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HAND LAY-UP VS MACHINE IMPREGNATION OF THE TEXTILE STRUCTURES

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ABSTRACT: *In this paper with the application of hand lay - up and machine impregnation technology, prepregs with suitable characteristics were produced and additionally processed into composite plates by using compression molding technology. Woven structure from E - glass fibers was used as a reinforcing component in the composite materials. For all manufactured composite plates, an analysis of the content of the constituent's components and the percentage of voids (%) was made. Determining the content of the constituent's components is significant from the aspect of modeling the properties (mechanical, physical, thermal or electrical) of the composite structure which are affected by the reinforcing component or matrix. The percentage of the voids of a composite material can significantly affect some of its mechanical properties. High void contents usually mean less fatigue resistance, greater susceptibility to moisture penetration and atmospheric influences and increased variation in strength. Knowing the content of the void in the composite material is desirable since it is a significant indicator of the quality of the composite.*

Keywords: *textile composite, prepreg, impregnation, void content*

RUČNO POLAGANJE TEKSTILNIH STRUKTURA NASUPROT IMPREGNACIJE MAŠINOM

APSTRAKT: *U ovom radu su predstavljene i primenjene različite tehnologije, ručnog polaganja i impregnacija sa mašinom.Ineprezi sa odgovarajućim karakteristikama su proizvedeni i dodatno obrađeni u kompozitne ploče uz pomoć tehnologije kompresije. Tkana struktura od E-staklenih vlakana je korištena kao ojačavajuća komponenta u kompozitnim materijalima. Za sve proizvedene kompozitne ploče napravljena je analiza sadržaja komponenata i procent pora (šupljina) (%). Određivanje sadržaja komponenti je značajno sa aspekta modeliranja svojstva (mehaničkih, fizičkih, toplotnih ili električnih) kompozitne strukture na koju utiče ojačivač ili matrica. Procenat pora kompozitnog materijala može značajno uticati na neke njegove mehaničke osobine. Visok sadržaj pora obično znači manju otpornost na zamor, veću osjetljivost na prodor vlage i atmosferske uticaje i povećane varijacije u snazi. Poznavanje sadržaja pora u kompozitnim materijalima je važan jer je to značajan indikator kvaliteta kompozita.*

Ključne reči: *tekstilni kompozit, prepreg, impregnacija, sadržaj pora*

1. INTRODUCTION

Textile structure and matrix are the two basic elements of textile composites. Textile composites are designed to perform unique physical – mechanical and thermal features and better performance features, which can not be accomplished by traditional materials [1, 2]. Depending on the type, purpose and properties that the composite material should possess, there are several methods and processes for production. The choice of the production process depends on the type of applied materials (matrix, textile structure), the temperature required for the formation of the composite structure, as well as the effectiveness of the process in terms of costs. Often, in the design of the composite structure, first, the production process is considered. This is because the selected production process must be suitable for obtaining a composite structure with a given design, and it should also take into account the costs, the volume and the rate of production. Therefore, the designer must know the advantages, disadvantages, costs, rate and volume of production, and typical application of different production processes [3].
Prepreg is a preimpregnated material reinforced with fiber where the resin is partially cured. The fibers can be in the form of a woven fabric with different weave structure, a unidirectional tape, or randomly oriented fiber sheets (chopped) (Figure 1). The most common fibers used are glass, carbon and aramid. The role of the matrix is to connect, to maintain the position and orientation of the fibers, to transfer the load between the reinforcement in all directions and to protect them from mechanical abrasion and negative environment [4, 5]. Most prepregs are made from thermoset resins (typically epoxy). There are several advantages to using a prepreg rather than using conventional hand layup: maximum strength properties, high fiber volume fraction, uniform fiber distribution, simplified manufacturing, part uniformity and repeatability and etc. Prepregs are widely used in high performance applications in the composites industry and also in other sectors. Typical applications include aerospace components, airgraft interiors, automotive parts, sporting goods, ballistic panels, pressure vessels and other commercial products [6].

