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UNION OF ENGINEERS AND TEXTILE TECHNICIANS OF SERBIA

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PROCEEDINGS

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PREFACE

The 3 rd International conference "Contemporary Trends and Innovations in the Textile Industry" CT&ITI 2020, is co-organized by the Union of Engineers and Textile Technicians of Serbia, the Union of Engineers and Technicians of Serbia, the Faculty of Technology and Metallurgy in Belgrade, the University of Faculty of Technology,Shtip, North of Macedonia, Society for Robotics of Bosnia i Herzegovina and Balkan Society Of Textile Engineering-BASTE of Greece.

The Ministry of Education, Science and Technological Development of the Republic of Serbia recognized the importance of this Conference, and thus, supported it. The aim of this Conference is to consider current technical, technological, economic, ecological, R&D, legal and other issues related to the textile industry, then the application of contemporary achievements and the introduction of technical and technological innovations in the production process of fiber, textile, clothing and technical textile by applying scientific solutions in order to improve the business and increase the competitive advantages of the textile industry on the domestic and global market.

Leading scientists and experts from the Balkans and other countries, working at faculties, textile colleges and institutes, but also individuals who professionally deal with the issues at hand are taking part in this Conference.

The Conference program involves papers dedicated to the scientific and practical aspects of the following topics: Textile and Textile Technology, Textile Design, Management and Marketing in the Textile Industry and Ecology and Sustainable Development in the Textile Industry. The Conference program includes 47 papers, and a total of 103 participants from 12 countries: Bosnia and Herzegovina, Bulgaria, Finland, Latvia, North of Macedonia, Montenegro, Romania, Russia, Serbia, Slovenia, Turkey and Ukraine.

Therefore, this Conference is an opportunity for establishing scientific, educational and economic cooperation of our country with other countries. Certain number of papers by domestic authors present the project results dealing with fundamental research and technological development, financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

I would like to thank all those who have made it possible to organize theconference Contemporary Trends and Innovations in the Textile Industry and make it a success. First, I would like to thank the Scientific and Organizing Committee for working hard, spending countless hours and finding the best solutions for numerous organizational aspects of our Conference. Also, I would like to express my gratitude to all sponsors who believed in the importance of this Conference and co-financed it. I alsothank all the other institutions that supported the Conference in various ways, because without their support, the Conference could not have been organized. Last but not least,I would like to thank plenary lecturers, all authors and co-authors and guests for their participation in the Conference.

On behalf of the Organizing Committee
Prof. dr Snežana Urošević, president

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THE DESIGNING OF LASER ASSISTED AUTOMATED TAPE LAYING PROCESS FOR OBTAINING OF THE THERMOPLASTIC COMPOSITE PARTS

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ABSTRACT: *Thermoplastic part manufacture by laser-assisted automated tape placement (LATP) process has a high potential for the cost-effective production. Within the frames of this paper it was applied a designing of the industrial LATP process, i.e. planning of the experiments and on the basis of the plan matrix, the specimens were manufactured. Namely, unidirectional thermoplastic prepreg material based on polyphenylene sulfide and carbon fibers (PPS/CF) was used. The planning of experiments was made for processing of the prepreg material and as the most influencedfactors were taken: laser temperature, compact pressure of roller and laser placement angle. The factors were changed on two levels: maximum and minimum, i.e.* 2^3 *factorial design was used. According to the plan matrix, eight experiments (composite samples) with LATR procedure were performed by varying the level of all three parameters. For all manufactured specimens the flexural strength was tested and on the basis of the received experimental data it was created the regression equations which the bestdescribes the processes.*

Keywords: *thermoplastic prepreg, experimental design, automated tape laying, composite plates, flexural strength.*

