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MOULDING SANDS GRAIN SIZE INVESTIGATIONS BY MEANS OF THE LASER METHOD OF MEASUREMENT

BADANIA UZIARNIENIA PIASKÓW FORMIERSKICH PRZY WYKORZYSTANIU METODY LASEROWEJ POMIARU

The knowledge of the grain size distribution in polydispersive materials, which are among others, moulding sands used in foundry industry, is essential for the proper interpretation of results of technological processes investigations influencing, in consequence, the castings quality.

Current tests of moulding sands grain size are performed by the sieve analysis methods according to the binding standards in the individual country. Those standards require recalculations of results obtained from different sources. Apart from a time-consumption of the sieve analysis methods their basic metrological and technique inconvenience is the limitation to grain classes, which number is determined by the number and mesh clearance of sieves applied in the set. However, in investigations of surface phenomena occurring in processes of preparation of multi-component moulding sands with binders moisturising the quartz matrix, in reclamation of spent sands, in washing out assessments, in investigating harmfulness of wastes, the high resolution of grain classes (in the total range of the technologically acceptable granular range) is necessary.

The results of comparable analysis of grain sizes of the selected moulding sands performed by means of the normalised classic method and by means of the ANALYSETTE 22 Nano Tec equipment for measuring grain sizes in a solid phase and in suspension, are discussed in the paper. This apparatus, which is the most recent technical novelty, a convergent laser beam is applied for the determination of the grain size distribution in solids, water suspensions, emulsions and aerosols. The repeatability and accuracy of measurements fulfils demands of ISO 13320 standards [9].

Taking as an example the grain size analysis of used moulding sands and dusts from the dry reclamation process, the possibility of their deeper assessment was pointed out in the paper. Such assessment is especially important in designing of dust collection devices, used in several foundry processes, where identification of the total spectrum of grain sizes is essential.

Keywords: polydispersive material, silica sand, sieve analysis, laser diffraction method

Znajomość rozkładu uziarnienia w materiałach polidyspersyjnych, którymi są między innymi piaski formierskie stosowane w odlewnictwie, ma istotne znaczenie dla właściwej interpretacji wyników badań procesów technologicznych wpływających w konsekwencji na jakość odlewów.

Aktualnie badania uziarnienia piasków formierskich są prowadzone metodami analizy sitowej zgodnie z obowiązującymi w danych krajach normami, które wymagają przetwarzania wyników uzyskiwanych z różnych źródeł. Pomijając pracochłonność metod analizy sitowej, ich podstawową niedogodnością metrologiczną i techniczną jest ograniczenie się do klas ziarnowych, których liczba jest determinowania przez ilość i rozmiary sit stosowanych w zestawie przesiewającym. W badaniach zjawisk powierzchniowych, zachodzących w procesach sporządzania wieloskładnikowych mas ze spoiwami zwilżającymi kwarcową osnowę, regeneracji mas zużytych, ocenie wymywalności, w badaniach szkodliwości odpadów – konieczna jest duża rozdzielczość klas ziarnowych w całym przedziale ziarnistości akceptowalnym przez technologię oraz tych, które tworzą odpad.

W artykule omówiono wyniki analizy porównawczej ziarnistości wybranych piasków formierskich dokonanej znormalizowaną metodą klasyczną oraz za pomocą aparatu ANALYSETTE 22 Nano Tec do pomiaru wielkości cząstek w fazie stałej i zawiesinie. W tym aparacie, który aktualnie stanowi nowość techniczną, wykorzystuje się zbieżny strumień laserowy do określania rozkładu uziarnienia w ciałach stałych, zawiesinie wodnej, emulsji i aerozolach z bardzo dużą powtarzalnością i dokładnością wyników, spełniających wymagania normy ISO 13320 [9].

W pracy, na przykładzie analizy uziarnienia masy zużytej formierskiej oraz pyłów z procesu regeneracji suchej, wykazano możliwości ich pogłębionej oceny, szczególnie ważnej w projektowaniu urządzeń odpylających, stosowanych w wielu procesach odlewniczych, gdzie ważna jest identyfikacja pełnego spektrum składu granulometrycznego.

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1. Introduction

Grain size analysis constitutes a substantial source of knowledge on polydispersive materials, applied often in industry. In the case of foundry industry this knowledge concerns mainly moulding materials, their processing and preparation, it means: high-silica sand, used sands, reclaimed sand as well as products formed during processing of these materials (dusts).

