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SIMULATION OF HEAT CONDUCTION IN PLASTICIZATION PROCESS OF NON–CLASSICAL MATERIALS

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ABSTRACT: Non–classical materials such as e.g. wood and sawdust require both special new machines as well as methods of shaping their geometrical characteristics. This issue deals with the characteristics of a plasticization process in a bounded layer of non-classical materials on the basis of material's actual structure and thermomechanical properties, being of importance in practical applications. This area of research has not been fully investigated either from the theoretical or applied perspective, yet. This issue is also of special importance for the development of methods of generating new characteristics of surface shaping, of its stereometry as well as designing machines and tools used for this purpose.

While modelling the process of sawdust briquetting the factor of principal importance is the critical effort of material when its plastic flow occurs. The value of this stress depends on the thermomechanical characteristics of the material and the basic parameters of the process, such as: exerted pressure, duration of the process and the temperature.

In this paper a mathematical model of heat conduction in the thin layer of a particulate material is given. Knowledge of temperature distribution in such materials is one of the basic elements of solving the problems of thin particulate material layer plastic yielding in briquetting process.

KEY WORDS: briquetting process, critical stress, temperature.

1. INTRODUCTION

The design of machines for compression of particulate materials is an important area of research, especially in view of the environmental protection requirements and the developments in processing of waste for power production applications. In the process described in this paper the briquettes are formed in an open chamber in binderless process (Fig.1). Cohesion and sufficient consolidation depends on the plastic flow state, which in the thin outer layer (crust) is effected by heat [1,4,5].

The work of friction related to pushing of sawdust through the main chamber and through the forming sleeve (Fig.1a, b) results in an increase of temperature in the outer layer of briquette to over 100 °C, which promotes plasticization of wood lignin [3]. In this way, a very thin crust is formed on the briquette, which after cooling down to the ambient temperature provides a uniform and smooth consolidating structure.

For effective plasticization and compression, the briquetting system must be designed with appropriate geometrical characteristics. Moreover, it is necessary to relate the compression resistance and the generated heat in order to stimulate the required critical stresses in the structure of formed briquette.

The experiences gained in the design, assembly and implementation of machines for refining of furniture components and briquetting of wood processing waste have been used in the present attempt to formulate consecutive equations describing the process of compression of particulate materials, allowing for the effect of temperature.

Hence, a mathematical model has been developed (the formulation process has been described in detail in [5,7,8]), based on a generalized model of a perfectly plastic body, which describes plasticization of a loose material in briquetting process. The limit energy of shape deformation was used to formulate the Huber – Mises yield condition [6], modified to allow for the effect of temperature.

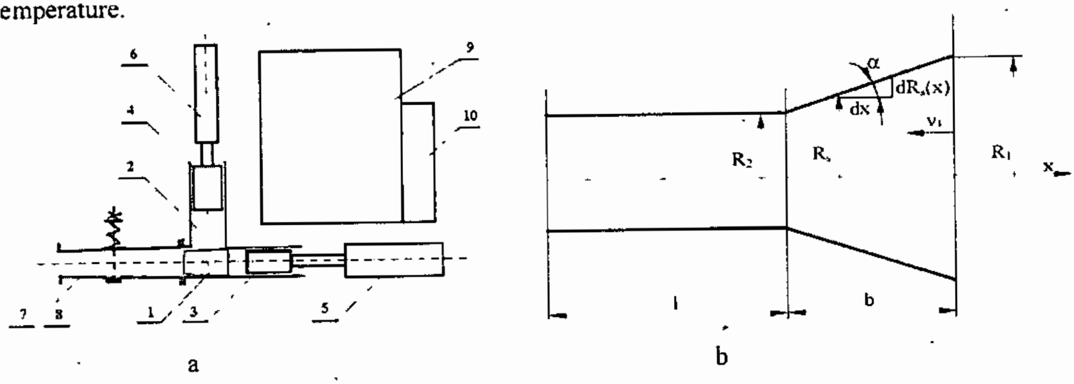


Fig.1: Hydraulic briquetting machine for processing of sawdust and other wood waste

