UDC 629.7:624

RESEARCH OF TECHNOLOGICAL PROCESSING OF SEMI-FINISHED PRODUCTS IN THE MANUFACTURE OF PROFILE PRODUCTS FROM COMPOSITE MATERIALS

V.B. Ihnatieva,
Candidate of Technical Sciences

Ternopil Ivan Puluj National Technical University,
Ruska str.,56,Ternopil. 46001

DOI: 10.32347/2410-2547.2024.112.268-272

This article examines the process of technological processing of semi-finished product in the manufacture of rod profile products from fibrous composite materials, in particular - round.

A method of determining the parameter of the degree of crimping of the element, which ensures the necessary impregnation of the winding layer during the forming of the profiled products, is proposed.

Key words:composite materials, binder, process, semi-finished product, technique, moulding, impregnation, pressure, rod, round cross-section.

Introduction. The quality of fibre composite profile rods depends on the quality of the binder impregnation of the reinforcing materials during the moulding process. This is most often the case with products which are produced by the pultrusion process. In such products the braiding layer is formed by dry reinforcement. Impregnation of the dry reinforcement is carried out during the technological processing of the semi-finished product.At the same time a series of problems are solved, one of which is the choice of technological process parameters [1-5].

Surplus binder is formed during the moulding process. However, the amount of remaining binder must be sufficient to ensure the required degree of filling of the element. Therefore, the question of the remaining amount of binder is still relevant.

The purpose of the research is to determine the theoretical value of the parameter, which ensures the necessary impregnation of the winding layer during the final moulding of the profiled products.

The realization of the goal implies the solution of the following task: to develop a method of determining the parameter of the degree of crimping of the element, ensuring the minimum values of impregnation of the winding layer during the final moulding of the profiled products.

Research of technological processing of semi-finished products in the manufacture of profile products from composite materials

In order to ensure a defined structure and degree of filling in the production of rod profile products from spirally reinforced semi-finished products, they are compacted.Compaction can take place in one of two methods: by pressing in a spinneret, crimping with winding. The second method is used in the production of round cross-section rods.

In this case, the spirally reinforced structural elements, which initially have a circular cross-sectional shape, deform and acquire an elliptical shape.At the same time, the degree of reinforcement filling of the central part of the structural element changes. It can be calculated using the formula[6]:

$$\varphi_1^e = \frac{\varphi_1\left[1,5\left(k_1+1\right)-\sqrt{k_1}\right]^2}{4k_1}, \tag{1}$$

where $k_1 = a/b$ a , b - large and small half-axes of the elliptical element.

Due to the increased filling ratio, part of the binder is removed from the structural element and moved into the inter-element space. In addition, it can impregnate the winding reinforcement. The volume of binder removed during deformation per unit time can be calculated according to the formula:

$$Q = \frac{\pi D^2 v_f}{4}\cdot\left(1-\varphi_1/\varphi_1^e\right). \tag{2}$$

Since φ_1^e depends on φ_1, then, taking into account (1), this volume can be represented as a function of the elliptic parameter:

$$Q = \frac{\pi D^2 v_f}{4} \cdot \left(1 - (4k_1) \Big/ \left[1{,}5(k_1 + 1) - \sqrt{k_1}\right]^2\right), \tag{3}$$

where D - diameter of the rod of the main reinforcement of the spirally reinforced element, v_f - forming speed.

The binder movement at steady-state moulding mode occurs only in radial direction. When developing mathematical models of processes occurring during molding and curing of products made of composite materials, the binder is usually considered as a viscous non-compressible fluid obeying Darcy's law during filtration [7].In this case the flow of liquid binder is considered separately from the stress state of rigid reinforcement.

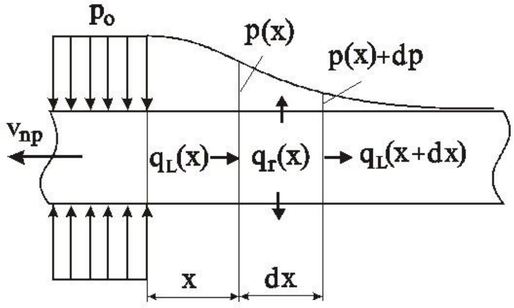

Fig. 1. Pressurevariationalongthelengthof a rodwhichisshapedfromcompositematerials

Determine the law of variation of the pressure gradient along the length of the element to be moulded before the moulding front (Fig. 1).

