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Mechanical Behavior of the PVC Windows Frames under Alternating Load

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ABSTRACT

In the present work, an analysis of the joint work of the glass-frame system at variable temperatures is performed, taking into report the climatic conditions in Bulgaria and the real properties of the materials. The properties of the window sash materials, expressed in SN curves, are taken from literature data. Goodman's method is used to convert the fluctuating in the compression zone load into a fully reversed load. All calculations are accomplished by Ansys Mechanical software. Results have been obtained for the long-term strength of the structure as a total and the maximum number of cycles that the window sash can withstand without fracture. These results can be used for the general design of windows and glass facades.

Keywords: *Window frames, alternating load, numerical simulation.*

INTRODUCTION

Due to the peculiarities of its geographical location, in the territory of our country are observed large temperature fluctuations as in the annual so in the day and night periods [1, 2]. For this reason, during exploitation, the structure consisting of a window frame and glazing experiences cyclic loads, caused by day and night temperature differences. Analysis of the influence of thermal load on double-glazed with elastic primary and secondary sealant is presented in [3 - 5]. It has been shown that the temperature change impacts the glass panels of the glazing not directly only but also through the thermal expansion of the insulating gas. In turn, the glass and the frame material have very different coefficients of thermal expansion, which in the temperature changes, it creates forces of interaction. During the installation of the glazing, the connection with the window frame is by free support, without sticking, so the forces of interaction can be only compression. As the coefficient of thermal expansion of the glass is significantly lower than that of the frame material [6, 7], it is expected that the induced compressive forces will be obtained, when the temperatures are lower than those during installation. Even when considered separately, the glazing and the frame

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are a complex system, it consists of glass panels, spacer, primary and secondary sealant, polymer body and metal reinforcement. This makes the analysis of this system too difficult to realize with known analytical methods. Some experiences are known [8, 9] for conjugate strength-thermal analysis of window structures with the help of software, that solves the process control partial differential equations by the finite element method. However, they do not take into account the fatigue of the material under cyclic loading during the day and night periods. In the present work, with the help of the Ansys Mechanical software, an analysis of the cooperative work of the glass-frame system at variable temperatures is performed, taking into report the climatic conditions in Bulgaria and the real properties of the materials.

One of the main problems of strength analysis at alternating stresses is the relationship of the mechanical properties of the material with the actual load regime. The most common mode in which the mechanical characteristics are obtained experimentally is the fully reversed cycle. On the other hand, in the best event, the actual load on the window sash can be modeled with some repeated cycle, the amplitude of which depends on the specific climatic conditions. Numerous complex fatigue tests with different cycle parameters are avoided by so-called „Mean stresses correction“[10]. Instead of constructing multiple curves, and interpolating between them, the correction of the mean stress can be done by calculating equivalent fully reversed cycles with the appropriate amplitude based on the properties of the material. There are several methods by which the amplitude of the equivalent full reversed cycle can be determined. The most commonly used of these methods are presented in Table 1, where S_a = alternating stress, S_{ca} = the corrected alternating stress (based on zero mean.), S_y = yield stress, and S_u = ultimate strength [11].

In the present work, Goodman's method is used to convert the fluctuating in the compression zone load into a fully reversed load. The properties of the window sash materials, expressed in SN curves, are taken from literature data. Results have been obtained for the long-term strength of the structure as a total and the maximum number of cycles that the window sash can withstand without fracture.

EXPERIMENTAL

The object of the study is a mechanical structure containing double glazing and a frame (Fig. 1). The frame (1) is made of unplasticized polyvinyl chloride with a steel profile (2). The glazing unit consists of two glass panels (4) with

Table 1. Most commonly used methods.

Method	Equation
Goodman method - generally suitable for brittle materials:	$S_{ca} = \frac{S_u S_a}{S_u - S_{mean}} = \frac{S_a}{1 - \left(\frac{S_{mean}}{S_u}\right)}$
Gerber method - generally suitable for ductile materials	$S_{ca} = \frac{S_a}{1 - \left(\frac{S_{mean}}{S_u}\right)^2}$
Soderberg method - generally the most conservative	$S_{ca} = \frac{S_y S_a}{S_y - S_{mean}} = \frac{S_a}{1 - \left(\frac{S_{mean}}{S_y}\right)}$

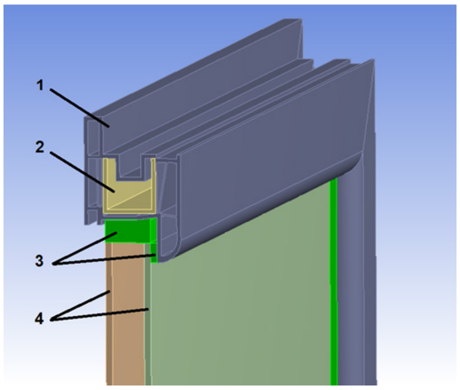

Fig. 1. Mechanical structure.

