UDC 629.12.023
DOI: 10.15587/1729-4061.2018.143674

# STABILIZATION OF PHYSICAL-MECHANICAL CHARACTERISTICS OF HONEYCOMB FILLER BASED ON THE ADJUSTMENT OF TECHNOLOGICAL TECHNIQUES FOR ITS FABRICATION

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***Об’єктивними передумовами більш ефективного застосування стільникових конструкцій у ряді галузей промисловості є не тільки вже реалізовані і доведені їх переваги, але і вирішення низки проблем. Незалежно від того, чи виготовляється стільниковий заповнювач безпосередньо на підприємстві або купується перед формуванням конструкції, він піддається тим чи іншим технологічним операціям. В процесі цих операцій змінюються деякі з його геометричних параметрів, а, отже, і фізико-механічні характеристики. В статті проведено дослідження забезпечення фізико-механічних характеристик стільникових заповнювачів в тих випадках, коли його характеристики виходять за рамки допустимих значень внаслідок певних відхилень в геометрії стільників, що підлягають цілеспрямованому коригуванню в процесі виготовлення цього матеріалу. З умов міцності стільникового заповнювача на рівномірний відрив в процесі розтягування пакета в блок проведено корекцію його фізико-механічних характеристик шляхом забезпечення регламентованого діапазону кута розтяжки чарунки стільників в межах заданої області коефіцієнтів зміни її форми.***

***Отримано регламентований зв’язок між технологічними параметрами та кутом розтяжки стільникового пакета і коефіцієнтом зміни форми чарунки. Залежність дозволяє виявити потрібний діапазон технологічних параметрів для реалізації необхідних по регламенту фізико-механічних характеристик стільникового заповнювача з заданими вхідними геометричними параметрами його чарунки. Проаналізовано всі існуючі технологічні способи нанесення клейових смуг на матеріал стільникового заповнювача на основі зв’язку між кроком нанесення смуг, коефіцієнтом зміни форми чарунки та розміром її сторони. Отримані результати дозволяють вдосконалити типові технологічні процеси виробництва стільників, що в свою чергу підвищить стабільність фізико-механічних характеристик стільникового заповнювача та конструкцій на його основі***

***Ключові слова: стільниковий заповнювач, корекція фізико-механічних характеристик, технологія, кут розкриття чаруки, коефіцієнт форми***

## 1. Introduction

A number of industries have widely applied three-layer (sandwich-type) structures with a honeycomb filler (HF) [1, 2]. The unique set of strength, technological and operational characteristics of honeycomb structures predetermines their ever-increasing application. In this case, the nomenclature of parts and components, along with those weakly-loaded, includes the highly-loaded strength structures for special purposes [3, 4]. The objective preconditions for more efficient application of the honeycomb structures are not only their advantages, already implemented and proven, but resolving several tasks as well. Thus, it is known [5, 6] that the quality of HF, its functional properties and its stability are predetermined by the technology of its fabrication. The pronounced technological heredity of HF could lead to significant changes in the functional properties of structures based on it. Consequently, there is a need for stabilization of the quality and operational characteristics of honeycombs, as well as designs based on them, by defining such technological techniques that would implement the desired permissible region of the controlled physical-mechanical characteristics (PMC) of HF.

## 2. Literature review and problem statement

There are certain patterns regarding HF. Regardless whether honeycombs are fabricated directly at an enterprise or purchased before forming a structure, they are treated with different technological operations (for example, stretching a honeycomb block, etc.). During these operations, some of the geometrical parameters of the honeycomb filler change, consequently, its PMC as well [6, 7]. Currently there are analytical dependences relating PMC and strength characteristics of HF to the geometrical parameters of a cell and the properties of honeycomb materials. However, such dependences provide an opportunity to select only acceptable fields for technological tolerances based on the level of responsibility when designing honeycomb structures [7, 8]. The data obtained could be checked (refined) based only on the reference data or specifications for a particular HF [9–11]. Until recently, papers [12–14], as well as fabrication manuals and other technical documents, have mostly registered the defects obtained in practice during execution of certain technological processes implemented at specific equipment and installations [15, 16]. Among the studies that address defining the technological techniques that implement the desired permissible region of controlled PMC of HF, we first and foremost point to papers [17–22]. Thus, authors of [17] provide an original mathematical model describing the process of stretching a honeycomb block. They also give analytical and empirical dependences for determining the opening angle of an HF cell $\beta$ when stretching a honeycomb block as a function of the strength parameters and PMC N. However, these dependences made it possible only to establish a defect tolerance $\Delta\beta$. The practical application of these dependences is associated with major difficulties. The results obtained are also limited to a few types of HF cell dimensions. Employing the empirical correction factors, proposed in this work, makes the results almost impossible to implement because of their dependence on parameters whose quantity comes close to 10. Thus, in paper [18], deviations in the thickness of glue and the step of glue bands are given for the methods of high, deep, and screen printing, depending on the rate of the process of glue application.

