ARCHIVES
of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 7
Issue 2/2007
101 – 106
21/2

Selected applications of ultrasonic method for moulding sand examination

S. Ciskowski [a], S. Fita [a], M. Ganczarek [b], T. Mikulczyński [a,*], J. Nowicki [a]
[a] Institute of Production Engineering and Automation, Wroclaw University of Technology, ul. Ignacego Lukasiewicza 3/5, 50-371 Wrocław, Poland
[b] EBCC Poland S.A., ul. Bystrzycka 89, 54-215 Wroclaw
*Contact: e-mail: tadeusz.mikulczynski@pwr.wroc.pl

Received 08.02.2007; Approved for print on: 12.03.2007

Abstract

Selected applications of ultrasonic method for examining basic technological and rheological properties of traditional moulding sands are presented. The ultrasonic method permits evaluation of basic technological properties of moulding sands on the grounds of the correlation curves $t = f(W)$, $R_c^w = f(E)$ and $L = f(k_C, W)$. This allows also determining the k_C and k_T coefficients which define viscoelastic properties of moulding sands based on the relationships $k_C = f(v_L)$ and $k_T = f(v_L)$.

Key words: Mechanization and automation of foundry engineering, measurement automation, moulding sand properties, ultrasonic method.

1. Introduction

Measurements of physical or technological properties of materials by ultrasonic methods are used in many industrial fields, among others in machine building, metallurgy, transportation, building industry, chemical industry, as well as in medicine, biology and veterinary medicine. The ultrasonic technique has also found an application in foundry practice, in particular for testing moulding sands and other moulding materials [1-6]. Especially large possibilities of using the ultrasonic technique were found and proved with respect to basic technological properties of moulding sands [7,8].

It was found and proved that the ultrasonic method can be used, among others, for:

- humidity measurements of traditional moulding sands,
- strength measurements of traditional moulding sands,
- evaluation of rheological properties of moulding sands,
- evaluation of active binder content in moulding sands.

2. Ultrasonic testing

Ultrasonic testing of moulding sands consists in measuring the delay time between the transmitted and received impulses of a longitudinal ultrasonic wave propagating in a properly prepared (densened) moulding sand specimen. The measurements of the ultrasonic wave propagation time can be performed on a stand schematically shown in Fig. 1. The test stand consists of the following components: tester type 543 (1), rammer LU (2), rectangular foot (3), measurement chamber (4), measuring line with ultrasonic heads (transmitting head (5) and receiving head (6)). On the presented measuring stand, moulding sand specimens can be dosed in two different ways: by volume or by weight. In the case of the most often used weight dosing, the weighted portion of the sand should be m = 350 g. Another important factor influencing exactness of ultrasonic measurements, beside dosing, is densening degree of the samples to be tested, obtained by a specified number of strokes of a laboratory rammer. It was found that good acoustic contact with the sand specimen and thus correct ultrasonic measurements, burdened with minimum scatter, are obtained already after fivefold densening of the specimen.

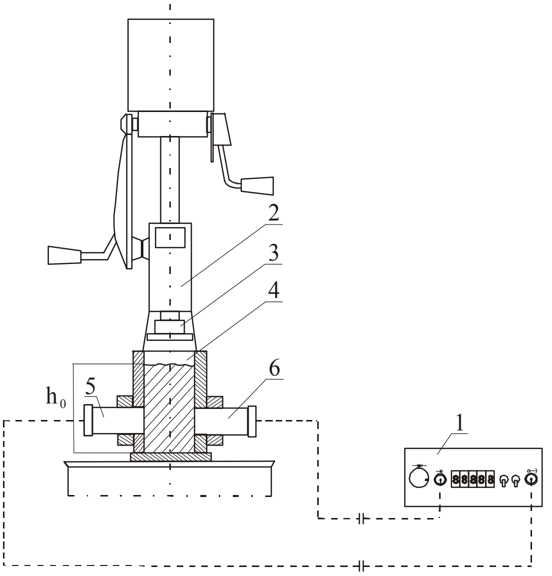


Fig. 1. Diagram of the test stand: tester type 543 (1), rammer LU (2), rectangular foot (3), measurement chamber (4), transmitting head (5), receiving head (6)