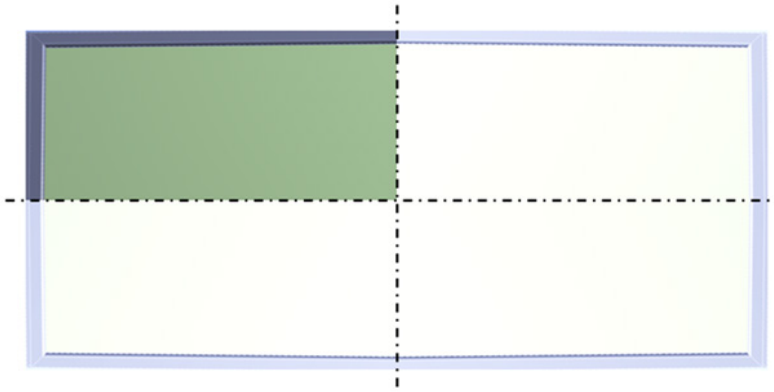

Fig. 2. Planes of symmetry.

Table 2. Material properties.

Materials	Properties		
	Young's Modulus [MPa]	Poisson's Ratio	Isotropic Secant Coefficient of Thermal Expansion [1/°C]
PVC	4000	0,3	1e-04
Steel	2e+05	0,3	1,2e-05
Glass	90000	0,3	9e-06

a thickness of 4 mm each, an aluminum spacer, a primary seal of polyisobutilene and a secondary seal (3) of silicone . Since for the studied processes the system of glass plane and the frame has double plane symmetry (Fig. 2), the analysis is limited to ¼ from the total area. The properties of the materials used are given in Table 2.

The structure was studied in climatic conditions of temperature fluctuations from 32°C (estimated installation temperature) to 12°C (estimated night temperature for the period). To assess the behavior of the investigated structure under this load, SN curves obtained by summarizing the data, given in [12] and [13] for the participating materials (Fig. 3), were used.

The study was conducted in two stages. In the first stage, the aim is to determine the parameters of the mechanical load, formed by the accepted climatic conditions. Since this results in a fluctuating load with a random cycle, in the second stage of the study, the cycle is transformed into a fully reversed one. Using the accepted SN curves, a decision is made to determine the continuous strength at a given number of load cycles, the fatigue limit at countless cycles and the safety factor.

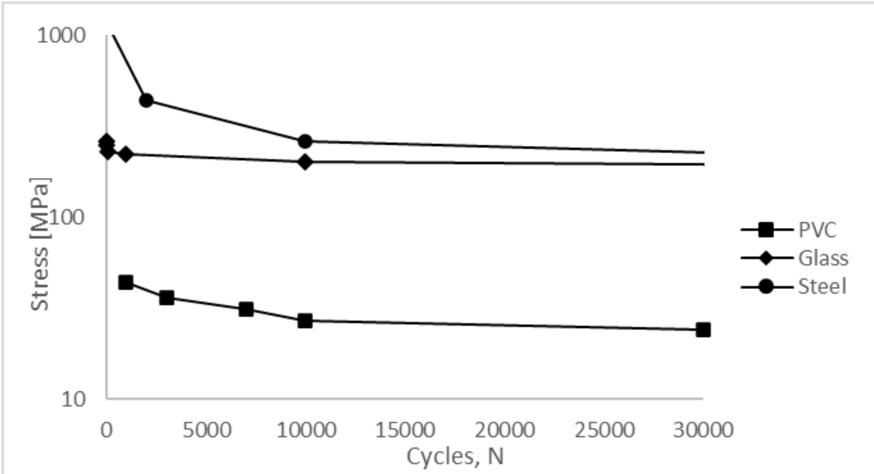

Fig. 3. Summarizing data of the materials.

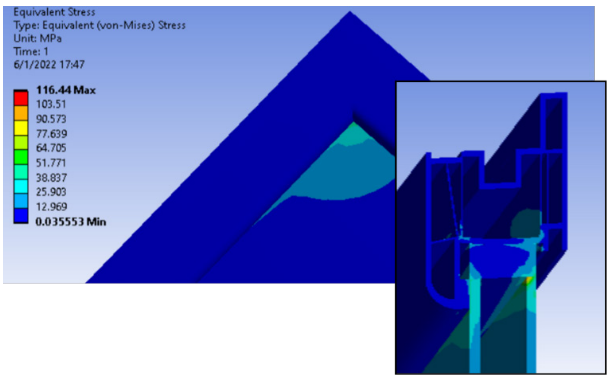

Fig. 4. Maximum Equivalent Stress.

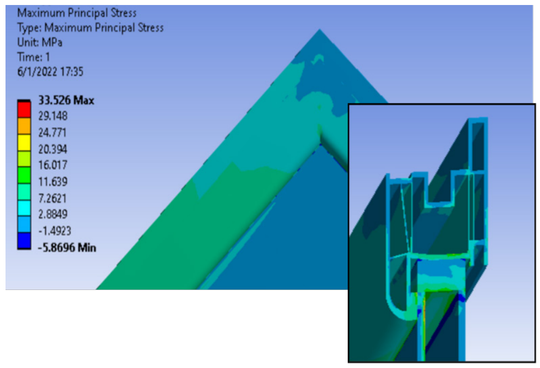

Fig. 5. Maximum Principal Stress.

