Software and research of fibrous composite materials elastic-plastic deformation

Askhad M. Polatov, Nodira A. Nodirjanova

Abstract— The paper describes the computer simulation of unidirectional fiber composite materials elastic-plastic deformation. Developed set of tools to automate the process of new fiber composite materials and structures designing with predetermined mechanical properties. Provides technology research process of elastic-plastic deformation of materials. Described the structure and functioning of specialized software. Computational experiment was carried out for investigate of materials strain state. Composite materials elastic-plastic analysis results are presented.

Index Terms— computer model, software, computer experiment, fiber composite, elastic-plastic state, toughness.

1 Introduction

Now in various areas of equipment and construction the elements of designs made of modern composite materials are widely used. The unidirectional fibrous composites or transversal and isotropic materials are of special interest. Automation of design of designs requires development of the settlement models and methods considering anisotropy of material and a configuration. The problem becomes complicated if material possesses elastic-plastic properties.

The integrated approach to the solution of the tasks connected with definition of rational structure of material is necessary for the effective accounting of advantages of constructional materials. Collaboration of fiber and a matrix gives the effect equivalent to creation of new material which properties differ from properties of its components. Due to the aforesaid, development of computer modeling of process of deformation of elements of the designs made of composite materials is very actually. The problem gains special importance at an assessment of durability of composite elements of designs in such areas as automotive industry, aircraft industry, astronautics, power, mechanical engineering, etc. and promotes development of researches in the field of the anisotropic theory of plasticity.

Creation of specialized software for research of elastic-plastic processes of deformation of constructional materials represents special relevance and, at the same time, is the theoretical and applied problem having important economic value. Great scientific interest is represented by development of effective systems of automation of design of new composite materials and an assessment of reliability of the developed elements of designs.

In computing experiments the numerical model by means of which gain new knowledge of the modeled object is used. For granting the convenient interface to the user at the description of real process and carrying out computing experiments, it is necessary to develop computing algorithms on the basis of which the program complex is under construction. Carrying out computing experiments gives the chance to automate process of design of composite materials with in advance set mechanical properties, to investigate influence of a volume ratio and mechanical parameters of fiber and a matrix on design durability. Essential feature of technology of computer modeling and computing experiment is possibility of carrying out a series of calculations for determination of necessary mechanical and geometrical parameters of the projected composite materials. The demand of researches is characterized by that for providing strength characteristics and widespread introduction of constructional materials in production, it is necessary to automate process of their design.

The technique of computer modeling applied at the solution of applied tasks is defined by creation of the model reflecting real process and the computing experiment revealing the acceptable process functioning parameters. The essential contribution to development of numerical modeling was made by Samarsky A. A. [1]. The triad "model-algorithm-program" is offered them, the methodology of computing experiment and technology of computer modeling are developed. In paper of Konovalov A. N. and Yanenko N. N., is considered the modular principle of creation of software packages [2]. Algorithmic approach to the solution of applied tasks is offered in researches of Kabulov V. K. and his co-researchers [3]. Such approach differs in high extent of formalization at the solution of a wide class of tasks and automation of process of the decision. Wide use in practice of various composite materials promoted development of researches in the field of the anisotropic theory of plasticity. For the description of process of elastic-plastic deformation of materials various versions of the theory of plasticity based on a method of averaging at which composite material will be replaced homogeneous anisotropic environment [4-6] are offered. Recently for the solution of problems of deformation of composite materials the method of finite elements [7] is used. For carrying out engineering calculations there is now a number of computing programs and systems to which it is possible to carry software packages of LIRA, FRONT, COSMOS/M, ANSYS, NASTRAN and others.