DIZAJNIRANJE AUTOMATIZOVANOG PROCESA POSTAVLJANJA TRAKE POMOCU LASERA ZA PROIZVODNJU TERMOPLASTIČNIH KOMPOZITNIH DELOVA

APSTRAKT: *Tehnologije automatskog postavljanja traka sa laserom (LATL) ima visok potencijal za ekonomičnu proizvodnju termoplasticnih kompozitnih delova. U okviru ovog rada primenjeno je dizajniranje LATL procesa tj. primenjeno je planiranje eksperimenata i na osnovu matrice plana proizvedeni su uzorci. Naime, primenjen je jednosmerni termoplastični prepreg materijal na bazi poly phenilen sulgid i* *jaglerodnigh vlakna (PPS/CF). Izvršeno je planiranje eksperimenata za obradu prepreg materijala, a kao faktori od najjačeg uticaja analizirani su: temperatura lasera, kompaktni pritisak valjaka i ugao postavljanja lasera. Faktori su menjani na dva nivoa: maksimalni i minimalni tj. korishcen je 2^3 faktorski dizajn. Prema matrici plana izvedeno je osam ekspreimenta (kompozitnih uzoraka) postupkom LATL promenom nivoa sva tri parametra. Za sve proizvedene uzorke ispitivana je čvrstoca savijajnja i na osnovu dobijenih eksperimentalnih podataka kreirana je regresiona jednačina koja najbolje opisuje proces.*

Ključne reči: *termoplastični prepreg, eksperimentalni dizajn, automatsko postavljanje traka, čvrstoca savijajnja.*

1. INTRODUCTION

Automated layup processes are highly suitable for an efficient production of carbon fiber reinforced parts, especially for aerospace applications. Heat input by means of radiative heating offers advantages for these processes and is well established in different forms. The increasing application of carbon composite materials in aerospace and automotive results in high requirements to production rate and cost efficiency. Different forms of automated layup are used to meet these challenges, utilizing both thermoset and thermoplastic materials. Thermoset prepreg deposition by automated-fiber-placement (AFP) and automated-tape-laying (ATL) is regarded as the key enabler for the cost-effective production of medium and large parts in today's composite aircrafts [1-4]. On the other hand, thermoplastic part manufacture by means of automated-tape-laying(ATL) has seen a long history of scientific research, as it has a high potential inaerospace and automotive industry, due to the possibility to avoid long and expensiveautoclave cycles and the generally favourable properties of thermoplastic composites [2,5,6].
Automated manufacturing is now being widely used to manufacture advanced composite laminates from unidirectional prepregs. Automated Tape Laying (ATL) is a technology that is used to make composite parts by using of 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 the required direction. Each tape is pressed to the mould by a roller for proper compaction. An important part of the whole system is control software. Typically, 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 [7,8]. Commercially available 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

systems used for structure build are thermoset materials. New generation ATL systems are equipped with a laser heat source to allow thermoplastic materials processing [9].
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 conductedto obtain a high material quality by means of using in-situ ATL technology with thermoplastic materials [3,4, 10].
While materials and applications are different, heat is used in all of these processes for different reasons, e.g. to adhere the material to a tool or melt the thermoplastic prepreg component. Different heating technologies have been investigated, including hot gas, infrared, contact heaters and different lasers [9]. Radiation based heating in the form of laser and infrared lamps offer advantages such as high heat flux, precise control, as well as quick response, and therefore are regarded as the favoured heat source for several processes [11-14]. Material properties, such as crystallinity and void content depend essentially on the thermal history of the laminate, thus also affecting mechanical properties of the final part [2, 12, 14-16]. Therefore, precise knowledge of temperatures is of high interest. The designing of the laser-assisted automated tape placement (LATP) and analysis for the most influenced factors have been thoroughly investigated forspecific applications [12- 16].

2. EXPERIMENTAL

The material used in this paper was thermoplastic unidirectional prepreg tape which is a semiproduct consisting of reinforcing fibers and thermosetting or thermoplastic polymer matrix. For the investigation in the frame of this paper thermoplastic unidirectional prepreg tapes with width of 25 mm based on AS4 carbon fibre and Polyphenylene sulfide (PPS were used.
The composite panel specimens with different technological parameters were produced by using a laser assisted tape laying head, manufactured by Mikrosam, Macedonia. Headis attached to a robot arm, as it is shown in Fig. 1. 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 8 layers of UD prepreg so that the thickness of ~1,5 mm in the composite plates was attained. and they were processed at different temperatures and different laser optics. During the tape laying, several factors were observed:layup speed, tape temperature, laser temperature, tape tension, the type of laser optics, cooling of mandrels, the cooling of the roller, compact pressure of roller etc..
There are lot of factors that influence the process, but there is only tree important that have a big influence on the output which we have used in the experimental design:
- laser temperature (factor 1),
- laser placement angle (factor 2),
- compact pressure of roller, (factor 3).