Sand grains size influences not only technological properties of moulding sands, formed already during sands preparation and compaction, but also effects occurring at mould fillings with liquid foundry alloys, their solidification and cooling since they result from a significance influence of sand grain size on permeability, sintering point and gas producing by moulding sands.

2. General characteristics of grain size analysis methods

2.1. Grain size sieve analysis

In a conventional grain size analysis method applied in Poland, according to PN-83/H-11077 [1, 2] a set of 10 sieves and a bottom is used. This set is completed by means of sieves normalized in such a way as to have sieve mesh clearances very similar to the clearances of the American set (according to ASTM method) [3], which is the most widely known and used.

Conventional methods of sieve analysis are sufficient for assessing materials characterised by a relatively good homogeneity and a small dusts content. In the case of foundry technologies it concerns, first of all, fresh, rinsed moulding sands, which were freed from contaminations and natural binders during the treatment process. However, an application of a conventional grain size analysis for materials more complex in shape, homogeneity and dust fraction content is in the case of sieve analysis less reliable, which is due to the following unfavourable phenomena occurring as a result of its application:

– Agglomeration and gluing of dust fractions into larger clusters of a strength higher than the disintegration force acting in vibratory sieving,
– Adhesion of dust fractions on sand grains fractions of larger diameters [4-5].

These effects, together with the limited number of sieves used in this method, significantly influence the obtained results, especially the grain specific surface determination according to PN-83/H-11078 [6]. The specific surface value is very important in the determination of the numerous specific applications [7, 8].

Apart from industrial applications, the grain size analysis is an essential parameter, allowing to assess the correctness of several treatment processes and its results help to optimise working parameters of devices. Due to this, it is very important to apply more accurate methods of assessing the polydispersive materials properties, such as: structural homogeneity, grain shape and size, as well as specific grain surface in accordance with the newest achievements of the measuring technique.

2.2. Laser diffraction method [9]

The newest devices for measuring particle size are instruments using the laser diffraction effect. A diffraction of the laser beam (laser diffraction) is now a days the most efficient method for the determination the grain size distribution in a very wide measuring range. A valuable point of this type of equipment, apart from the high accuracy of measurements, is a very fast (approx. 10 s) and fully automated measurement. One of such devices is Analysette 22 NanoTec produced by FRITSCH, enabling measuring particle size in the range: 0.01 μm-2000 μm, in a dry or wet mode. The apparatus has two semi conductive lasers of class III, of a wavelength 650 nm and a laser power: 7 mW. All elements of the optical system are placed on a vertical aluminium rail (Fig. 1).

Heads of the apparatus applied for measuring grain size of materials introduced in a suspension and for dry measurements are assembled on separate rails. This equipment, due to the application of the solution based on measuring a dispersed light from the backside, allows covering a wide range of measuring band “high end” and a measurement of particle diameters from 10 nm. Maximum measurement range of the device is from 0.01 μm to 2000 μm [9, 10]. Due to zoom equipment a steples matching of measurement range to the tested sample and high resolution is obtained.

The LaPass control and visualisation program [10] was prepared for servicing the equipment. This program enables viewing the analytical results, comparing them with each other as well as performing a large number of analysis, calculations and diagrams, which are substantial for a better interpretation of the obtained results. In addition, it provides characteristics and basic properties of several dozen – most often applied – fine-grained materials. An example of visualization of the obtained results is presented in Fig. 2.

