Lishchenko Natalia

Лищенко Наталия Владимировна

Ліщенко Наталя Володимирівна

Larshin Vasil

Ларшин Василь Петрович

Ларшин Василий Петрович

Marchuk Irina

Марчук Ирина Викторовна

Марчук Іріна Вікторівна

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Abstract

A mathematical model is developed for a grinding temperature cycle, invariant to the machining material properties and grinding modes with the managed dimensionless parameters of forced cooling, taking into account the heat exchange and grinding fluid temperature. The influence of these parameters on the dimensionless and dimensional grinding temperature is investigated. A grinding temperature cycle mathematical model includes the heating and cooling stages with and without grinding fluid application. The influence of the grinding fluid temperature and the heat transfer coefficient on the grinding temperature is established. Comparative studies of one- and two-dimensional solutions of the heat conduction differential equation that take into account the forced cooling during grinding have been carried out. The difference in the results of calculating the dimensionless temperature by the solutions of one- and two-dimensional mathematical models does not exceed 4.5–10.6%. The comparison of the two models is performed for the Peclet number with the value of more than 4 which just takes place in contemporary profile grinding.

The obtained one-dimensional mathematical model with two equations (4) and (5) was compared with a similar two-dimensional model with equation (2) analyzed above which contains one equation both for heating and cooling stages. The equation (2) is obtained under the boundary conditions of the third kind, but with a number of assumptions that allow us to take into account the non-homogeneous (discontinuous) boundary conditions of the real problem [19]. Thus, a one-dimensional mathematical model containing two equations (4) and (5) differs only in the absence of a coordinate z in the direction of which the strip heat source moves at a velocity V.

Comparative studies of one- and two-dimensional mathematical models according to equations (4) and (5), on the one hand, and equation (2), on the other hand, were performed with the following input data: $a = 5\cdot10^{-6}$ m^2/s; $\lambda = 25.54$ W/m·°C; $\alpha_h = 36000$ W/m^2·°C; $V = 3$ m/min (0.05 m/s); $h_H = 1$ mm (half width of the contact); $H_H = \frac{Vh_H}{2a} = 5$; $Bi = \frac{\alpha_h h}{\lambda} = \frac{36000\cdot1\cdot10^{-3}}{25.54} = 1.41$; $k = 1.54$; $\beta = \frac{2a}{V}\frac{\alpha_h}{\lambda} = \frac{2\cdot5\cdot10^{-6}}{5\cdot10^{-2}}\frac{36000}{25.54} = 0.282$ (or the same $\beta = Bi/H_H$ = 1.41/5 = 0.282). The dimensionless coordinate along the depth of the surface layer in equation (2) was taken equal to $X = 0$, $X = 1$, $X = 3$ (Fig. 3). It is seen that the temperature fields for the one- and two-dimensional models are similar in heating and cooling stages. At the heating stage ($+1 \geq Z/H_H \geq -1$), as the magnitude X increases the dimensionless temperature Θ decreases. In the area of stable cooling, i.e. in the interval of $-4 \geq Z/H_H \geq -5$, on the contrary, as the magnitude X increases the dimensionless temperature Θ increases. However, according to a one-dimensional solution (interrupted lines in Fig. 3), the temperature at the cooling stage throughout the investigated range X is lower (intermittent lines are below the level of the corresponding continuous lines).

Taking into account that during grinding the most dangerous are high temperatures in the range of $-0.5 \geq Z/H_H \geq -1.5$ (the trailing edge of the source), we can conclude that the results of the grinding temperature calculation are closely related, to wit: in the interval of the argument $-0.5 \geq Z/H_H \geq -1.5$ the difference in the calculation results does not exceed 4.5-10.6%. It is known that for an overwhelming number of grinding schemes, the change interval for the Peclet number H_H is $20 \geq H_H \geq 4$ [22] and even $H_H \geq$ 20 [24]. Moreover, the difference between the one-dimensional and two-dimensional models increases as the value H_H approaches the lower value of this interval, i.e. at $H_H = 4$ [22]. Thus, the comparison of two solutions in an unfavorable situation, e.g. at $H = H_H = 5$ is methodologically justified since in the interval of $H_H \geq 5$ the difference in the calculations will be less than indicated.

The trend of contemporary grinding technology is the transition to high [10] and super-high [24] speeds. Consequently, the lawfulness of using a one-dimensional solution increases and the difference in the results of the grinding temperature determination decreases in terms of one- and two-dimensional solutions.

Keywords

Grinding temperature Modeling Heat conduction Heat exchange

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