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APPROXIMATE ANALYSIS OF THE THERMAL OPERATING REGIME OF A CHAMBER FOR TREATING MATERIALS WITH THERMAL ENERGY*

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UDC 537.32

A thermal operating regime is studied for the walls of a chamber for deburring materials. Often these chambers are made in the form of thin-walled cylindrical vessels whose walls have thermal protection (a thin internal layer of material with high thermal conductivity). The chamber wall is modeled by an infinite two-layer plate, the external surface of the plate is maintained at a prescribed temperature, and at the internal surface the heat flow is prescribed [1] characterizing the heat transfer of gas mixture detonation products into the chamber wall. It is assumed that at the interface of the layers a condition of ideal thermal contact is fulfilled. The chamber operating regime for deburring materials is defined by the periodicity of treatment cycles which as a rule are 15-20 sec.

The temperature field for the chamber wall is constructed both for the first cycle and with several of the first treatment cycles. The construction with the first cycle is carried out by two standard methods. It is revealed that introducing thermal protection makes it possible to reduce by several factors the temperature of the internal surface and to increase by about an order of magnitude the time for reaching the maximum temperature of the internal surface compared with a single-layer chamber.

The temperature field in a time interval corresponding to five material treatment cycles is obtained by the method of numerical modeling (Fig. 1). The broken line relates to a single-layer chamber wall, and the solid line relates to a two-layer chamber. It can be seen

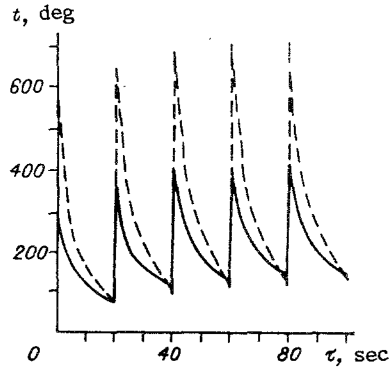

Fig. 1

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that the peaks of the curves emerge into a certain steady level. Thus, from the results of a numerical experiment it follows that the temperature field in the chamber wall after five to six material treatment cycles almost emerges into a steady periodic regime. A periodic thermal regime for the chamber walls is most critical, and therefore it is necessary to use this regime in evaluating thermoelastic stresses in the chamber walls. In addition, the maximum temperature of the internal chamber wall should not exceed the ignition temperature of the gas mixture for deburring.

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NUMERICAL CALCULATION OF THERMOELASTIC STRESSES IN CHAMBERS FOR DETONATING A GAS MIXTURE

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With detonation of a gas mixture in a chamber as a result of induced detonation product convection, caused by a shock wave, the thermal flow towards the walls of the chamber is described by a rapidly decreasing time function so that the maximum temperature at the internal surface of a chamber with a size of the order of ~0.4 m is reached in a time $\sim 10^{-2}$ sec. This time in order of value is the same as the typical time for the decrease in thermal flow or shock-wave attenuation [1]. In time $\tau_0 \approx 10^{-2}$ sec a layer of metal with thickness $\delta = \sqrt{4a\tau_0} \approx 10^{-3}$-$3 \cdot 10^{-3}$ m (a is thermal diffusivity) is heated [2], and the thickness of the chamber wall is normally several centimeters. Simple estimates of circumferential stresses in the internal surface of a steel chamber according to data in [2] with detonation of a propane–oxygen mixture $C_3H_8 + 10O_2$ with initial pressure $P_0 = 0.8$ MPa are as follows: thermal stresses $\sigma_t = E_1\alpha_1\Delta T \approx 1330$ MPa, elastic static stresses as a result of gas pressure with instantaneous combustion $\sigma_y = (Pr_0)/H \approx 40$ MPa (P is pressure at the internal surface), dynamic stresses taking account of the reflection of detonation waves $\sigma_d \approx 10\sigma_y = 400$ MPa. Here it assumed that $E_1 = 21 \cdot 10^4$ MPa, $\alpha_1 = 12.1 \cdot 10^{-6}$ deg^{-1}, $\Delta T = 524$ deg, $r_0 = 0.16$ m, $H = 0.04$ m (E_1 is elasticity modulus, α_1 is linear expansion coefficient, ΔT is the increase in temperature over the initial temperature, r_0 is chamber internal radius, H is thickness). These estimates show that in chambers for treating materials by gas detonation thermal stresses σ_t in the surface layer are the main factor in failure. For this reason there is specific interest in accurate calculation of the thermal stress fields in the walls of a chamber using the distribution of temperature fields obtained in [3].

The aim of the present work is numerical calculation of the thermoelastic stress fields in the chamber walls and then on the basis of the calculation, recommendation of some simple approximate approach for estimating the maximum thermal stresses. In the last case the periodicity of thermal flow at the internal surface is considered.

1. Pressure at the Internal Surface Required in Order to Calculate Thermal Stresses. The pressure of gas mixture detonation products within the chamber in relation to time may be found by proceeding from an equation of state for an ideal gas

$$P(\tau) = (\rho R T(\tau))/\mu \tag{1.1}$$

(P, ρ, R, μ, T are pressure, gas density, gas constant, molecular weight, and gas temperature). The change in gas temperature with time in the chamber is determined from the first rule of thermodynamics

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