Despite the achieved success, a problem of development of computer modeling, computing algorithms and software for the solution of problems of elastic-plastic deformation of constructional materials it is impossible to consider complete. The insufficient attention is paid to the questions connected with increase of efficiency of computing algorithms, specialized software for automation of process of carrying out computing experiments at design of new composite materials and designs with in advance set mechanical properties. In an incomplete measure impact on durability of designs of structural features,

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such as anisotropy of material, the volume content of fiber in materials, and also constructional not uniformity is studied.

Research of the new direction in a solution of the problem of automation of design of constructional materials assumes development and modification of a wide range of methods, algorithms and specialized program complexes for designing of fibrous composites which scientific and methodical bases promote development of the existing technologies.

2 TECHNOLOGY OF THE SOLUTION

The elastic-plastic environment which represents the non-uniform continuous material consisting from two components is investigated: the reinforcing elements and a matrix (or binding) which ensures collaboration of the reinforcing elements. It is known that fibrous material and the transversal and isotropic environment are equivalent concepts. Thus replacement of the non-uniform environment with the anisotropic environment adequate to it with effective mechanical parameters gives the chance to consider inhomogeneity of composite materials. In this regard, at the solution of a problem of elastic-plastic deformation of fibrous composites the theory of small elastic-plastic deformations for the transversal and isotropic environment offered the prof. Pobedrya B. E. [8] is applied. Calculation of effective characteristics of fibrous composites is carried out on the basis of the expressions received by asymptotic a method that gives the chance to consider the radial interaction of components caused by distinction of coefficients of Poisson of a matrix and fiber [9, 10]. Elastic-plastic calculation is carried out on the basis of iterative process of a method of elastic decisions of Ilyushin A.A. For creation of the allowing system of the equations the method of finite elements in movements is used. The decision of system of the equations is carried out by method of square roots, taking into account symmetric and tape structure of a matrix of coefficients.

3 SOLUTION METHOD

In reinforced composites investigation, when stiffness of reinforcing elements significantly exceeds the stiffness of binding agents, simplified strain theory of plasticity could be used. It allows applying theory of small elastic-plastic strain for solution of specific applied tasks. Simplification is based on assumption that the simple stretching in the axis direction of the composite's transversal isotropy and in perpendicular direction to it, plastic strains do not occur.

For transversely isotropic solids the ratio between the stresses and strains is presented in the form of the stress tensor decomposition on the spherical and deviatory parts:

$$\sigma_{ij} = \tilde{\sigma}(\delta_{ij} - \delta_{i3}\delta_{j3}) + \sigma_{33}\delta_{i3}\delta_{j3} + \frac{P_u}{p_u} p_{ij} + \frac{Q_u}{q_u} q_{ij},$$

where: P_u, Q_u and p_u, q_u - stress and strain tensor intensity (respectively plane isotropy and isotropy transversal axis):

$$P_u = \sqrt{\frac{1}{2}P_{ij}P_{ij}} = \frac{\sqrt{2}}{2}\sqrt{(\sigma_{11} - \sigma_{22})^2 + 4\sigma_{12}^2},$$

$$p_u = \sqrt{\frac{1}{2}p_{ij}p_{ij}} = \frac{\sqrt{2}}{2}\sqrt{(\varepsilon_{11} - \varepsilon_{22})^2 + 4\varepsilon_{12}^2},$$

$$Q_u = \sqrt{\frac{1}{2}Q_{ij,}Q_{ij}} = \sqrt{\sigma_{13}^2 + \sigma_{23}^2},$$

$$q_u = \sqrt{\frac{1}{2}q_{ij}q_{ij}} = \sqrt{\varepsilon_{13}^2 + \varepsilon_{23}^2}.$$

The stress tensor ratio:

$$P_{ij} = \sigma_{ij} + \tilde{\sigma}(\delta_{i3}\delta_{j3} - \delta_{ij}) + \sigma_{33}\delta_{i3}\delta_{j3} - (\sigma_{i3}\delta_{j3} + \sigma_{3j}\delta_{i3}),$$

$$Q_{ij} = \sigma_{i3}\delta_{j3} + \sigma_{3j}\delta_{i3} - 2\sigma_{33}\delta_{i3}\delta_{j3}, \ \tilde{\sigma} = (\sigma_{11} + \sigma_{22})/2.$$

