Ultrasonic measurements of rheological properties of disintegrated media

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Abstract: *Applying the ultrasonic method for evaluation of rheological parameters of a disintegrated medium is presented. The measurement stand and principle of ultrasonic measurement is described. Results of ultrasonic measurement and relationships $k_C = f(\delta)$ and $k_T = f(\delta)$ for moulding sand with bentonite Bentomak are included.*

Keywords: moulding sand, rheological model, ultrasonic method, measurement

1. Introduction

Rheological properties of a real material can be modelled if the material structure, the deformation process and the related changes of the material physical properties are known. However, direct analytical description of rheological characteristics of the material is an extremely complex and difficult question, and in many cases unrealisable. For this reason, to describe rheological properties the models are used that represent idealised simple substances combined to describe real rheological properties of the material are as exactly as possible [1,2].

Basically, selecting a suitable model representing rheological characteristics of a real material is possible on the grounds of an analysis of its experimentally determined dynamical properties. Dynamic properties of physical objects can be evaluated on the grounds of their time or frequency characteristics. In the case of disintegrated media (e.g. moulding sands), most advantageous is using a time characteristics, e.g. the step characteristics. Analysis of time characteristics of moulding sands proved that their rheological properties can be modelled using the viscoelastic rheological model shown in Fig. 1.

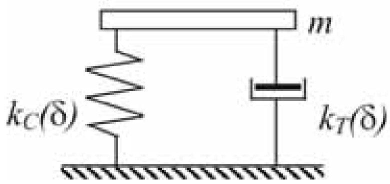


Fig. 1. Layout of viscoelastic rheological model of moulding sand: k_C – deformability-related factor, k_T – internal friction related factor, m – mass, δ – compression ratio of moulding sand

Application of a rheological model of moulding sand for modelling and simulating the deformation and densening process requires knowing the parameters characterising its deformability and internal friction. Deformability can be expressed as a function of the elastic constant $\boldsymbol{E}$ and Poisson's ratio ν, and internal friction can be expressed by means of elastic wave velocity $\boldsymbol{v}$ and material density ρ. Considering that, for a viscoelastic medium, elastic wave velocity (e.g. ultrasonic wave velocity $\boldsymbol{v_L}$) is [3]

$$v_L = \sqrt{\frac{E}{\rho}}\,, \tag{1}$$

the coefficients $k_C = f(\delta)$ and $k_T = f(\delta)$ can be expressed as

$$k_C(\delta) = a_1 \cdot exp[a_2 \cdot v_L(\delta)]$$
$$k_T(\delta) = b_1 \cdot exp[b_2 \cdot v_L(\delta)] \tag{2}$$

where: a_i , b_i – coefficients dependent on composition and type of the moulding sand.

So, it can be said that knowing the results of ultrasonic testing of moulding sand is the necessary and sufficient condition for determining the parameters of a rheological model of moulding sand.

2. Ultrasonic testing of moulding sand

A layout of the stand for ultrasonic testing of moulding sands is shown in Fig. 2. The transmitting and the receiving ultrasonic heads are rigidly fitted to opposite walls of the rectangular measuring chamber. This assures constant sample length and its good contact with the ultrasonic heads, which results in good repeatability of measurement results. The measurement error of ultrasound transition time is $\Delta t = \pm 1.5$ μs or $\Delta v_L = \pm 4.5$ m/s as calculated for accuracy of ultrasonic wave velocity in moulding sand.

a) b)

