RESEARCHES OF PRODUCTION OF THE SPATIALLY REINFORCED CARBON-CARBON COMPOSITION

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Annotation. The results of the research in the field of scientific basis creation for technological manufacture preparation of reinforced carbon- carbon compositions (CCC) are given. The concept of CCC production with rectilinear location of reinforced fibers is presented. The results of theoretical and experimental investigations explaining the functions of technological production preparation are analyzed. They are: to provide the adaptability to manufacture, to work out the technological processes (TP), to create the control system and the system of TP operation, to design and to make the facilities of technological equipment. The results of TP testing and equipping which confirm that they are successful ones are given.

Key words: thermo- loaded parts, carbon- carbon compositions, the functions of technological production preparation, technological production readiness.

STATE OF PROBLEM

Making of modern constructions (structures) used under the conditions of high temperatures and higher thermo mechanical loadings is not effective without carbon-carbon composition (CCC) usage. CCC is used to make nozzle blocks, bells, tips of the chute vehicles, besides they are used in the elements of steering and mobile engines of space vehicles, that allows to extend substantially the resources of the construction serviceability and raise their efficiency [Sanin, Kuchma, Dgur 1999, Starchenko, Kushchenko, 2010]. CCCs get the highest characteristics at the even, rectilinear location of carbon braids without any damages in the material while the matrix and fibers work jointly in the material [Sokolkin, Votinov, Tachkinov 1996]. When the arms race was stopped the consumption of CCC by space-rockets had been reduced greatly. Converting CCC usage is developing. They began to be used widely for the production of friction and anti-friction products, crucibles and press-forms; in medicine for the production of implants and others. The volumes of CCC world production are constantly being increased, because the technologies have been mastered by the Chinese People's Republic, India, South Korea and other countries. The improvement of CCC production technology in the whole world is considered to be of priority directions, determining the defense and scientific -technical potential of the state, due to them. [Guryn, Zelenskiy 1999].

CCC operating characteristics and its competitiveness are determined by the level of the achieved production. Considerable scientific-technical potential is accumulated in the area of CCC production in Ukraine. The method of Chemical Vapor Infiltration is developed and improved under the supervision of Professor V.A.Gurin (CVI) [Guryn, Zelenskiy 1999]. The technologies of pre-forms making are developed and their experimental production is created. To increase the efficiency of CCC production is possible due to the reduction of resource usage while preparing the braids for processing

and making pre-forms, upgrading CVI pre-forms. To provide technological readiness of CCC production it is necessary to create scientific base of technological pre-production and their realization, and it is an important scientific-engineering problem [Chesnokov, Gaydachuk, Potapov, Guryn 2008].

CONCEPTION OF PRODUCTION

A part and CCC is made simultaneously. Stabilization of part properties is possible only at steady operation of all TP for CCC making that allows to reduce the safety margin of parts and the product weight in the whole. To provide TP stability the requirements to every TP must be determined and their interconnection must be found out.

In spite of the variety of CCC production methods [Sokolkin, Votinov, Tachkinov 1996] the following order of TP is obligatory: the preparation of carbon braids to process them into pre-forms; making of pre-forms; satiation of the pre-forms with matrix carbon; machining. To prepare manufacturing process for CCC production the functions of technological production preparation are realized on the basis of scientifically-grounded approaches. They include: the provision of construction technology, the development of TP; planning and making of technological equipment facilities; control and operate of TP.

The concept of CCC production includes the followings principles:

- The application of present production base of highly-productive CVL method.

- The provision of favourable conditions to perform every TP of CCC making on the basis of technological criteria determination for every TP.

- The application of technological methods to increase the pre-forms gas-penetrability, keeping the location linearity and uniformity of reinforcing fibers.

- Complex automation of production processes and TP control.

- The application of resource-saving technologies, allowing to achieve the level of waste less production.

PROVIDING OF ADAPTABILITY TO MANUFACTURE

For the estimation of technological rationality the quality vector of output characteristics for the production objects is applied:

$$K_i = \left(K_{i,1}, \ K_{i,2}, \ ..., \ K_{i,j} \right), \tag{1}$$

where: $K_{i,1}, \ ..., \ K_{i,j}$ are private qualitative characteristics after I TP.