2. EXPERIMENTAL TEST

In this study preimpregnated composite materials (prepregs), were produced by using hand lay - up and machine impregnation technology (vertical impregnation machine manufactured by Mikrosam AD). For the production of prepregs E-glass fabric with plain weave structure and a two-component thermosetting system of epoxy resin (DER 3821) and a hardener (Polypox H 766) were used. In table 1 and table 2 are given the properties of used E-glass fabric and epoxy resin. For production of composite laminates total of ten piles of manufactured prepreg (E glass fabric/ epoxy resin) with dimensions 250 mm x 200 mm were used. The plies were stacked in press machine, where final curing of the preforms was performed at a certain temperature of 145°C and Textile structure and matrix are the two basic elements of textile composites. Textile composites are designed to perform unique physical-mechanical and thermal features and better performance features, which can not be accomplished by traditional materials [1, 2]. Depending on the type, purpose and properties that the composite material should possess, there are several methods and processes for production. The choice of the production process depends on the type of applied materials (matrix, textile structure), the temperature required for the formation of the composite structure, as well as the effectiveness of the process in terms of costs. Often, in the design of the composite

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Standard methods and procedures were used to test the physical and mechanical properties of polymer composite plates. The content of the constituents is determined according to ASTM D3171 standard [7], while the content of void in composite samples is determined according to ASTM D792 / ASTM D2734 standards [8, 9].

Table 1: Properties of plain E- glass fabric

Properties of E- glass fabric	
Type of weave	Plain
Density (g/m^2)	300
Thickness (mm)	0,3
Width (cm)	2000
Count warp (ends/cm)	8±1
Count weft (ends/cm)	7±1
Strength warp (N/25mm)	≥2000
Strength weft (N/25mm)	≥1800

Table 2: Properties of the components of the resin system

Properties of Epoxy resin (D.E.R 3821)/	
Epoxide equiv. weight (g/eq)	176 – 183
Epoxide percentage (%)	23,5 – 24,4
Epoxide group content (mmol/kg)	5460 – 5680
Color (Platinum cobalt)	125 max.
Viscosity @ 25°C (mPa·s)	9000 – 10500
Hydrolyzable chlorine cont. (ppm)	500 max.
Water content (ppm)	700 max.
Density @ 25°C (g/ml)	1,16
Epichlorohydrin content (ppm)	5 max.
Shelf life (Months)	24
Properties of Polypox H 766	
Density at 25°C, [g/cm^3]	0,94 ± 0,05
Viscosity at 25°C, [mPa·s]	14
Amine number [mg KOH/g]	540 ± 15
H – equivalent weight [g/Equiv.]	55
Colour (Gardner)	blue

Determining the content of the constituent's components is significant from the aspect of modeling the properties (mechanical, physical, thermal or electrical) of the composite structure which are affected by the reinforcing component or matrix. Also, knowledge of the constituent content is required for evaluation of the quality of a fabricated material and the processes used during fabrication. The percentage of the voids of a composite material can significantly affect some of its mechanical properties. High void contents usually mean less fatigue resistance, greater susceptibility to moisture penetration and atmospheric influences and increased variation in strength. Knowing the content of the void in the composite material is desirable since it is a significant indicator of the quality of the composite. In order to determine the content of the reinforcing component and the polymer matrix in the composite samples, it is necessary to know the theoretical density of the constituent materials i.e. the glass fibers and the epoxy matrix. The individual density of the constituents is usually obtained as final values from the manufacturer and for the calculations a glass fiber density of 2,56 g/cm^3 and density of epoxy resin of 1,10 g/ cm^3 were used. The percentage of the voids (%) of composite samples is calculated using equation 1.

$$V = 100\,(T_d - M_d)T_d \qquad (1)$$

where: V = void content, volume %, Td = theoretical composite density, and Md = measured composite density.

3. RESULTS AND DISSCUSSION

The results of the examined reinforcement and matrix content in weight percent, the volume ratio of the constituents, the theoretical and experimental density of the samples as well as the calculated percentage of voids in the obtained composite samples (sample

1) from prepreg manufactured by hand –lay-up technology are given in Table 3. In Table 4 are presented the same characteristics for composite structures (sample 2) manufactured from prepreg by machine impregnation.

Table 3: Mass and volume ratio of components, theoretical, experimental density and percentage of voids in the obtained composite samples by hand lay-up technique

