LASER ASSISTED AUTOMATED TAPE LAYING PROCESS FOR PRODUCTION OF COMPOSITE LAMINATES

Sara Srebrenkoska[1], Vladimir Dukovski[2], Svetlana Risteska[3]

[1]Faculty of Mechanical Engineering, University "Goce Delcev" Stip, Republic of North Macedonia
[2] Faculty of Mechanical Engineering, "Ss.Cyril and Methodius" University, Republic of North Macedonia
[3] Institute for Advanced Composites and Robotics, Prilep, Republic of North Macedonia

ABSTRACT: *In the frame of this work, composite laminates based on two types of thermoplastic prepreg and processed at different temperatures and different laser optics were produced by using laser assisted Automated Tape Laying (ATL) process. The properties of the two types of prepreg materials has been tested and some mechanical properties of the obtained composite laminates has been performed. Based on the obtained results, conclusions for the influence of the temperature and laser optic in the ATL process on the quality of composite laminates were made.*

Keywords: *automation, lay-up, prepreg, laminates*

AUTOMATIZOVANI PROCES POSTAVLJANJA TRAKE POMOCU LASERA ZA PROIZVODNJU KOMPOZITNIH LAMINATA

APSTRAKT: *U okviru ovog rada, proizvedeni su kompozitni laminati pomocu tehnologije automatsko postavljanje traka (ATL) sa laserom. Kompozitni laminati su proizvedeni na bazi dva tipa termoplasticnog preprega, procesirani su na razlicitim temperaturama i koristena je razlicna laserska optika. Obavljeno je ispitivanje odredenih svojstva prepreg materijala i ispitivanje odredenih mehanickih svojstva dobijenih kompozitnih laminata. Na osnovu dobijenih rezultata izvedeni su zaključci o uticaju tipa preprega i temperatura u ATL procesu na kvalitet kompozitnih laminata.*

Ključne reči: *automatizacija, polaganje, prepreg, laminati*

1. INTRODUCTION

Composites are ideal materials for aerospace, automotive and other mechanical industries where the use of high performance advanced materials directly enhances their capability. The structures made of advanced composites have been majorly manufactured by hand layup of prepreg tapes to produce composite parts that are finalized by a consolidation and a curing process in an autoclave. However, widespread use of composite materials for aerospace, automotive and other applications has been limited due to high manufacturing costs, long processing times and size limitations of an autoclave. To achieve both desired quality and lower costs, for manufacturing high performance composite structures, the applying of automated manufacturing process with out-of-autoclave advanced prepreg systems has to be done [1].

Automated manufacturing is now being widely used to manufacture advanced composite laminates from unidirectional prepregs. Automated Fiber Placement (AFP) and Automated Tape Laying (ATL) are the two main technologies that are used to make composite parts. Both processes use robotic system to lay one or several layers of unidirectional prepreg tape onto a tool to manufacture a part. Each layer can be laid with different orientation, which benefits a structure capable to carry load in their acquired direction. Each tape is pressed to the mould by a roller for proper compaction. The essence of this technology is shown in Figure 1 [2].

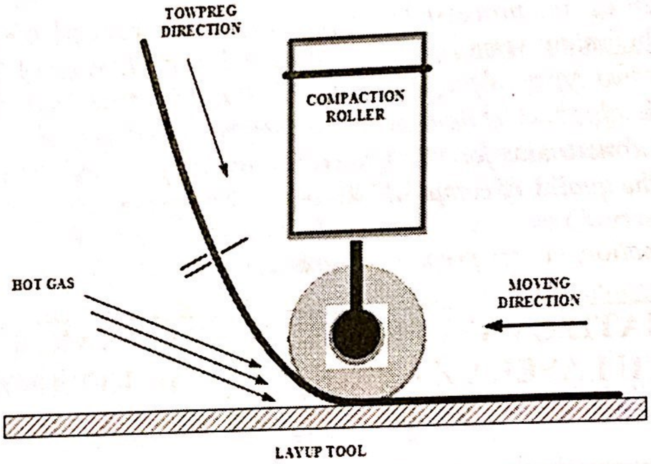

Figure 1: Functioning of the ATL process

Figure 1 shows the functioning of ATL (or AFP) and representing the layup direction prepreg direction, compaction roller, heating by hot gas and the layup tool. The AFP/ATL systems are typically individually suited for a particular application, however, each of those systems has a typical component, such as: head with compaction roller; fiber feeding system; robotic arm; control panel (Figure 2).

An important part of the whole system is control software. Typically, AFP/ATL producers provide a dedicated software together with the system. The software controls the robot motion and technology parameters like tape laying speed, compaction force, heat source temperature. The software can also analyse fiber direction and perform simulation. The system presented in Figure 2 is designed for small part manufacturing [4-6].

