A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 54 2009 Issue 2

J. DAŃKO*, J. ZYCH*, R. DAŃKO*

DIAGNOSTIC METHODS OF TECHNOLOGICAL PROPERTIES AND CASTING CORES QUALITY

METODY DIAGNOZOWANIA WŁAŚCIWOŚCI TECHNOLOGICZNYCH I JAKOŚCI RDZENI ODLEWNICZYCH

The presentation of the developed diagnostic methods of technological properties and qualities of casting cores produced by shooting method is the aim of the hereby paper. Special attention was directed towards parameters decisive for the obtained apparent density of casting core sand, its porosity and permeability in cores made of various kinds of core sands. Those factors, of a significant influence for the effectiveness and quality of produced castings, force laboratories to apply simple, fast and simultaneously reliable quality assessment methods, allowing to determine optimal operation conditions of a blowing machine for the given core sand. To determine quality of a core compaction performed by blowing and shooting method, Boenisch and Knauf proposed a complex analysis of several factors. The technological tests, together with the special method for assessing the core box filling ratio FG as well as the equipment suitable for the realisation of this method, were developed. The physical meaning of coefficient denoted as filling ratio FG is useful at assessing of an apparent compactability of various sands in the same core box. Proposed own method of assessment of a core compaction quality is based on the analysis of the filling ability factor of sands, determined by the value of coefficient K_{zr} which is simplier and better exhibits the influence of a complicated shape of the core box cavity on a sand core compaction.

Experiments presented in the article encompass an operational pressure range p_r=0.4÷0.7 MPa and diameters of shooting nozzles d_1=15÷25 mm. The examination results obtained by the approximation, of various measurements data from the examined range of variables, done by means of the arbitrarily selected analytical curve of an extended structure similar to the one applied in Aksionov's works, take into account, for the given shooting machine and kind of core sand, an initial apparent density of loosely poured sands ρ_{us}, a shooting pressure p_r, and also a diameter of a shooting head outlet d_1.

The analysis of ultrasound examinations of classic sands and sands with chemical binding agents confirmed the possibility of utilising the ultrasound technique for the development of non-destructive investigation methods of cores assessing the compaction distribution uniformity, strength and permeability. In this aspect the examination results performed for a broad range of working parameters constitute the reference basis allowing for a practical application of an ultrasound technique as a modern alternative diagnostic method assessing the quality and correctness of the employed core production technology.

Celem artykułu jest prezentacja opracowanych metod diagnozowania właściwości technologicznych i jakości rdzeni odlewniczych wykonywanych metoda wstrzeliwania. Szczególną uwagę zwrócono na czynniki i parametry procesu decydujące o uzyskanej wartości gęstości pozornej masy rdzeniowej, jej porowatości oraz przepuszczalności w rdzeniach wykonywanych z różnych rodzajów masy rdzeniowej. Czynniki te, mające istotne, a czasami nawet decydujące znaczenie dla efektywności i jakości produkowanych odlewów wymuszają w laboratoriach stosowanie prostych i szybkich, a zarazem miarodajnych metod oceny jakości rdzenia, pozwalających na określenie optymalnych warunków pracy maszyny dmuchowej dla konkretnej masy rdzeniowej. W celu określenia jakości zagęszczenia rdzeni metodą nadmuchiwania i wstrzeliwania Boenisch i Knauf zaproponowali kompleksową analizę szeregu czynników. Opracowana została próba technologiczna i specjalna metoda oceny stopnia napełnienia FG rdzennicy masą oraz aparat służący do realizacji tej metody. Sens fizyczny współczynnika FG wyraża względną ocenę skłonności do zagęszczania się w danej rdzennicy różnych rodzajów masy. Zaproponowany, własny sposób oceny realizacji procesu zagęszczania i jakości zagęszczenia masy polegający na analizie wartości współczynnika zapełnialności rdzennicy K_{zr}, jest prostszy i lepiej eksponuje wpływ skomplikowania wnęki rdzennicy na efekt zagęszczania w niej masy rdzeniowej. Zamieszczone w artykule badania gęstości pozornej średniej i/lub gęstości w wybranych rejonach rdzenia, przepuszczalności i porowatości obejmują zakresy ciśnienia roboczego p_r=0,4÷0,7 MPa oraz zakresy średnic dysz strzałowych d_1= 15÷25 mm. Wyniki badań opracowane przez aproksymacje licznych danych pomiarowych za pomocą arbitralnie wybranej krzywej analitycznej, o strukturze rozszerzonej w stosunku do stosowanej w pracach Aksionova uwzględniają, dla określonej strzelarki i rodzaju masy rdzeniowej, początkową gęstość pozorną masy luźno usypanej ρ_{us}, ciśnienie strzału p_r, a także średnicę otworu wylotowego z głowicy strzałowej d_1.

* FACULTY OF FOUNDRY ENGINEERING, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKOW, 23 REYMONTA STR., POLAND

Przeprowadzona analiza wyników badań ultradźwiękowych mas klasycznych i mas ze spoiwami chemicznymi potwierdza możliwość wykorzystania techniki ultradźwiękowej między innymi do opracowania nieniszczącej metody badania rdzeni w aspekcie oceny równomierności rozkładu zagęszczenia, struktury wytrzymałości i przepuszczalności. W tym sensie wyniki badań przeprowadzonych dla szerokiego zakresu parametrów roboczych procesu stanowią bazę odniesienia pozwalającą na zastosowanie w praktyce również techniki ultradźwiękowej jako nowoczesnej alternatywnej metody diagnozowania jakości i prawidłowości stosowanej technologii rdzeni.

Introduction

Optimisation of a core production process by shooting, consists of the selection of working parameters of filling the core-making machine and compaction of moulding sands as well as methods of sands hardening by means of gaseous or thermal agents. Out of the parameters decisive on time-history of the process of technological cavity filling and moulding sands compaction such values as: kind of a core moulding sand, complexity of a core shape, shooting pressure, recommended areas of shooting and venting holes, should be taken into account. The mentioned problems were investigated previously by J. Dańko [7] and concerned the traditional core binders (linseedoil or linseedoil varnish, water-glass, resins for hot-box processes). However, in the cold-box technology the necessity of certain changes in blowing process parameters – as compared to the previous ones – occurs. This is related to physical and chemical properties of core moulding sands (e.g. high reactivity, application of low viscosity binding agents) as well as to conditions of their hardening after filling the core box, the most often via blowing gaseous hardening agents. For instance, it is favourable to fill the core box through a larger number of blowing holes, which facilitates a proper and uniform filling of core boxes of complicated shapes of a working cavity and a uniform hardening of the entire volume of the compacted mass. Venting of core boxes – apart from its traditional function i.e. the proper filling and sand compaction – gains, in the modern cold-box technologies, additional functions. It has to assure favourable conditions of sand hardening by its run-purge in a core box and to remove harmful substances formed during this process [2, 4, 6, 7].