Papers [18, 19] devised models and methods for standardizing the tolerances for defects of HF cells, which made it possible to establish the dependence of PMC of HF on geometrical parameters of the cell and the properties of foil, as well as the respective fields of tolerances for these characteristics. Studies [20, 21] address the development of scientifically-based technological methods for reducing defects and improving quality indicators of HF made from polymeric papers, as well as their PMC. A generalization of these works is monograph [7], which tackles the development of scientifically-substantiated methods for standardizing the tolerances of technological parameters for the basic operations in the process of fabricating HF from various materials, as well as defects emerging in them.

Paper [22] reports new theoretical and practical results of study into the possibilities for taking into consideration, when designing three-layer panels with HF, the technological imperfections of its manufacture. The authors proposed a procedure for the optimization of tolerances when making HF for a three-layer panel, which would ensure the predefined load bearing capacity of the structure. However, the approach proposed for standardizing the tolerances for the parameters of a cell's shape is aimed not at the technological capabilities of implementation of the related operations of the HF manufacturing process. It only seeks to ensure the regulated load capacity deviation of a specific honeycomb structure. Therefore, being undoubtedly useful at the stage of design of honeycomb structures, a given approach does not resolve the issue of standardization of tolerances when fabricating HF.

It follows from a brief analysis of the above publications that at present the issue on improving the structures with HF has been resolved to a certain degree. In this regard, it is an important task to devise methods that could predict ensuring all regulated PMC of HF for those cases when one or more of its characteristics are beyond the limit of permissible values.

## 3. The aim and objectives of the study

The aim of this work is to define technological techniques that would ensure the stabilization of quality and operational characteristics of HF and the structures based on it.

To accomplish the aim, the following tasks have been set:

– to model mathematically the technological techniques to correct PMC of HF based on the results of implementing a matrix overlay method;

– to investigate ensuring all regulated PMC of HF in the cases when one or more of its characteristics are beyond the limit of permissible values due to certain deviations in the geometry of honeycombs.

## 4. Research materials and methods

When constructing and implementing a mathematical model of stretching a honeycomb packet into a honeycomb block, devising methods for determining the tolerance fields of the technological parameters for the process of fabricating HF, we employed methods of technological mechanics, mathematical analysis, computer technology, as well as the analog methods. They are based on the generally recognized methods of construction mechanics, strength of materials, a parametric three-dimensional simulation using the finite element method. For the method of targeted adjustment of PMC of HF and their strength, we applied the refined analytical models that relate the properties of honeycomb material and their selective screening to the geometrical parameters and characteristics of the technological process of HF formation.

The proof of the validity of the conclusions drawn in this work is the adequacy of the calculation models and the data obtained when testing the standard samples of HF and the structures based on it.

## 5. Results of research into technological techniques to adjust PMC of HF

Among the many kinds of HF, differing in cell configuration and fabrication technology [1, 2], the most widely used are the hexagonal honeycombs. These honeycombs are typically formed upon assembling a honeycomb packet, its gluing and stretching into a hexagonal cell (Fig. 1), of irregular shape in the general case, which passes into a regular hexahedron at a cell opening angle $\beta=60°$.

However, it should be noted that a given method has a significant difference for the aluminum foil and polymeric paper, which requires that their technological processes should be analyzed separately [6, 7, 15].

The shape of a cell, shown in Fig. 1, was acquired as a result of applying a band of glue with width $a_s$ at step $t$ on the rolled foil using a forming cylinder, followed by arranging the rolled material in a packet with a staggered offset of the glue bands at half a step, that is, $t/2$ (Fig. 2).