Such characteristics as durable, geometrical and the others received by the measurement are used as private characteristics of the production objects. The complete list of measurable characteristics is given in the specifications for TP performance.

It is necessary to use unification of principles, to develop efficient TP with a high indication of production flexibility while designing parts made of CCC and developing TP. Indications of adaptability to manufacture also refer to the parameters of construction rationality and TP. To find out the indexes which fully reflect the achievement of optimum expenses to produce such parts is only possible on the basis of a technological cycle analysis of their production. To optimize the technological cycle

the model covering all stages of CCC parts making is built, and classification of models according to the part levels is made. [Chesnokov 2010]. TP models are interdependent. The analysis of TP interdependence for CCC parts making is done. [Chesnokov 2010]. The initial parameters of processes, the factors influencing the TP motion and the output parameters are revealed. The requirements to TP stability are determined, from which the indexes of adaptability to manufacture are received.

The models of bars strong interaction while assembling and under pressure test are the models of TP stage which connect the bars characteristics and the stability of automated pre-forms assembling. [Chesnokov 2010]. The behavior of bars interaction depends on the correlation of attended bars diameters (vertical d_B and horizontal d_Γ) and the step of vertical bars t location, measured perpendicular to the given bar [Chesnokov 2009]. Mating with tension results the bars deformation, which gives the bar curve axis and section deformation. The curvature of bar axis is determined taking into account the displacement of contiguous cross section relatively to each other, and the contact deformation is determined examining the contact of cylindrical bodies made of the same material. Tension is fully compensated by the sum of deformations:

$$\frac{(d_B + d_\Gamma) - t}{2} = \frac{5P_i H_B^3}{6\pi d_B^4 E_e}\left(1 + \frac{9d_B^2 k_G}{2H_B^2}\right) + n_\delta \frac{1}{2}\sqrt[3]{\frac{36\left(1 - \mu_n^2\right)^2(d_B + d_\Gamma)}{E_n^2 d_B d_\Gamma}P_i^2} \; , \quad (2)$$

where: P_i – is the force of bars interaction; H_B –is the height till the guiding plate; E_e, E_n – are the modules of bars pressure lengthwise and transverse the fibers; μ_n – is Poisson coefficient of transverse fibers; k_G – is a relativity coefficient of module characteristics for the examined material $k_G = \dfrac{E_e}{G}$.

Equation (2) after transformations to the cubic kind is solved relatively P_i for bars interaction at d $=d_\Gamma=$d using of Kardano formula. In a general view the function of bar interaction forces can be presented as:

$$P_i = f(d; H_B; t; E_e; E_n; k_G) . \tag{3}$$

Efforts of different directions received by bars while assembling of pre-forms and the conditions of durability depending on the type of receiving loading are determined. Bars strength must correspond to the followings conditions:

$$[\sigma_e] \ge \sigma_e = \frac{4N}{\pi d^2}; \qquad [E_e] \ge E_e = \frac{P_i\left(3H_B^2 + \pi^3 k_G d^2\right)}{3d^4}, \tag{4}$$

where: N – is squeezing force, acting to the bar; $[\sigma_e]$, $[E_e]$ are maximum values of a parameter.

It is determined that at a single bar the resistance effort of the bar penetration into the pre-form is considerably less than in a layer. It is noted that it is impossible to use bars as a layer while having a tension in bars mating. [Chesnokov 2008].

The bars loading conditions during the pre-forms assembling are considered to determine objectively the bars strength characteristics. The force P_{ycm} for the separation P_p is determined on the basis of bars tests for their stability. Their efficient

characteristics module Yunga $E_в^Э$ and strength limit $\sigma_B^Э$ which are used in calculations as maximum values taking into account the coefficient of margin of safety are determined from the conditions of bars loading.[Chesnokov 2010].

The model of gas penetration reveals the connection of pre-forms parameters and TP and their making with efficient of CVI. [Chesnokov 2010].