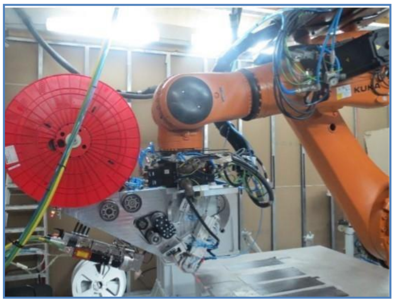

Figure 1. Production of composite samples

Next step was determination of the factor levels as shown in the Table 1, namely for the first factor the low and high levels are set at 420 °C and 480 °C, respectively, second factor – at 22° and 25°, respectively, and for the third factor – at 385N and 530N. Each factor has two factor levels, a low one and a high one. The low one has the value of (-1), the high one has a value of (+1). There are two factor levels with p = 2 and eight combinations (N= 8):

$$N = p^k = 2^3 = 8 \tag{1}$$

where: N = combinations; k = factors; p = factor levels.

Table 1: Factor levels

	p=2	**(-1)**	**(+1)**
X_1	laser temperature (°C)	420	480
X_2	laser placement angle (°)	22	25
X_3	compact pressure of roller (N)	385	530

For the statistical analysis five tests of each combination were realized so the number of replications is five. With that assumption, we took the first order linear model with interactions to predict the response function i.e. the flexural strength of the composite samples within the stated study domain (420– 480) °C x (22-25)° x (385 - 550)N. The full factorial experimental design allows making mathematical modeling of the investigated process in the vicinity of a chosen experimental point within the study domain [3,4]. To include the whole study domain we chose the central points of both ranges to be the experimental points. For the laser temperature of the composite plates, we chose the experimental point to be 450 °C, for the laser placement angle – 23,5 ° and for the compact pressure of roller – 457,5 (which corresponds to previously defined levels). Based on the three-point bending test (3pb), prepared specimens were elongated till rupture with help of test fixture and the flexural strength is calculated respectively, according to ASTM D 790 standard. The three-point bending tests were performed at room temperature using universal testing machine with max load of 50 kN and loading speed of 5 mm/min.

3. RESULT AND DISCUSSION

The experimental matrix are presented in Table 2 and the test results with five replications of each combination are presented in Table 3. The statistical parameters: $\bar{y}$ the arithmetic mean of the results and $S^2{}_j$- the variance of the results were calculated at first.

Table 2: Experimental matrix

N	*Experimental matrix*								*Factors*		
	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	x_1 (°C)	x_2 (°)	x_3 (*N*)
1	+1	+1	+1	+1	+1	+1	+1	+1	480	25	530
2	+1	-1	+1	+1	-1	-1	+1	-1	420	25	530
3	+1	+1	-1	+1	-1	+1	-1	-1	480	22	530
4	+1	-1	-1	+1	+1	-1	-1	+1	420	22	530
5	+1	+1	+1	-1	+1	-1	-1	-1	480	25	385
6	+1	-1	+1	-1	-1	+1	-1	+1	420	25	385
7	+1	+1	-1	-1	-1	-1	+1	+1	480	22	385
8	+1	-1	-1	-1	+1	+1	+1	-1	420	22	385