3. Humidity Evaluation

Humidity of moulding sands is evaluated using the function $t = f(W)$, representing the relationship between the ultrasound propagation time and the sand humidity [7,8]. Fig. 2a shows the relationships $t=f(W)$ for moulding sands with various contents of the Bentomak bentonite, and Fig. 2b shows those relationships for various bentonites.

Analysis of the presented relationships $t = f(W)$ indicates that measurements of moulding sand humidity consisting in measuring the propagation time through the examined specimen and reading the humidity from the obtained relationship must be based on a correlation curve valid for the given type and composition of moulding sand.

4. Evaluation of strength factor R_c^w

The strength factor R_c^w can be evaluated on the ground of the correlation function between strength R_c^w and longitudinal elasticity modulus E characterising elastic properties of the moulding sand. To that end, the relationships $K_C = f(v_L)$ and $E_t = f(v_L)$ are used [6,8]. Here, the elasticity modulus E can be expressed by square velocity v_L of the longitudinal ultrasonic wave, i.e. its value can be determined on the ground of ultrasonic testing from the formula:

$$E_t = \rho \cdot v_L^{\ 2} \qquad (1)$$

where: ρ = density of moulding sand.

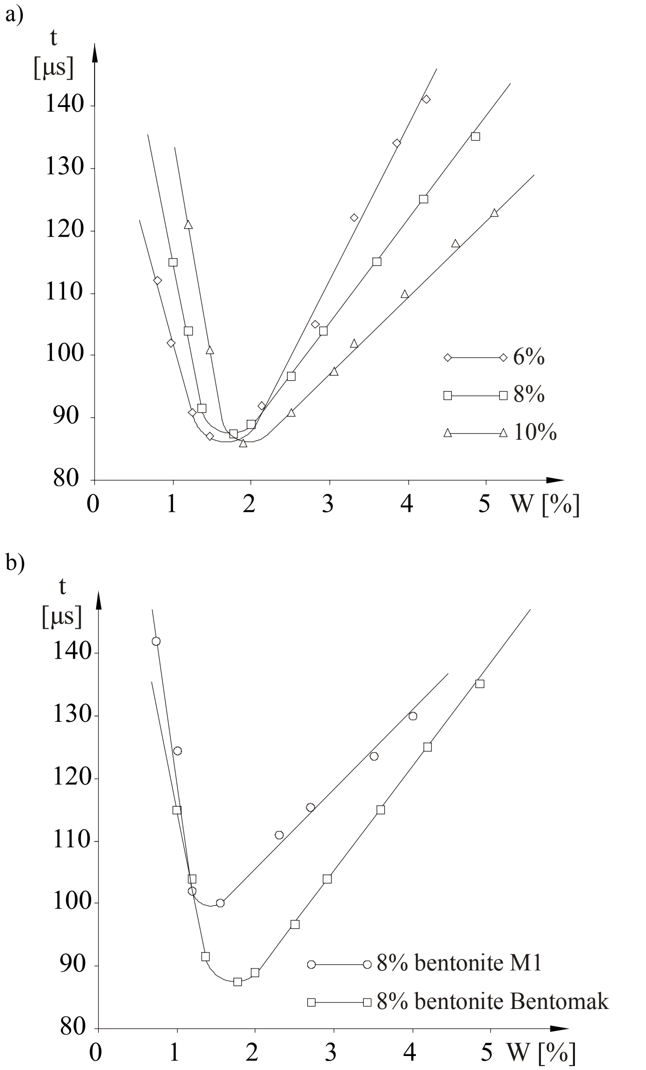


Fig. 2. Relationship $t = f(W)$ for moulding sands with various Bentomak bentonite contents (a) and for various kinds of binder (b)

Figure 3a shows the relationship $E_t = f(R_c^w)$ for moulding sands with various contents of Bentomak bentonite, and Fig. 3b shows that relationship for moulding sands with various bentonites.