1. Apparent density, porosity and permeability in cores produced by a shooting method

Under similar realisation conditions of the blowing process (blowing, shooting) i.e. the same values of a shooting hole diameter, blowing pressure, time of opening of a shooting valve for various kinds of core sands the different core box filling ratios and significant scatter of compactness values and their distribution in a core – is obtained. This is a reason of technological properties variability of cores represented by their permeability, strength and a degree of projection of a core box surface. Thus, this influences an accuracy and smoothness of castings. Those factors, of a significant influence for the effectiveness and quality of produced castings, force laboratories to apply simple, fast and simultaneously reliable quality assessment methods, allowing to determine optimal operation conditions of a blowing machine for the given core sand.

1.1. Boenisch and Knauf's assessment method of a core compaction quality

To determine quality of a core compaction performed by blowing and shooting method, Boenisch and Knauf [2, 3, 6] proposed a complex analysis of several factors. They have introduced two notions, according to which the assessment of a sand compaction ability in a core box is being made. Those are:

– Maximum core box filling ratio obtained by shooting,
– Maximum degree of a sand matrix compaction.

The technological tests, together with the special method for assessing the core box filling ratio as well as the equipment suitable for the realisation of this method, were developed. The physical meaning is expressed by Equation:

$$FG = \frac{M_r}{M_{\max}}100\% = \frac{V_c \cdot \rho_{pm}}{V_c \cdot \rho_{p\max}}100\% = \frac{\rho_{pm}}{\rho_{p\max}}100\%, \quad (1)$$

where:
M_r – core sand mass obtained at the given conditions, kg,
M_{max} – maximum core sand mass (standard), kg,
ρ_{pm} – average density of core sand compacted by shooting, kg/m^3,
V_c – core volume, m^3,
ρ_{pmax} – apparent density of the standard core sand compacted by vibration, kg/m^3.

The standard core is made of a typical sand for the classic cold-box technology, where phenol and polyisocyanate resins, hardened by blowing – through the core – of amine compounds (from Ashland and Hüttenes-Albertus Company), are the binding agents.

Maximum degree of a sand matrix compaction is obtained by means of vibrating of the core box filled with dry high-silica sand carried on until no increase of density is observed.

1.2. Proposed method of assessment of a core compaction quality

Another, presented in several own papers [3, 6, 7], way of assessment of compaction quality is based on the analysis of the filling ability factor of sands, expressed by Equation:

$$K_{zr} = \frac{M_r}{M_{st}} 100\% = \frac{V_c}{V_c} = \frac{\rho_{pm}}{\rho_{st}} 100\%, \qquad (2)$$

where:
M_r, ρ_{pm}, V_c – markings as in Equation (1),
$M_{st} = V_c \cdot \rho_{st}$ – apparent core sand weight, kg/m^3,
ρ_{st} – apparent density of a core sand obtained in a cylindrical sample after ramming performed three times by the standard rammer, kg/m^3.

The question, concerning the relation between Equation (1) developed by Boenisch and Knauf and Equation (2) presented in publications of the authors of the hereby paper, arises.

Comparison of Equations (1) and (2) in consideration of ρ_{pm} brings the following:

$$K_{zr} \cdot \rho_{st} = FG \cdot \rho_{pmaks} \qquad (3)$$

and

$$K_{zr} = FG \cdot \frac{\rho_{pmaks}}{\rho_{st}}; \quad FG = K_{zr} \cdot \frac{\rho_{st}}{\rho_{pmaks}} \qquad (4)$$

As can be noticed both the filling ability factor K_{zr} and the filling ratio FG are determined by means of measurements of the same values, i.e. ρ_{pm} and ρ_{st}. According to the method given in paper [7] the determination of the core apparent density ρ_{pm} in the sand sample compacted by shooting into a core box of a standard sample dimensions and comparing it with the sand density ρ_{st} obtained in a cylindrical sample after ramming (performed three times by the standard rammer) is easier than the determination of an apparent density of the so called standard core sand ρ_{pmax} compacted by vibrations.

Analysis of a physical meaning of coefficients K_{zr} and FG indicates that the factor K_{zr} better exhibits the influence of a complicated shape of the core box cavity on a sand core compaction, while the filling ratio FG is advantageous at assessing of an apparent compactability of various sands in the same core box.

Testing stand and examination methods

Examinations of shooting core sands – of a composition given in Table 1 – were carried on according to the method presented in papers [3, 6, 7]. Experimental core shooting machines of charge chambers capacity of 3-5 dm^3 and perpendicular or cylindrical core boxes of a capacity of 0.8 -1.5 dm^3 were used. Shooting machines were equipped with an automatic control of a shooting time and a pressure recording device both in a charge chamber and in a core box. Experiments shown below encompass an operational pressure range p_r = 0.4 - 0.7 MPa and diameters of shooting nozzles d_1 = 15 - 25 mm. Measurements of the apparent average density and/or the density in the selected region of the core were performed for the given shooting parameters. Permeability was determined according to the Polish Standard – 80/H-11072 on cylindrical samples of ϕ50 x 50 mm compacted in a standard way or shot into a cylindrical bush of the same internal dimensions.

Porosity was determined on the basis of the known value of the apparent and specific density of the mass:

$$\varepsilon = \left(1 - \frac{\rho_{pm}}{\rho_w}\right) \cdot 100\%, \qquad (5)$$

where:
ρ_{pm} – marking as in Equation (1),
ρ_w – specific density depending on the sand composition [g/cm^3].

The obtained results

Data of Boenisch and Knauf as well as of authors' own, for some selected kinds of sand cores at the application of a uniform scale (filling ratio FG) are presented in Figure 1. An additional scale was introduced in this Figure to illustrate the core box filling ability factor KZR for three sands used in own examinations, marked by symbols Ol, SW and B.