In disclosing these ratios look like:

$$P_{11} = (\sigma_{11} - \sigma_{22})/2,\ P_{22} = (\sigma_{22} - \sigma_{11})/2,\ P_{12} = P_{21} = \sigma_{12},$$

$$Q_{13} = Q_{31} = \sigma_{13},\ Q_{23} = Q_{32} = \sigma_{23}.$$

Similarly prescribed ratio of strain tensor:

$$\varepsilon_{ij} = \tilde{\theta}(\delta_{ij} - \delta_{i3}\delta_{j3}) + \varepsilon_{33}\delta_{i3}\delta_{j3} + p_{ij} + q_{ij},$$

where

$$p_{ij} = \varepsilon_{ij} + \frac{\tilde{\theta}}{2}(\delta_{i3}\delta_{j3} - \delta_{ij}) + \varepsilon_{33}\delta_{i3}\delta_{j3} - (\varepsilon_{i3}\delta_{j3} + \varepsilon_{3j}\delta_{i3}),$$

$$q_{ij} = \varepsilon_{i3}\delta_{3j} + \varepsilon_{3j}\delta_{3i} - 2\varepsilon_{33}\delta_{i3}\delta_{j3}, \tilde{\theta} = \varepsilon_{11} + \varepsilon_{22}.$$

It is assumed that the transverse isotropy axis coincides with the axis OZ.

Relationship between stresses and strains intensity is represented as:

$$P_u = 2\lambda_4(1 - \pi(p_u))p_u,$$

$$Q_u = 2\lambda_5(1 - \chi(q_u))q_u,$$

where

$\pi(p_u)$ and $\chi(q_u)$ - function of plasticity which value is zero at elastic zone.

For simplified transversely isotropic plasticity theory the relationship between stresses and strains is given by the relations:

$$\tilde{\sigma} = (\lambda_4 + \lambda_7)\tilde{\theta} + \lambda_5\varepsilon_{33},$$

$$\sigma_{33} = \lambda_5\tilde{\theta} + \lambda_3\varepsilon_{33},$$

$$P = P(p);\ Q = Q(q),$$

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where

$$P=\begin{cases}2\lambda_7\, p, \text{ if } & p<p^*\\ 2\lambda_7\, p^*+2\lambda_7'(p-p^*), \text{ if } & p>p^*\end{cases},$$

$$Q=\begin{cases}2\lambda_9\, q, \text{ if } & q<q^*\\ 2\lambda_9\, q^*+2\lambda_9'(q-q^*), \text{ if } & q>q^*\end{cases},$$

p*, q* - appropriate limit of elastic strain.
Introducing the notations:

$$\alpha=\left(1-\frac{\lambda_7'}{\lambda_7}\right)\left(1-\frac{p^*}{p}\right),\ \beta=\left(1-\frac{\lambda_9'}{\lambda_9}\right)\left(1-\frac{q^*}{q}\right),$$

expressions for stressed state components in plasticity zone could be written as:

$$\sigma_{11}=(\lambda_4+2\lambda_7)\varepsilon_{11}+\lambda_2\varepsilon_{22}+\lambda_3\varepsilon_{33}-\lambda_7\alpha(\varepsilon_{11}-\varepsilon_{22}),$$
$$\sigma_{22}=\lambda_4\varepsilon_{11}+(\lambda_4+2\lambda_7)\varepsilon_{22}+\lambda_3\varepsilon_{33}-\lambda_7\alpha(\varepsilon_{22}-\varepsilon_{11}),$$
$$\sigma_{33}=\lambda_5(\varepsilon_{11}+\varepsilon_{22})+\lambda_3\varepsilon_{33},$$
$$\sigma_{12}=2\lambda_7\varepsilon_{12}-2\lambda_7(1-\alpha)\varepsilon_{12},$$
$$\sigma_{23}=2\lambda_9\varepsilon_{23}-2\lambda_9(1-\beta)\varepsilon_{23},$$
$$\sigma_{31}=2\lambda_9\varepsilon_{31}-2\lambda_9(1-\beta)\varepsilon_{31}.$$