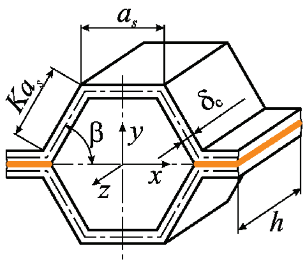

Fig. 1. HF with a hexahedral cell shape: $a_s$ — width of a double cell; $K$ — cell shape factor; $\beta$ — cell opening angle; $\delta_c$ — thickness of a honeycomb material

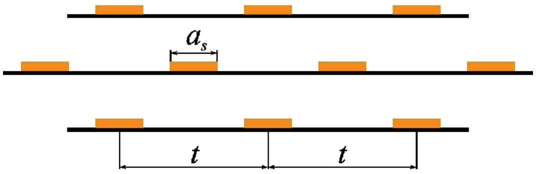

Fig. 2. Forming a honeycomb packet

Papers [7, 23] show, by using a specific example, the implementation of the overlay method of PMC matrices and the HF durability for determining their zone in which all these properties meet the requirements of a particular norm or standard. This zone is matched by a relatively narrow interval of change in the parameters of the HF opening angle $\beta_{\min} \le \beta \le \beta_{\max}$, implemented for a specific range of coefficients in the HF cell shape change $K_{\min} \le K \le K_{\max}$ (Table 1).

Table 1

Matrix of the permissible region of the desired HF parameters $\beta$ and $K$

| $\beta$ \ $K$ | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 |
|---|---|---|---|---|---|---|
| 58° | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ |
| 60° | ☒ | ☒ | ☒ | ☒ | permissible region | permissible region |
| 62° | ☒ | ☒ | ☒ | ☒ | ☒ | permissible region |
| 64° | ☒ | ☒ | ☒ | ☒ | ☒ | ☒ |

However, in order to implement these ranges of $\beta$ and $K$ technologically, it is necessary to substantiate the appropriate techniques that would enable obtaining them.

To this end, it is advisable to consider the conditions for obtaining the required (regulated) value $\beta_r$ when stretching a honeycomb packet.

The effort applied to the glued connection on the site of the surface of one cell $4a_sh$, required to move the site from the original position (non-stretched packet) over distance $a_sK\sin\beta$, for the case of an irregular hexahedral shape, is derived from formula (Fig. 3) [7]:

$$P_t = \frac{4M_p}{a_s} + \frac{4M_p\beta}{a_sK\sin\beta}, \tag{1}$$

where $M_p$ is plastic linear bending moment; $0 < \beta \le \pi/2$ is the bending angle, $a_s$ is the width of a double cell; $K$ is the cell shape factor; $h$ is the height of the honeycomb filler (Fig. 1).

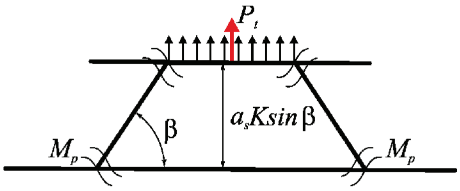

Fig. 3. Bend of the foil when forming an elementary cell

Since:

$$M_p = \frac{\sigma_{tc}h\delta_c^2}{4}, \tag{2}$$

where $\sigma_{tc}$ is the yield strength of the foil material; $h$ is the height of HF, mm; $\delta_c$ is the thickness of the foil, then:

$$P_t = \frac{\sigma_{tc}h\delta_c^2}{a_s} + \frac{\sigma_{tc}h\delta_c^2\beta}{a_sK\sin\beta} = \frac{\sigma_{tc}h\delta_c^2}{a_s}\left(1 + \frac{\beta}{K\sin\beta}\right). \tag{3}$$

The glue tensile strength limit is determined from:

$$\frac{P_t}{4a_sh} = \frac{\sigma_{tc}\delta_c^2}{4a_s^2}\left(1 + \frac{\beta}{K\sin\beta}\right) \le \sigma_{b\eta}. \tag{4}$$

Solving (4) relative to β° (in degrees), we obtain:

$$\frac{\beta°}{\sin\beta°} = 57.4K\left(\frac{4\sigma_{b\eta}a_s^2}{\sigma_c^2} - 1\right). \tag{5}$$

Formula (5) produces the link, previously undetected, between parameters $\beta$ and $K$, which is missing in the case for a regular hexahedral cell ($K = 1$).