Analysis of the relationships shown in Fig. 3 indicates that measurement of the strength factor R_c^w must be based on the correlation curve $E_t = f(R_c^w)$ valid for the given type and composition of moulding sand.

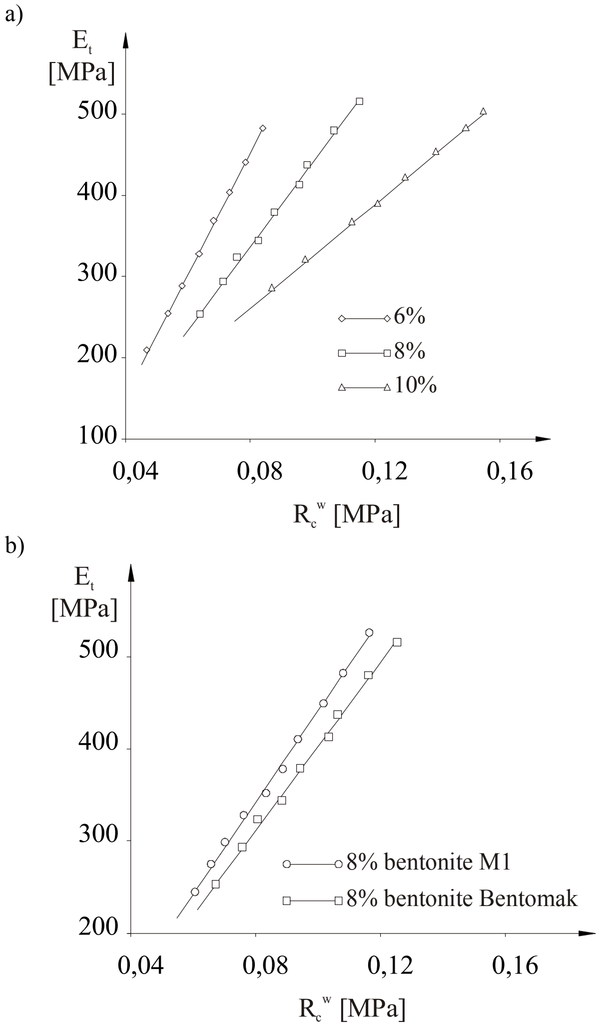


Fig. 3. Relationship $E_t = f(R_c^w)$ for moulding sands with various bentonite contents (a) and with various bentonite grades (b)

5. Evaluation of rheological properties

Rheological properties of a moulding sand can be modelled by the viscoelastic rheological model. Application of that model e.g. for a simulating research of the dynamic process of moulding sand densening requires knowing viscous and elastic properties of the moulding sand, i.e. elasticity coefficients $k_C = f(\delta)$ and viscosity coefficients $k_T = f(\delta)$, where δ is the densening degree.

To determine the relationships $k_C = f(\delta)$ and $k_T = f(\delta)$, it is enough to know the $v_L = f(\delta)$ relationships, which can be determined by ultrasonic testing [9-13].

Figure 4 gives a graphic presentation of ultrasonic measurements of a moulding sand with the Bentomak bentonite together with the relationships $k_C = f(\delta)$ and $k_T = f(\delta)$.

