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PROBLEMS WITH ABRASIVE DOSING IN EROSIVE WEAR PROCESS MODELLING

PROBLEMY DOZOWANIA ŚCIERNIWA W MODELOWANIU PROCESU ZUŻYCIA EROZYJNEGO*

The article characterises problems occurring during erosion tests conducted in a laboratory environment. The authors consider the issues connected with the precise dosage of the abrasive in a system for the simulation of an erosive wear process. Additionally, the authors present an original system for the dosage of the erodent, and show the results of verification tests aimed at the determination of the precision of the dosage of the abrasive depending on the parameters of the control system.

Keywords: *erosion, verification tests, abrasive dosage, feeder test methodology.*

Artykuł prezentuje charakterystykę problemów występujących podczas badań erozji w warunkach laboratoryjnych. Rozpatrzono zagadnienia związane z precyzyjnym dawkowaniem materiału ściernego w systemie badawczym do symulacji procesu zużycia erozyjnego. Przedstawiono autorskie rozwiązanie układu dozowania erodenta. Zaprezentowano wyniki badań weryfikacyjnych wykonanych w celu określenia dokładności dozowania w zależności od stosowanych parametrów systemu sterowania.

Słowa kluczowe : *erosion, verification tests, abrasive dosage, feeder test methodology.*

1. Introduction

Technological progress is the counterpart to the growing demand for novel machines and devices that should be characterised by high reliability, functionality, and an extended time of operation in extreme conditions. The development of aviation, as well as power and petrochemical industries, has resulted in greater expectations as far as structural and functional materials are concerned, particularly when mechanical properties and the resistance to corrosion and erosion are taken into account [8, 18]. These requirements have in turn led to the increased number and availability of advanced materials and innovative technologies in the area of materials engineering [5]. Traditional materials have started to be replaced with composite materials that are lighter and can carry higher loads. Due to the area of their application, modern structural and functional materials need to be comprehensively examined, particularly for resistance to erosion. Impact erosion tests are regulated by different standards, depending on the type of the coating and the structural material used.

The method presented in the ASTM-G76 standard is directed at erosion tests for structural and functional materials. A material tested is subjected to the influence of a mixture of abrasive and air. The erodent, by means of gravity, is deposited in the mixing chamber, where it is mixed with compressed air. The mixture is then released from the mixing chamber through the nozzle and impacts the test sample [12].

Normative erosion tests complying with the PN-76/C-81516 standard are directed at testing the resistance of paint coatings. The tests can be conducted using two methods. One consists in the creation of an elliptical hole in the tested coating by means of an abrasive, while in the other, an abrasive disc moves along the surface of the sample along the defined section and at constant load [13].

The method described in the PN-EN ISO 16282 standard is used for the verification of resistance to erosive wear of refractory materials. The measure of the abrasion resistance is the volume of the material removed from the flat surface of the sample located perpendicularly to the nozzle through which silicon carbide is discharged [14, 7].

Nonstandard methods can also be applied. In most cases, they use centrifugal force in a tumbler for the dispersion of the particles of the abrasive. The agent leading to erosion is the mixture of the abrasive agent and water [15,16].

Extreme tests enabling the reconstruction of real conditions of the wear process play an important role in the characterisation of resistance to erosive wear, and they ensure the determination of the expected life of the tested structural element. Tests conducted according to the ASTM-G76, PN-76/C-81516, and PN-EN ISO 16282 standards are performed in standardised conditions that are different from real operation conditions.

Exploitation of structural elements of machines and technical devices usually significantly differs from the parameters in the above listed standards. The conditions in flow machines are different from the conditions in jet engines, fans, suspension furnaces, or cyclones. This particularly concerns thermal forces and impact energy, which greatly influence the erosion resistance of structural and functional materials. The diversity of operating environments in which erosive wear takes place created the demand for test and research apparatus and simulation methods enabling the reconstruction of the process in a way resembling real life operation conditions [19,1,20]. The developed apparatus can be a useful tool for researchers and constructors, because it helps in the explanation of the physical aspects of the erosion process.

2. General concept of the stand for erosive wear tests

The available research apparatus enables the execution of standard tests, but its application for nonstandard tests is significantly limited. Only a few devices enable tests in high temperatures to be conducted [10, 17]. The main functional barrier is the proper dosage of the abra-

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(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** sive agent. Such precision is influenced by the size of the particles of the erodent, its moisture content, and the type of the feeder used. Most feeders do not comply with the requirements of the proper dosage of the abrasive, and they cannot ensure the repeatability of the results of the dosing process [8,21,9]. For the erosion tests to be precisely conducted, new generation research devices enabling precise adjustment of the parameters of the test, particularly the ones of the dosage of the erodent, need to be developed.