Coefficients of λ_i are associated with mechanical parameters of a transversely isotropic material in the following relationships:

$$\lambda_3=E'(1-\nu)/l,\ \lambda_4=E(\nu+k\nu'^2)/[(1+\nu)/l],\ \lambda_5=E\nu'/l,$$
$$\lambda_7=G=E/[2(1+\nu)],\ \lambda_9=G',\ l=1-\nu-2\nu'^2k,\ k=E/E'.$$

STRUCTURE OF A SOFTWARE

As a rule, many modern packages comprise a preprocessor (the program which is carrying out creation of settlement model, preparation of data for further calculations), the processor (the program which is carrying out calculations) and the postprocessor (the program which is carrying out visualization of calculations) [11, 12]. The purpose of this work is creation of tools for automation of process of design of new fibrous composite materials and designs with in advance set mechanical properties. The automated systems are developed for achievement of this purpose:
– creation of a finite element grid of areas (preprocessor);
– solutions of a problem of elastic-plastic deformation of composites (processor);
– visualization of results of calculation (postprocessor).

Such structure allows making computing experiments on reduction of time and material inputs at design of new composite materials and designs, to investigate influence of constructional features of material on design durability, to submit recommendations about increase of the bearing ability and to decrease in a material capacity of elements of designs.

The technology of calculation, computing algorithms and specialized software forms, in total, the concept of structural parameters forecasting of the projected fibrous composite materials and durability of designs' elements.

4.1 Preprocessor

The technology of representation of area of a difficult configuration is developed for automation of process of creation of a finite element grid by means of association or removal of "elementary" subareas [13]. Definition according to which the area is called "elementary" if there is an algorithm of creation of its finite element grid is for this purpose entered. The finite element grid of area is described by a set

$$\Omega=\{\ N, M, MK, MN\ \},$$

where N – number of knots; M – quantity of finite elements; MK – the massif of coordinates of knots; MN – an array of numbers of knots on finite elements. Further the ratio which allows by means of association or removal of elementary subareas is given to form a finite element grid of area of a difficult configuration:

$$\Omega=\sum_{i=1}^{k1}\Omega_i^I-\sum_{j=1}^{k2}\Omega_j^{II}$$

where Ω_i^I and Ω_j^{II} – the corresponding elementary subareas, k1 – number of the subareas which are subject to association, k2 – quantity of the deleted subareas.
Are for this purpose developed: computing algorithms of formation of a finite element grid of elementary subareas; associations and removals of subareas; definitions of the initial front and streamlining of numbers of knots on the basis of the modified frontal method allowing to minimize width of a tape of nonzero coefficients of the allowing system of the equations.

4.2 Processor

Process automation construction and the decision of system of the allowing equations of a finite element methods and realization of iterative process of a method of elastic decisions of Ilyushin A.A. [14]. Algorithms are developed: creation of coefficients of a matrix of rigidity of finite elements; formations of the allowing system of the equations on the basis of the principle of line-by-line preparation of data for each knot separately. It captures the essence of summation and provides creation of tape system of the algebraic equations of a high order taking into account symmetry of its coefficients; decisions of system of the equations by the modified method of square roots taking into account symmetric and tape structure of a matrix of coefficients.