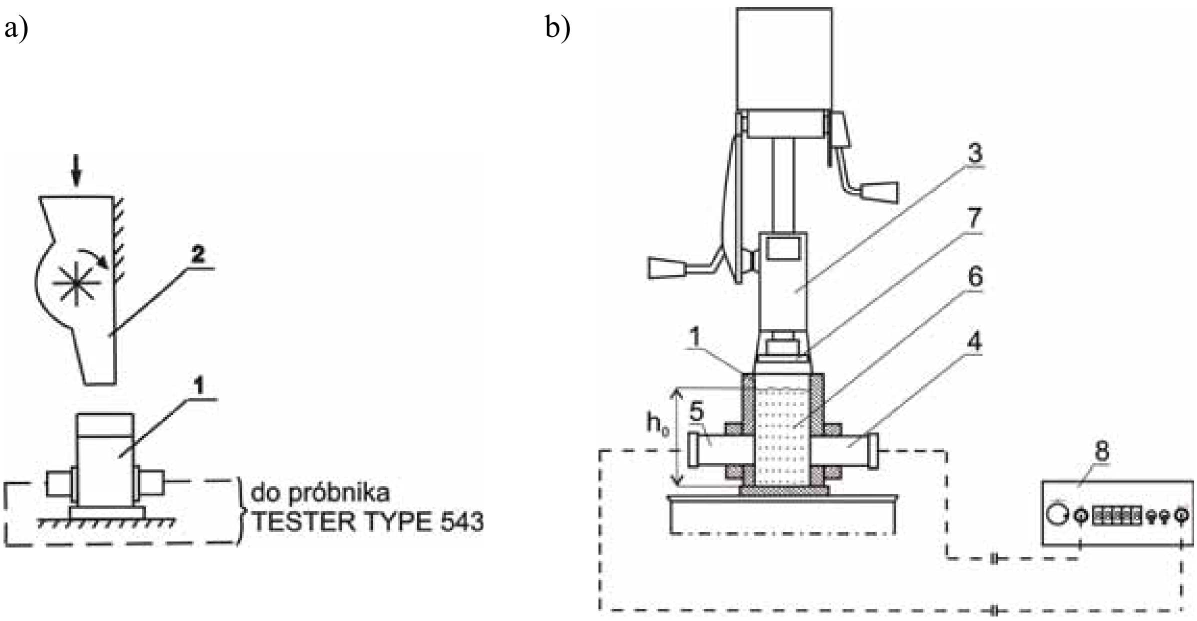


Fig. 2. Layout of ultrasonic test stand: moulding sand dosing stand (a) – measuring chamber (1), disintegrator (2); measuring stand (b) – rammer LU (3), transmitting (4) and receiving (5) ultrasonic heads, Moulding sand sample (6), rectangular foot (7), material tester type 543 (8)

Ultrasonic measurements are performed in the following way: After a 350-g sample was metered to the measuring chamber and placed on the laboratory rammer, the foot of the rammer was lowered and the moulding sand densened by single stroke of the rammer weight. Then, the ultrasound transition time t_1 was read out and sample height h_1 measured. Measurements of the transition time t_i and height h_i were repeated several times, each time for the consolidation degree increased with the rammer. The measurement results t_i and h_i were used for calculating the ultrasound propagation velocity and the moulding sand consolidation degree. The relationship $v_L = f(\delta)$ can be approximated with the following function:

$$v_L = C_1 \cdot exp(C_2 \cdot \delta) \quad (3)$$

where: C_1, C_2 – coefficient dependent on type and composition of the moulding sand.

Fig. 3 shows the relationship $v_L = f(\delta)$ for moulding sand with 6 % of bentonite Bentomak and humidity W = 2.44 – 2.80 – 3.70 %.

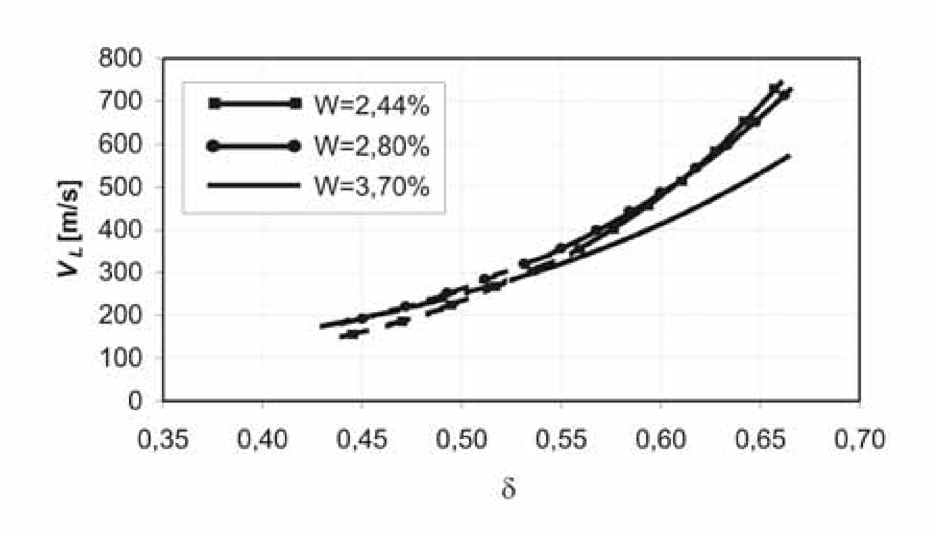


Fig. 3. Relationship $v_L = f(\delta)$ for moulding sand with 6 % of bentonite Bentomak and with various humidity

3. Parameters of the rheological model of moulding sand

The relationships $k_C(\delta)$ and $k_T(\delta)$ can be determined by substituting $v_L = f(\delta)$ to the formulae (2). Figure 4 shows the relationships $k_C(\delta)$ and $k_T(\delta)$ obtained for the moulding sand with 6 % of bentonite Bentomak and with various humidity.

