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ANALYSIS OF FLATTENING PROCESS PARAMETERS FOR THE CARBON COMPOSITE MATERIAL

Kondratiev A. V.
Doctor of Technical Sciences, Professor,
Head of Department of Technology of Construction Production and Building Materials
O. M. Beketov National University of Urban Economy in Kharkiv

Gaidachuk V. Ye.
Doctor of Technical Sciences, Professor
National Aerospace University «Kharkiv Aviation Institute»

Nabokina T. P.
PhD, Associate Professor
National Aerospace University «Kharkiv Aviation Institute»
Kharkiv, Ukraine

Carbon fiber reinforced plastics and structures based on them find expanding applications in various fields of science and technology [1]. Widespread use of the carbon fiber led to the development of technologies, which allowed improving the performance characteristics of composite materials based on them. Promising technology for producing super-thin prepregs is the rolling of carbon strands impregnated with a binder which consist of 400…700 and more elementary fibers (filaments) with the use of special equipment [2, 3].

Whereas the carbon fiber thickness is 0.005...0.01 mm [1], we can make a conclusion about a possibility in principle of creating super-thin prepregs. Therefore, it seems relevant to make an analytical assessment of the technology for obtaining of monolayers at the level of elementary fiber thicknesses.

The paper deals with the results of research on the development of the mathematical model and method of estimation of parameters of the strand rolling process to obtain prepregs of the carbon composite material of specified thickness.

The following assumptions were made [4, 5]: all fibers in the strand n_{sk} are round; they have the same diameter d_f and are located strictly parallel to each other (with no twisting); rolling of the strand impregnated with the binder of η viscosity is made between rotating rolls with the radius R_{sh}.

Maximum width of the strip obtained by rolling of the impregnated strand was determined based on the model of introduction of the last fiber of diameter d_f between the ordered layer $2n_f$ of the fibers. Introduced fiber is loaded by the force P_f from the process roll and interacts with the layer of ordered fibers. When the roll interacts with the fibers, there are contact stresses

$$q = \frac{2P_f}{\pi d_f \sqrt{2R_{sh} d_f}} \leq [q], \quad (1)$$

where $[q]$ – permissible contact pressure on the monofiber not causing its destruction or formation of microcracks, which reduce its ultimate strength F_f and elastic modulus E_f.

Under the action of force P_f the introduced fiber pushes the adjacent ones apart, which is prevented by the hydraulic resistance of the binder R_h and friction forces between adjacent fibers F_x. The fiber movement can occur under the action of force:

$$F_x = R_h = \frac{P_f \left(0.5 - 1.866 f_{fr}\right)}{\sqrt{3} + f_{fr}}, \quad (2)$$

where f_{fr} – coefficient of friction at the boundary of filaments in the binder.

Maximum overcome hydraulic resistance of fibers by the binder with the viscosity η will be equal to:

$$R_h = \frac{32\eta^2 n_f d_f l}{\pi \delta^2 \rho_f}. \quad (3)$$

where δ – gap between the fiber layer and process roll, ρ_f – microfiber density.

The length of travel of the fiber section l is determined from the condition of limiting the stresses in the fiber pinched by the process roll in the course of movement of the other edge pinched between adjacent fibers:

$$l = d_f \sqrt{\frac{1,5E_f}{[\sigma]}} \, , \tag{4}$$

where $[\sigma]$ – maximum permissible normal stress in the fiber.

Substituting (4) in (3), we get in the final form:

$$R_h = 12.475 \frac{\eta^2 n_f d_f^2}{\delta^2 \rho_f} \sqrt[3]{\frac{E_f}{[\sigma]}} \, . \tag{5}$$

Maximum width of strip B_b at a given force P_f is equal to:

$$B_b = 2n_f d_f + d_f = d_f(2n_f + 1) \, . \tag{6}$$

The required technological parameters of rolling at a given force in the rolls P_f were determined according to the following algorithm:

1. From the formula (5), taking (2) into account, we determine the number of fibers n_f from the condition of overcoming of the hydraulic resistance:

$$n_f = \frac{P_f \left(0,5 - 1.866 f_{fr}\right) \delta^2 \rho_в}{12.475 \left(\sqrt{3} + f_{fr}\right) \eta^2 d_f^{\,2}} \sqrt{\frac{[\sigma]}{E_f}} \, . \tag{7}$$