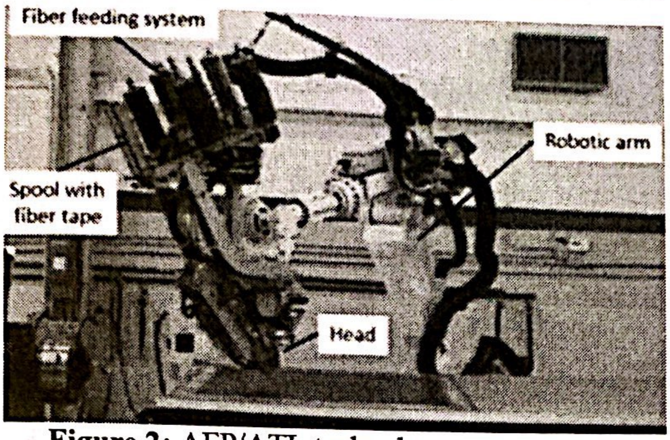

Figure 2: AFP/ATL technology - components

Commercially available AFP/ATL systems can work with 3 types of composite materials: thermoset prepreg; thermoplastic prepreg; dry fiber (unsaturated). Each material is supplied on a standard spool as a unidirectional tape. The most common material system used for structure build are thermoset materials. New generation AFP/ATL systems are equipped with a laser heat source to allow thermoplastic materials processing [7].

A combination of system with thermoplastic materials with an aim to achieve in-situ parts fabrication can be very beneficial from the cost standpoint. That technology has been used in industry for several years. Nowadays, the research is still being conducted to obtain a high material quality by means of using in-situ AFP/ATL technology with thermoplastic materials [3,4]. Thermoplastic composites have several advantages [8]: good damage tolerance properties; superior chemical resistance; non-limited storage time; recyclability. These advantages make thermoplastic composites a very interesting material for structures parts manufacturing, not only from the cost perspective but also from structural strength capability standpoint. The main advantages of AFP/ATL system are producibility; fiber direction accuracy, part to part repetability; low amount of material waste. AFP/ATL systems have also several disadvantages and limitations. Typical limitations are related to the mould shape, compaction roller diameter, head geometry etc [9-11].

2. EXPERIMENTAL

The materials used in this paper were thermoplastic unidirectional prepreg tapes. Prepreg is a semiproduct consisting of reinforcing fibers and thermosetting or thermoplastic polymer matrix. This material can be further processed at a certain temperature depending on the polymer matrix and the appropriate pressure for forming a composite structure with certain strength characteristics. For the investigation in the frame of this paper two types of thermoplastic unidirestional prepreg tapes with width of 25 mm were used, supplied by Suprem:

- CF/PEEK: UD prepreg based on AS4 carbon fibre and Polyether ether ketone (PEEK).
- CF/PPS: UD prepreg based on AS4 carbon fibre and Polyphenylene sulfide (PPS).

The composite laminates were produced by using a laser assisted tape layng head, manufactured by Mikrosam, Macedonia. Head is attached to a robot arm, as it is shown in Fig. 3. The tape head consists of: (1) a consolidation roller (outer diameter of 90 mm); (2) a tape feed, guidance, tensioning, and cutting system for UD tape; (3) an optic lens connected via a fibre-optic cable to a remotely-located 3 kW diodelaser heat source; and a temperature sensor (pyrometer). Specimens were produced with 6-8 layers of UD prepreg and they were processed at different temperatures and different laser optics. The parameters which were used for the production of the composites are given in the Table 2.

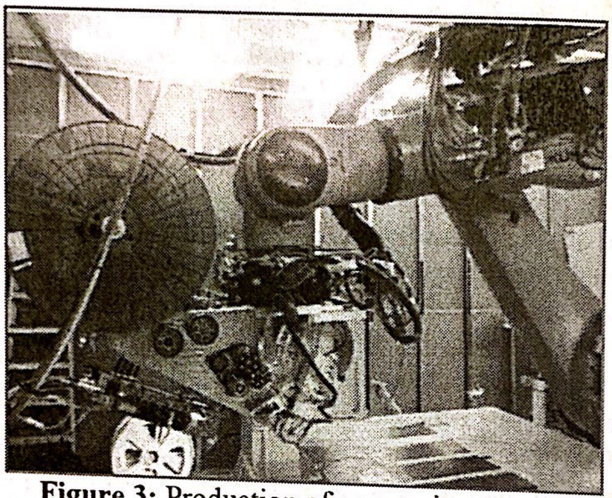

Figure 3: Production of composite samples

Table 1: Technological parameters for production of samples with ATL process

Type of material	Codes of composite samples	Temperature (°C)	Type of laser optics
PEEK/CF	1	400	LL2.20/LL2.10 68 x34mm^2 f:300mm
	2	420	LL2.20/LL2.10 56 x28mm^2 f:250mm
PPS/CF	3	330	LL2.20/LL2.10 68 x34mm^2 f:300mm
	4	350	LL2.20/LL2.10 56 x28mm^2 f:250mm

Mechanical properties of the composites such as flexural strength and the modulus (ASTM D 790) and tensile strength and the modulus (ASTM D 3039) were determined. The tests samples were carried out at room temperature by using the universal testing machine with max load of 50kN and loading speed of 5mm/min.