Table 3: Results of experiments

N	y_{j1}	y_{j2}	y_{j3}	y_{j4}	y_{j5}	$\bar{y}$	S_j^2
1	975,77	980,43	1028,89	1120,00	1078,96	1036,81	3916,11
2	1026,43	955,57	932,83	862,76	931,07	941,73	13795,70
3	1010,29	1062,21	927,05	987,78	1070,17	1011,50	13709,17
4	837,18	963,41	1014,33	882,96	903,15	927,41	14355,64
5	869,12	815,17	931,19	977,36	926,56	903,88	3934,51
6	783,96	919,37	885,71	913,09	792,39	858,90	17352,05
7	847,68	858,76	919,25	991,11	992,34	921,83	19254,82
8	922,32	901,20	840,96	943,84	853,55	892,37	7773,27
						$\sum_{N=1}^{8} S_j^2$	78390,14
						$\frac{\sum_{N=1}^{8} S_j^2}{8}$	9798,768121

By implementing the 2^3 factorial experimental design we found out that the response function in coded variables, yk, is:

$$y = 965{,}11 + 68{,}00X_1 - 2{,}28X_2 + 50{,}98X_3 + 25{,}22X_{12} - 19{,}40X_{13} + 43{,}13X_{23} + 7{,}92X_{123} \quad (2)$$

By analyzing the regression equation, it can be noted that the main positive contribution to the y is given by the laser temperature and the compact pressure of roller. The influence of the laser angle and the interaction of the two and three factors affectinsignificantly on the flexural strength (factors X_2, X_1X_2, X_1X_3, X_2X_3 and $X_1X_2X_3$).

The test which compares the formula and the results of the experiments were made by using the Fisher's criteria (Table 4). The values for y_p are calculated by using formula 2. If the variability of the model is smaller than the experimental standard deviation, then the model can be accepted and further bused (Formulas 3 - 5).

$$F_p \leq F_t \quad (3)$$

$$F_p = \frac{S_{ad}^2}{S_j^2} \quad (4)$$

$$S_{ad}^2 = \frac{\sum_{j=1}^{N}(\overline{y_j} - y_j)^2}{N-k} \qquad N - k = 8 - 3 = 5 \quad (5)$$

Table 4: Calculation of the differences between calculated and experimental values

N	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	$\bar{y}$	y_p	$(\bar{y}-y_p)$	$(\bar{y}-y_p)^2$
1	+1	+1	+1	+1	+1	+1	+1	1138,67	1084,09	54,585	2979,477573
2	-1	+1	+1	-1	-1	+1	-1	975,20	948,09	27,10926	734,911971
3	+1	-1	+1	-1	+1	-1	-1	990,69	1084,09	-93,392	8722,066849
4	-1	-1	+1	+1	-1	-1	+1	959,78	948,09	11,69816	136,8468416
5	+1	+1	-1	+1	-1	-1	-1	973,42	982,13	-8,71007	75,86527534
6	-1	+1	-1	-1	+1	-1	+1	764,03	846,13	-82,1093	6741,933225
7	+1	-1	-1	-1	-1	+1	+1	1029,65	982,13	47,51748	2257,911174
8	-1	-1	-1	+1	+1	+1	-1	889,44	846,13	43,30186	1875,051146

$$\sum_{j=1}^{N}(\bar{y}-y_p)^2 = \mathbf{23524{,}06405}$$

Based on the calculation of the differences between calculated and experimental values it was found that Fp=0,1861468.The tabular value for Fisher's criteria for P = 0,95; f = (n-1) = 5 – 1 = 4 and N = 8 x (5-1) = 32 is 2,69 and that means that the variability of the model is smaller than the experimental standard deviation so, the model can be accepted and further used.

4. CONCLUSION

In the frame of this paper, the experiments for determining the influence of parameters on flexural strength of thermoplastic composites based on PPS and carbon fibers produced by laser-assisted automated tape laying process were carried out. The compaction force applied during the lay-up process and the laser temperature play a crucial role in achieving of obtaining of defect-free laminates using the thermoplastic prepreg materials. Experimental measurements of the flexural strengths of composite pipes for determined ranges of parameters have been carried out implementing 2^3 full factorial experimental design. Regression equations were established for flexural strengths as a function of the compact pressure of roller, laser temperature and laser placement angle. The test results indicated that the change of the compact pressure of roller and laser temperature cause a variation in the final mechanical results, whereas the influence of the other parameter: laser placement angle is much lower, and the interaction of the factors has a negligible effect on the response.

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