In a given general case, it is necessary to test the feasibility of the implementation of the required cell opening angle $\beta$ given the regulated $K$ for these cell dimensions $a_s$, foil thickness $\delta_c$, and its yield point $\sigma_{tc}$, as well as the tensile strength of a given glue for the uniform detachment $\sigma_{b\eta}$.

An analysis of (4) shows that it is satisfied at any value of the parameters, included in it, that is in ranges $80 \le \sigma_{tc} \le 300$ MPa; $0.03 \le \delta_c \le 0.04$ mm, $2 \le a_s \le 8$ mm, with respect to $\sigma_{b\eta} \ge 17$ MPa.

Hence, it follows that the condition for the foil gluing connection strength when stretching a honeycomb packet is not critical and cannot be used to establish the regulated cell opening angle $\beta$ range depending on parameter $K$.

Next, we proceed to establishing the desired relation between parameters $\beta$ and $K$ within the regulated ranges of their reciprocal changes by analyzing the process of stretching the honeycomb packets with respect to its ability to spring.

Fig. 4 shows schematic of stretching a honeycomb packet into a honeycomb block.

To study the process of stretching a honeycomb packet, we shall apply a mathematical model proposed earlier in [18] and generalized in [7], by developing it for a HF cell of irregular hexahedral shape ($K \ne 1$). Underlying the model is a shape of a single face, acquired by it while stretching HF, observed both in experiment and at finite-element calculations (Fig. 5).

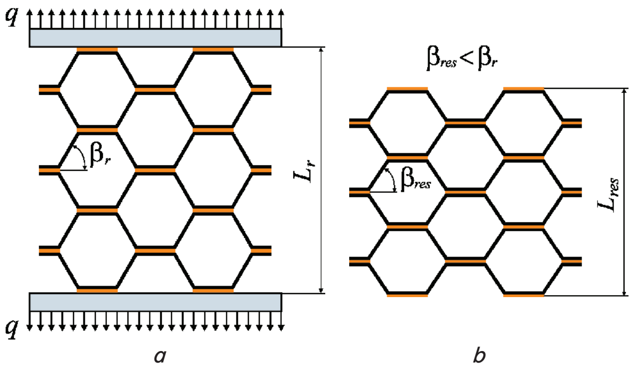

Fig. 4. Schematic of stretching a honeycomb packet: *a* – at load moment *q* ($\beta_{res}>\beta_r$); *b* – after removing the load

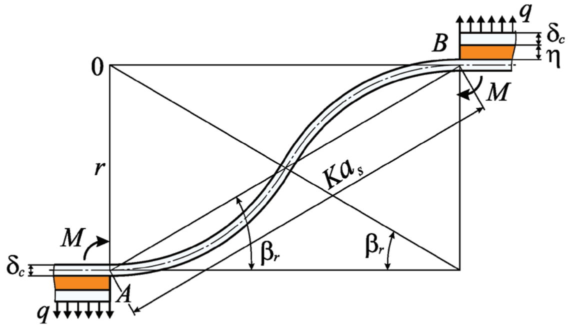

Fig. 5. Schematic of deformation of a single HF face in the process of stretching a honeycomb packet

The cause of bending the HF single faces are the bending moments arising in the end zones of double faces *M* (Fig. 5). We assumed that the deformations of the dual faces themselves, in contrast to the single ones, are small, and the character of bending of the latter is such that the inflection point corresponds to the middle of the face $a_s$ with the radius of curvature *r* being constant.

Thus, the cross-section of the bent median surface of the single face is described by equation [24]:

$$y''=\frac{1}{r}=\frac{M}{EI}=\frac{12M}{E^{*}h\delta_c^3}, \tag{6}$$

where $E^*$ is the module of the face's material corresponding to the level of high stresses arising due to moments *M* in the $\sigma-\varepsilon$ diagram. The simplified form of the $\sigma-\varepsilon$ diagram in the nonlinear region for aluminum foil is shown in Fig. 6 [25, 26].