The researchers at the ITeE-PIB carried out research aimed at the design of test and research apparatus for the reconstruction of erosive wear mechanisms for structural and functional materials. The device in question enables the performance of both normative and nonstandard tests. An important assumption was the ability to control precisely a wide range of the erosion process parameters, defined based on the actual conditions prevailing in the machines vulnerable to impact erosion. Basic assumptions concerning these parameters are presented in Table 1.

Table. 1. Basic parameters of the device for erosive wear tests

No.	Description	Parameters
1	Airstream temperature	20 – 600°C
2	Air pressure	0 – 0.6MPa
3	Air speed in the nozzle	0 – 100m/s
4	Consumption of the abrasive	2 – 10g/min

The range of parameters was selected in a way enabling full execution of both tests according to the ASTM G 76 standard and non-normative tests according to our own experiments. The structure of the system for the simulation of erosive wear (Fig. 1) was developed. It has a modular character enabling the reconstruction of an impact erosion mechanism stemming from the impact of the mixture of the abrasive and air.

The research apparatus available on the market have limited functionality and do not allow a full range of erosion tests to be performed, particularly in repeatable conditions, for a significant number of samples. The modular structure and functionality of the device developed by the authors of the paper ensures flexible control over a wide range of erosion process parameters and allows for up to eight samples made of different materials to be placed in the test chamber. Additionally, each of the samples can be tilted at a different angle to the stream of the abrasive agent.

Moreover, commercially available devices provide a limited possibility to conduct tests at high temperatures, because they do not allow the temperature of the sample and the stream of the abrasive agent to be controlled independently. This problem is non-existent in the apparatus described in this article, because two separate heating modules were used, which constitutes an important advantage of the system for the simulation of the erosive wear process.

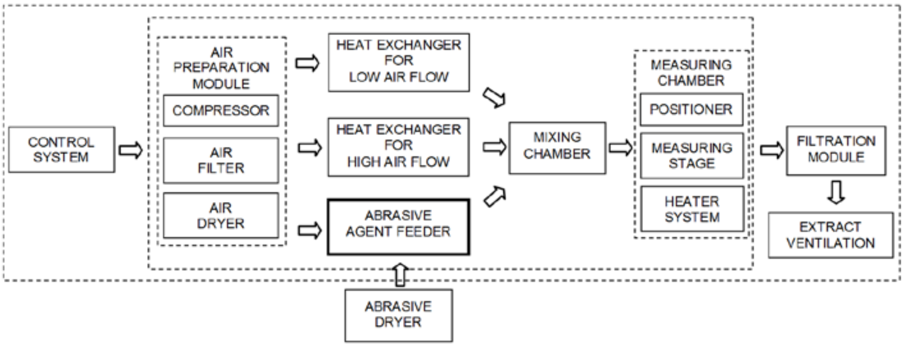

Fig. 1. Block diagram of the system for the simulation of the erosive wear process

The device is composed of an air preparation module, heat exchangers, an abrasive agent feeder, a mixing chamber, a measurement chamber module, a set of filters, and a control system. Depending on the value of the intensity of the stream flow, the filtered and dried air flows through one of the exchangers. Once the air is heated to the temperature required for the test, it is directed to the mixing chamber, where it is combined with the abrasive agent. The mixture created in this way leaves the chamber through the nozzle and bombards the test sample. Then, a gaseous agent flows through the set of filters that absorb the particles of the worn out abrasive agent.

Considering erosive wear tests, an important role is played by the accuracy and repeatability of the dosage of the abrasive agent. Imprecise dosing can result in a misrepresentation of the modelled wear process, which leads to erroneous results. Since accuracy of the dosing process significantly influences the erosion process, the authors analysed commercially available dosing devices, developed an original device, and then subjected it to verification.

3. Erodent dosing system

Dosage of the erodent depends on the structure of the device that has an influence on both the precision and the even supply of the abrasive agent.

Ejectors are most commonly applied in the systems feeding the abrasive agent in which disc or screw feeders are used. In the ejector system, the Venturi effect is used in which the air stream automatically sucks in the particles of the abrasive agent from the feeder (Fig.2a).