Let the binder flow through a cross section of the element at a distance X is determined from the expression [7]:

$$q_L(x) = \frac{k_{per}^L p(x)}{\eta x} \cdot S_L \tag{4}$$

and at a distance $(x + dx)$ from the expression:

$$q_L(x + dx) = \frac{k_{per}^L \left[p(x) + dp\right]}{\eta(x + dx)} \cdot S_L \approx \frac{k_{per}^L p(x) S_L}{\eta x} + \frac{k_{per}^L S_L dp}{\eta x}, \tag{5}$$

where $p(x)$ - pressure at distance X, $\left[p(x) + dp\right]$ - pressure at distance $(x + dx)$, η - the viscosity of the binder, k_{per} - permeability coefficient, S_L - filtration area.

In this case, a part of the binder is squeezed out of the considered volume of the element in the radial direction

$$q_r(x + dx) = \frac{2k_{per}^r \left[p(x) + (dp/2)\right]}{\eta D} \cdot S_r. \tag{6}$$

Here we assume a linear dependence of $p(x)$ on the dx section.

The permeability in the radial direction is determined according to the formula:

$$S_r = n_r e^2,$$

where $n_r = \dfrac{2Ddx}{(d + e)^2}$ – number of filtration channels, d – fibre diameter of the fittings, $e = d\left(\sqrt{0{,}907/\varphi_1}\right) - 1$ – distance between adjacent fibres.

Composing the flow balance equation and considering [6], that $\dfrac{k_{per}^r}{k_{per}^L} = \dfrac{27}{4\pi^2} = 0{,}68$, we obtain

$$\frac{dp}{p(x)} = \frac{6\left(\sqrt{0{,}907/\varphi_1} - 1\right)^2 x dx}{D^2 (1 - \varphi_1)}, \tag{7}$$

The solution to this equation is

$$\ln p(x) = -\beta x^2 + \ln C \quad \text{or} \quad p(x) = C \cdot e^{-\beta x^2}, \tag{8}$$

$$\text{where } \beta = \frac{3\left(\sqrt{0,907/\varphi_1} - 1\right)^2}{D(1-\varphi_1)}. \tag{9}$$

The constant C is determined from the initial conditions. At $x = 0 \Rightarrow C = p_0$.

Thus, the law of pressure change is described by an exponential dependence

$$p(x) = p_0 \cdot e^{-\beta x^2}. \tag{10}$$

Obviously, the volume of binder removed during the formation of the tourniquet per unit time must be equal to the total volume of binder passing through the surface of the tourniquet.

$$Q_r = \int_0^\infty \frac{4\sqrt{3k_{per}^r \varphi_1}}{\eta}\left(\sqrt{0,907/\varphi_1 - 1}\right)^2 \cdot p_0 e^{-\beta x^2} dx. \tag{11}$$

Since $k_{per}^r = \dfrac{4,27 \cdot 10^{-2}(1-\varphi_1)^2 d^2}{k_6 \varphi_1^2}$, where k_6 is the channel shape factor, φ_1 and η do not depend on X, and $\int_0^\infty e^{-\beta x^2} dx = 0,5\sqrt{\pi/\beta}$, then we obtain:

$$Q_r = \frac{2\sqrt{\pi}\, k_{per}^r}{\eta} D p_0 \varphi_1 \sqrt{(1-\varphi_1)}\left(\sqrt{0,907/\varphi_1} - 1\right). \tag{12}$$

The moulding pressure necessary for a given degree of filling φ_1^e can then be calculated using the formula:

$$p_0 = \frac{\sqrt{\pi} D v_f \eta (1 - \varphi_1/\varphi_1^e)}{8k_{per}^r \varphi_1 \sqrt{1-\varphi_1}\left(\sqrt{0,907/\varphi_1} - 1\right)}. \tag{13}$$

Or, if a certain size ratio of the structural element k_1 is given , taking into account (1), we obtain:

$$p_0 = \frac{\sqrt{\pi} D v_f \eta}{8k_{per}^r \varphi_1 \sqrt{1-\varphi_1}\left(\sqrt{0,907/\varphi_1} - 1\right)}\left\{1 - (4k_1)\Big/\left[1,5(k_1+1) - \sqrt{k_1}\right]^2\right\}. \tag{14}$$

When the structure of the product is formed, the space between the elements is filled with binder, which is displaced when they are deformed. Obviously, it is possible to calculate the parameters of the deformed element that will ensure that the space between the elements is filled with binder.