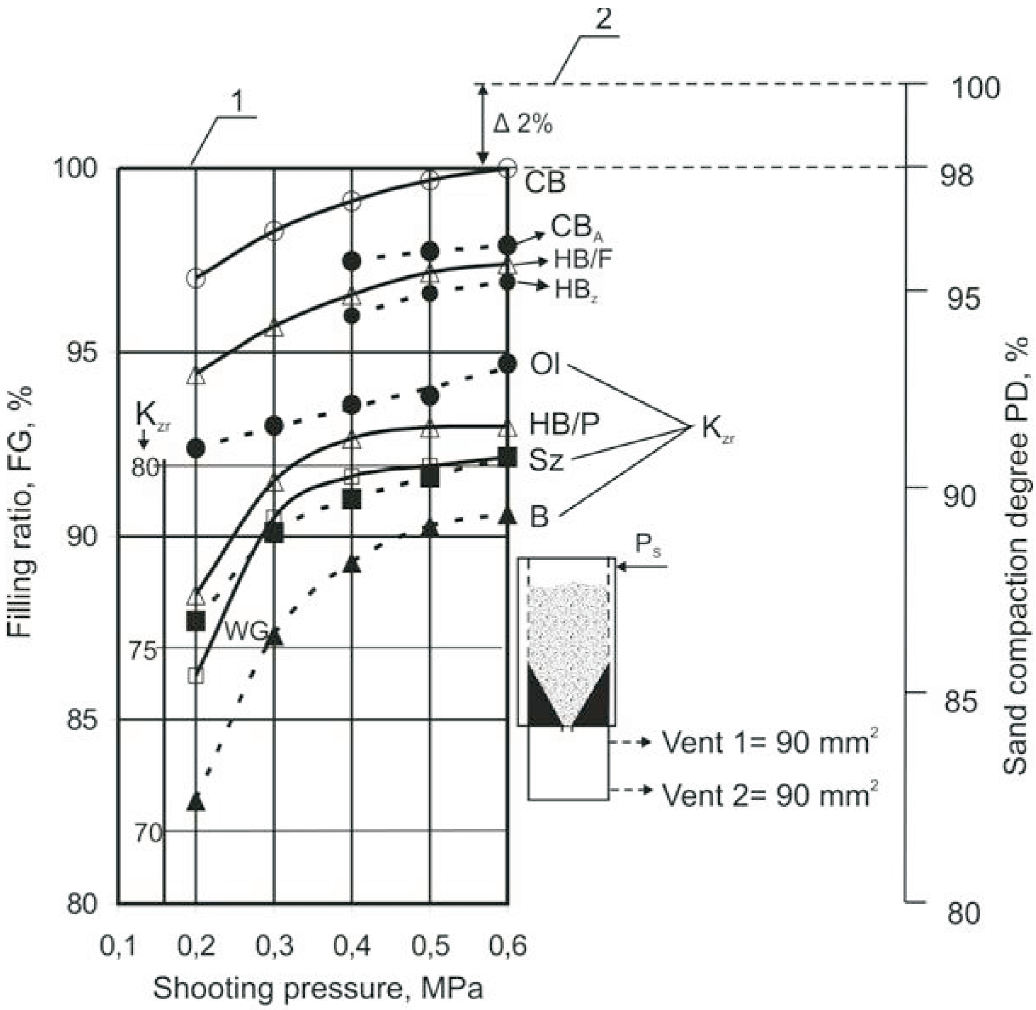

Fig. 1. Influence of pressure on the filling ratio FG for various core sands according to Boenisch and Knauf [2] (continuous lines) and authors' own results (broken lines [3]). Marking: CB – cold-box technology sand, HB/F – hot-box technology sand containing furan resin, HB/P – hot-box technology sand containing phenol resin, WG and SW – sand with water glass, Ol – sand with linseedoil, B – sand with bentonite

The examination results of an average density, apparent porosity and permeability in cores made by the shooting method are presented in Figures 2-4. In these Figures there are also values obtained by the approximation, of various measurements data from the examined range of variables, done by means of the arbitrarily selected analytical curve of a structure similar to the one applied in Aksionov's works [1].

Data presented in Figure 2 exhibit the fact that, regardless of the sand core kind, there is a continuation of the obtained dependences of a porosity (linear dependence), as well as permeability (exponential dependence), which justifies their mutual presentation in the form of a synthetic graph in Figure 3. It should be emphasised, that examinations of an apparent density, permeability and porosity were determined on core sand samples of normalised dimensions compacted by shooting of the given sand into a bush of ϕ 50 x 50 mm at various pressures and diameters of the shooting hole.

Empirically selected curves take into account, for the given shooting machine and kind of core sand, an initial bulk density of loosely poured sands ρ_{us}, a shooting pressure p_r, and also a diameter of a shooting head outlet d_1. The structure of empirical equations is similar to the one proposed by Aksionov [1] for the description of compaction by moulding sand pressing. However, in authors' own equations, presented below, the diameter of shooting hole was additionally taken into account. A general form of the Equation is as follows:

$$\rho_m = \rho_{us} + c \cdot p_r^n \cdot d_l^m, \qquad (6)$$

where: ρ_{us} – density of a loosely poured sand; g/cm^3,

c, n, m – empirically determined values – on the basis of the measurement data.

TABLE

Composition and properties of sands used in authors' own examinations [5]

Sand composition – in parts by weight					
Average high-silica sand 1K 0.20/0.16/0.32 – J90-1673 K		Ol	SW	B	HU404
		100	100	100	100
Linseedoil varnish		2.0	–	–	–
Sodium water-glass M= 2.5		–	5.0	–	–
Urea-furfuryl resin Kaltharz U404U (Hüttenes-Albertus)		–	–	–	1.2
Hardener 100T3 (Hüttenes-Albertus)		–	–	–	0.6
Bentonite		–	–	6.5	–
Clay		–	3.0	–	–
Water		1.0	1.0	2.0	–
Sand properties					
Strength of fresh sand R_c	[N/cm^2]	0.4 – 0.5	0.8 – 1.0	5.0 – 8.0	0,6 – 0.8
Permeability	[cm^4/Gmin]	150	188	170	165
	[m^2/MPas]	2.5	3.2	2.9	2.8
Flowability P_s	[g]	35.4	28.3	12.5	37.0
Bulk density ρ_{us}	[kg/m^3]	1250	1050	900	1200
Standard density ρ_{st}	[kg/m^3]	1720	1685	1590	1710