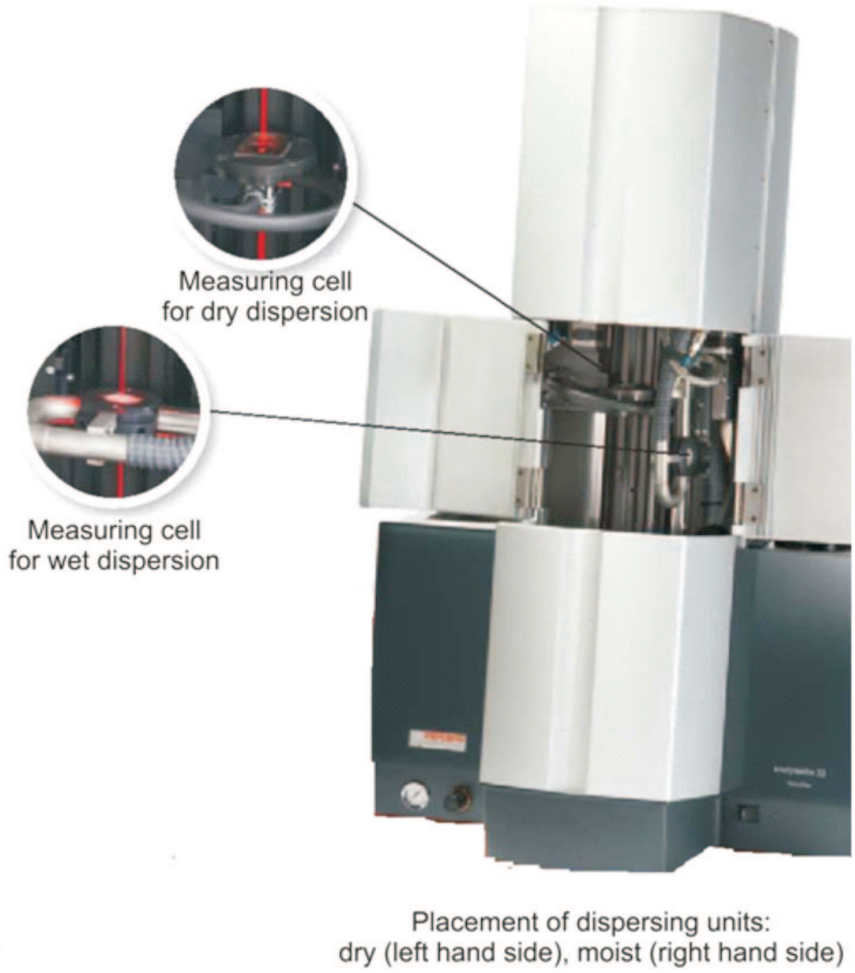

Fig. 1. General view of the laser measuring apparatus Analysette 22 NanoTec [9]

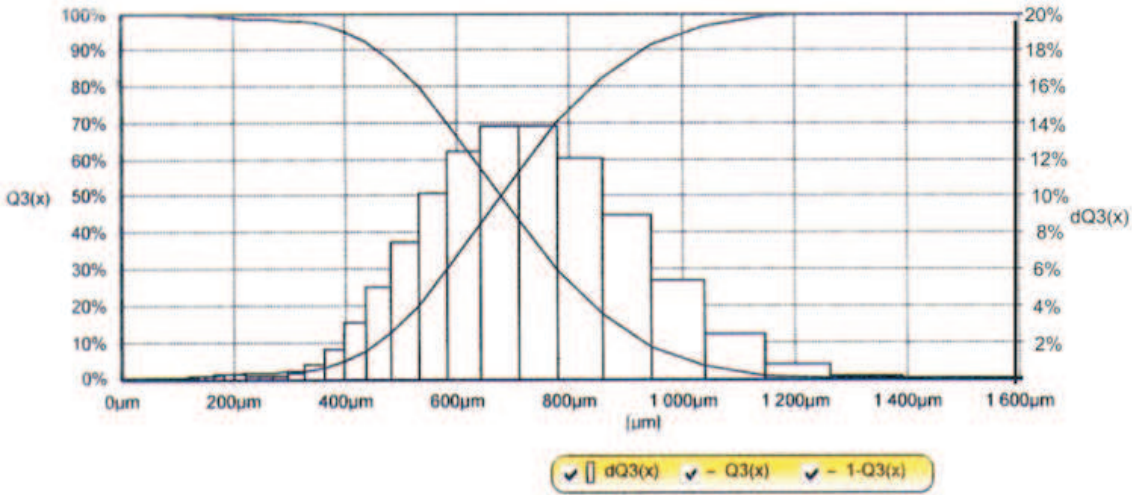

Fig. 2. Example of visualisation of the grain size distribution of polydispersive material, obtained by means of Analysette 22 NanoTec apparatus (fractioned high-silica sand 0.80/0.63/0.4)

3. Material preparation for testing moulding sands grain size

High-silica sand fractions 0.80/0.63/0.40 were used in tests. This sand, after separation of the chosen fractions was undergoing abrasion in a test device, being simultaneously the model of the rotor mechanical reclaimer (Fig. 3). Algorithm of tests is presented schematically in Figure 4, for the applied rotational speed of the rotor system and three various times (5, 10 and 15 minutes) of an abrasive reclamation treatment, to which 2 kg of the tested moulding sand was subjected. The test apparatus allows applying wide changes of rotational speeds: 140 rot. /min, 280 rot./min, 420 rot./min, 560 rot./min, 840 rot./min.