Sample Number		Mass before burning, M_i (g)	Mass after burning, M_f (g)	Mass of resin, m_m (g)	Mass of fabric, m_f (g)	Mass ratio of resin, W_m (%)	Mass ratio of fabric, W_f (%)
I	1	1,7516	1,2125	0,5391	1,2125	30,78	69,22
	2	1,6386	1,1348	0,5038	1,1348	30,75	69,25
	3	1,555	1,083	0,472	1,083	30,35	69,65
	4	1,3685	0,9315	0,437	0,9315	31,93	68,07
	5	1,5469	1,0687	0,4782	1,0687	30,91	69,09
Average		**1,57212**	**1,0861**	**0,48602**	**1,0861**	**30,94**	**69,06**
Sample Number		**Volume of resin, V_m (%)**	**Volume of reinforce., V_f (%)**	**Theor. density T_d (g/cm³)**	**Theor. density T_d (g/cm³)**	**Experime. density, M_d, (g/cm³)**	**Percentage of voids, (%)**
I	1	50,19	48,50	1,8175	1,8175	1,7938	1,308375
	2	49,23	47,64	1,8181	1,8181	1,7612	3,129702
	3	48,90	48,21	1,8248	1,8248	1,7721	2,890281
	4	51,22	46,91	1,7980	1,7980	1,7644	1,864374
	5	49,18	47,22	1,8152	1,8152	1,7499	3,598619
Average		**49,74**	**47,70**	**1,815**	**1,8147**	**1,7683**	**2,5383**

Table 4: Average value for mass and volume ratio of components, theoretical, experimental density and percentage of voids in the obtained composite samples by machine impregnation

Sample Number	Mass before burning, M_i (g)	Mass after burning, M_f (g)	Mass of resin, m_m (g)	Mass of fabric, m_f (g)	Mass ratio of resin, W_m (%)	Mass ratio of fabric, W_f (%)
II	**3,93**	**2,773**	**1,157**	**2,773**	**29,44**	**70,56**
	Volume of resin, V_m (%)	**Volume of reinforce., V_f (%)**	**Theoretical density T_d (g/cm³)**	**Experimen. density, M_d, (g/cm³)**	**Percentage of voids, V (%)**	
	49,27	**50,73**	**1,76510**	**1,75887**	**0,35295**	

Based on the obtained results for the content of constituents in composite samples (Table 3 and Table 4), it can be concluded that there is a good content of glass fabric and epoxy resin in the obtained composite samples (sample 1 and sample 2). The average reinforcement content in weight percent is 69-71 %, while the epoxy resin is represented by 29-31%, which indicates that the produced composite structures will posses good mechanical properties. Although a good ratio is achieved between the reinforcing component and the epoxy resin, the percentage of the voids in the sample 1 produced from prepregs manufactured by hand lay –up technique is relatively high (2,54 %). This is due to the applied impregnation process because in hand lay -up the prepared two-component resin system is applied, i.e., is distributed equally throughout the surface of the E-glass textile material with the help of an improvised roller, which we adjust manually and the quality depends on the skills of the workers (Figure 1).

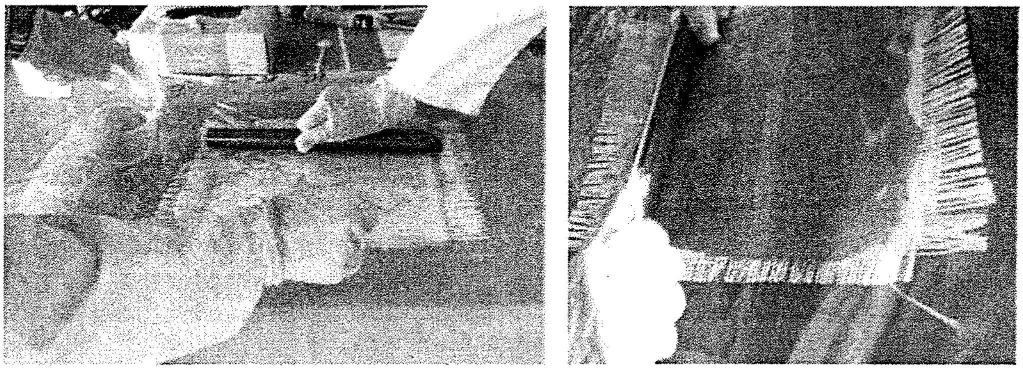

Figure 1: Application of resin on E - glass fabric

Although the percentage of the void is considerably higher in these composite samples, however, the examination of the mechanical properties (bending strength) has shown that the obtained results are comparable to those of the samples obtained by machine impregnation [10, 11].

4. CONCLUSION

When machine impregnation is used for production of prepregs, the percentage of voids in the final composite samples will be significantly lower. This composite structure will result in material with better mechanical properties. When impregnation is done by hand, voids, dry and resin-rich areas can be really a problem. But hand lay-up technology is widely used, because it is a simple but effective process which takes relatively low capital investment but high labor cost. By applying machine impregnation, productivity and quality of composite structure can be significantly improved.

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