a) Kinematic diagram of the pressing system, where: 1 – main chamber, 2 – primary compression chamber,
3 – main piston, 4 – primary compression piston, 5 – main cylinder, 6 – primary compression cylinder,
7 – forming sleeve, 8 – compression resistance adjustment device, 9 – hydraulic power unit, 10 – control system,
b) Pressing channel geometry, where: R_1 – radius of the main chamber inlet, R_2 – radius of the main chamber outlet, R_s – radius as a function of the main chamber length,
l – length of the forming sleeve, α – half of the main chamber convergence angle, b – main chamber length.

The work related to the actual deformation during pressing has been compared against the equivalent work expressed by the product of representative yield point of perfectly plastic body and the final deformation taken from the stress-strain curve:

$$\sqrt{3}\cdot k_T\cdot\varepsilon_k = \iint_a \sigma\varepsilon d\sigma d\varepsilon \qquad (1)$$

where: ε_k – final deformation taken from the actual stress-strain curve,

σ – stress during actual compression taken from the chart, $\sqrt{3}\cdot k_T$ – representative yield limit based on Huber – Mises hypothesis, k_T – stress equivalent to shear yield point, a – limits of integration.

The pressing force F (2) has been determined from the balance of externally applied forces used for energy dissipation power in the plasticization zone and power necessary to overcome the friction resistance, as described by the following equation:

$$F = 3\pi k_T R_1^2[\sqrt{3}\ln\frac{R_1}{R_2} + \frac{2}{3}(f_1\frac{\sqrt{1+(tg\alpha)^2}}{\cos\alpha}\ln\frac{R_1}{R_2} + f_2\frac{l}{R_2})] \qquad (2)$$

where: f_1 and f_2 – friction coefficients for the main chamber and the forming sleeve respectively.

Equation (1) may be used to determine the value of k_T – average stress of plastic flow equivalent to the shear yield point of the pressed material. However, this should be preceded by determining the distribution of temperature in the analyzed layer of briquette.

2. THE EFFECT OF TEMPERATURE ON BRIQUETTE FORMING PROCESS

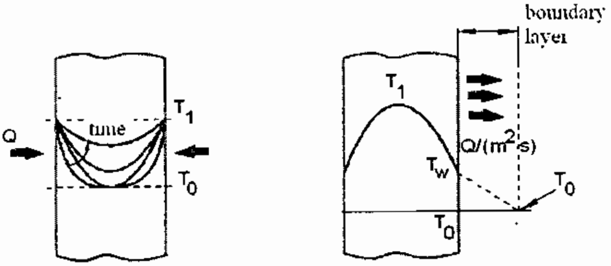
The temperature has been the key parameter in formulation of the consecutive equations describing the analysed process. A direct measurement of temperature in the crust of pressed briquette is hardly practicable, and hence the attempt to determine its distribution through theoretical analysis.

There are various ways in which heat penetrates inside a body. Here, we will briefly describe two of them, which are relevant to the process under analysis (Fig. 2a,b) due to the actual transfer of heat between the hot wall of the forming sleeve 1 (Fig. 1) and closely abutting briquette side. Unsteady heat conduction (Fig. 2a) (which is the case here) is described by the second Fourier law [2]:

$$\frac{\partial T}{\partial t} = a\nabla^2 T = a\frac{\partial^2 T}{\partial x^2} \tag{3}$$

where: $a = \dfrac{\lambda}{c_p \gamma}$ – thermal diffusivity, T– temperature, t – time, γ – specific gravity,

c_p – specific heat, λ – thermal conductivity,



a) b)

Fig. 2: Transfer of heat into the material

Highly relevant to the process under analysis is to consider convective transfer of heat (Fig. 2b), described by the following equation:

$$Q = \alpha\,(T_p - T_0),\ B_i = \frac{\alpha d}{\lambda} < 1 \tag{4}$$

where: T_p – surface temperature, T_0 – temperature of the boundary layer, α – heat transfer coefficient, in air = 5 – 50 [W/(m^{2}K)], B_i – Biot number, d – layer thickness.