One of the aspects of examinations performed in the test apparatus was the determination of a "safe" rotational speed range of the abrasive device, at which sand grains in moulding sands were not undergoing destruction (crushing), and the elementary processes of rubbing, abrasion and crushing of binder coatings (which is necessary for its removal) were dominating in the tested material.

4. The obtained results

As a result of an abrasive and reclamation treatment 15 samples of materials and 1 reference sample of the initial material were prepared. Comparative investigations, presented below, contain the results of grain size measurements of moulding sands obtained by the conventional sieve analysis and handled by the authors' program Labasit [11] as well as obtained in the device Analyssette 22 NanoTec, where they were automatically calculated within the program serving this equipment. Average values of diameters characteristic for the given grain set: arithmetic mean d_a, harmonic mean d_h, geometric mean d_g, diameter equivalent d_r, all expressed in mm, was used as the main coefficients used for comparison of the results. The specific surface S_t expressed in cm^2/g was the additional coefficient [5]. In addition, the analysis of grain surface morphology was systematically performed and used as a supporting element in the visual identification of the starting moment of the silica matrix crushing.

The results of a sand grain size analysis performed by the conventional method (SA) and by the laser diffraction (LA) are presented in Tables 1-5.

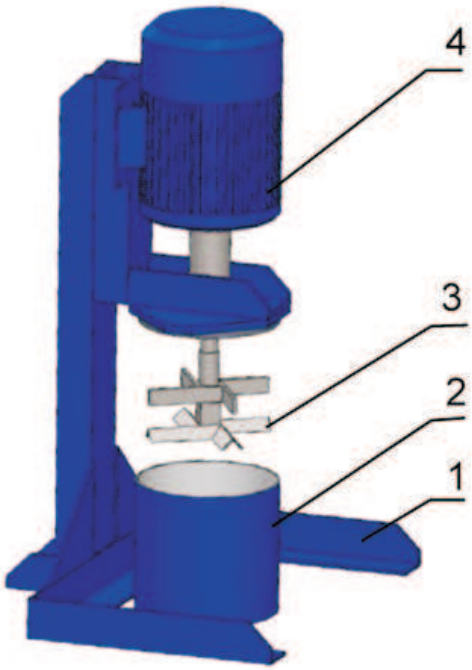

Fig. 3. General view of the abrasive device (test apparatus) for investigation of reclaimability of various kinds of used moulding sands: 1-stand, 2- sand container, 3- rotor with crushing-abrasive elements, 4- motor fixed on slidable frame

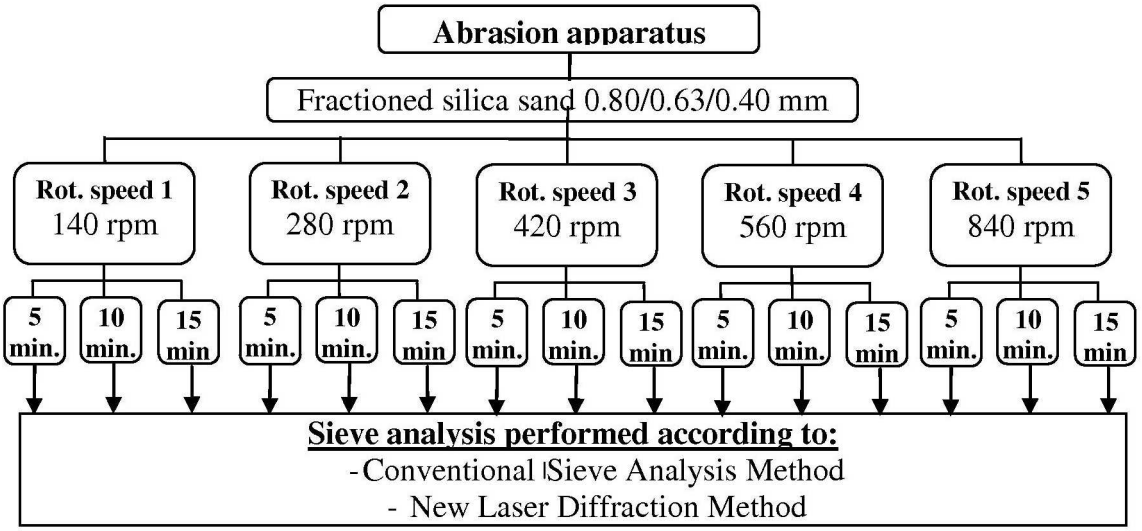

Fig. 4. Algorithm of tests realised in moulding sand grain analysis

TABLE 1

Results of the sand grain size measurements of the initial material as well as after an influence of the device operating with a rotational speed of 140 rpm