RESULTS AND DISCUSSION

The parameters of the mechanical load, which are determined in the first stage of the study are Equivalent von Mises Stress, serving as a general assessment of the stress state, Maximum Principal Stress, causing the formation and opening of existing cracks of the first mode, and Maximum Shear Stress causing the formation and growing of cracks of the second and third mode.

Fig. 4 presents the area with Maximum Equivalent Stress. Maximum Stress of 116 MPa has been registered, concentrated in a limited area at the corner joint of the profiles, forming the windows frame.

Fig. 5 presents the area with Maximum Principal Stress. Maximum Stress of 33,5 MPa has been registered, which in this case plays the role of maximum stress in the fluctuating load cycle. Thus, the parameters of the real load cycle average stress s_m = 33.50 MPa and amplitude s_a = 16.75 MPa are formed.

The area with maximum shear stress is represented in Fig. 6. The maximum stress of 60.5 MPa was registered, which in this case plays the

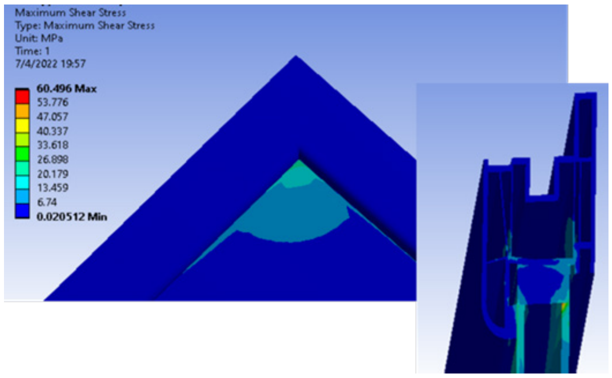

Fig. 6. Maximum Shear Stress.

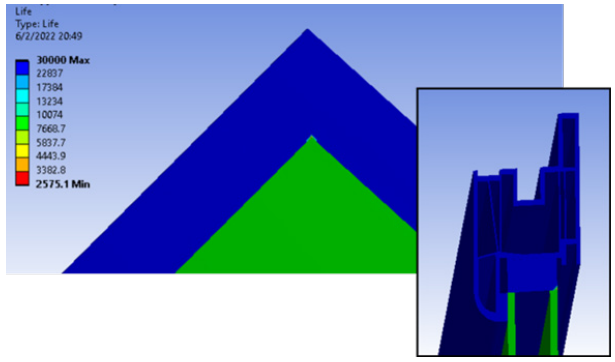

Fig. 7. Number of cycles to failure.

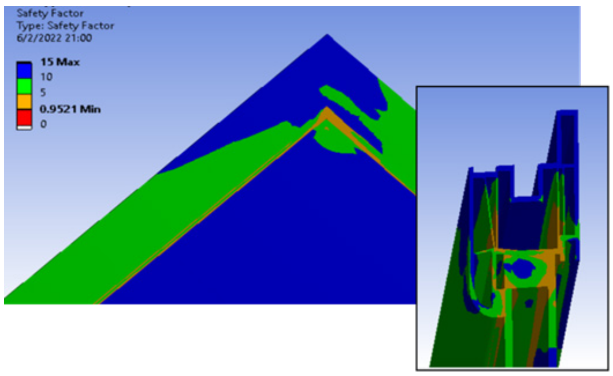

Fig. 8. Safety Factor.

role of maximum stress in the fluctuating load cycle. Thus, the parameters of the real load cycle average stress t_m = 60.50 MPa and amplitude t_a = 30.25 MPa are formed.

Fatigue calculations were performed with the load cycles thus obtained, using the Goodman method for Mean stress correction. The main results obtained are for the long-term strength and the safety factor. Fig. 7 shows the most unfavorable results for the number of cycles to failure in the area of the corner joint. It can be assumed that the maximum number is 3000, which roughly corresponds to a service of 8 years life under these operating conditions. For this period, the results exceed the safety factor in a very limited area (Fig. 8), which can be accepted from a technical point of view. As an additional result, the Biaxiality Indication that displays a contour diagram of the biaxiality of the stress on the model, which in turn indicates the state of stress throughout the body, can be specified. A biaxiality of 0 corresponds to uniaxial tension, a value of -1 corresponds to pure shear, and a value of 1 corresponds to a purely biaxial state.

CONCLUSIONS

During operation, the window frame and the glazing experience cyclic loads, caused by day and night temperature differences. Analysis of the cooperative work of the glass-frame system at variable temperature, taking into report the climatic conditions in Bulgaria and the real properties of the materials, can be performed with the help of the Ansys Mechanical software. Of the methods for linking one of the mechanical properties of the material with the actual load regime, available in the software, the Goodman method can be successfully used. The obtained results show that for the loads formed by the climatic conditions in Bulgaria, the parameters of the real load cycle are average stress s_m = 16.75 MPa and amplitude s_a = 16.75 MPa for the normal stress and average stress t_m = 60.50 MPa and amplitude t_a = 30.25 MPa for the shear stress. These results can be used in the general design of windows and glass facades.

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