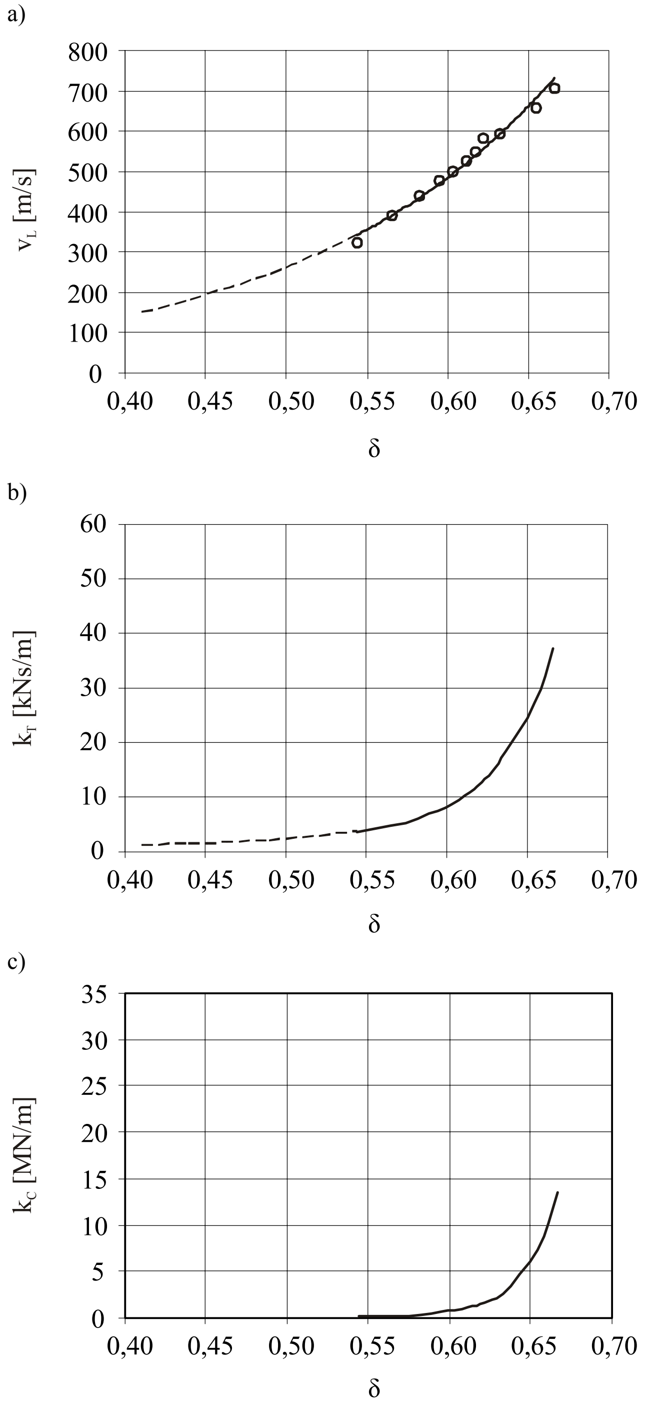
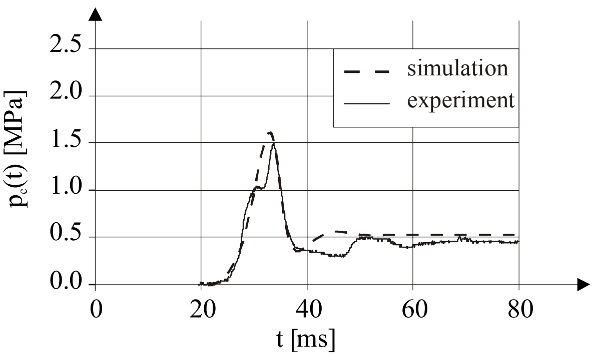


