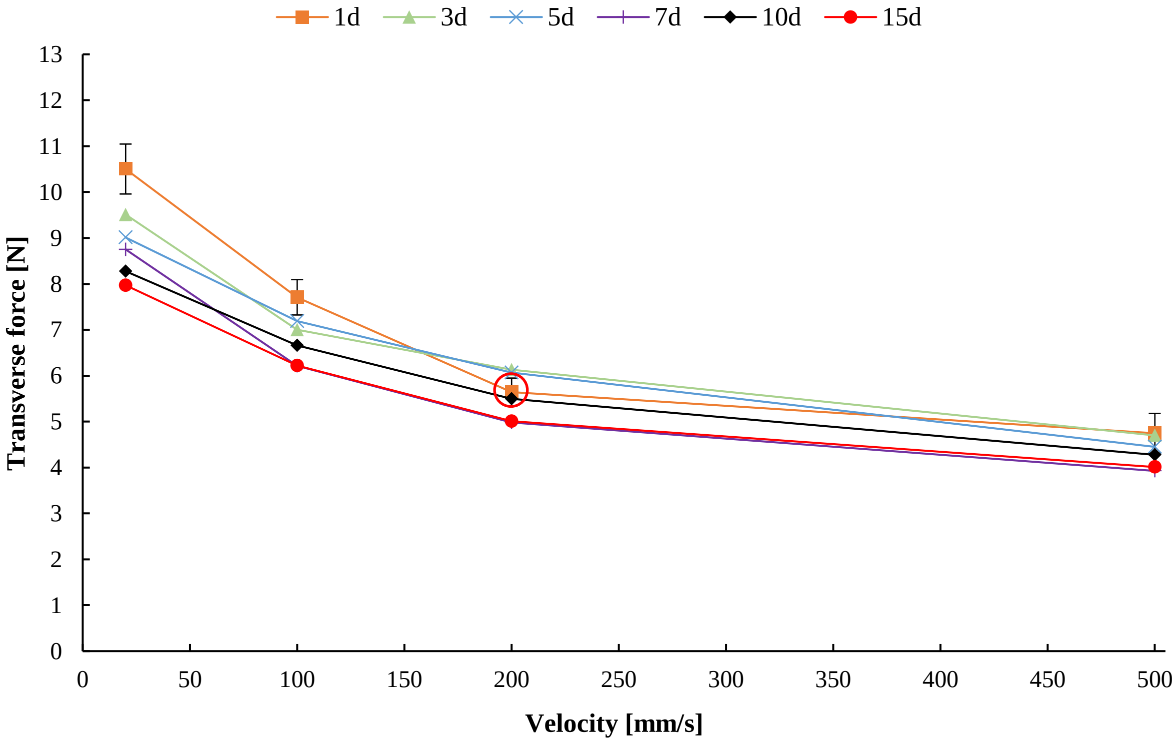

Figure 5. Transverse force as function of velocity for different states of aging (F_c=14.3 N). Outlier highlighted with red circle.

4. Conclusions and outlook

A novel measuring principle was developed in order to enable the online measurement of the tack of prepreg slit tapes. The principle uses the transverse force generated by the slit tape as it slides over a probe. A test bench was designed for validating the measuring principle and investigating the influence of the compaction force used to push the tape against the probe, the velocity and the state of aging, i.e. the tack of the material. Experiments showed, that the measured transverse force increases with increasing compaction force and decreases with increasing tape velocity. Moreover, the loss of prepreg tack over time led to a decrease of the transverse force.

Further experiments with an improved test bench are necessary for enabling precise predictions of the actual tack on the basis of transverse force measurements. In this context also the comparison to other tack measurement principles such as the peel test will be necessary. Parametric studies including the variation of the temperature of the material need to be carried out in order to gain more thorough understanding of the behavior of the prepreg on the test bench. Finally, the integration of the monitoring system into an industrial AFP machine can be realized.

Acknowledgments

The authors would like to thank the Bavarian Ministry of Economic Affairs, Energy and Technology for funding this work in context of the research project “Integriertes System zur Prozesskettendatenerfassung” (funding code: LABAY 93D).

References

[1] Brüning J, Denkena B, Dittrich M-A, Hocke T. Machine Learning Approach for Optimization of Automated Fiber Placement Processes. Procedia CIRP 2017;66:74–8.
[2] Lukaszewicz DH-JA, Weaver P, Potter K. The impact of processing conditions on the final part quality in automated tape deposition technologies. In: SEICO SAMPE Europe: 30th International Jubilee Conference and Forum, Paris, 23.-25.03.2009.
[3] Aized T, Shirinzadeh B. Robotic fiber placement process analysis and optimization using response surface method. The International Journal of Advanced Manufacturing Technology 2011;55(1-4):393–404.
[4] Crossley RJ, Schubel PJ, Warrior NA. The experimental determination of prepreg tack and dynamic stiffness. Composites Part A: Applied Science and Manufacturing 2012;43(3):423–34.
[5] Stelzl D, Carsi RM, Hollerith M, Roth J, Lacalle J, Drechsler K. A peel tack test bench for automated fiber placement processes. In: TexComp-11, Leuven, Belgium, 19.-20.09.2013.
[6] ASTM D2979-16. Test Method for Pressure-Sensitive Tack of Adhesives Using an Inverted Probe Machine. West Conshohocken, PA: ASTM International; 2016.
[7] Ahn KJ, Peterson L, Seferis JC, Nowacki D, Zachmann HG. Prepreg aging in relation to tack. Journal of Applied Polymer Science 1992;45(3):399–406.
[8] Mizumachi H. Theory of tack of pressure sensitive adhesive. I. Journal of Applied Polymer Science 1985;30(6):2675–86.
[9] ME-Messsysteme GmbH. Data sheet 3-axis force sensor K3D40 ±50 N. [April 19, 2018]; Available from: https://www.me-systeme.de/product-pdf?product_id=1663&lang=en.
[10] Airtec Pneumatic GmbH. Data sheet Pneumatic compact cylinder NXE-012-010-000. [April 19, 2018]; Available from: http://www.airtec.de/tl_files/products/Pneumatikprogramm/Pneumatikzylinder%20mit%20Kolbenstange/pdf-en/GB%20NXE.pdf.
[11] Nanotec Electronic GmbH & Co. KG. Data sheet PD2-N41 stepper motor. [April 19, 2018]; Available from: https://en.nanotec.com/fileadmin/files/Baureihenuebersichten/Plug_Drive/Product_Overview_PD2-N41.pdf.
[12] Hexcel Corporation. Data sheet HexPly 8552. [April 19, 2018]; Available from: http://www.hexcel.com/user_area/content_media/raw/HexPly_8552_eu_DataSheet.pdf.