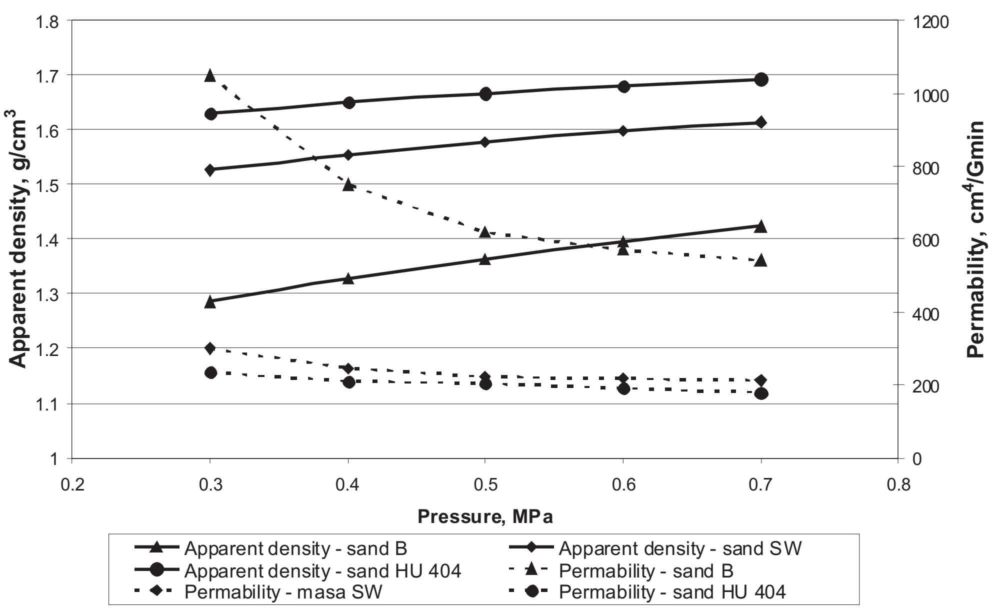

Fig. 2. Dependence of the average apparent density and permeability on the shooting pressure for various kinds of sands [5]

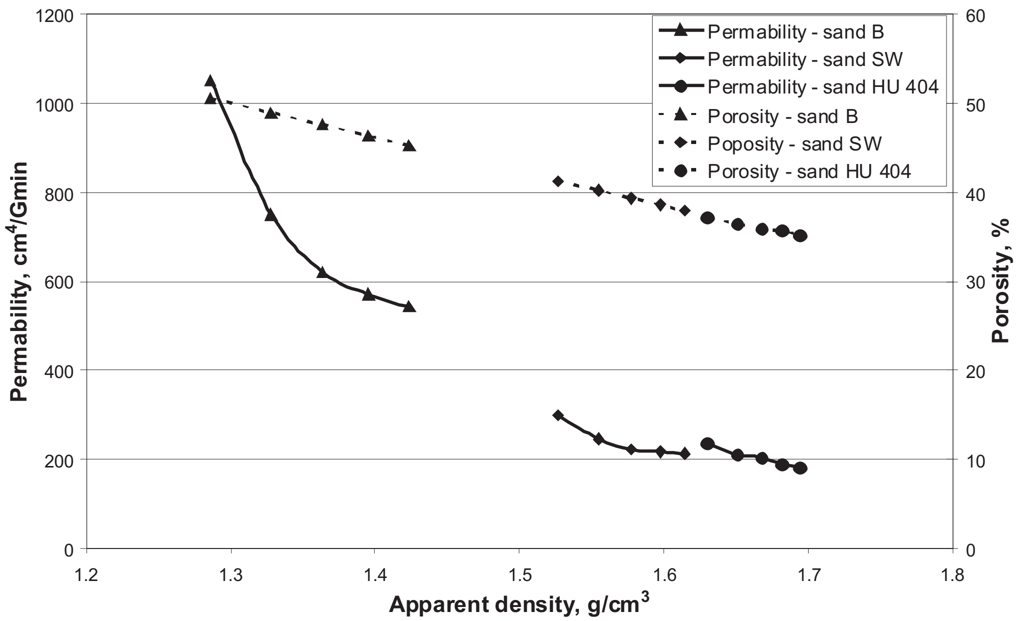

Fig. 3. Dependence of the permeability and porosity on the average apparent sand density for the tested sands [5]

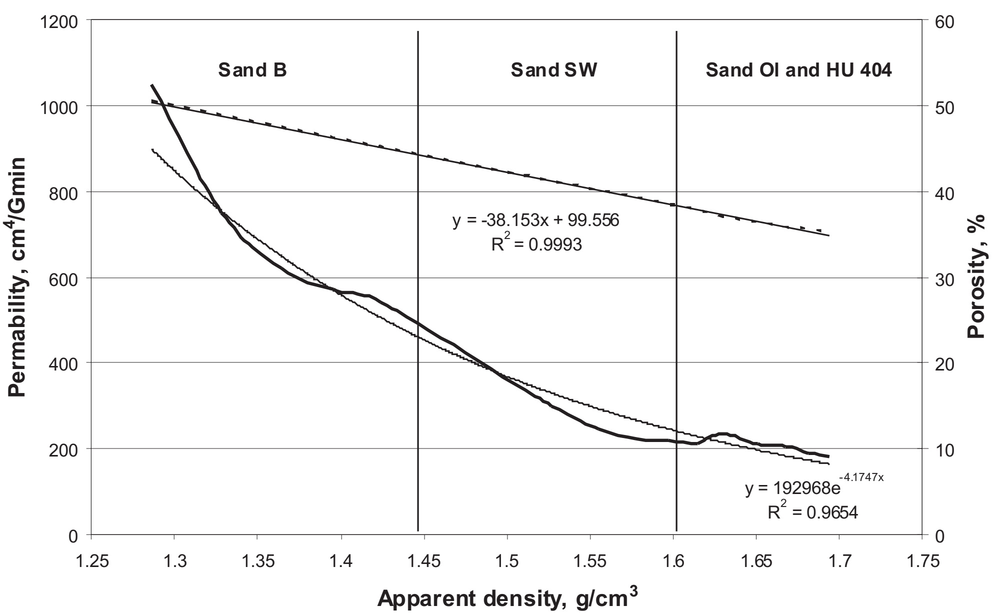

Fig. 4. Interpolation of data from Figure 2 illustrating the influence of the sand apparent density on its permeability and porosity, for the examined sands [5]

