

Novel Method for Strength Analysis of Damaged High-Loaded Composite Panel

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Abstract. The paper is devoted to the creation of automated methods for calculating the strength of composite structures, taking into account the influence of impact damage and temperature effects in the range from -60° to $+60^{\circ}$. To solve this problem, a program for automated finite element modelling of a typical reinforced composite panel was created. Program allows to conduct parametric studies of strength and stability in an automatic mode, to model panel impact damage and to parameterize the temperature dependence of the strength of a composite. Using this method, results were obtained on the strength and stability of the panel in the temperature range and in various damage parameters.

1 Introduction

The beginning of use of composite materials in aviation has opened up new prospects in the aircraft industry, making it possible to reduce the weight of the structure compared to weight of traditional aluminium-alloyed structures. However, features of composite materials such as structural heterogeneity, reduced crack resistance, climatic degradation and low survivability after damage, are serious obstacles to the complete transition to composites in aircraft design.

The mentioned problems can be solved by accumulating a significant experimental and computational experience in composite materials. Experimental studies of strength taking into account climatic influences are traditionally carried out in the natural environment, in large-sized climatic chambers for a full-scale experiment, and in portable chambers for testing small specimens. Each of these methods has its own field of application, its own advantages and disadvantages.

Experimental studies are usually accompanied by computational methods of analysis of the strength. Currently, the finite element method has the greatest use in strength analysis. Climatic effects modelling has its own features. For accurate modelling of local zones, the structure is simulated at the micro level. For modelling aircraft structures, it is entirely more expedient to model the composite at the macro level using 2D elements. However, in this case, mathematical dependences have to be taken from the experiment to successfully

simulate the effect of temperature. Thus, to create models of temperature dependences, it is necessary to conduct series of experiments.

On the other hand, experimental studies of composite materials are always connected with the influence of many effects, therefore, to increase the efficiency and reduce the cost of research, it is necessary to bring the computational support of the experiment to a higher level. The management of the experiment and the adjustment of the experimental program should occur in online regime. Thus, for the effective study of the composite materials strength, it is necessary to create calculation-experimental methods.

2 Creation of a calculation-experimental method for strength analysis of reinforced composite panel

During the development of the concept of a perspective research complex the optimal experimental setup and software package was proposed. At the initial stage, work was carried out in two directions: the development of the optimal experimental setup for conducting strength tests at various temperatures and the creation of a computational program for the automated creation of a parametric model with conditions corresponding to the experiment.

2.1 Experimental setup

During the development of an appropriate experimental setup, it was decided to move away from the use of traditional climate chambers in favour of a cheaper and more universal way of transmitting temperature effects. It was decided to use a jet blowing system for cooling and heating due to several advantages over climate chambers. Jet blowing systems have a simpler design and, as a result, lower cost and higher reliability, and higher rates of energy transfer. The more powerful heat transfer simplifies the model isolation requirements, the insulating shell can be quickly assembled from cheap materials, which allows testing samples with a wide range of geometric dimensions. For specimens heating it was decided to use a modified electric air heater and for cooling – a nitrogen-air cold generator developed in TsAGI. The principle scheme of the cold generator is shown in the figure 1. Gas cooling is achieved by mixing air with liquid nitrogen. Cyclotron evaporator is used for efficient nitrogen evaporation.

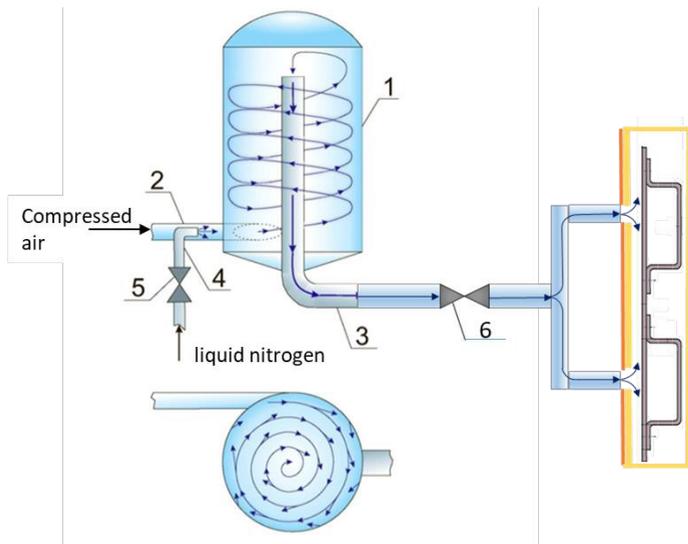


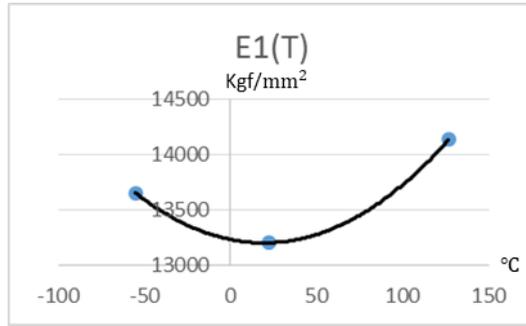
Figure 1. 1 - Cyclotron evaporator. 2 - Air pipeline. 3 - Pipeline with nitrogen-air mixture. 4 - Pipeline with liquid nitrogen. 5, 6 - throttle plates for flow control.

