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NUMERICAL SIMULATION OF LAMINATED PLASTICS PULSE RIVETING PROCESS

The list of existent problems within the limits of considered process is brought; the aim and tasks to perform is described; the analysis and analytical model type, the geometrical, physics-mechanical, finite element and contact features of numerical model are viewed; specificity of equations system solution is brought; the part of first approximation results of process computation is shown.

Numerical simulation, laminated plastics, pulse riveting process, finite element method, implicit and explicit solutions, parametrical model, Mooney-Rivlin model, optimization

Problem definition

The mechanics of laminated plastics pulse riveting process in airframe manufacturing application is a complicated and not enough investigated phenomenon of general mounting and assembling technology. The research and further optimization of such interior process parameters via rare natural experiment involves severe difficulties like significant labour expenditures in preliminary and test works; significant financial, time and material expenditures. Hence combined natural [1] and numerical series of experiments assumes to be implemented.

Insufficiently studied aspect of considered technology is the determination of mutual geometrical, physical, mechanical and energy parameters influence which affects on quality of riveted joint [2, 3] (the quality of riveted joint hereafter means the conformity of obtained joint with certain geometrical limitation during simultaneous keeping of strength rates).

To realize a qualitative numerical section of planned experiment it is necessary to get entire parametrical model of dynamic nonlinear contact problem, which will allow to perform the automatic definition and analysis of sought response function.

Finite element method (FEM) (as one of the most accurate and reliable [4]) and method of statistical analysis assumed to be the base of numerical simulations.

Research aim and tasks to perform

The aim of research is the combined natural and numerical experiment determination of optimal process energy parameters in the view of required riveted joint quality ensuring.

To achieve the aim of experiment it is necessary to complete the following tasks: selection of analysis and analytical model type; creation of parametrical solid model; defining parametrical material properties, particularities of finite element (FE) properties and behaviour; creation of FE initial parametrical mesh, defining contact conditions; defining parametrical initial and boundary conditions; solution of initial equations system; variation of initial FE mesh parameters, determination of optimal values ensuring minimum expenditure of CP time and satisfactory convergence of obtained results; creation of post-processor procedures on the base of optimized FE mesh; implicit solution of optimized equations system in an adopted range of varied parameters of the technological process (TP); analysis of results, determination of TP optimal parameters ensuring high quality of riveted joint.

The numerical experiment schedule at present phase covers first six tasks and independent part of post-processing, which will reply to automatic rebuilding of model geometry, reassignment of properties, in-system variables and comparing numerical results with natural ones in preliminary defined checkpoints [3].

Research results

Selection of analysis and analytical model type. Because of geometrical and load symmetry of the process being investigated it is possible to decrease dimensionality of the numerical model using a quarter of the whole 3-D model with the regard at corresponding boundary conditions; 2-D model application is impossible because of the particularities of the composite material mechanical properties.

Components of the numerical model are the rivet, the washer, composite plate (2 items), polyurethane clamping device, tool (riveting set). The bucking bar was taken into account by means of application of the corresponding boundary conditions as reacting force in certain zone of the manufactured head.

The rivet and the washer are subjected to an elastic-plastic deformation. The composite plates and the polyurethane clamping device are subjected to an elastic deformation. The tool is considered as perfectly rigid body moving either with defined initial velocity or at fixed distance for certain period of time.

The ranges of the parameters variation which are mentioned in [3] have been expanded 1.5 times. Besides there was opportunity to modify the following additional parameters: rivet shank diameter and length; Prepreg quantity and mechanical properties; tool initial conditions (velocity, displacement); material properties; washer and polyurethane clamping device inner and outer diameters; plates dimensions, rivet whole diameter. The range of the varied parameters was expanded and the quantity of such parameters was increased to create analytical model more multifunctional and valid for the wider range of the varied parameters than for the real test was realized.

Creation of parametrical solid model. The components of the numerical model may be represented by the following geometrical parameters (fig. 1). The rivet (position 1) is defined by shank diameter, total length, height of the manufactured head, fillet radius between the manufactured head and the shank of the rivet, fillet radius near the end of the shank, bottom diameter of the manufactured head, diameter of the shank end. The washer (position 2) is defined by inner diameter, outer diameter, the height, chamfer angle and size of the chamfer. The tool (position 3) is defined by outer diameter, height, spherical dimple diameter, depth of dimple. Elastic washer (position 4) is defined by inner diameter, outer diameter and thickness. The upper composite plate (position 5) is defined by thickness, hole diameter, outer diameter, chamfer size and angle. The lower composite plate (position 6) is defined by thickness, hole diameter, outer diameter.