Equations for the determination of an average density of an apparent sand can be applied for core boxes of not complex cavity shapes, when meeting the following requirements limiting the capacity of the shooting machine charge chamber $V_b \leqslant 0.005$ m^3, ratio $V_b / V_c \geqslant 2.5$, pressure range: $p_r = 0.4 - 0.7$ MPa, $d_1 = 15 - 25$ mm. The following detailed equations can be applied for the sands included in Table 1:

- sand „Ol" and „Z_{U404}" $\quad \tilde{n}_m = 1.25 + 0.30\, p_r^{0.184} \cdot d_1^{0.177}$ (3)
- sand „SW" $\quad \tilde{n}_m = 1.05 + 0.40\, p_r^{0.20} \cdot d_1^{0.15}$ (4)
- sand „B" $\quad \tilde{n}_m = 0.90 + 0.45\, p_r^{0.36} \cdot d_1^{0.101}$ (5)

When the sand compaction process is performed by blowing methods, the characteristic increase of an apparent density is observed at the prolongation of the shooting hole axis, as compared to the core or mould zones in which sand-air stream does not act directly on sand layers. Such distribution of compactness decreases the ability of central core zones to removal of gases after the mould has been filled with liquid metal. It is also disadvantageous for fast-hardening sands in which hardening is done by means of blowing gaseous hardening agents through a core or mould.

Compaction unevenness often causes cores destruction – due to their deformation or cracking – and other casting defects.

Unevenness of compacting occurs for each kind of core sands, and depends both on the shooting pressure and the shooting hole diameter (see Figure 5). The most unfavourable distribution of sand compaction – from the point of view of its permeability – takes place in long, horizontal cores shot by a single hole (Fig. 5a). The smallest sand permeability occurs there at the prolongation of the shooting hole axis. Substituting one outlet by two or more holes in the shooting head (Fig 5b) allows to decrease the compaction unevenness, creating a zone of a relatively better permeability in the core central part.

a)

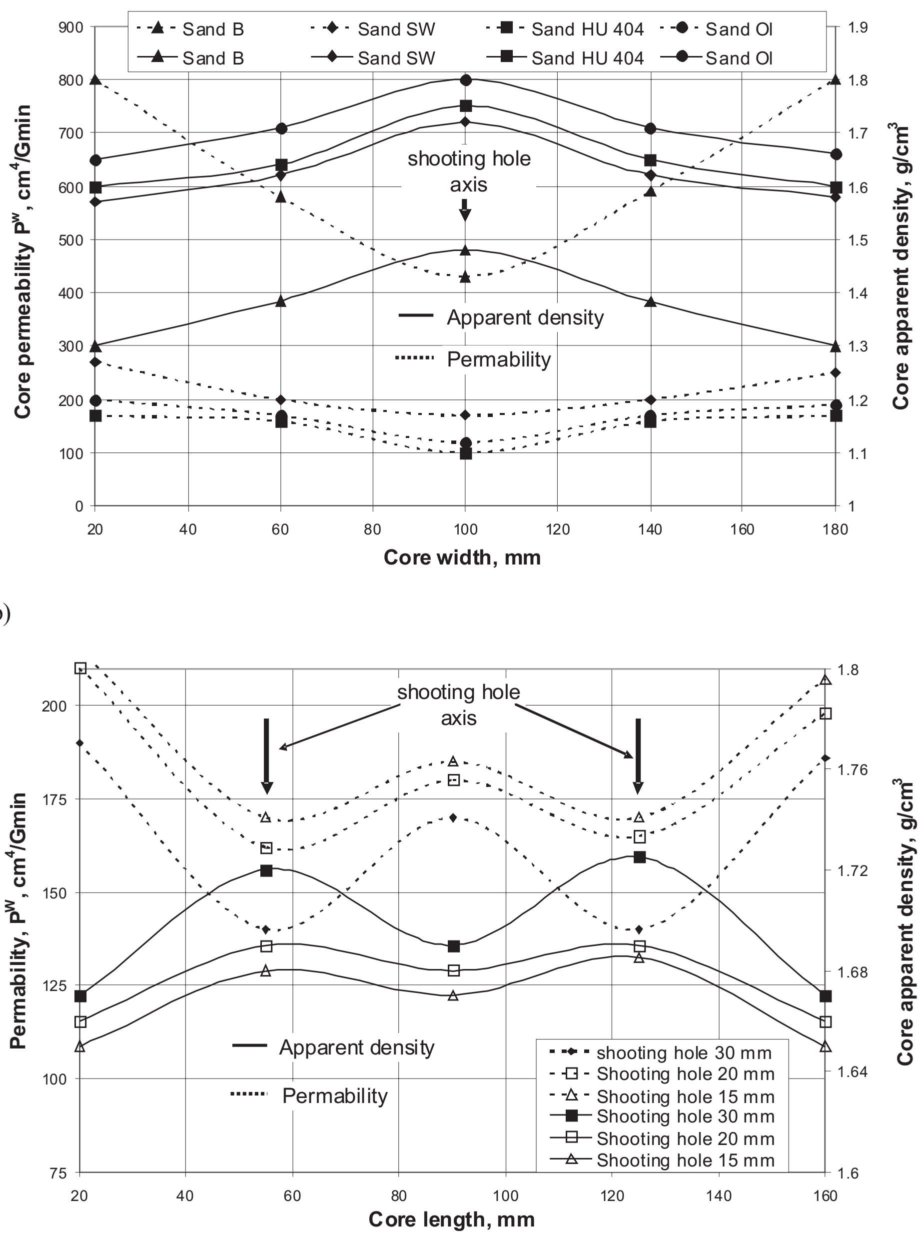

Fig. 5. Distribution of the apparent density and permeability along the width and length of the core made by sand shooting at a pressure of 0.65 MPa: a) by a single shooting hole of diameter d_1 = 20 mm, 1 - sand "Ol", 2 – sand "HU 404", 3 – sand "SW", 4 – sand "B", b) by two shooting holes of diameters 15 - 30mm. sand "Ol" [5]

A comparison of the apparent density distribution – of a moulding sand with the Carbophen binding agent – in cores of the same dimensions but different ways of sand shooting are presented in Figure 6. When the shooting nozzle was placed in the middle of the longer perpendicular wall of the core box the distribution curves were analogical to the ones shown in Figure 4a, but when the nozzle was placed in the middle of the shorter wall of the core box the density distribution was illustrated at the core height.