2. Using the formula (6), the maximum width of strip B_b, obtained at the given process force P_f, is determined.

3. The number of monolayers N, into which the strand is rolled at the specified force P_f, is found:

$$N = ent \left(\frac{n}{2n_f} \right) . \tag{8}$$

Substituting in (8) instead of n_f its value from (7), taking into account that

$$P_{\mathrm{f\,max}} = \pi d_f \sqrt{R_{sh} d_f} \left[q_f \right] \tag{9}$$

we get:

$$N = ent\left\{ \frac{12.475n\left(\sqrt{3} + f_{fr}\right)\eta^2 d_f}{\pi\sqrt{2R_{sh}d_f}\left[q_f\right]\left(0.5 - 1.866 f_{fr}\right)\delta^2\rho_f}\sqrt{\frac{E}{[\sigma]}} \right\}. \quad (10)$$

4. According to the formula (10), we determine the number of monolayers into which it is possible to roll the strand containing the number of fibers n at the fixed force on the fiber P_f, expressed through the roll radius R_{sh}, with specified input parameters $d_f, \eta, \delta, \rho_f, E_f, [\sigma]$ and $[q]$.

5. $N = f(\eta)$ is determined for different values R_{sh} (or $P_{\text{f max}}$) fixed values of the coefficients of friction f_{fr}.

According to the given algorithm, we calculate the number of monolayers N, into which the carbon strand is rolled, containing 400 elementary fibers of d_f =10 μm [6], at different values of the binder viscosity, coefficients of friction and forces exerted on the elementary fiber, which is realized by the corresponding roll diameter $2R_{sh}$.

Analysis of the results (table) showed that at the probable coefficients of friction of $0.05 \le f_{fr} \le 0.2$ the rolling of the thinnest commercially available strand with n =400 [4 – 6] of elementary fibers in one layer is possible in the viable range of the binder viscosity of $0.1 \le \eta \le 0.4$ Pa·s [6] at different radii of the rolls ($25 \le R_{sh} \le 150$ mm).

Moreover, when choosing a roll radius, the limiting factor is not the force itself (their level per fiber is quite small: $0.44 \le P_f \le 1.06$), but the limiting allowable pressure on the fiber $\left[q_f\right]$=40 MPa. The range of the number of monolayers not exceeding 10, corresponding to commercially available prepregs of 0.1 mm thick [4 – 6], is implemented at relatively high values of viscosity of $0.3 \le \eta \le 1$ Pa·s depending on the coefficient of friction f_{fr}, and this range is wide enough within the limits of non-metal-intensive rolls with the radius of R_{sh} =25...50 mm.

Table

Research results

f_{fr}	P_f, N	η, Pa·s R_{sh}, mm	Number of monolayers *N*									
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.05	0.44	25	1	1	1	1	2	3	5	6	8	10
	0.63	50	1	1	1	2	3	5	7	9	11	14
	0.77	75	1	1	1	2	4	6	8	11	14	17
	0.88	100	1	1	1	3	5	7	10	13	16	20
	1.06	150	1	1	2	4	6	9	12	16	20	25
0.2	0.44	25	1	1	3	5	9	12	17	23	29	36
	0.63	50	1	2	4	8	12	18	25	32	41’	51
	0.77	75	1	2	5	9	15	22	30	39	50	62
	0.88	100	1	2	6	11	18	25	35	46	58	72
	1.06	150	1	3	7	14	22	31	43	56	71	88

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ДОСЛІДЖЕННЯ ВПЛИВУ ІОННО-ПЛАЗМОВИХ ПОКРИТТІВ НА ЗНОС ТРИБОСПОЛУЧЕНЬ ОБ'ЄМНОГО ГІДРОПРИВОДУ

Щукін О. В.
кандидат технічних наук, доцент,
кафедра будівельних і дорожніх машин
Харківського національного автомобільно-дорожнього університету

Орел О. В.
кандидат технічних наук, доцент,
кафедра будівельних і дорожніх машин
Харківського національного автомобільно-дорожнього університету

Рєзніков О. О.
кандидат технічних наук, доцент,
кафедра будівельних і дорожніх машин
Харківського національного автомобільно-дорожнього університету
м. Харків, Україна

На сьогоднішній день основними методами нанесення плазмових зносостійких покриттів, які істотно підвищують експлуатаційні характеристики матеріалів робочих поверхонь, є хімічне осадження з газового середовища і конденсація твердої речовини в умовах іонного бомбардування (КІБ) [1, с. 43; 2, с. 98]. Він використовується, як ос-