Particle size distribution determination methods comparison based on sieve analysis and laser method

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Abstract: *The article presents the methods of size analysis implementation. It contents a sieving method and laser diffraction method (also known as a laser method). The content includes the characteristics of the selected methods which were presented. Comparison is supported by results of sieve analysis and the laser method. The subject of the researches was iron powder applied in the production of metal cored electrodes used for welding of steel. This powder is characterized by a particle size of about 250 μm.*

Keywords: *sieve analysis, laser method, particle size distribution*

Streszczenie: *Artykuł prezentuje metody wykonania analizy granulometrycznej. Wśród nich należy wymienić metodę sitową oraz metodę dyfrakcji laserowej (zwanej również metodą laserową). W treści zawarto charakterystykę po szczególnych metod oraz zwrócono uwagę na istotne różnice między nimi. Analizę porównawczą poparto wynikami otrzymanymi z metody sitowej oraz metody laserowej. Przedmiotem badań był proszek żelaza mający zastosowanie przy produkcji rdzeni drutów proszkowych stosowanych do spawania stali. Proszek ten charakteryzuje się wielkością ziaren rzędu 250 mikrometrów.*

Słowa kluczowe: *analiza sitowa, analiza laserowa, rozkład wielkości cząstek*

1. Introduction

The article presents the results of analysis by the method of sieving and laser diffraction method. The tests were performed for the iron powder which found an application in the production of metal cored electrode used for welding of steel. It is used as a filler. Preliminary microscopic studies of iron powder allowed to define the maximum particle size observed. That size was about 300 μm.

The term of fraction is often repeated in the article and is worth explaining. In the context of the researches, the fraction should be understood as a part of a whole, which is obtained from the separation of the material. Obtaining fractions is possible due to various physical properties of the material. Referring to tests to determine the particle size distribution, the feature is the particle size.

Grain size analysis is a type of research materials in order to determine the participation of particles with specific sizes. For materials that can be examined by this method are, for example, clay, metal powders, excavated material. To perform the analysis of the grain size, one of the following methods can be used:

- aerometric - belonging to the group of sedimentation methods,
- pipette - belonging to the group of sedimentation methods,
- sieve - belonging to the group of mechanical methods,
- electronic - which included the laser diffraction method.

Depending on the size of the examined particles different methods of researches are used. For particles with size more than 0.07 mm preferable is sieve method. Whereas for particles with size below this value it is recommended to use one of aerometric methods. When the particles are in the two above-mentioned ranges, the combined method is used. It is based on a combination of sieving and sedimentation method (eg. Pipetting).

Even though there is a size limit of particles that suggest the use one of the method, the choice of research should be borne in mind according to the possibility of measuring devices.

Each of these specified methods has different physical value which is measured and which is the basis for determining particle size distribution. Differentiation also comes from the phenomena on which these methods are basing, and for example the amount of material which is needed to carry out the measurement.

Accordingly, the results obtained by different methods can not be compared directly [1]. There is a chance that the results will be similar, but they can not be treated synonymously.

The article presents the results of sieve analysis and the analysis included laser diffraction method.

In the case of performing the analysis manually (the mechanical group) a set of sieves should be prepared. Received result of shaking is the material divided into fractions. The ranges in which fraction will be occurring depends on the nominal size of the holes in the sieve mesh. Their sizes are standardized and included in the norm [2]. Number of compartments (and fractions) will depend on the amounts of the sieves. Today more common method is the sieve analysis performed on special equipment designed for this purpose.

The position to carry out the sieve analysis consists of various elements like vibration shaker, a set of sieves, laboratory weight and ultrasonic washer.

2. Materials and methods

2.1. Sieve analysis

This method of analysis belongs to the group of mechanical methods. In order to conduct researches an adequate apparatus and equipment is needed. During the sieving, the most important parameters are the amplitude and time of shaking. Before starting the sieving, the right amount of sample of the material should be kept. The guidelines can be found in the standard [2]. Sieve analysis was performed by using:

- vibratory shaker FRITCH model Analysette 3 PRO,
- set of sieves FRITCH of the nominal mesh size of: 20, 40, 50, 56, 63, 71, 80, 100, 125, 160, 180, 200 i 250 μm,
- laboratory weight RADWAG model: WPS 1200/C/2 with an accuracy of 0.01g,
- ultrasonic cleaner ULTRON U-24 model; washing parameters: wash time was 10 minutes with vibration frequency of 21.5 kHz and wash temperature 28°C.

The study used a sample of the iron powder with a mass of 362 g. Before starting shaking, used sieves were weighted. The analysis was carried out on a dry sieves at an amplitude of 1.5 mm for 5 minutes on a vibratory shaker. After the end of sieving, each of the sieve was weighted together with the set material. The difference in a sieve weight before and after analysis allowed to determine the mass of each fraction. Referring to the mass of summarized deposits collected on sieves, percentages of each fraction was calculated.