3. RESULT AND DISCUSSION

Table 2 shows the results of the tested characteristics of UD prepreg materials. The prepared test specimens (five specimens of all 4 different types of composite laminates) according to the appropriate standard for flexural and tensile strength are given in Fig. 4 Table 3 shows a summary of the flexural and tensile properties for composite laminates.

Table 2: Tested characteristics of UD prepred materials

Type of material	% wt. Carbon fibers	% vol. Carbon fibers	ρ_c (g/cm^3)	Prepreg areal weight (g/m^2)	Strength (MPa)	Modulus (GPa)
PEEK/CF	66,81	59,39	1,3314	203,2	2255,9	96,1
PPS/CF	65,72	59,67	1,3549	205,1	2146,7	94,4

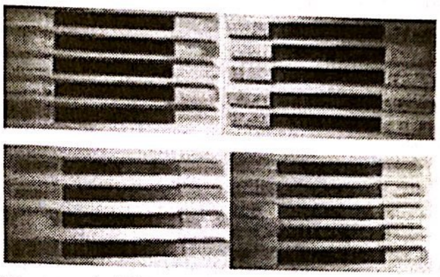

Figure 4: The prepared test specimens

Table 3: Flexural and tensile properties for composite laminates

Samples	Flexural tests		Tensile tests	
	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)
1	786,2	27,8	1383,9	78,3
2	1088,1	63,2	1891,1	112,4
3	765,3	29,5	1605,0	88,1
4	1066,0	75,0	2213,2	121,4

On the basis of the obtained results, it can be noticed that the parameter temperature as well as the type of laser optics have a significant impact on the performance of the composite laminates. Namely, the higher temperature gives better consolidation of the layer prepreg, which results in higher flexural and tensile strengths in the composites. The application of a higher temperature and the change in laser optics led to the production of composite laminates with approximately 40% higher values for mechanical performance.

4. CONCLUSION

In the frame of this paper, the experiments for determining the influence of temperature and laser optics in obtaining composite laminates with good mechanical performance based were carried out. The obtained results showed that temperature and optics significantly influence on the mechanical properties of laminates. Namely, the higher temperature and the appropriate choice of laser optics in the automate laying of thermoplastic prepreg result in higher strengths in laminates. This means that the exact technological parameters during the laying of the prepreg layer have a significant influence on the mechanical properties of the composite laminate.

REFERENCES

[1] Dirk H.-J. A. Lukaszewicz, Carwin Ward, Kevin D. Potter. (2012). The engineering aspects of automated prepreg layup: History, present and future. *Composites Part B: Engineering* Vol. 43, pp. 997–1009.

[2] Comer A. J., Ray D., Obande W.O., et al. (2015). Mechanical characterisation of carbon fibre–PEEK manufactured by laser-assisted automated-tape- placement and autoclave. *Composites Part A: Applied Science and Manufacturing* Vol. 69, pp.10–20.

[3] Beyeler E., Phillips W., Güçeri S. I. (1988). Experimental Investigation of Laser-Assisted Thermoplastic Tape Consolidation. *Journal of thermoplastic composite materials* Vo l, No.1, pp. 107–121.

[4] Schledjewski R. (2009). Thermoplastic tape placement process – in situ consolidation is reachable. *Plastics, Rubber and Composites,* Vol. 38, No. 9-10, pp. 379–386.

[5] Yousefpour A., Ghasemi Nejhad M. N. (2001). Experimental and Computational Study of APC- 2/AS4 Thermoplastic Composite C-Rings. *Journal of Thermoplastic Composite Materials,* Vol.14, No. 2, pp. 129–145.

[6] Pistor C.M.M., Yardimci M.A., Güçeri S.I. (1999). On-line consolidation of thermoplastic composites using laser scanning. *Composites Part A: Applied Science and Manufacturing,* Vol. 30, No. 10, pp. 1149–1157.

[7] Khan M.A., Mitschang P., Schledjewski R. (2010). Identification of some optimal parameters to achieve higher laminate quality through tape placement process. *Advances in Polymer Technology,* Vol. 29, No. 2, pp. 98–111.

[8] Rosselli F., Santare M.H., Güçeri S.I: (1997). Effects of processing on laser assisted thermoplastic tape consolidation. *Composites Part A: Applied Science and Manufacturing,* Vol. 28, No. 12, pp. 1023–1033.

[9] F.O. Sonmez, M. Akbulut. (2007). „Process optimization of tape placement for thermoplastic composites“. *Composites Part A: Applied Science and Manufacturing,* 38, 9, pp. 2013–2023.

[10] Grove S. M. (1988). Thermal modelling of tape laying with continuous carbon fibre-reinforced thermoplastic. *Composites,* Vol. 19, No. 5, pp. 367–375.

[11] Pitchumani R., Gillespie J.W., Lamontia M.A. (1997). Design and Optimization of a Thermoplastic Tow- Placement Process with In-Situ Consolidation. *Journal of Composite Materials,* Vol.31, No. 3, pp. 244–275.