Since the maximum stresses $\sigma_b$ in the elongated layer of the bending face are equal to:

$$\sigma_b=\frac{6M}{h\delta_c^2}, \tag{7}$$

then, with respect to (7), we obtain from (6):

$$\sigma_b=E^{*}\frac{\delta_c}{r}. \tag{8}$$

Radius of the curvature (Fig. 4) is equal to:

$$r=2a_sK\cos\beta_r, \tag{9}$$

where $\beta_r$ is the cell opening angle under the action of load *q* (Fig. 5).

Given (9), expression (8) is transformed to the form:

$$\sigma_b=E^{*}\frac{\delta_c}{a_sK\cos\beta_r}=E^{*}\varepsilon_r, \tag{10}$$

where $\varepsilon_r$ is the maximum deformation of stretching the face at cell opening angle $\beta_r$.

After removal of the efforts for stretching a honeycomb packet, residual deformation $\varepsilon_{res}$ will be equal to:

$$\varepsilon_{res}=\varepsilon_r-\varepsilon_{0.2}=\frac{\delta_c}{a_sK\cos\beta_{res}}, \tag{11}$$

where $\beta_{res}$ is the resulting angle of HF cell opening (the spring angle, formed upon removal of efforts).

We obtain from (11):

$$\cos\beta_{res}=\frac{\delta_c}{a_sK\left(\varepsilon_r-\varepsilon_{0{,}2}\right)}. \tag{12}$$

With respect to (10), we shall transform (12) to the form:

$$\beta_{res}=\arccos\left[\frac{\delta_c}{\dfrac{\delta_c}{\cos\beta_r}-a_sK\varepsilon_{0{,}2}}\right]. \tag{13}$$

Dependence (13) establishes the desired relationship between parameters β and *K* within the limits of the regulated ranges of their reciprocal change.

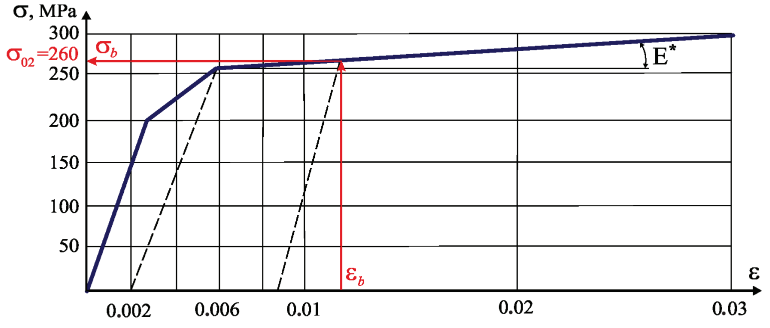

Fig. 6. The $\sigma-\varepsilon$ diagram when stretching an aluminum foil

Thus, there is reason to believe that the representation of the mathematical model in the form of dependences (5) and (13) has been substantiated since it is such a representation that makes it possible to link the existing technological ways of applying glue bands onto HF material to the geometrical parameters of the filler obtained. That ultimately allowed us to explore ensuring PMC of HF in the cases when its characteristics are beyond the limits of permissible values as a result of certain deviations in the honeycomb geometry that are to be purposefully adjusted in the process of making a given material.

A range of the coefficient for an HF cell shape change $1.47 \le K \le 1.65$ (Table 1), in which all parameters were to ensure PMC of HF that would meet the regulatory documentation at $\delta_{cc}=0.03$ mm, $\varepsilon_{0,2}=0.002$, $a_{sc}=2$ mm, $50.2^{\circ} \le \beta^{\circ}_{res} \le 51.3^{\circ}$. However, as shown in Table 1, in reality, the application of the described procedure, with the accepted accuracy in the derived formulae, the level of all PMC in a given HF has not been achieved.

In this case, values for the modules of elasticity and shear strength limit $G_{xz}$, $G_{yz}$, $F_{xz}$ considerably exceed the regulated values, while $\rho_{hf}$ are below the regulated values at the insufficient value $F_{yz}$, equal to 0.8 MPa, instead of the required $F_{yz}=0.9$ MPa, and $F_{yz}^{\exp}=1.18$ MPa obtained experimentally [7, 23].