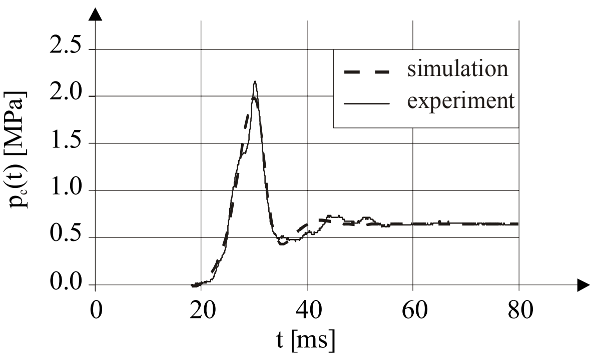
Fig. 4. Measurements of ultrasonic wave velocity $v_L = f(\delta)$ (a) and the relationships $k_T = f(\delta)$ (b) and $k_C = f(\delta)$ (c) for a moulding sand with 6 % of Bentomak bentonite and 2.8 % of water

Figure 5 shows the results of experimental and simulating examination of the moulding sand squeezing process. The results prove that the relationships $k_C = f(\delta)$ and $k_T = f(\delta)$ determined by ultrasonic testing very well describe rheological properties of the moulding sand.

a)



b)



c)

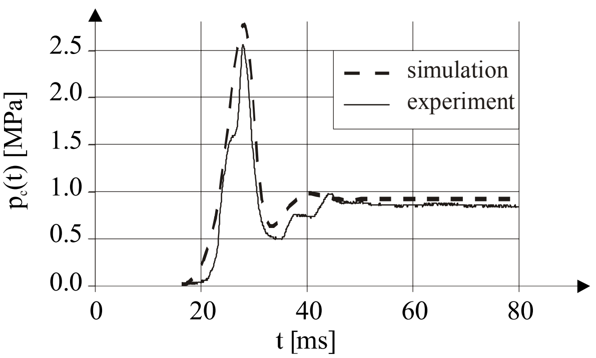


Fig. 5. Ultrasonic testing results and simulating results of the densening process of a moulding sand with 7% of Bentomak bentonite obtained at initial supply pressure $p_0 = 0,4\ MPa$ (a), $p_0 = 0,5\ MPa$(b), $p_0 = 0,6\ MPa$(c)

6. Evaluation of active binder content

In the previous chapter, the methodology was presented of determining the coefficients $k_C = f(\delta)$ and $k_T = f(\delta)$, characterising rheological properties of moulding sands. For instant, the coefficient k_C, characterising elastic properties of a sand, can be described by the relationship [8,14,15]:

$$k_C(\delta) = k_1 \cdot \exp[k_2 \cdot v_L(\delta)] \tag{2}$$

where: k_1, k_2 = coefficients.

Figure 6 shows exemplary relationships $k_C = f(\delta)$ for moulding sands with Bentomak bentonite and various humidity contents. Their analysis demonstrates that different humidity results in different elastic properties. A similar effect on elastic properties is demonstrated by binder content in the sand.

For this reason, it is possible to present the relationship describing changes of active binder content in the moulding sand as a function of its elastic properties k_C for various humidity contents. This relationship is:

$$L = a(W) \cdot k_C \tag{3}$$

where:
L = active binder content,
a = directional coefficient, a function of the sand humidity.