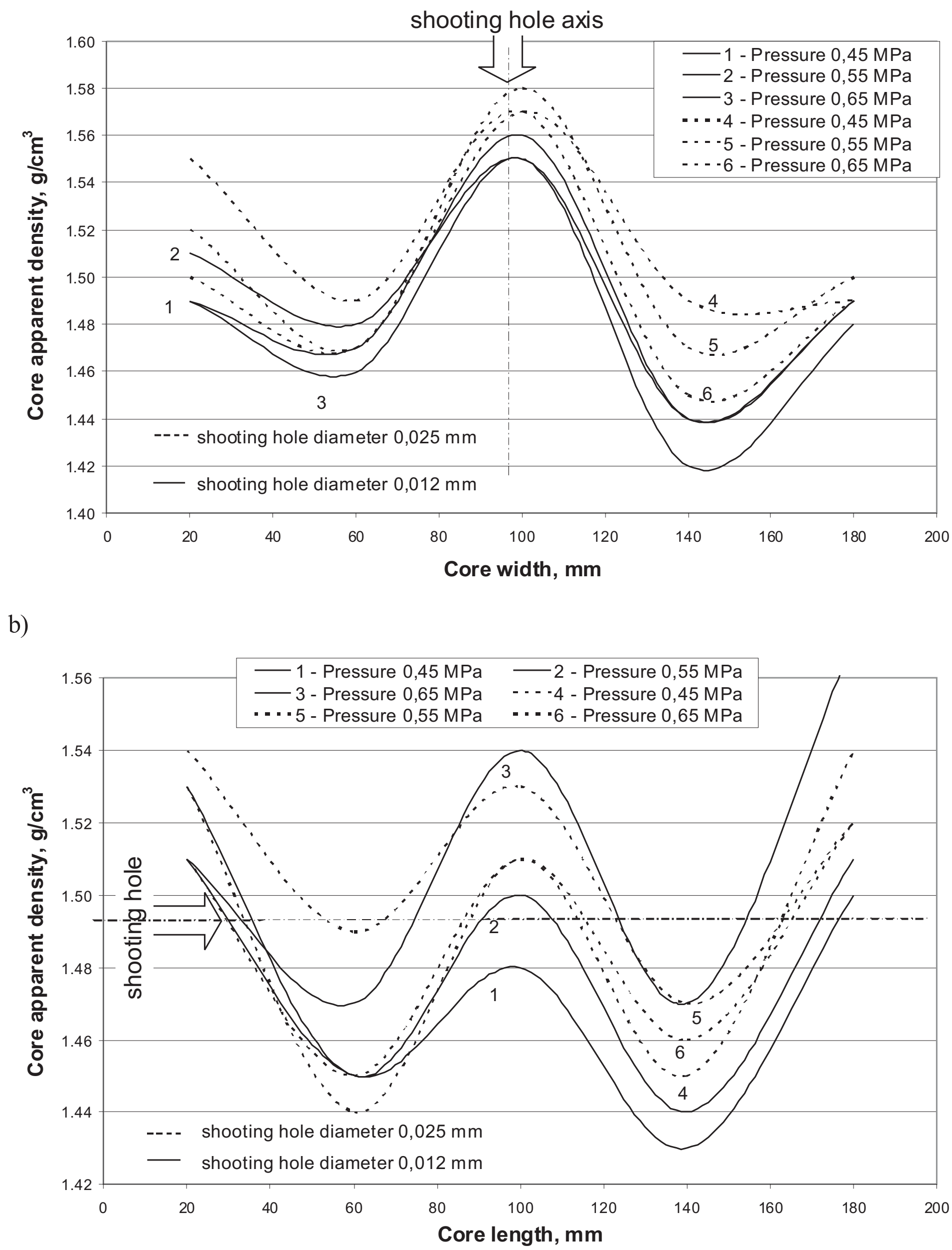

Fig. 6. Distribution of an apparent density of the sand with Carbophen resin shot at various pressures by a single shooting hole of a diameter d_1 = 20 mm. The shooting hole placed in a symmetry axis of a longer (a) and shorter (b) core box wall [8]

2. Ultrasound diagnostic method of the quality of cores shot from different moulding sands

Theoretical analysis as well as analysis of ultrasound examinations of classic sands and sands with chemical binding agents – carried on by J. Zych [6] – indicate that there is a well correlated dependence between a physical state of a binding agent (defined by its visco-elastic properties) and a velocity of an ultrasound wave. Changes of the sand core compacting degree are followed by the ability to sound waves propagation, what creates the possibility of utilising the ultrasound technique for the development of non-destructive investigation methods of cores assessing the compaction distribution uniformity, strength and permeability [7].

Application of ultrasound technique, presented in [6], for the examination the compaction distribution and sand permeability in monolithic and double layered cores obtained by shooting, indicate that there is a linear dependence between a wave velocity and an apparent sand density, which means that the density increase causes the proportional wave velocity increase.

At the dependence determination between ultrasound wave parameters and properties of compacted sands, all measurements are based on standard samples of ϕ 50 x 50 mm. The following values are successively determined: apparent density (ρp_m), permeability (P), velocity of a longitudinal wave (c_L), strength (R_c, R_m lub R_g).

Obtaining such data collection constitutes the basis for the determination – by means of mathematical statistics – the following empirical dependencies: $P = f(\rho_m)$, $P = f(c_L)$, $c_L = f(\rho_m)$, $R_c = f(\rho_m)$ etc.

Examples of this type of dependency for core sands representing sands with bentonite (B), and with resin – are presented in Figures 7 - 10.