It is obvious that formula (13) requires adjustment that would provide for increased $\beta_{res}$. That will be the case when assigning $\beta_r$ with the positive tolerance $\Delta\beta_r=5...6°$, that is:

$$\beta_{res} = \arccos\left[\frac{\delta_c}{\dfrac{\delta_c}{\cos(\beta_r+\Delta\beta_r)} - a_s K \varepsilon_{0,2}}\right]. \tag{14}$$

When assigning $\Delta\beta_r=6°$ and at the initial values for input parameters, we obtain $60.5^{\circ} \le \beta^{\circ}_{res} \le 61.2^{\circ}$ with all the values for PMC of HF within the range defined from Table 1 [7, 23].

The relationship between a step of applying glue bands $t$ and the HF cell shape factor (Fig. 2) takes the following form:

$$t = 2a_s(1+K\cos\beta). \tag{15}$$

Solving it relative to $K$, we obtain:

$$K = \left(\frac{t}{2a_s}-1\right)\frac{1}{\cos(\beta_r+\Delta\beta_r)}. \tag{16}$$

Substituting (16) in (14), we obtain a link between angle $\beta_{res}$ and step $t$:

$$\beta_{res} = \arccos\left[\frac{2\delta_c\cos(\beta_r+\Delta\beta_r)}{2\delta_c - \varepsilon_{0,2}(t-2a_s)}\right]. \tag{17}$$

At previous initial data and $t=10$ mm, we obtain $\beta_{res}=59.5°$, close to the range of opening angles determined above. However, for angle $\beta_{res}$ to fully match the range $60.5^{\circ} \le \beta^{\circ}_{res} \le 61.2^{\circ}$, step $t$ must be different from the constant value $t=10$ mm, postulated earlier.

Solving (17) relative to $t$, we obtain:

$$t = 2\left[a_s + \frac{\delta_c}{\varepsilon_{0,2}}\left(1-\frac{\cos(\beta_r+\Delta\beta_r)}{\cos\beta_{res}}\right)\right]. \tag{18}$$

Substituting $\beta_{res}=59.5°$ in (18), at the same initial data, we obtain $t=9.4$ mm.

The following dependence was derived in paper [7]:

$$y_\eta = \frac{a_s\eta\rho_\eta}{(a_s+t)}, \tag{19}$$

linking the mass application of glue $y_\eta$ to the thickness of a glue layer $\eta$, the glue layer density $\rho_\eta$, the width of a glue band, accepted to be equal to the side of an HF cell $a_s$, and a step of glue bands $t$.

Solving (19) relative to step $t$, we obtain:

$$t = a_s\left(\frac{\eta\rho_\eta}{y_\eta}+1\right). \tag{20}$$

## 6. Discussion of results of an analysis of existing technological techniques for forming honeycombs at different stages of their fabrication

The research we conducted has made it possible to model mathematically the main technological techniques to adjust PMC of HF based on the results of implementation of a matrix overlay method. In contrast to papers [7, 23], which proposed and implemented a specific method for the targeted adjustment of PMC of HF, our results allowed us to directly establish the unequivocal technological technique that ensures the implementation of the required permissible region of regulated properties. To this end, we have established a previously unidentified link between the regulated range of the cell stretching angles in an irregular hexahedral honeycomb and a coefficient of cell shape changes (5). The dependence was derived based on meeting the condition for HF strength in terms of the uniform detachment in the process of stretching a honeycomb packet into a honeycomb block (4). Underlying the model is the shape of a single face, acquired by it when stretching HF, observed both in experiment and in the course of finite element calculations. In contrast to the results in papers [7, 18], the proposed mathematical model takes into consideration a technique for the formation of HF with the cell in the general case of an irregular hexahedral shape.