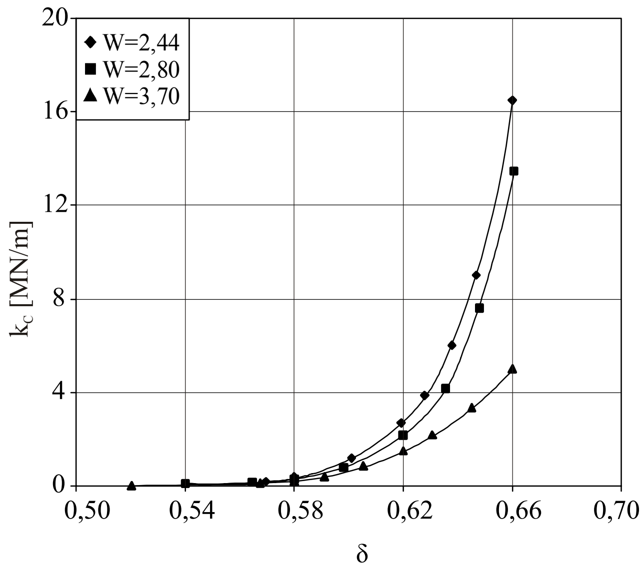
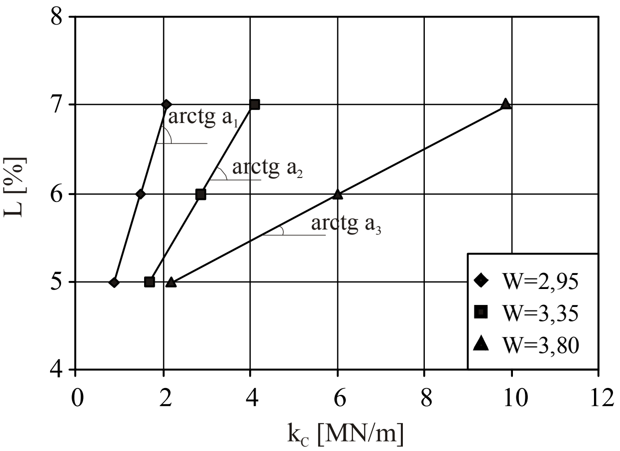


Fig. 6. Relationships $k_C = f(\delta)$ for a moulding sand with Bentomak bentonite and various water contents $W = 2,44 – 2,80 – 3,70\%$

Figure 7a shows the relationships $L = f(k_C)$, each of them representative for a moulding sand with a strictly defined humidity. Figure 7b shows correlation between directional coefficient *a*, of $L = f(k_C)$ curve, and moulding sand humidity *W*. On the ground of those relationships and equation (3), it is possible to determine the correlation $L = f(k_C, W)$ in the following form:

$$L = (k_C, W) = (1{,}41 \cdot W - 3{,}94) \cdot k_C \quad (4)$$

a)



b)

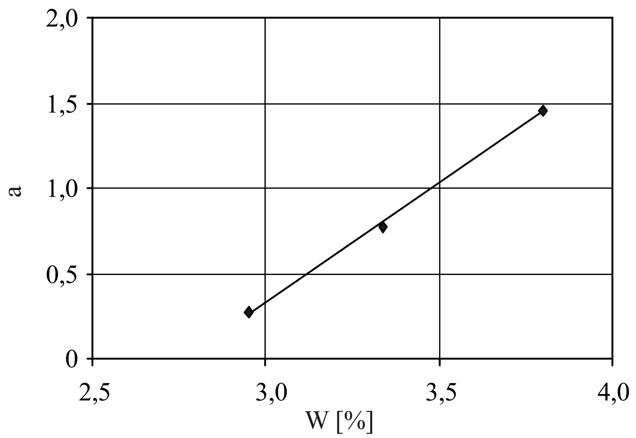


Fig. 7. Relationships $L = f(k_C)$ (a) and $a = f(W)$ (b) for a moulding sand with various humidity contents $W = 2{,}95 – 3{,}35 – 3{,}80\%$.

Therefore, to determine the active binder content in a moulding sand, it is necessary to take two measurements: humidity measurements of the sand and ultrasonic testing to define the coefficient k_C.

7. Conclusion

The ultrasonic method developed at the Laboratory of Basic Automation of the Institute of Machine Engineering and Automation of Wroclaw University of Technology permits evaluating several significant technological properties of traditional moulding sands.

Analysis of ultrasound propagation in a densened moulding sand whose rheological properties can be modelled by the viscoelastic rheological model proved that there are explicitly defined relationships between its technological properties and velocity of longitudinal ultrasonic wave. These findings permit, among others, using the ultrasonic method for:

- humidity measurement of moulding sands,
- strength factor measurement of moulding sands,
- evaluation of rheological properties of moulding sands,
- evaluation of active binder content in moulding sands.