	Initial sand		Rotational speed 140 rpm					
	0 minutes		5 minutes		10 minutes		15 minutes	
	SA	LA	SA	LA	SA	LA	SA	LA
S_t [cm^2/g]	**33.650**	33.431	**33.280**	34.494	**34.880**	35.988	**35.140**	36.340
d_a [mm]	**0.7460**	0.7520	**0.7630**	0.7288	**0.7230**	0.7076	**0.7230**	0.7056
d_g [mm]	**0.7110**	0.7464	**0.7180**	0.6996	**0.6830**	0.6788	**0.6800**	0.6759
d_r [mm]	**0.5930**	0.6772	**0.5970**	0.6291	**0.5800**	0.6204	**0.5440**	0.6145
d_h [mm]	**0.6730**	0.7837	**0.6800**	0.7526	**0.6490**	0.7323	**0.6440**	0.7259

TABLE 2

Results of the sand grain size measurements of the initial material as well as after an influence of the device operating with a rotational speed of 280 rpm

	Initial sand		Rotational speed 280 rpm					
	0 minutes		5 minutes		10 minutes		15 minutes	
	SA	LA	SA	LA	SA	LA	SA	LA
S_t [cm^2/g]	**33.650**	33.431	**34.360**	35.7840	**34.020**	35.955	**35.350**	36.200
d_a [mm]	**0.7460**	0.7520	**0.7370**	0.7083	**0.7460**	0.7026	**0.7130**	0.6950
d_g [mm]	**0.7110**	0.7464	**0.6800**	0.6940	**0.6940**	0.7020	**0.6730**	0.6686
d_r [mm]	**0.5930**	0.6772	**0.5860**	0.6255	**0.5880**	0.6290	**0.5460**	0.6327
d_h [mm]	**0.6730**	0.7837	**0.6590**	0.7245	**0.6650**	0.7300	**0.6400**	0.7194

TABLE 3

Results of the sand grain size measurements of the initial material as well as after an influence of the device operating with a rotational speed of 420 rpm

	Initial sand		Rotational speed 420 rpm					
	0 minutes		5 minutes		10 minutes		15 minutes	
	SA	LA	SA	LA	SA	LA	SA	LA
S_t [cm^2/g]	**33.650**	33.431	**34.040**	36.343	**34.280**	36.990	**34.230**	37.323
d_a [mm]	**0.7460**	0.7520	**0.7450**	0.7068	**0.7390**	0.6952	**0.7410**	0.6900
d_g [mm]	**0.7110**	0.7464	**0.7020**	0.6867	**0.6960**	0.6779	**0.6980**	0.6533
d_r [mm]	**0.5930**	0.6772	**0.5360**	0.6229	**0.5340**	0.6120	**0.5640**	0.6066
d_h [mm]	**0.6730**	0.7837	**0.6650**	0.7418	**0.6610**	0.7309	**0.6600**	0.6990

TABLE 4

Results of the sand grain size measurements of the initial material as well as after an influence of the device operating with a rotational speed of 560 rpm

	Initial sand		Rotational speed 560 rpm					
	0 minutes		5 minutes		10 minutes		15 minutes	
	SA	LA	SA	LA	SA	LA	SA	LA
S_t [cm^2/g]	**33.650**	33.431	**33.700**	36.391	**33.820**	36.662	**33.830**	37.542
d_a [mm]	**0.7460**	0.7520	**0.7510**	0.7026	**0.7490**	0.6930	**0.7500**	0.6908
d_g [mm]	**0.7110**	0.7464	**0.7080**	0.6786	**0.7060**	0.6679	**0.7060**	0.6666
d_r [mm]	**0.5930**	0.6772	**0.5640**	0.6242	**0.5790**	0.6176	**0.5570**	0.6066
d_h [mm]	**0.6730**	0.7837	**0.6720**	0.7232	**0.6690**	0.7119	**0.6670**	0.6990