Convection is more appropriate than conduction in describing the heat transfer when the Biot number is less than one (4), and for $B_i > 1$ heat is transferred by conduction.

Transfer of heat by unsteady conduction is the closest approximation of the actual transfer of heat between the hot wall of forming sleeve and the briquette. The hot wall of the forming sleeve is in contact with the surface of the formed briquette, and thus we can assume that the heat transfer coefficient α tends to infinity, and consequently the Biot number (4) is greater than 1. Thus, the criterion for conductive heat transfer is met.

The penetration of heat depends to a large extends on the dimensions of air voids and is reduced when the voids are smaller. Since the sawdust briquetting process under external pressure results in densification and plasticization of a layer of the processed material, the voids are reduced in size, which in turn reduces the amount of air and water they contained. Consequently, the effect of heat convection in air and water on the penetration of heat through the structure of wood is reduced and the transfer of heat may be considered as limited to conduction through fibres and pores only. Therefore, the analysis of the constitutive relations describing the heat transfer between the wall of forming sleeve and the briquette will be related to conduction only.

Heat conduction in the outer layer of briquette will be solved using equation (3), upon finite element discretisation. For the analysed unsteady heat transfer the equation will assume the following matrix form:

$$C\frac{d}{dt}[\Phi] + K[\Phi] = Q, \qquad (5)$$

where: **C** – thermal capacitance matrix; **K** – conductivity matrix; **Q** – heat load vector; $[\Phi]$– nodal temperature vector.

I-DEAS software program has been used to determine the distribution of temperature in the layer of briquette. The input data were the geometrical characteristics, process parameters and the sawdust properties, as used on the briquetting machine actually operating in a furniture factory.

Dirichlet boundary condition has been adopted, assuming known briquette surface temperature and Cauchy initial conditions i.e. at the time t = 0 the sample temperature is equal to the ambient temperature.

For more accurate solution of the temperature distribution in the briquette crust the grid density has been increased at the point of contact between the hot forming sleeve and the surface of plasticized material.

As the laminar representation of the spatial distribution of temperature does not allow for qualitative evaluation of the calculation results, they have been presented as curves (Fig. 3), related to the flat cross-section of a briquette, representing the increase of temperature as a function of time in the subsequent layers (1, 2, 3, 4) in the direction inwards the briquette.

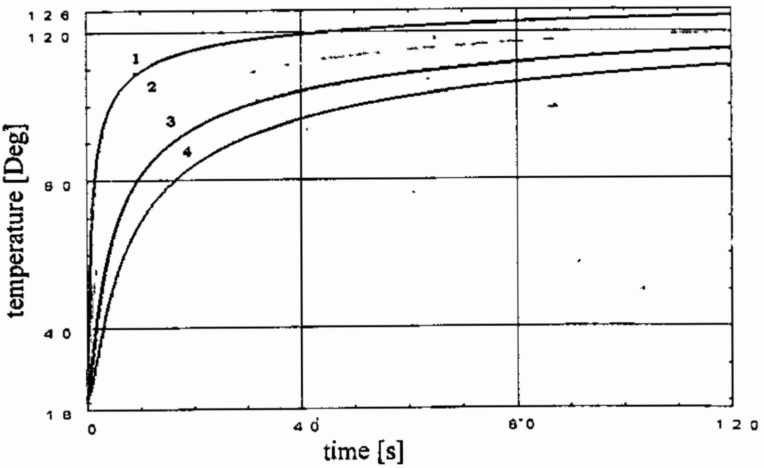


Fig. 3: Temperature as a function of time and depth inwards the briquette, where the temperatures correspond to the depths inwards the briquette as follows: 1 – 0.5 mm, 2 – 1 mm, 3 – 1.5 mm, 4 – 2 mm.