As in transformations of a method operation of multiplication of a matrix by a vector is generally used, the corresponding algorithm is developed for a case when only coefficients of a tape of the lower triangular matrix are set. These coefficients settle down in a rectangular matrix of S_{ij} with sizes, where n – an order of system of the equations, the l width of a tape of

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nonzero coefficients, including diagonal elements. And diagonal elements of an initial matrix settle down on the last of *l*-ohm S_{ij} matrix column. In this case for multiplication of a matrix of S_{ij} by a vector of x_j the ratio is used (1):

$$y_i = \sum_{j=1}^{p} s_{i,q} x_r + \sum_{j=i}^{m} s_{j,i+l-j} x_j \ , (1)$$

where

$$p = \begin{cases} i-1, 1 \le i \le l \\ l-1, \text{else} \end{cases}, \quad q = \begin{cases} l+j-i, 1 \le i \le l \\ j, \text{else} \end{cases},$$

$$r = \begin{cases} j, 1 \le i \le l \\ i-l+j, \text{else} \end{cases}, \quad m = \begin{cases} i+l-1, 1 \le i \le n-l+1 \\ n, \text{else} \end{cases}.$$

The given ratio allows at realization of a method of square roots, with use only of coefficients of a tape of the lower triangular matrix and diagonal.

4.3 Postprocessor

The algorithms allowing displaying a picture of the intense deformed condition of the studied object on the monitor screen are developed for visualization of resultant parameters. As values of movements are small in comparison with the design sizes, in algorithm not real movements, but their values multiplied by the correcting k coefficient are used: $(u', v', w') = k \cdot (u, v, w)$. This coefficient is selected the user depending on the solved task. To provide evident visualization, values of coordinates of knots are also multiplied by the correcting multiplier. Compliance between the parameter and color of filling is defined from the following ratio (2):

$$c = C\left(\begin{cases} \dfrac{p}{p_{max}}, & \text{if } p \ge 0 \\ \dfrac{p}{p_{min}}, & \text{if } p < 0 \end{cases} \right) \ (2), \qquad c = \begin{cases} c_1 & \text{if } p < i_1 \\ c_2 & \text{if } p < i_2 \\ \dots \\ c_n & \text{if } p < i_n \\ c^* & \text{if } p \ge i_n \end{cases} \ (3),$$

where p_{min}, p_{max} – respectively, the minimum and maximum value of parameter, C – the machine-dependent function which is linearly displaying a numerical piece [-1; +1] in space of flowers from dark blue to the dark red. Then process of gradient filling begins. Only thus dependence between values of parameter and color is set by a ratio (3), where n – number of isolines, c_1, …, c_n – values of flowers by which section areas will be painted over. The remained area of section will be painted over in the c* color. For convenience of the user color is set in the form of numbers from -100 to +100.

5 Functioning of a Software

The ARPEK specialized program complex is developed for carrying out computing experiment in the environment of Delphi. The software has modular structure data exchange between modules is carried out through configuration files and files of data.

5.1 Finite element model

Automation of process of creation of a finite element grid of a three-dimensional design of a prismatic form of a difficult configuration is carried out in the APKEM program module. Visualization of results is carried out with use of opportunities of library of the program OpenGL [15] interface. By means of the index of a mouse on the screen of the monitor the design projection is drawn. Three-dimensional representation of a design is formed by the operation of expression applied to a projection surface. For work of the user on the screen the working area (fig. 1.a) is formed.

As the beginning of coordinates of working area the point serves in its top left corner. In the top right corner the toolbar (fig. 1.b) is presented, and in right lower – the actual coordinates of the index of a mouse are displayed. The main tools used for generation of finite element representation of a design are used as follows: 1–4 - for drawing of border and fixing of basic tops (fig. 2.a); 5–8 - for finite element representation of elementary subareas; 9 (+) - for consecutive association ("sewing together") of elementary subareas.