2.2 Automated computational program

In a perspective computational-experimental complex, the interaction between the calculation and the experiment occurs online, so the program complex must have a high degree of automation. At this stage, a program was developed for the automated creation of a model of a reinforced panel taking into account the influence of temperatures and damage. The program code is written in Patran Command Language and the finite element calculation is conducted in Nastran.

The program takes geometric parameters as input, i.e. type of reinforcement (“L”, “Z”, “T”, “hat” -stringers), the number of layers in the package and the parameters of the finite element

Modeling the effect of temperature on the mechanical properties of the composite is as follows. Mechanical properties such as elasticity, maximum stresses and strains are taken from the experiment for 3 temperature points. To obtain values at any point in the temperature range, the dependences of the mechanical properties are modelled by extrapolation by a polynomial. An example of such extrapolation for Young's tensile modulus is shown in the figure below.



Graph 1. Temperature dependence of the elastic modulus in the longitudinal direction for material T 300 17k / 976.

The load and boundary conditions are set based on the conditions of the experiment. At this stage, the program models distributed load with load components assignments.

To calculate the strength of the damaged panel the method of reducing the mechanical characteristics was used. The structural features of the composite are such that after the impact the destruction of the material can be both visible and invisible (inner structural destructions). The visible part can be localized by visual methods, invisible internal damage can be localized using ultrasound. These areas are modelled by two concentric circles and its mechanical characteristics are changed in compare with undestroyed material by multiplying it by the reduction coefficients. Coefficients can take values from 0 to 1. Mathematical dependencies for the coefficients depending on the impact force, panel thickness and temperature are to be obtained in future experiments

3. Parametric study of the reinforced panel

For a parametric study, a typical panel 488x400 mm reinforced by hat stringers was taken, which has the geometry that is shown in Fig. 2. The panel is made of T 300 17k / 976 composite

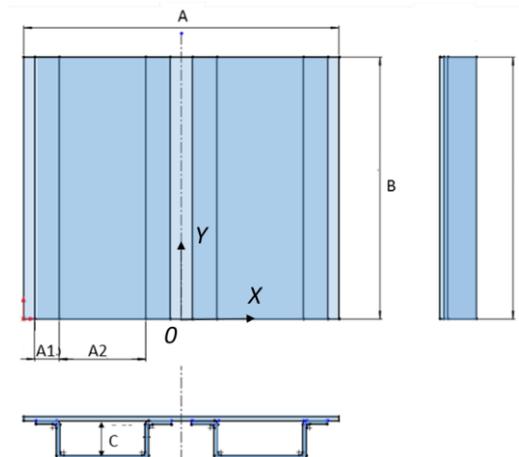


Fig.2 A variant of a reinforced panel.

The mechanical characteristics of the material were taken from [4] and approximated to obtain values in the temperature range -60 ... +60. Impact damage was modeled by internal and external circles with diameters of 30 and 105 mm, respectively as shown in fig 3.

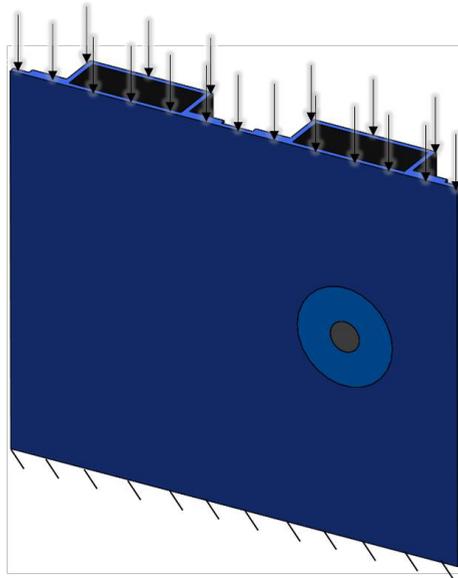


Fig. 3. The model of the damaged area on the panel.