The opened porosity is the important index of efficient satiation. The cavities connected between each other by means of ducts are appeared in the pre-forms between reinforcing materials. The form and sizes of ducts depend on the type of pre-forms and the forms of reinforcing material. Pores space figuratively is divided into transport and inter-fiber pores to determine the penetrability of different pre-forms. [Chesnokov 2009]. The reagent motion along the transport pores is described which is widely used in the theory of filtration using Darsi equation taking into account Klinkenberg effect. Gas motion along inter- fiber pores is described considering gas sliding along the walls of capillaries. The coefficients of penetrability for the reagent motion in inter- fibers are defined.

The parameters which reflect the change of gas penetrability through inte-fiber pores are determined on the basis of the analysis of received dependences and the coefficient of relative penetrability through inter- fiber pores, reflecting a change gas-penetrability while changing the structure or pre-forms parameters is introduced:

$$k_{np} = \frac{1}{d}\left(\frac{1-\varphi_{cm}}{\varphi_{cm}}\right)^2 , \qquad (5)$$

where: φ_{cm} – is filling the bar with fiber.

To increase the pre-forms gas-penetrability it is offered to remove connecting pre-forms after assembling. [Chesnokov 2009]. In this case fibers occupy all free space, limited by fibers of different directions. Such a state is called a free form. If the shape of a section is changing the filling of the bar with a fiber is changing too. The changing into a free shape of a bar section influences the coefficient of relative pre-forms penetrability and it confirms that it is necessary to remove binders from bars after pre-forms assembling. It is impossible to remove earlier applied binders and that's why on the basis of the analysis of substance chemical composition and its usage as binder, oxygen has been chosen which hasn't been used as a binder for Km before.

As a result special indexes of adaptability to manufacture reflecting TP stability and the suitability of a received semifineshed item for steady operation of subsequent TP for CCC making are determined additionally to the indexes of adaptability to manufacture, recommended by GOST 14.205-83 Chesnokov 2009].

DEVELOPMENT OF TECHNOLOGICAL PROCESSES

TP structure and the requirements to the technological stages of bars examining for carbohydrate binders are grounded in the paper. [Chesnokov 2010]. The processes taking place at TP stages are studied to find the best parameters for bars making; the model covering the whole TP for bars making and pre-forms assembling is made. [Chesnokov 2010].

At the stage of impregnation-pressing the impregnated braid is presented as a capillary-porous body in the inner part of which the liquid filtration occurs. The dependence of maximum pressure in a semi finished product at pressing from the parameters of process is received. The influence of an angle of a die input cone and the semi finished product on the relative parameter of maximum pressure in a die and on the motion resistance through a die is determined by a great number of models. [Chesnokov 2010]. Single-factor experimental researches of the stage [Chesnokov 2010] defined the degree of technological parameters influence on the impregnation quality which was estimated by the applied binder mass. As a result main significant factors of this stage such as impregnation pressure and the binder concentration are determined during the experiment.

The process of drying is investigated to find a rational mode of heat transfer. The mechanism of binder motion while drying the semi finished product depending on the temperature gradient directions and moisture content is determined. To increase the bar monolithic nature and the drying processes intensification the efficiency of warming-up inside part of the semi product by means of electric current is grounded. [Chesnokov 2010] The blowing with heated air is used to remove efficiently the moisture from the surface. The experimental research of the drying stage allowed to define the range of the applied energy. It is possible to operate the binder distribution along the bar section by tension (stage factor), applied to the carbon braid.

At the stage of shaping binder redistribution relatively to fibers which are in the inner part of the semi product occurs in a die input cone. For calculations the binder is a viscous plastic system and is described by Shvedov-Bingama generalized equation. The semi product motion resistance through a forming die consists of overcoming shaping pressure, lateral side friction and tripping forces [Chesnokov 2009]. As a result of preliminary single-factor experiments the rational location of forming dies and basic significant factors of this stage such as a diameter and a number of forming dies are determined. [Chesnokov 2009]. Application of the «cascade» shaping by dies with a less diameter allows to reduce the fibers damage and stabilize the bar diameter.