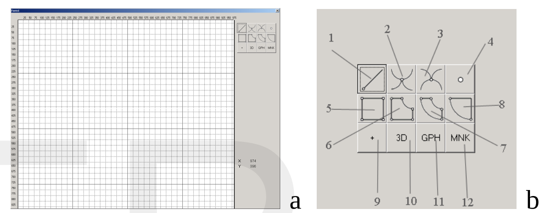

Fig. 1. Workspace of the user on the monitor and a tool kit

The tool 10 (3D) is used to formation of a three-dimensional finite element grid of a design on the basis of its projection. Thus the index of a mouse fixes one of tops which stretches further on the demanded distance. And, at the set distance from an initial surface the parallel trace is formed and three-dimensional representation of a design is formed (fig. 2.b, c). For visualization of a design the tool 11 (GPH) is used. At its activization the window in which left part the general view of a finite element grid of a design is arranged, and in the right part - the tool for comprehensive viewing (fig. 2.d) opens. The tool 12 (MNK) becomes more active for saving of information on finite element representation of a design.

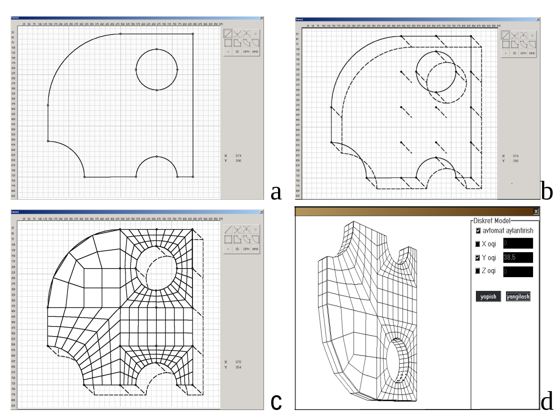

Fig. 2. Stages of formation of a finite element grid

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5.2 Software functioning

Functioning of settlement modules of the ARPEK software is carried out as follows. Further settlement modules of the NERPEK program module are carried out. Calculation of effective mechanical parameters of material is carried out by means of the module EFFECT. Formation of the allowing system of the equations of MKE is carried out in the RAM10 module. The method of square roots modified for systems of the equations with symmetric and tape structure is applied to the decision of system of the equations. Process of the decision consists of two stages: on the first - the RAM12 module carries out calculations according to algorithm direct, on the second - the RAM13 module - reverse motion of a method of the decision. The vector of nodal movements is as a result formed. In the course of work the RAM11 module carries out calculation of values a component of the intense deformed state who registers in the output file of the module – PARAMS. At the solution of physically nonlinear tasks the PLASN module for specification of the elastic-plastic decision on the basis of iterative process of a method of elastic decisions of A. A. Ilyushin is carried out. Zones of plastic deformations are defined on the basis of Mizes's criterion. At the exit the module writes down resultant values of an elastic-plastic state in the PARAMS file.

5.3 Visulaization

For graphic interpretation of results of calculation the program module of visualization of TASVIR is used. It allows: to visualize a picture of distribution of values of the intense deformed state in the set sections; to execute gradient filling with use of red color for positive value of parameter and blue – for negative; to visualize isolines which values are set by the user; to draw diagram of parameters on the borders of section adjoining axes; to correct and display pictures of deformation of designs; to execute combination of a finite element grid with diagram and gradient filling (only 10 modes of display of one section); to remove all values of the stress-strain state components for a control point; to keep the received images in the graphic file.

We will describe parameters by means of which task it is possible to receive a picture of distribution of the stress-strain state of the studied design. The file of data includes addresses of files with parameters of a finite element grid and the stress-strain state; total number of final elements and nodal points. The configuration file consists of coefficients of correction of movements and the sizes of a design; values component of movements and tension; intensity of deformations and tension; values of isolines with corresponding values of temperature of color; variable setup of the interface; loading parameter stress-strain state component; type of a grid and design; parameter of a form of display of a design; video card parameters.