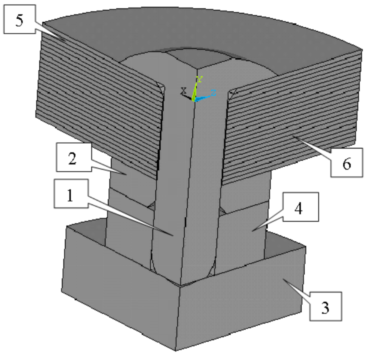

Fig. 1. Solid model of investigated objects: 1 – rivet; 2 – washer; 3 – tool; 4 – elastic washer; 5, 6 – upper and lower laminated plates respectively

Defining parametrical material properties, particularities of FE properties and behaviour. The solution of the dynamic problem of the deformed body needs consideration of the inertia forces. It may be done by means of transferring the magnitudes of density fields (tables 1–3) for every FE node in each component of numerical model into corresponding matrix [5]. The materials of all components are assumed to be isotropic excluding composite.

The behaviour of components (fig. 1, positions 1 and 2) material in numerical model being subjected to plastic deformation and is described by the law of bilinear isotropic strain hardening. The absolute values of the approved properties for material of BT-16 series are given below in table 1 [6].

Because of deforming tool (fig. 1, position 3) is assumed- to be the rigid body only the density matrix $[\rho_i]$

(ρ =7800 kg/m^3) is taken into account for defining the properties of the tool.

Behaviour of the elastic washer (fig. 1, positions 4) material – polyurethane СКУ-7Л is described by isotropic superplasticity Mooney-Rivlin model [7]. The values of the model parameters are represented below in the table 2.

Behaviour of the composite plate material – Prepreg CE 1250-230-39 is described by anisotropic elastic formulation [5]. The properties of the material model are represented in the table 3.

Discretization of the space is carried out by volumetrical 10-node FE adapted for meshing of irregular volumes. There is three degree of freedom at every node of each element – displacements in x, y, z directions. After solution of the corresponding equations system the set of the sought quantities is assigned to every node of FE. This set includes the principal stresses, stress intensity, equivalent stresses, strains X, Y, Z, XY, YZ, XZ; the principal strains, strain intensity, equivalent strains.

Table 1

Properties of the material ВТ-16

Poisson's ratio μ	Young's modulus E , Pa	Yielding limit σ_S , Pa	Yield constant Π , Pa	Density ρ , kg/m^3
0,3	$1,1\cdot10^{11}$	$8,85\cdot10^8$	$1,16\cdot10^6$	4600

Table 2

Properties of the material СКУ-7Л

Poisson's ratio μ	Young's modulus E , Pa	Material constant C_{01} , Pa	Material constant C_{10} , Pa	Density ρ , kg/m^3
0,499	$2,82\cdot10^6$	$1,38\cdot10^5$	$5,52\cdot10^5$	1259

Table 3

Properties of the material CE 1250-230-39

Lay-up monolayer angle, grade	Poisson's ratio μ			Young's modulus E , Pa			Shear modulus G , Pa			Density ρ , kg/m^3
	XY	YZ	XZ	X	Y	Z	XY	YZ	XZ	
0	0,31	0,04	0,04	75,9	3,9	3,9	0,9	0,9	0,9	1550
45	0,18	0,04	0,18	6,97	3,9	6,97	27,9	0,9	27,9	
-45	0,18	0,04	0,18	6,97	3,9	6,97	27,9	0,9	27,9	

Creation of FE initial parametrical mesh, defining contact conditions. The accuracy of the FEM analysis results depends on characteristic dimension and shape of the FE [5] so the parameters of final meshing of the object under consideration are determined on the base of estimation of the approximation error with the help of several tentative numerical experiments. Finally, approved degree of the object meshing mustn't exceed value for which error equals 5%. The parameters of initial Discretization of region under consideration are represented in table 4.

Interaction of the contact surfaces of the components of the system under consideration, which are in the region of the existing or possible contact, is described by the following condition: normal contact loads both of the deformed and of deforming body are equal; there are shear stresses on contact surfaces according Coulomb mode [8].

The static and dynamic coefficients of friction for corresponding contact pair are represented in table 5.