As a result of the researches of the broach stage the influence of broach method on the ellipse and bars axis curvature is determined. [Chesnokov 2008].The binder broach at all technological stages is recommended to be performed with the help of a drive bobbin the diameter of which is 4 m. Received bar ellipse is to 0,03 mm and axis curvature is done by casual factors, namely by oscillation of braids tension and their location along the bar section.

To receive the model covering all TP of bars making and reflecting interconnection of TP stages of TP, the planned multivariable experiment is made. As a result of preliminary researches five key factors were determined and according to the experiment plan the range of varying was divided into four levels. Sixteen different factor combinations have been repeated three times, the order of experiments making was determined by the table of random numbers. During the experiments the followings response parameters were controlled: the bar diameter, the bar stability and stratification, the binder mass in a bar, the semi product motion resistance through spring-tongue and pilchard die. Results are processed by the mathematical statistics methods, the regression equations are received, designing response factors are found out.[Chesnokov 2010].

The TP model of bars making is included into the model of CCC parts making as a structural module. The TP optimization of bars making is performed taking into account the TP interconnection of CCC making. [Chesnokov 2010]. Geometrical and strength characteristics of bars influence the forced parameters of pre-forms automatic assembling and its stability. The objective function of optimization was to increase the minimum coefficient of bar margin of safety at pre-forms assembling. Optimization results are presented in [Chesnokov 2010]. Using the accepted values of the varied factors the bars parameters and pre-forms assembling are calculated. Having received minimum coefficient of bar margin of safety 22 it provides the stability of pre-form assembling. The results of conducted researches give scientific bases to develop TP for braids preparation to be assembled with the guaranteed providing of the given technological characteristics; the methods of quality control for the braids preparation are developed.

The pre-forms assembling is executed by two operations: the installation of vertical bars into the guide plates and the piling of horizontal bars layers, the structure of operations execution is defined. The installation of vertical bars is carried out by bars replacement on a vibrating plate into the holes and after hitting into them they move along them. The piling of horizontal bars layers consists of feeding the bar by rollers along the guide between the rows of vertical bars at a given depth and its trimming. Having chosen the set of bar layers the pressure test and the pre-forms turn is performed; the set of layers is done according to a given height.

To learn the mechanism of bars motion on a vibrating surface and to find out the rational vibration parameters the motion of massive bars depending on the vibration direction and intensity is described. [Chesnokov 2009]. The dependences are experimentally confirmed; almost 100% of braid filling by bars under the action of vibration is received.

The results of complex tension researches, arising at the stage of a bar feeding while piling horizontal layers [Chesnokov 2008], allowed to define the nature of bar interaction with rollers and the parameters of a feeding device; the bar behavior in a guide and critical force of a bar stability loss is defined. The force parameters of a bar feeding into a pre-form from the depth of introduction and the distance to the guide plate are experimentally investigated. Results having been received earlier refer to the theoretical dependences of bars interconnection quite well. [Chesnokov 2009, Chesnokov 2008]. The parameters of a feeding device are defined.

Researches of pressure-test force parameters of horizontal bar layers are conducted for pre-forms of structure 4D-l; the effort dependence of pressure test from the given step of layers piling and the pre-forms size are defined. The parameters of knot pressure test are determined.

If it is necessary pre-forms bar trimming is executed but with minimum damage of a bar butt end. The frequent trimming of high-modulus fibers results the rapid wear of a cutting edge. The researches influenced the angle and the cutting tool type on the tool durability and on the bar butt end deformation haves been made. [Chesnokov 2009]. Design execution of a knot and tool angels is determined; tool durability is increased by 4 times.

CONTROL AND OPERATION OF TECHNOLOGICAL PROCESSES

A model of functionally-technological interconnection of the pultrusion installation knots and technological stages allowing to define the controlled parameters and the location of control sensors is developed. Automatic TP control system taking into consideration time delay during which a semi product moves to the next stage is developed. The algorithms of TP adjustment are received [Chesnokov 2009].

The system of the installation placement and its interconnected coordinates which are used to pile the layers of horizontal bars is developed. The algorithms and dependences are received to calculate the co-ordinates of supporting points of a feeding device. A kinematical scheme of installation is developed. The installation system to operate and control knots is developed [Chesnokov 2009].