On an entrance the TASVIR module reads out data of a finite element grid from the DISKR1.DAT file, nodal values of the stress-strain state from the PARAMS.TXT file and parameters from the configuration CONF.TXT file. The module of visualization uses the INIT module for line-by-line analysis of the configuration file. Color display of distribution of values of the stress-strain state parameters according to inquiries of the user is result of operation of the module.

To remove all values of the stress-strain state components for a control point; to keep the received images in the graphic file.

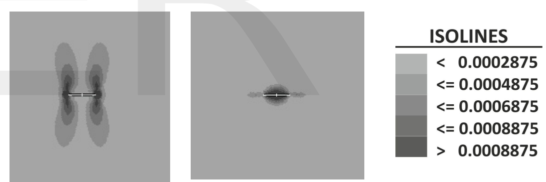
6 Computing Experiment

6.1 Problem One

Problem of elastic-plastic uniaxial tension (P_{zz} = 300 MPa) of rectangular plate with concentrators in the form of cracks are being solved. Boron / aluminum is used as fiber composite. Effective mechanical parameters for boron / aluminum are as follows:

$$E=160*10^3 \text{ MPa}, \mu=0.32, E'=260*10^3 \text{ MPa}, \mu'=0.254, G'=51*10^3 \text{ MPa}, G=E/(2*(1+\mu)).$$

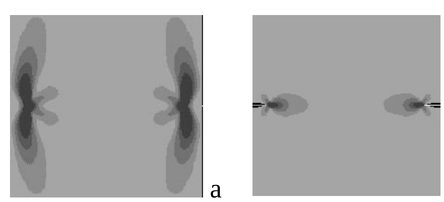
Problem of uniaxial tension plate with a horizontal isolated linear crack in the center with length l = 0.1cm is being considered. Intensity values distribution of strains q_u and p_u is shown in Fig. 3. Maximum intensity values of strains q_u are concentrated in the vicinity of the crack tip, but they do not reach ultimate tensile strength (Fig. 3.a). Strain intensity distribution investigation shows that the plasticity zones are concentrated in crack area (Fig. 3.b).



a b

Fig.3. Intensity values distribution of q_u and p_u

Further, uniaxial tension problem of plate with horizontal rectilinear cracks (l = 0.05 cm), located on plate's side edges is considered. Intensity values distribution of strain q_u is shown in Fig. 4.a. Distortion of construction sides and disclosure of crack edges are observed under tension. Increased values of q_u concentrated in area of crack tips and spread vertically. Elastic-plastic strains - p_u are formed in the vicinities of the crack tips (Fig. 4.b).



a b

Fig.4. Distribution of q_u and p_u values

Component values of stress - strain state in crack tips under uniaxial tension of plate with isolated crack and of plate with

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lateral cracks are shown in Table 1.

TABLE 1
STRAIN AND STRESS INTENSITY VALUES

crack	p_u	P_u, [MPa]	σ_{xx}, [MPa]	σ_{zz}, [MPa]
central	0.000390	47.2	188.2	805.4
laterals	0.001468	142.8	361.8	769.4

6.1 Problem Two

In this paragraph stress reducing process by changing of contour shape with minimal distortion stress are being studied. Improvements in stresses distribution and increased constructional strength

In the present paper elastic-plastic stress-strain state of fibrous boron/aluminum plates is being investigated. It is stretched uniaxial in direction of fiber. Circular hole was cut off in the center of plate for constructional purposes. Rectangular plate's dimensions are: height - 1 cm, width - 0.5 cm, thickness - 0.1 cm. Boron fiber volume fraction - 35%, hole radius R = 0.05 cm, external loading P_{zz} = 950 MPa.

Analysis of solution results are given below. As it is known, distribution of stresses in the plate in isolated holes presence is considerably distorted. Increased stress is observed in vicinity of hole (Fig.5.a). Second hole addition to existing hole is assumed (Figs.5.b-d).