TABLE 5

Results of the sand grain size measurements of the initial material as well as after an influence of the device operating with a rotational speed of 840 rpm

	Initial sand		Rotational speed 840 rpm					
	0 minutes		5 minutes		10 minutes		15 minutes	
	SA	LA	SA	LA	SA	LA	SA	LA
S_t [cm^2/g]	**33.650**	33.431	**33.720**	36.281	**33.600**	38.138	**34.090**	40.276
d_a [mm]	**0.7460**	0.7520	**0.7520**	0.6815	**0.7540**	0.6772	**0.7450**	0.6643
d_g [mm]	**0.7110**	0.7464	**0.7060**	0.6684	**0.7110**	0.6512	**0.7010**	0.6316
d_r [mm]	**0.5930**	0.6772	**0.5360**	0.6030	**0.5370**	0.5921	**0.5090**	0.5621
d_h [mm]	**0.6730**	0.7837	**0.6740**	0.7026	**0.6720**	0.6972	**0.6640**	0.6525

4.1. Analysis of the obtained results

The analysis was focused on the comparison of results obtained by two applied methods of testing. The results of measurements of the specific surface of the investigated materials which diameters were determined by the conventional method and by the laser method are presented in Fig. 5a and 5b – respectively.

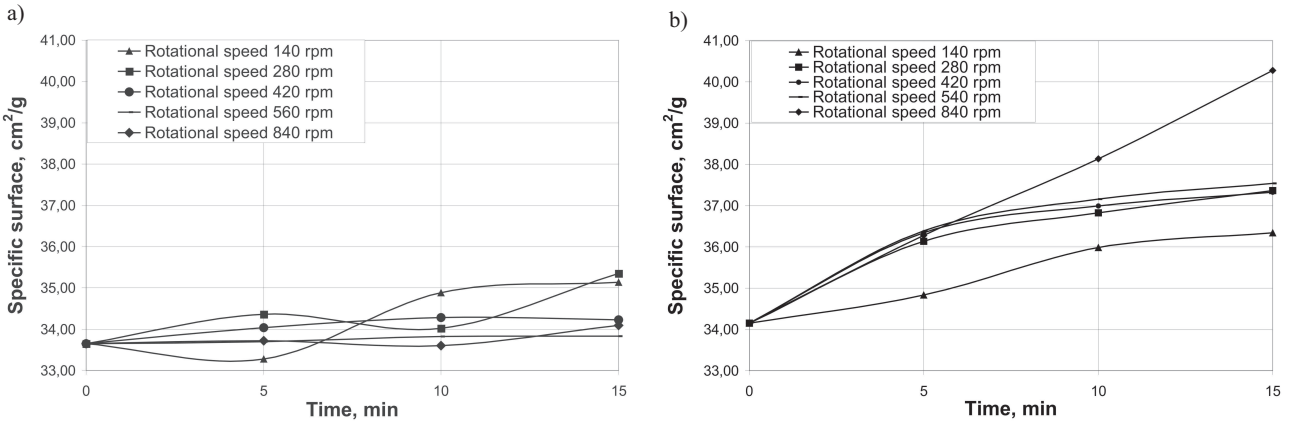

Fig. 5. Specific surfaces of grains determined on the basis of the performed sand grain size analysis: a) sieve analysis, b) laser diffraction method

In order to present differences more distinctly, the same scale was applied in both diagrams.

It can be noticed, that the assessment of an increase of the matrix specific surface caused by the prolonged reclamation treatment time – by means of the conventional sieve analysis of polydispersive material – is very difficult. In addition, a flattening and interleaving of curves is observed, which can lead to erroneous conclusions if there are no other verification measures.

Analysis of data given in Fig. 5 and Tables 1-5 indicates, according to the laser measurements, that the prolongation of the abrasive-reclamation treatment causes the specific surface increase while the conventional sieve analysis shows certain "anomalies". At the rotational speed 140 rpm, the specific grain surface after 5 minutes of treatment is smaller than in the initial state. The analogical situation occurs in the range 5-10 min (at speeds: 280 and 840 rpm) and 10-15 min (at speed: 420 rpm).

The similar graphical analysis was also performed for the selected arithmetic mean grain diameter d_a, determined by these two methods. The results are presented in Fig. 6a and 6b.