The adjustment of PMC of HF by implementing the relation between the cell opening angle and the step of applying glue bands has revealed that the derived condition (4) is met throughout the entire range of possible changes in the geometrical and strength parameters of HF components (glue and foil). Consequently, the criterion (5) did not make it possible to establish (regulate) the range of mutually unambiguous dependence between parameters $\beta$ and $K$. To this end, we have investigated a possibility of obtaining a regulatory relationship between the angle of honeycomb packet stretching and a coefficient of the cell shape change, providing for the implementation of the required PMC of HF. In contrast to studies [18, 19], which established the dependence of PMC of HF only on the geometrical parameters of the cell, the properties of foil, and tolerance fields for these characteristics, our dependence has revealed their range required for the implementation of PMC of HF, required by the standard, with the predefined input parameters. Thus, when assigning $\Delta\beta_r=6°$ and at the original values for input parameters, we obtained $60.5^{\circ} \le \beta^{\circ}_{res} \le 61.2^{\circ}$ and all the values for PMC of HF are within the range determined from Table 1.

Studying the ranges of possible change in the step of glue bands $t$ depending on the technique for applying a glue [2, 7, 12] has revealed the following.

At intaglio printing, parameters that are included in (20) change in the range

$$0.003 \le \eta \le 0.005 \text{ mm}; \ (15 \le y \le 17) \cdot 10^{-7} \text{ g/mm}^2;$$

$$\rho_\eta = 1.3 \cdot 10^{-3} \text{ g/mm}^3.$$

At these parameters and with the range of change $1.9 \le a_s \le 2.1$ mm, we obtain the range of possible changes in the step of applying glue bands $6.9 \le t \le 11.2$ mm.

At intaglio printing:

$$0.008 \le \eta \le 0.018 \text{ mm}; \ (50 \le y \le 85) \cdot 10^{-7} \text{ g/mm}^2;$$

$$a_s = a_{sc} \pm 0.6 \text{ mm},$$

that is $1.4 \le a_s \le 2.6$ mm, we obtain from (19) $3.1 \le t \le 14.8$ mm.

At flowing:

$$0.01 \le \eta \le 0.05 \text{ mm}; \ (60 \le y \le 230) \cdot 10^{-7} \text{ g/mm}^2;$$

$$1.6 \le a_s \le 2.4 \text{ mm},$$

we obtain from (19) $2.5 \le t \le 28.4$ mm.

At screen printing:

$$0.01 \le \eta \le 0.17 \text{ mm}; \ (60 \le y \le 80) \cdot 10^{-7} \text{ g/mm}^2;$$

$$1.6 \le a_s \le 2.4 \text{ mm},$$

we obtain from (19) $4.2 \le t \le 11.24$ mm.

The analysis of techniques for applying the glue bands has made it possible to demonstrate the following:

– complete unsuitability of the outdated outflow technique due to a possible range in the change of step of glue bands at deviations, that typically occur in practice, from the average value of other parameters of the HF cell, and, therefore, PMC of HF;

– the intaglio printing technique is not acceptable, in terms of the range of change in the step of applying glue bands, for HF that are applied to modern structures;

– the preferred technique for applying glue bands for HF in special-purpose products is the technique of intaglio printing.

The possibilities of obtaining higher PMC of HF are apparently implemented in the course of input control over materials of HF base through their selective screening [27].

The results obtained make it possible to ultimately improve the standard honeycomb production processes, which in turn will enhance their quality and operational characteristics. They do not make it possible to directly define the unique technological technique that would provide for the implementation of the desired permissible region of regulated PMC of HF. Consequently, the need to analyze existing and prospective technological techniques for the formation of HF at various stages of its fabrication remains to be met.

## 7. Conclusions

1. We have analyzed, identified and recommended technological techniques to adjust PMC of HF based on the results of implementation of a matrix overlay method, which ensure the creation of honeycombs with enhanced functional characteristics.

2. We have investigated the possibility to adjust PMC of HF at different stages of their fabrication. Thus, ensuring the required level of PMC of HF is achieved by the regulated range of the honeycomb cell opening angle $60.5^{o} \le \beta^{o}_{res} \le 61.2^{o}$ within the assigned region of coefficients of the shape change $1.47 \le K \le 1.65$. The adjustment of PMC of HF by implementing the relation between the cell opening angle and the step of applying glue bands has shown that the range of $60.5^{o} \le \beta^{o}_{res} \le 61.2^{o}$ is best achieved at step $t = 9.4$ mm. Studying the possibility of adjusting the PMC of HF using the minimization of deviations in the steps of applying glue bands at different technological techniques for applying glue on foil has demonstrated that the preferred technique for applying glue bands on HF for special-purpose products is the technique of intaglio printing.

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