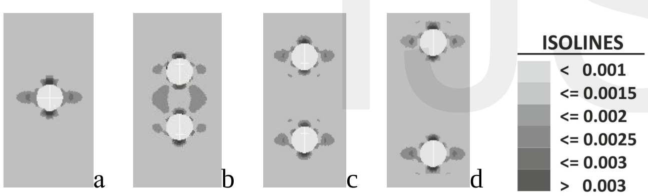

Fig.5. Distribution of strain intensity values

Computational experiment is carried out for investigating of two vertically positioned holes influence. It turns out that additional hole also causes stress increase in surrounding area. However, it is known that holes interference reduces overall stress. The values p_u for distance between centers of holes h = 0.2 cm decrease in external points to 7.7%, and in internal - to 26.7% (Fig.5.b). It is interesting to note that the elastic problem values are, accordingly, 6.7% and 32.7%. Increasing stresses in this case are less than in case with isolated hole (Tables 2-3).

TABLE 2
PARAMETER VALUES IN EXTERNAL POINTS OF HOLE CONTOURS

hole	elastic-plastic problems	
	p_u	P_u [MPa]
isolated	0.00449	322.7
2-vertical, h=0.2	0.00414	307.7
2-vertical, h=0.3	0.00451	323.8
2-vertical, h=0.4	0.00507	347.7

TABLE 3
PARAMETER VALUES IN INTERNAL POINTS OF HOLE CONTOURS

hole	elastic-plastic problems	
	p_u	P_u [MPa]
isolated	0.00449	322.7
2-vertical, h=0.2	0.00325	269.4
2-vertical, h=0.3	0.00433	315.9
2-vertical, h=0.4	0.00491	340.9

Single stress concentrator is formed by two vertically arranged holes. With distance increasing of holes from each other at h = 0.3 and 0.4 cm their interference disappears (Figs.5.c-d).

This phenomenon could be explained using the power flow idea. External forces create a flow that spreads along the construction. Pressure line (power flow) is rejected by the second hole. Influence of hole after rejection of passing power flow cannot grow anymore.

Stress components τ_{zx} values distribution is given in Fig.6. Maximum τ_{zx} values concentrated on holes' sides at an angle from $\pi/6$ to $\pi/4$ relative to the horizontal diametric section. In the vicinities of isolated holes τ_{zx} has negative values (Fig.6.a). Two vertical holes form both negative and positive zones (Figs.6.b-c).

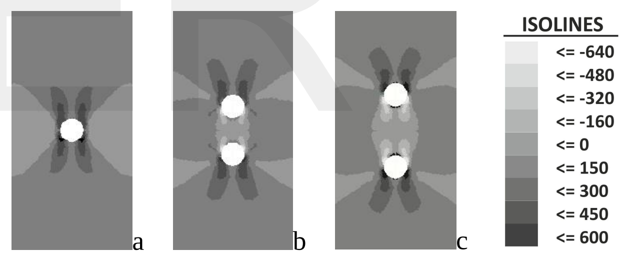

Fig.6. Stress components values τ_{zx} distribution

7 CONCLUSION

The developed in work computer model, computing algorithms and a specialized program complex of the solution of problems of elastic-plastic deformation of constructional materials allow to automate process of design of earlier inaccessible, essentially new elements of designs with in advance set mechanical properties and a configuration. The computing algorithm and the program module of creation of a finite element grid of designs are developed. The projection of a three-dimensional design is drawn by means of the index of a mouse on the computer monitor. Visualization of results is carried out by means of use of opportunities of library of the program OpenGL interface. The computing algorithm and the program module of visualization of results of calculation allowing to carry out are developed: gradient filling; visualization of isolines which values are set the user; creation of an diagram of values of parameters on section borders; combination of a finite element grid with schedules and

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gradient filling; a conclusion of values of resultants a component in a control point. Carrying out computing experiment allowed to investigate the deformed condition of the unidirectional composite material D16 (boron aluminum) and to confirm the regularities connected with influence of the volume content of fiber in a composite.

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