2.2. Laser diffraction method

The laser analysis was performed using Mastersizer S (Malvern Instruments Ltd). Parameters of laser which was used in the analysis were: 2 mW He-Ne laser with 633 nm wavelength and 18 mm beam diameter, collimated and spatially filtered to a single transverse mode [3].

The construction of the device can be divided into three parts. The first includes the optical elements. There are: laser, spatial filter, collimating lenses, focusing lens. Next part which include recording elements that are directly connected with optical elements. These include the detector (which is the common element between the two parts), electrical coupling, serial communication connection and a computer. The last part of this system is the dispersing starter with a flow cell. In the starter, the powder is poured into a liquid for example water. Then, the mixture moves through the pipes to the flow cell where is the laser light scattering.

2.3. Difference between sieve and laser method

Significant difference between the described methods is the amount of test material for example powder. For the laser method only approximately 1 g of material is enough. This is a small amount that allows to obtain the results showing the size distribution of the particle size without the need to dedicate a main part of the test material. For comparison, in a sieve analysis about 100 cm^3 of material is required. Weight of the sample depends on the powder density. This can relate to a sample mass of a few hundred grams.

Another difference is the time of the analysis. The sieve analysis of a single shaking time is 5 minutes. This is only fraction of the time needed for the investigation of the powder. It should be noticed that during the shaking, on the vibratory shaker only six sieves can be placed. For example, when a sample needs 14 of sieves, the same time of the analysis is extended to 15 minutes. More time should be added for weighing the sieves before and after analysis. In addition, it is required to clean and dry the surface of the sieves, which takes additionally about 40 minutes. Depending on the arrangement of the used devices and the number of sieves, the total range of time for a single powder investigation may take from 1.25 hours to 2 hours. Whereas execution of the analysis using laser diffraction takes about one minute. Time for the calibration and cleaning equipment after the analysis

should be added. It can be assumed that the total analysis time is approximately 20 minutes.

Next difference between these methods is the influence of particle shape on the results of analyzes. In the laser analysis, the effect of the shape of particles is significant. This is due to the way the of registration the size of the particle. In this method, each particle, regardless of the shape is approximated by a circle. In addition during the registration the particles of larger size can cover particles of the smaller size [1]. Then the received spectrum do not consist the results from the all of parts. The effect of the particle shape in a sieve analysis is not so significant.

3. Results

3.1. Results of sieve analysis

The results of the analysis and the used parameters with the exact characteristics of the equipment taking into account the shape and size of the sieves, a mesh shape or the way of shaking are always presented in the table like table 1. In column number 1 there are limit values of the size of each fractions. In the second column the difference in weight of the sieve before and after sieve analysis was placed. Third column shows the percentage of each fractions. Column 4 contains the nominal mesh size of sieve. In the last column the percentage of grain collecting is placed. The results could be presents as a diagram of collective grain [%] and nominal mesh size [μm] or sieve fractions [%] and nominal mesh size [μm]. The second way is more clearly and it is needed to compare sieve and laser analysis.

Tab. 1. Table for results from sieve analysis

Material:				
Method of sieving:			Dry / Wet	
The size [mm] and shape of the sieve:			200	
			Round / Squared	
Sieving element:			Woven wire / Perforated sheet / Electrochemically perforated sheet	
Signage sieve:			Manually / mechanically	
Type:			xyz	
The shape of the mesh:			Round / squared	
Time of sieving [min]			5	
Amplitude [mm]			1.5	
1	**2**	**3**	**4**	**5**
Grain size	**The sieve fractions**		**Nominal mesh size**	**Collective grain**
μm	**g**	**%**	**μm**	**%**
315≥d>250			250	
250≥d>200			200	
200≥d>180			180	
180≥d>160			160	
160≥d>125			125	
125≥d>100			100	
100≥d>80			80	
80≥d>71			71	
71≥d>63			63	
63≥d>56			56	
56≥d>50			50	
50≥d>40			40	
40≥d>20			20	
d≤20			The final undersize grain	
Sum				
Output mass:				
Sum of the fractions mass:				
Losses:				

3.2. Results of laser diffraction method

The results of analysis which uses laser diffraction method carried out for iron powder with a particle size less than 250 microns are presented in this subsection. Table 2 contains the results of only a fraction with participation greater than 0%. Particles which size was in the range below 3.21 micrometers and above 265.4 μm had a zero percentage of participation.

On the basis of this values, the relation was plotted (fig. 1). It shows that the major grain size is in section from 24 up to 200μm. Their participation is bigger than 1%. There is only one section from 93 to 108 μm which is definitely lower then adjacent sections. The partitions out of this range were detected, but their participation is minimal. They have too small size or they can be a measurements error.