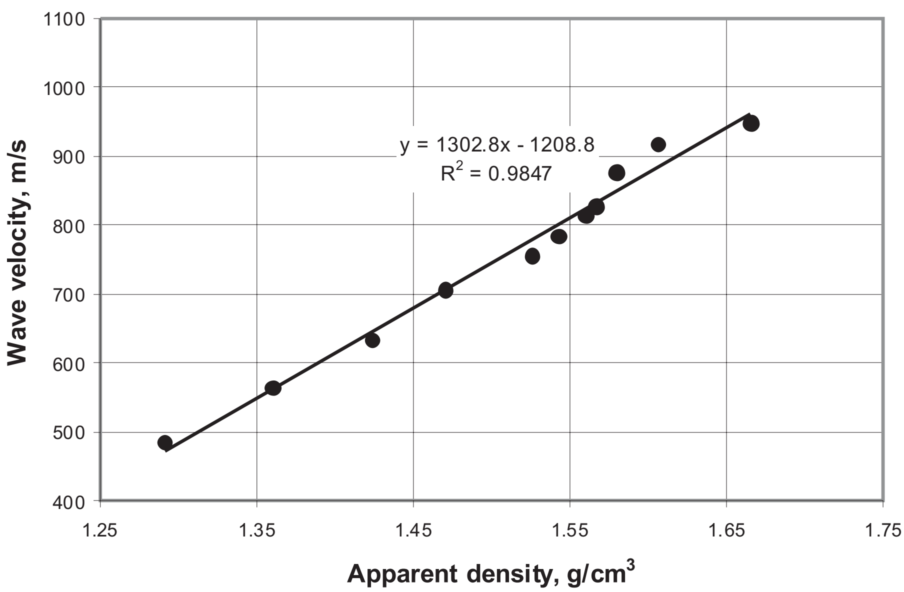

Fig. 7. Wave velocity versus the apparent density of the sand with bentonite (W = const) [5, 11]

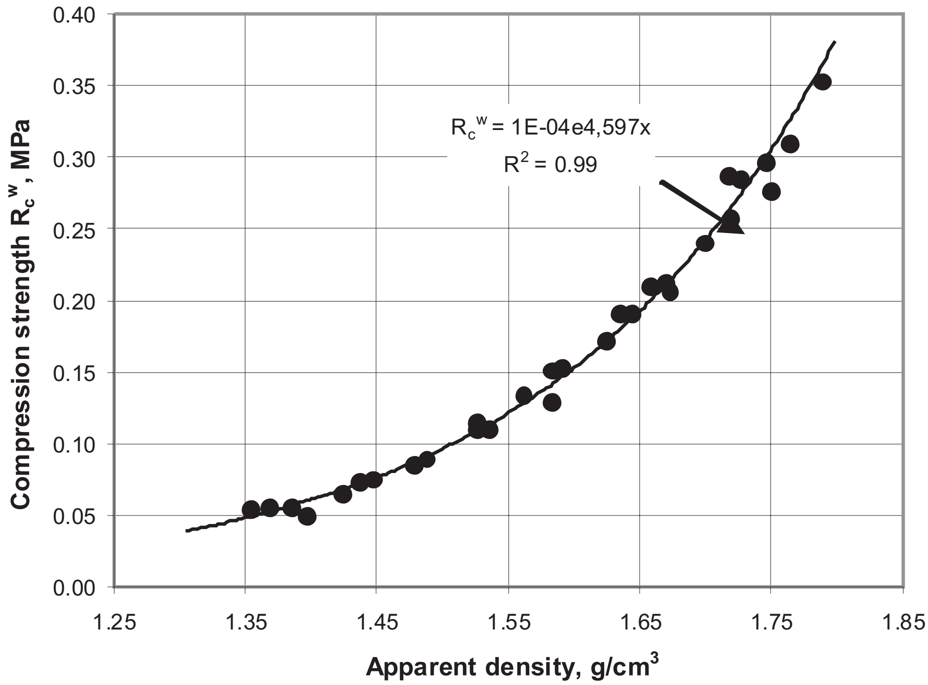

Fig. 8. Influence of an apparent density of the sand with bentonite on its compressive strength R_c^w [5. 11]

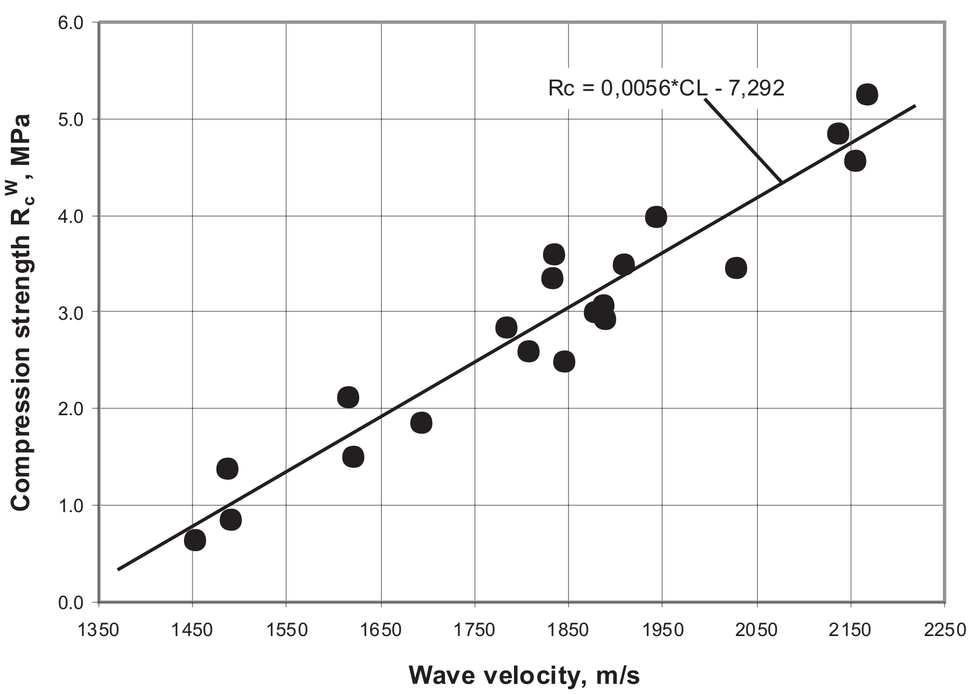

Fig. 9. Dependence of the wave velocity in the sand with furan resin Kaltharz U404 (HU 404) on the compressive strength, for samples of various apparent densities [5, 11]