The volume of displaced binder can be determined by formula (3). The volume of filled inter-element space after the composite structure is formed can be calculated from the expression:

$$Q' = (4-\pi) k_1 b^2 v_f. \tag{15}$$

Considering the constancy of the perimeter of the deformable structural element, the relation between b and D is as follows:

$$b = \frac{D(1+\delta/D)}{1,5(k_1+1) - \sqrt{k_1}}, \tag{16}$$

where δ - is the thickness of the winding layer of the structural element.

Then from equality (3) and (15) it can be written:

$$\frac{\pi}{4}\left\{1 - \frac{4k_1}{\left[1,5(k_1+1) - \sqrt{k_1}\right]^2}\right\} = \frac{(4-\pi) k_1 (1+\delta/D)}{\left[1,5(k_1+1) - \sqrt{k_1}\right]^2}. \tag{17}$$

Supposing, $\left[1,5(k_1+1) - \sqrt{k_1}\right]^2 \neq 0$ we obtain:

$$\pi\left[1,5(k_1+1) - \sqrt{k_1}\right]^2 = 16k_1 + (16k_1 - 4\pi k_1)\delta/D. \tag{18}$$

Or, by introducing the parameter $m = 16 + (32 - \pi\delta)\delta/D + (16 - 4\pi)(\delta/D)^2$:

$$2,25\pi k_1^2 - 3\pi k_1\sqrt{k_1} + (5,5\pi - m)k_1 - 3\pi\sqrt{k_1} + 2/25\pi = 0 . \tag{19}$$

Thus, the equation of the fourth power is obtained with relative to $\sqrt{k_1}$. By solving this equation, it is possible to obtain the desired values of the parameter k_1 depending on the diameter of the semi-finished product used and the thickness of the winding layer.

Table 1 shows the critical values of the parameter $k = 1/k_1$, which is used in the theoretical calculations. The critical values of the parameter k are given as a function of the diameter of the semi-finished product D and the thickness of the winding layer δ .

The specified values of the k_{cr} parameter ensure that the inter-element space is filled with the binder displaced from the structural elements. With $k < k_{cr}$, excess binder is displaced from the product structure. In the case of $k > k_{cr}$, additional resin impregnation is necessary.

Table 1

δ	$D = 0,4$	$D = 0,8$	$D = 1,2$	$D = 1,6$
0,02	0,34	0,38	0,40	0,41
0,10	0,32	0,37	0,39	0,40
0,18	0,30	0,36	0,38	0,39
0,26	0,28	0,35	0,37	0,39

Conclusions. A method of determining the parameter of the degree of crimping of the element, which ensures the necessary impregnation of the winding layer during the forming of the profiled products, is proposed.

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Стаття надійшла 20.04.2023

Ігнатьєва В.Б.

ДОСЛІДЖЕННЯ ПРОЦЕСУ ТЕХНОЛОГІЧНОЇ ОБРОБКИ НАПІВФАБРИКАТУ ПІД ЧАС ВИГОТОВЛЕННЯ ПРОФІЛЬНИХ ВИРОБІВ ІЗ КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ

У даній статті досліджується процес технологічної обробки напівфабрикату виробу під час виготовлення стрижневих профільних виробів із волокнистих композиційних матеріалів, зокрема - круглих.Метою є визначення теоретичного значення параметра, який забезпечує необхідне просочення обмотувального шару під час остаточного формування профільних виробів.

Зазначено, що для забезпечення заданої структури та ступеня наповнення під час виготовлення стрижневих профільних виробів зі спірально армованого напівфабрикату здійснюється їх ущільнення. Ущільнення може відбуватися одним із двох способів: шляхом фільєрного пресування, опресовуванням за допомогою обмотки. Другий спосіб застосовується під час виготовлення стрижнів круглого поперечного перерізу. При цьому спірально армовані структурні елементи, які спочатку мають круглу форму перерізу, деформуються і набувають форми, схожої на еліпс. Водночас змінюється ступінь наповнення арматурою центральної частини структурного елемента.