The results presented in Figures 6a and 6b confirm previous observations, that in the case of sieve analysis it is very difficult to determine the character of changes occurring in the investigated polydispersive material. As a result of the abrasive treatment – due to partial matrix destruction – the decrease of the average grain diameter should occur, and at a significant intensification of this treatment even a total destruction exhibited as decreasing of characteristic diameters could occur. Similar curves are obtained for the remaining characteristic diameters, which are listed in Tables 1-5.

The probable explanation of such distinct differences in the results of the performed analysis can be electrostatic phenomena occurring on the sand grain surface during the abrasive action. The electrostatic forces caused that grinded material which is very fine sticks to the quartz surface so strongly that its removal during conventional sieve analysis, is impossible. An additional impediment to obtain more accurate results constitutes a low resolution of this method (limited to 10 classes).

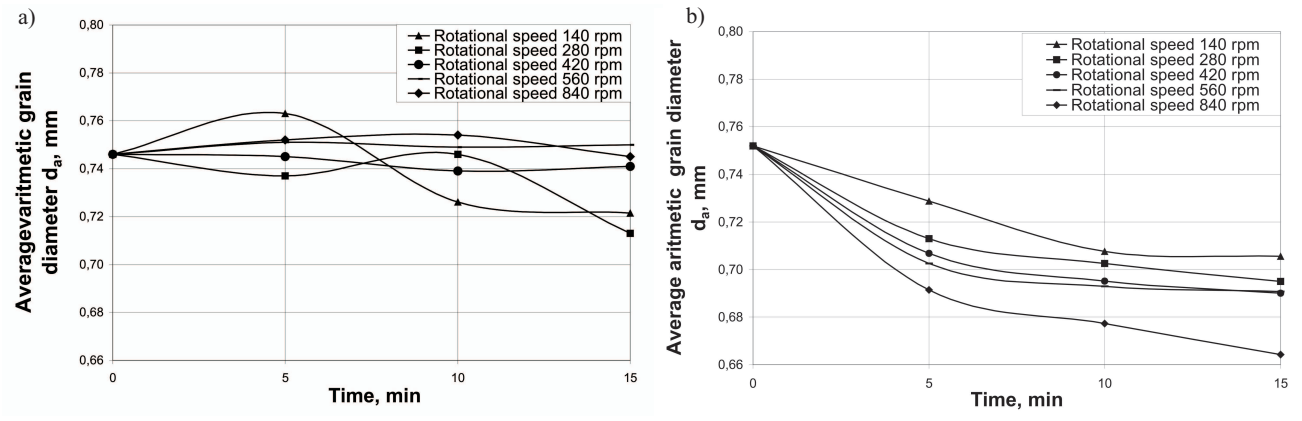

Fig. 6. Arithmetic mean grain diameter d_a determined on the basis of the performed grain size analysis: a) sieve analysis, b) laser diffraction method

These inconveniences are eliminated when grains are analysed by means of the laser diffraction method. The analysis is performed in liquid medium, and an intensive flow of a mixture of silica sand and liquid washes out fine particles from surfaces of analysed grains. The analysis is done with a high resolution encompassing up to 520 grain classes. In the presented investigations the number of classes was 111, which significantly improved the interpretation of results.

On the basis of the examinations done by means of the laser diffraction method it can be stated, that the treatment of the polydispersive material with rotational speeds of 140-420 rot/min does not cause a destruction of matrix grains. The observed changes in grain diameters are the result of grinding surface irregularities and their partial cleaning and polishing. An increase of the rotor rotational speed causes partial matting of sand grains, which can be explained by occurrence of the first dust particles on their surfaces. At the highest rotational speed of the abrasive machine rotor the effect of grain destruction along with electrostatic surface covering by dust particles can be observed.

5. Conclusions

On the basis of the performed investigations the following conclusions, concerning the applicability of the laser diffraction method for the grain size analysis, can be suggested:

– The laser grain size analysis method is more precise tool for the determination of polydispersive materials grain size than the conventional sieve analysis. The advantage of laser diffraction method rely on very high resolution encompassing up to 520 grain classes while in conventional sieve analysis resolution not excess 14 classes and the sieve clearance is restricted to 0.042 mm.
– In the case of research and design investigations (e.g. at designing of crushing-grinding devices for fine-grained materials) this method is more reliable for the degree of fineness assessment than the conventional sieve analysis,
– The laser method, where measurements are performed in liquid medium, allows for elimination of electrostatic phenomena and reliable measuring of powdery fractions, adhering to surfaces of larger grains and being behind the estimation range of the conventional methods.

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