The system to control products at the production stages according to the data of assembly line and selective choice allows to signal that it is necessary to conduct TP and the knots states parameters monitoring.

The analysis of methods of CCC parts test for nozzle confirmed the high cost of natural tests conducting and their harmful ecological consequences. The results of comparisons of CCC samples test conditions working with high temperature plasma nozzle confirm that it is possible to use plasma for comparative tests.

DEVELOPMENT OF FACILITIES OF TECHNOLOGICAL EQUIPMENT

On the basis of operation analyzed results ofbraids preparation and pre-forms making basic principles of technological equipment facilities planning are defined. Special attention is paid to provide rational parameters and stability of the technological stages, to minimize the production costs. The indicated principles are realized by module arrangement of equipment, by complex approach to automation and operation of technological equipment.

Setting up braids preparation for processing with pultrusion has a module arrangement; New knots structures providing the technological modes are developed. Technological possibilities of the installation cover the bars of all sizes. The installation productivity while making the basic dimension-type of bars $\varnothing 1,19\,^{+0,03}_{-0,02}$ mm (on the basis of braid three additions of UKN-5000) is 2,0 m/min, that allow to produce bars 860 gr/hour.

Facilities of technological equipment are designed for pre-forms making, including the equipment with vertical bars setting and with setting up layers piling of horizontal bars. The equipment is aimed at cored pre-forms making with sizes not exceeding external $\varnothing 530$ mm, the hole is $\varnothing 245$ mm and the height is to 350 mm.

To increase the productivity while setting up the layers piling of horizontal bars two independent knots for bar feeding are placed. High accuracy of placement and bar feeding is achieved using the foot-pace drives. The developed scheme of installation operation is realized with the use of a micro-processor system of drives control. Software and installation control system allowing to introduce framework parameters to pass to the process of pre-forms making of another dimension-type or form are developed. The equipment is aimed at the CCC mass production.

Using the equipment with vertical bars setting by vibration allows to reduce time for operation comparing with a manual method by 64 times. The labour intensivety of layers piling of horizontal bars of indicated dimension-type of pre-forms was 240 people /hour that by 6 times less than comparing with the manual assembling. Received pre-forms (Fig.1) are suitable for a CVI compression.

Fig. 1. A model is of ring (after treatment) and cylindrical pre-forms

CONCLUSIONS

The result of the executed work on creation of scientific bases for technological pre-production of CCC reinforcing fibers is given. As a result the conception of CCC production based on the application of CVI performs is developed; the interconnection of TP models for CCC making is classified and found out. Characteristics of TP stability are found out and on their basis the indexes of adaptability to manufacture are determined; the technological stages of bars making are investigated, the TP models with the purpose to increase TP stability are received and optimized. The requirements are systematized and the methods to calculate the knots of technological equipment are determined; the principles of TP automation for braids preparation and pre-forms assembling, algorithms and software are worked out; principles are developed and facilities of technological equipment are worked out. All this allowed to improve the engineering-economical indexes of CCC making. While producing bars and pre-forms the specific consumption of material is reduced to the level of waste less production, the economy of carbon braid producing pre-form of maximum size is 18, 6 kg. The time which is necessary to make a pre-form is cut by 3, 9 times (by 1100 hours).

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ИССЛЕДОВАНИЯ ПРОИЗВОДСТВА ПРОСТРАНСТВЕННО АРМИРОВАННЫХ УГЛЕРОД-УГЛЕРОДНЫХ КОМПОЗИТОВ

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Аннотация. *Приводится обзор результатов исследований в области создания научных основ технологической подготовки производства пространственно армированных углерод–углеродных композитов (УУК). Приведена концепция производства УУК с прямолинейным расположением армирующих волокон. Анализируются результаты теоретических и экспериментальных исследований, раскрывающих функции технологической подготовки производства: обеспечение технологичности, разработка технологических процессов (ТП), создание системы контроля и управления ТП, проектирование и изготовление средств технологического оснащения. Приведены результаты апробации ТП и оснащения, подтверждающие успешность исследований.*

Ключевые слова: *термонагруженные детали, углерод-углеродный композит, функции технологической подготовки производства, технологическая готовность производства.*