. With reduction coefficients taken as 0.1 and 0.5, respectively, the strain field and the first form of buckling occurs as shown in the figure:

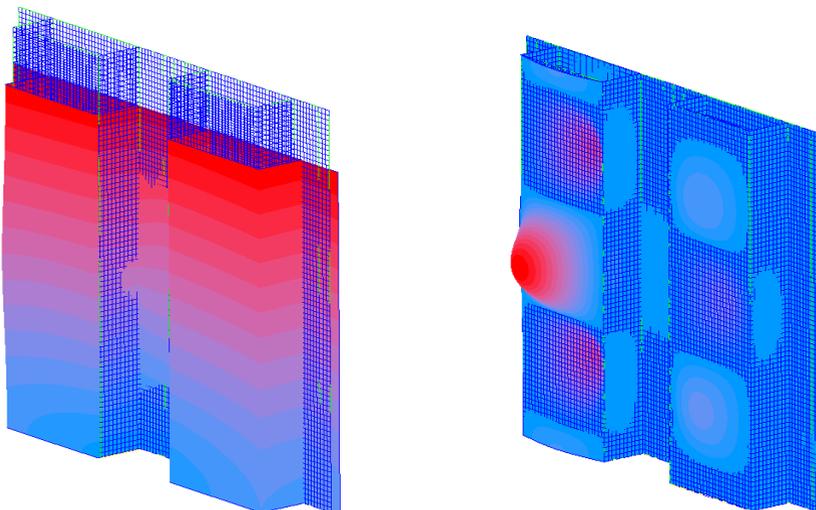
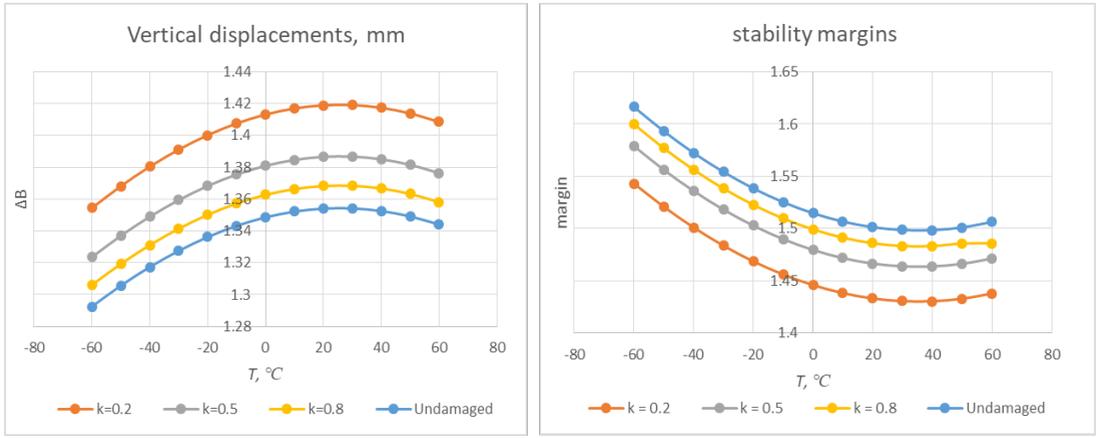


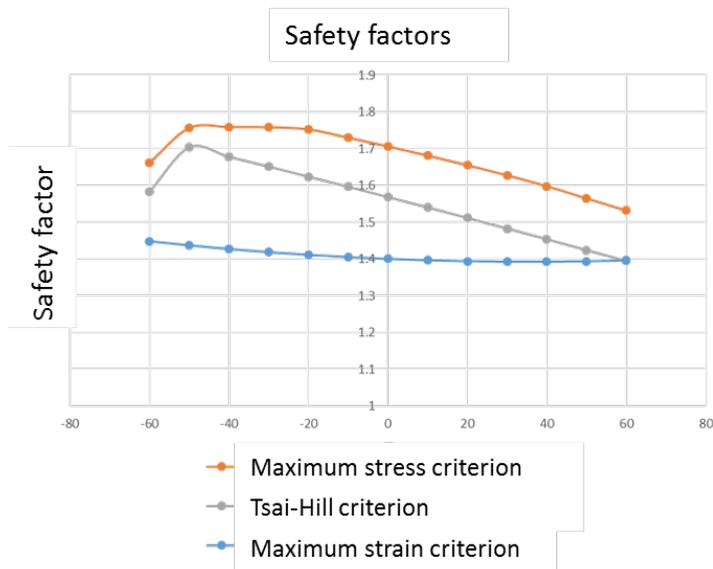
Fig. 4. The deformation and first mode of buckling.

Parametric dependences of panel edge displacement and stability margins (the ratio of the current load to the load when the first mode of buckling occurs) on temperature and reduction coefficient were studied using the program. The results are shown in graph 2. You can see that with a decrease in the reduction coefficients, the deformation of the panel increases and the stability margins decrease. Selecting various reduction coefficients and comparing the calculation results with experiment, we can obtain mathematical models for the reduction coefficients



Graph 2 Vertical displacements and stability margins in different temperatures and reduction coefficients

For one of the damage options, there are temperature dependences for safety factors (how much stronger a system is than it needs to be for an intended load) according to various strength criteria shown on the graph 3:



Graph 3 Parametric dependences of safety factors on temperature.

3. Conclusion

An approach to testing under the influence of temperature and damage is proposed, consisting in the online interaction of calculation and experiment.

A calculation program that has been developed allows to build and solve a finite element model in an automated mode with various parameters

Mathematical models of temperature dependence and reduction coefficients will be validated in further research

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