У вигляді функції від параметра еліпсності представлено об'єм сполучної речовини, що видаляється під час деформування за одиницю часу. Розглянуто переміщення сполучного при сталому режимі формування.Визначено закон зміни градієнта тиску по довжині формованого елемента перед фронтом формування.Визначено об'єм сполучного, що видаляється під час формування джгута за одиницю часу. Визначено необхідний тиск формування, необхідний для забезпечення заданого ступеня наповнення.

Показано можливість розрахунку параметрів деформованого елемента, які забезпечать заповнення сполучною міжелементного простору.Отримано рівняння для визначення значення параметра ступеня опресовування елемента залежно від діаметра використовуваного напівфабрикату і товщини шару обмотки.Наведено дані про критичні значення параметра ступеня опресовування елемента, залежно від діаметра напівфабрикату і товщини шару обмотки.Запропоновано методику визначення параметра ступеня опресовування елемента, що забезпечує необхідне просочення обмотувального шару при формуванні профільного виробу.

Ключові слова: композиційні матеріали, сполучна речовина, процес, напівфабрикат, методика, формування, просочення, тиск, стрижень, круглий поперечний переріз.

Ihnatieva V.B.

RESEARCH OF TECHNOLOGICAL PROCESSING OF SEMI-FINISHED PRODUCTS IN THE MANUFACTURE OF PROFILE PRODUCTS FROM COMPOSITE MATERIALS

This article examines the process of technological processing of semi-finished product in the manufacture of rod profile products from fibrous composite materials, in particular - round. The purpose is to determine the theoretical value of the parameter which ensures the necessary impregnation of the winding layer during the final moulding of profile products.

It is mentioned that in order to ensure a defined structure and degree of filling during the production of rod profile products from spirally reinforced semi-finished products, they are compacted. Compaction can take place in one of two methods: by pressing in a spinneret, crimping with winding. The second method is used in the production of round cross-section rods. In this case, the spirally reinforced structural elements, which initially have a circular cross-sectional shape, deform and acquire an elliptical shape. At the same time, the degree of reinforcement filling of the central part of the structural element changes.

The volume of binder removed during deformation per unit time is presented as a function of the ellipse parameter.The displacement of the binder at steady-state mode of moulding is considered.Law of change of pressure gradient along the length of formed element before molding front is defined. The volume of binder removed during bundle formation per unit time is determined. Required molding pressure necessary to ensure a given degree of filling has been determined.

It is shown that it is possible to calculate the parameters of a deformed element that will ensure that the binder fills the space between the elements. An equation for determining the value of the parameter of the degree of crimping of an element, depending on the diameter of the used semi-finished product and the thickness of the winding layer is obtained. Data on critical values of a parameter of a degree of crimping of element, depending on diameter of a half-finished product and thickness of a layer of a winding is resulted. A method of determining the parameter of the degree of crimping of the element, which ensures the necessary impregnation of the winding layer during the forming of the profiled products, is proposed.

Key words: composite materials, binder, process, semi-finished product, technique, moulding, impregnation, pressure, rod, round cross-section.

УДК 629.7:624

Ігнатьєва В.Б. **Дослідження процесу технологічної обробки напівфабрикату під час виготовлення профільних виробів із композиційних матеріалів**// Опір матеріалів і теорія споруд: наук.-тех. збірник. – К.: КНУБА, 2024. – Вип. 112. – С. 268-272.

Запропоновано методику визначення параметра ступеня опресовування елемента, що забезпечує необхідне просочення обмотувального шару при формуванні профільного виробу.

Табл. 1. Іл. 1. Бібліогр. 7 назв.

UDC 629.7:624

Ihnatieva V.B. **Research of technological processing of semi-finished products in the manufacture of profile products from composite materials//** Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2024. – Issue 112. – P. 268-272.

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Tabl. 1. Fig. 1. Ref. 7.

Автор (науковий ступінь, вчене звання, посада): кандидат технічних наук, доцент, доцент кафедри будівельної механіки ТНТУ ім. Івана Пулюя ІГНАТЬЄВА Вікторія Борисівна.

Адреса: 46001 Україна, м. Тернопіль, вул. Руська 56, ТНТУ ім. Івана Пулюя, кафедра будівельної механіки, Ігнатьєва Вікторія Борисівна.

Мобільний тел.: +38(099)729-87-10

E-mail: vikto-igna@ukr.net

ORCID ID: https://orcid.org/0000-0002-9688-4992