Table 4

Discretization degree of volumetrical regions

Volume i / FE volume$_i$	V_1/ FE$_1$	V_2/ FE$_2$	V_3/ FE$_3$	V_4/ FE$_4$	V_5/ FE$_5$	V_6/ FE$_6$
Value	3700	1500	8500	9500	131500	130500

Table 5

Static and dynamic friction coefficients

Contacting components	1-2	1-3	1-4	1-5	1-6	2-4	2-6	3-4	5-6
Static friction c-t ν_{st}	0,3	0,25	0,4	0,25	0,25	0,4	0,25	0,4	0,25
Dynamic friction c-t ν_{dyn}	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01

Defining parametrical initial and boundary conditions. Using of the FE of the lower dimensionality for modelling implies certain requirements for boundary conditions in the nodes which are at YZ and XY planes respectively. Such requirements are: displacement and constraints in all directions except direction of the main load (ensuring symmetry relatively mentioned planes). For ensuring only the axial movement of the tool and for elimination of the deviation of the rivet axe from the axe of symmetry, the radial displacements and rotational constraints are applied on all nodes at Y-axis.

Deformation of the rivet, stack, washer and elastic washer may be realized in two way: a – by means of nodes displacements at lower end of the striker by a value corresponding to necessary strain rate of the rivet; b – initial velocities assignment to the nodes at lower end of the striker. Both methods are used in solution of the problem under consideration.

At initial moment the striker is fixed. The lower end of the rivet shank is based freely at it. The varying forces during the time reaction are applied at the upper end of the manufactured head which, they simulates interaction with bucking bar. The constraint at all degrees of freedom is assigned at the nodes in lower and upper plates.

The accuracy of the nonstationary process modelling depends on chosen time step. The magnitude of the time interval is chosen on the base of estimation of the relative integral error of time approximation [5]. The several tentative numerical experiments are realized for this purpose. Initially chosen time interval is $T_{cal}/20$, where T_{cal} – calculated time of the impulse action (T_{cal}=0,001 s).

Solution of initial equations system. The solution of the initial system of the formed equations is realized in two stages. The first stage is realized by implicit solver for finding model response on dynamic loading; the second stage is elastic unloading realized by explicit solver. The parts of results are represented in fig. 2 and 3.

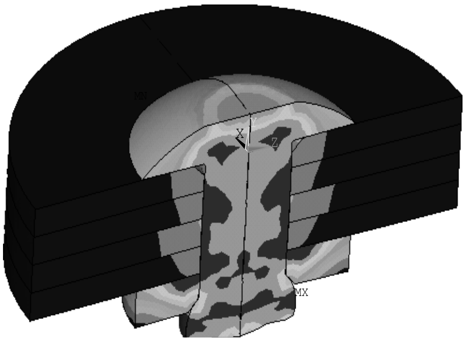

Fig. 2. Stress intensity distribution in the rivet after elastic unloading

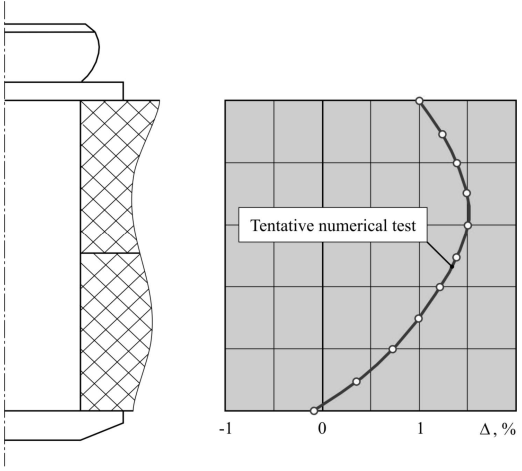

Fig. 3. Radial interference distribution along the rivet shank generatrix

Conclusions

Gained prior numerical model is the base for further development of its structure with the aim of complete verification procedures complex carrying out and establishing of strict analytical relations between investigating geometrical, physics-mechanics and energetic process parameters. The results, gained by prior numerical model even in present level of research, allows to make a conclusion about satisfaction of qualitative conformity with real natural experiment (Fig. 2) [3, 9, 10] of investigated parameters series.

However, the use of developed model at the present phase don't allow to realize the complete full-scale experiment as a result of absence of computer-time costs vs. accuracy of gained results function and incomplete work under complex verification of entire model.

Prospects of further research work

To complete full-scale experiment it is necessary to realize unsolved tasks from "Research aim and tasks to perform" section. In case of complete realization of these tasks, the gained results may become usable for achieving of following aims:

1) verification and optimization of process parameters with similar physics base but with different initial and boundary conditions;

2) optimization and determination of analytical relations between inner technological and design parameters of investigated technological process;

3) guidelines formulation to mechanization and automation of investigated process.

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