Evaluation of *W*, R_c^w and *L* by ultrasonic method consists in determining individual parameters on the grounds of the defined correlation curves $t = f(W)$, $R_c^w = f(E)$, $L = f(k_C)$ valid for the given type and composition of moulding sand. Evaluation of rheological properties of moulding sands is based on a correlation between the parameters defining elastic and viscous properties of the sand and velocity of longitudinal ultrasonic wave.

The basic advantages of the ultrasonic method applied for evaluation of selected technological properties of moulding sands include short time and high measurement exactness, evidenced by the measurement time of ca. 10 s and humidity measurement error of ± 0.2 % for the moulding sand examined in one of Polish cast iron foundries.

References

[1] L. Brunarski, Research of materials, elements and constructions. Concrete building engineering, vol. 8, Warsaw, Arkady 1970 (in Polish).
[2] J. Matuschek, Ultrasonic technics, Warsaw, WNT 1961 (in Polish)
[3] Z. Pawłowski, Internal friction of metals and the problem of damage cumulation with static and variable loadings, Proc. Viler. Problems, Warsaw, vol.4, 1963 44-64.
[4] Z. Pawłowski, Ultrasonic attenuation during cyclic streining, Proc. Fourth International Conference on Non-destructive Testing, Butterworths 1964, London 1967 192-195.
[5] Z. Pawłowski, Evaluation of physical and mechanical state of polycrystaline in internal friction in materials, Wroclaw, Ossolineum 1968.
[6] Z. Pawłowski, Ultrasonic measurements of strength of fragile materials, IPPT, No. 13, Warsaw 1967 (in Polish).
[7] Z. Samsonowicz, Ultrasonic waves in moulding sand humidity measurements, Przegląd odlewnictwa, No. 5 1969 169-172 (in Polish).
[8] T. Mikulczyński, Application of ultrasound method in examining moulding sands and materials, Scientific papers of the Institute of Production Engineering and Automation, Wroclaw University of Technology, No. 54, Monographs No. 15, 1994 (in Polish).

[9] M. Ganczarek, Mathematical model of moulding sand dynamic squeezing, doctoral dissertation, ITMiA, PWr, 2003 (in Polish).
[10] M. Bogdan, S. Fita, T. Mikulczyński, R. Więcławek, Ultrasonic measurements of rheological properties of disintegrated media, Measurement Scientific Review vol. 6, sect. 3, No. 4 (2006) 66-69.
[11] W. Kollek, T. Mikulczyński, D. Nowak, R. Więcławek, Experimental identification of rheological model of disintegrated media, Archives of Foundry vol. 4, No. 11 (2006) 322-331 (in Polish).
[12] W. Kollek, T. Mikulczyński, K. Naplocha, D. Nowak, Ultrasonic measurements of rheological model of moulding sand, Archives of Foundry vol. 4, No. 13 (2004) 127-132 (in Polish).
[13] M. Ganczarek, W. Kollek, T. Mikulczyński, Experimental and simulation research of moulding sand dynamic squeezing, Archives of Foundry vol. 2, No. 6 (2002) 55-60 (in Polish).
[14] T. Mikulczyński, J. Bogdanowicz, Ł. Dworzak, M. Ganczarek, Ultrasonic measurements of active binder content, Archives of Foundry vol. 6, No. 20 (2006) 59-64 (in Polish).
[15] T. Mikulczyński, M. Ganczarek, S. Ciskowski, Ł. Dworzak, New method for evaluation of active binder content in moulding sand, Przegląd Odlewnictwa vol. 56, No. 10/11 (2006) 574-577 (in Polish).
[16] L. Lewandowski, Moulding and core sands, Warsaw, PWN, 1991 (in Polish).
[17] N.A. Cytović, Soil mechanics, Moscow, GILSA 1951 (in Russian).
[18] T. Jeske, T. Przedecki, B. Rossiński, Soil mechanics, Warsaw, PWN 1966 (in Polish).