Tab. 2. Results of the analysis of the laser iron powder

No.	Size [μm]	Volume [%]
1	3.46	0.01
2	3.73	0.02
3	4.02	0.03
4	4.33	0.02
5	4.66	0.02
6	5.03	0.03
7	5.42	0.03
8	5.84	0.03
9	6.29	0.04
10	6.78	0.04
11	7.31	0.04
12	7.88	0.05
13	8.49	0.05

14	9.15	0.06
15	9.86	0.07
16	10.62	0.09
17	11.45	0.10
18	12.34	0.13
19	13.30	0.16
20	14.33	0.19
21	15.45	0.24
22	16.65	0.29
23	17.94	0.36
24	19.33	0.45
25	20.84	0.55
26	22.46	0.66
27	24.20	0.80
28	26.08	0.96
29	28.11	1.15
30	30.29	1.35
31	32.65	1.58
32	35.18	1.83
33	37.92	2.10
34	40.86	2.38
35	44.04	2.68
36	47.46	2.98
37	51.15	3.29
38	55.12	3.60
39	59.41	3.90
40	64.02	4.19
41	69.00	4.45
42	74.36	4.67
43	80.14	4.89
44	86.36	5.12
45	93.07	5.25
46	100.3	2.19
47	108.1	5.01
48	116.5	4.77
49	125.6	4.47
50	135.3	4.07
51	145.8	3.61
52	157.2	3.13
53	169.4	2.64
54	182.5	2.16
55	196.7	1.70
56	212.0	1.29
57	228.5	0.83
58	246.2	0.20

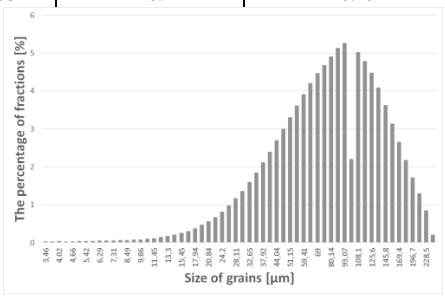

Fig. 1. Graph is showing the results of analysis of laser carried out on iron powder. It presents the particle size distribution

3.3. Comparison of sieve analysis and the laser diffraction method

In order to observe the difference between the results of sieve analysis and the results of the laser analysis, they were compared with each other. Due to the greater number of ranges of particle size in the laser analysis, they were assigned to the ranges from the sieve analysis (table 3). The ranges are the same as nominal mesh size of sieves which were used in sieve analysis. Percentages participation of every part from laser analysis were summed for every range which was determinate by used sieves.

The participation of each fractions from sieve and laser analysis are presented in figure 2.

The comparison shows that the results of both methods can be related to each other and the differences are acceptable.

Tab. 3. The results of the analysis of the laser on the iron powder, which are assigned and summarized

Number	Nominal mesh size [µm]	Percentage share [%]
1	d≤20	2.1
2	40≥d>20	9.33
3	50≥d>40	7.16
4	56≥d>50	6.27
5	63≥d>56	3.6
6	71≥d>63	8.09
7	80≥d>71	4.45
8	100≥d>80	14.68
9	125≥d>100	15.45
10	160≥d>125	16.92
11	180≥d>160	3.13
12	200≥d>180	4.8
13	250≥d>200	3.82
14	315≥d>250	0.2

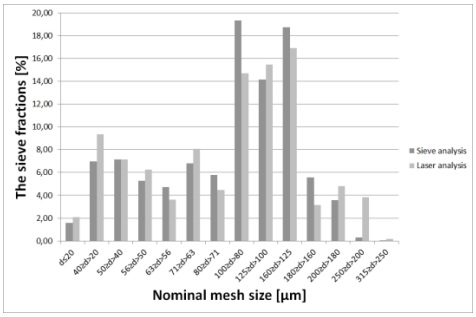

Fig. 2. Comparison of sieve and laser analyses

5. Conclusions

Today, the method of analysis of grain size have a wide range of applications and possibilities. Depending on the amount of testing material, the required accuracy or time of analysis, many available analyzes can choose.

Both presented methods can be successfully used to carried out the grain size partition. Sieve analysis is more time-consuming, but one the advantage of this method is small influence of shape of partitions. Moreover, the price for all unnecessary equipment is lower than device which uses laser diffraction.

During comparison of both methods, every differences between them must be well know. Moreover, the result should be bring to equal groups in order to correct assigned.

The analysis of the results of the carried out method (sieve and laser), allows to draw the conclusion that they can be successfully compared with each other according to material with similar construction to this presented in the article.

Analysis of the laser is the right choice in a situation when short time of examination is expected. The limitations connected with the used technology and the method of measurement should be noticed.

References

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