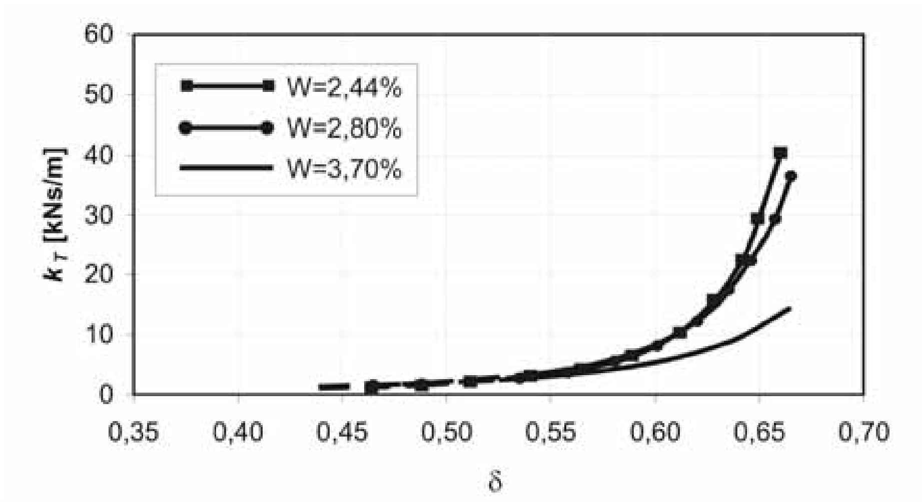
It can be found on the grounds of the results shown in Fig. 4 that slight changes in moulding sand humidity result in significant changes in its rheological properties. In other words, humidity decisively affects mechanical properties of moulding sand, including its mechanical properties.

4. Summary

It was proved on the grounds of the presented results that:

- Modelling rheological properties of moulding sand with the viscoelastic rheological model requires knowing the coefficients $k_C(\delta)$ and $k_T(\delta)$ that characterise deformability and internal friction of moulding sand as a function of its consolidation degree.
- Taking ultrasonic measurements of moulding sand is the necessary and sufficient condition for determining the relationships $k_C(\delta)$ and $k_T(\delta)$.
- On the grounds of ultrasonic testing it is possible to determine the relationship $v_L = f(\delta)$ representing longitudinal ultrasonic wave velocity as a function of consolidation degree of moulding sand.
- The relationship $v_L = f(\delta)$ makes the grounds for approximation of the coefficients $k_C=f(\delta)$ and $k_T = f(\delta)$ representing elastic and viscous properties of moulding sand.

a)



b)

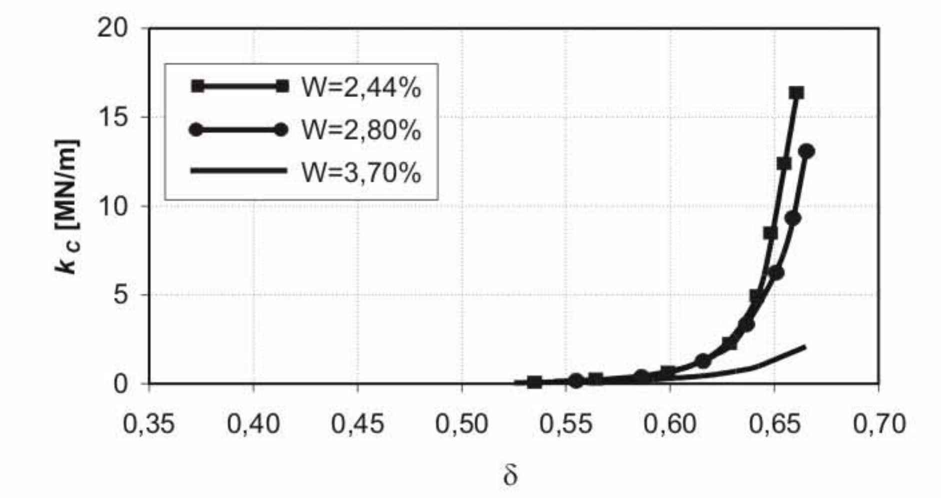


Fig. 4. Relationships $k_T(\delta)$ (a) and $k_C(\delta)$ (b) obtained by approximation of the relationship (2) for ultrasonic testing results of moulding sand with 6 % of bentonite Bentomak and with various humidity

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