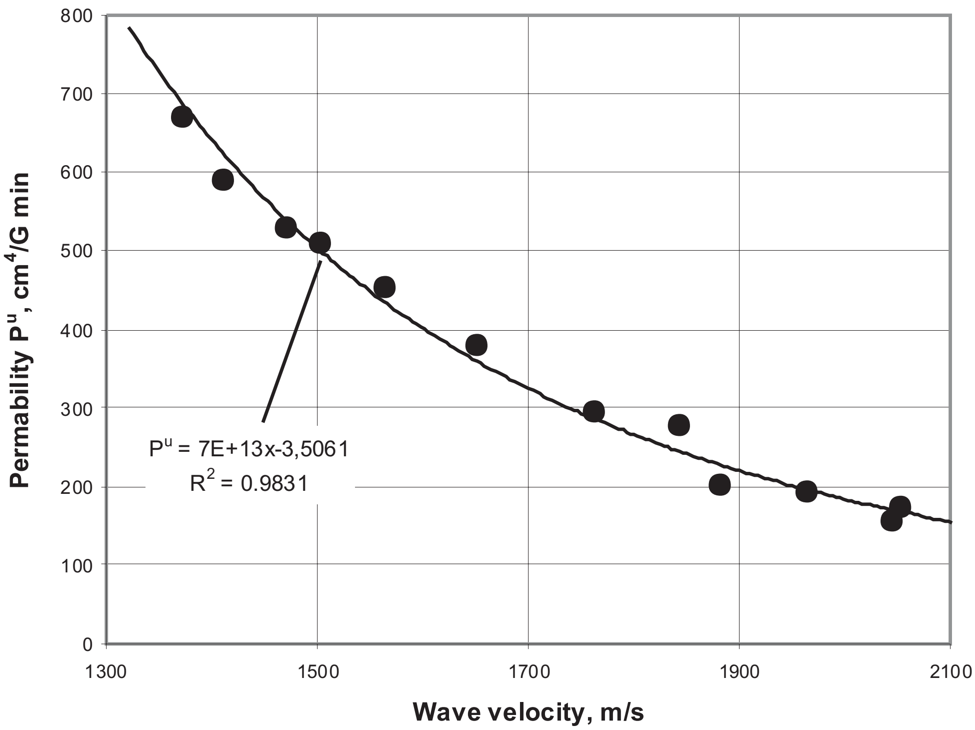

Fig. 10. Dependence of the wave velocity in the hardened core made of sand with furan resin Kaltharz U404 (HU 404) and its permeability, for samples of various apparent densities [5, 11]

3. Conclusions

The presented diagnostic methods of technological properties and qualities of casting cores made by the shooting method together with experimental examinations of the core box filling and compacting of various kinds of sand allowed to statistic working out of numerous measurements data concerning the apparent sand density, its porosity and permeability. It has been shown that the empirical dependencies – developed for the given shooting machine and kind of core sand – are of a structure similar to the one proposed by Aksjonow [1] for the description of compacting done by pressing of moulding sands. They allow to determine the value of the apparent density on the bases of knowing the initial apparent density ρ_{us}, shooting pressure p_r, and a diameter of a shooting head outlet d_1. Regardless of the kind of sands and parameter values at which the given value of the apparent density was obtained there is a continuation of the time-history of porosity (linear dependence) as well as permeability (power dependence) on the obtained apparent density.

Investigations concerning the application of ultrasound technique for examination the compaction distribution and permeability of sands on monolithic and two-layered cores obtained by shooting indicated that changes in compaction degree of core sands are followed by the ability of the sand of a sound wave propagation. This creates the possibility of utilising ultrasound technique for the development of a non-destructive method of core investigating by assessing the compaction uniformity distribution, structural strength and permeability [5, 11].

The results of examinations performed for the wide range of working parameters of the process constitute the reference base allowing for a practical application of the ultrasound technique as a modern alternative diagnostic method assessing the quality and correctness of the employed core production technology.

REFERENCES

[1] P. N. Aksjonow, Wybrane zagadnienia z teorii maszyn odlewniczych. Wyd. „Śląsk", 87-144, (1965).
[2] D. Boenisch, M. Knauf, Kernschiessen – Untersuchungen mit neuartigen Prufkorpern und verschiedenen Kernbindern. Giesserei, nr 18, 640 -646 (1991).
[3] J. Dańko, R. Dańko, Zależność zagęszczal-

ności masy od współczynnika jej ewakuacji z aparatu strzałowo-dmuchowego. Nowoczesne Technologie Odlewnicze – Ochrona Środowiska (2000).

[4] J. Dańko, Ł. Jamrozowicz, Badania czynników wpływających na jakość rdzeni wykonanych w procesie cold-box za pomoca wstrzeliwania. Materiały XXX Konferencji Naukowej „Nowoczesne Technologie w Odlewnictwie", Wydział Odlewnictwa AGH, 117-123 (2006).

[5] J. Dańko, J. Zych, Badania właściwości technologicznych rdzeni w aspekcie ultradźwiękowej metody diagnozowania ich jakości. Materiały XXXII Konferencji Naukowej „Nowoczesne Technologie w Odlewnictwie", Wydział Odlewnictwa AGH, 25-32 (2008).

[6] J. Dańko, Ocena przebiegu procesu dmuchowego i jego efektów w świetle badań Boenischa i Knaufa oraz własnych. Materiały XIX Sympozjum Naukowego Wydziału Odlewnictwa AGH, cz. 1,187-194 (1993).

[7] J. Dańko, Proces wytwarzania rdzeni i form odlewniczych metodami dmuchowymi. Badania i teoria. AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne. Seria: Rozprawy i Monografie nr 145, PL ISSN 0372-9443. (1992).

[8] S. Gorski, T. Sowa, Główne parametry robocze maszyn dmuchowych i nowe metody ich pomiaru. Praca dyplomowa inżynierska. Wydział Odlewnictwa AGH, Kraków 2008.

[9] J. Zych, J. Dańko, Ł. Jamrozowicz, Zastosowanie techniki ultradźwiękowej do badania rozkładu zagęszczenia oraz przepuszczalności masy w rdzeniach monolitycznych oraz dwuwarstwowych uzyskanych przez wstrzeliwanie. Materiały XXXI Konferencji Naukowej „Nowoczesne Technologie w Odlewnictwie", Wydział Odlewnictwa AGH, 13-20 (2007).

[10] J. Zych, J. Dańko, Non-destructive method of core examination to determine the uniformity of sand compaction and the distribution of strength and permeability. Proceedings International Conference „Modern Methods of Core Production", Ceskomoravska vrchovina. Milovy, 45-53 (2003).

[11] J. Zych, Synteza zastosowań techniki ultradźwiękowej w analizie kinetyki wybranych procesów zachodzących w tworzywach formierskich. AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne. Seria: Rozprawy i Monografie nr 163, (2007).

Received: 10 May 2009.