The amount of the abrasive agent supplied depends on the speed of the air stream and the particle size of the erodent. Such solutions exclude the possibility of an independent control over the amount of the abrasive agent and the speed of the mixture, because the number of the abrasive particles supplied depends on the speed of the air stream.

In a disc feeder, the abrasive is removed through the nozzle, deposited by means of gravity on the rotating disc (Fig. 2b) and then, using an immovable scraper, moved to the mixing chamber. The consumption of the abrasive agent depends on the rotational speed of the disc and the distance between the disc and the nozzle of the feeder.

Screw feeders are used for the dosing of powders by means of a volumetric method (Fig. 2c). The amount of the abrasive depends on the rotational speed and the geometry of the screw. The device enables precise and constant dosage of the agent regardless of the speed of the air stream.

In erosive wear tests, abrasives characterised by high hardness are used; therefore, the feeders should be highly resistant to the influence of the erodent, while ensuring a high precision of the dosing process. Only one of the above devices enables precise supply of the transported material, i.e. the screw feeder; however, the negative influence of the abrasive agent on the screw and the elements cooperating with it leads to quick wear of individual elements, resulting the uncontrollable changes in the parameters of the dosing process.

Based on the analysis of different feeders that are available on the market, the authors developed their own concept of the abrasive agent feeder. The main assumption was to design a dosing system that would ensure the dosage of the abrasive agent with a grain size between 20 and 150 μm, with an accuracy of ±0.5 g/min, and an efficiency of 2 – 10 g/min. Additionally, the assumptions also took into consideration the parameters defined by the ASTM G76 standard.

The developed abrasive dosage module (Fig. 3) consists of a conveyor belt, an exchangeable orifice, and an abrasive feeder. In the system in question, a conveyor belt for the

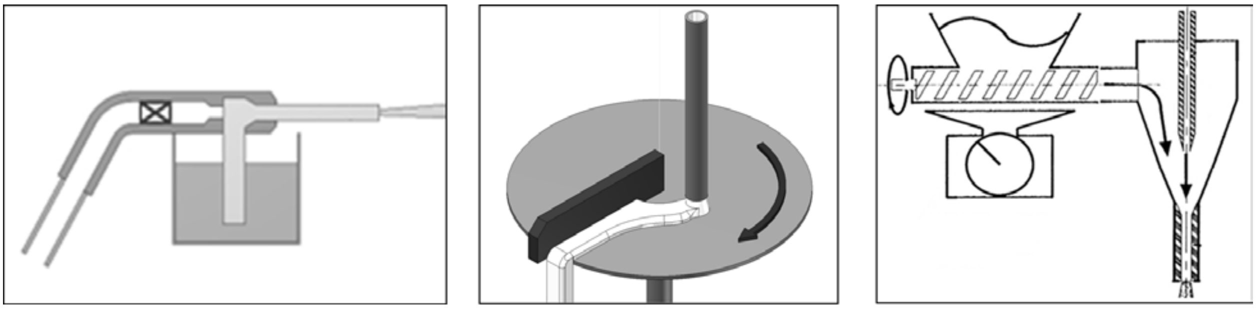

Fig. 2. Dosing systems used in stands for erosion tests: a) ejector feeder [20], b) disc feeder, c) screw feeder [4].

transportation of corundum in water cutting machines was used. As the grain size of the erodent and the dosage range differ from the values used for corundum, an original dosage system was designed. For that purpose, in the feeder, additional pneumatic and electromechanical systems were applied, which significantly increases the precision with which the consumption of the erodent is adjusted, and it prevents any uncontrolled breaks in the dosage. The electro pneumatic system used prevents the blockage of the particles of the erodent in the orifice. The main problems connected with the application of conveyor belts stem from the negative impact of powders on the belt [2,3]. The problems concern the flow and the direction of the transported material, causing additional resistance in the feeder, blockage of the pouring, and the wear of conveyor components [6]. However, during the pouring of the transported material onto the belt, dynamic interactions can be observed. They are difficult to model using analytical methods and cause irregularities in a way powders are supplied [11].

In order to stabilise the dosing parameters, the device was equipped with an electromagnet with a vibrating core, which prevents clogging of the channel in the orifice.

The electromagnet was placed in the upper lid of the feeder with a pusher mounted to the core. Due to the size of the orifice in which the pusher moves, an electromagnet was used with a stroke of 6 mm, a pushing force of 30 N, and a vibration frequency between 1.5 and 15 Hz. During the operation of the electromagnet, the pusher performs reciprocating movements that enable smooth movement of the abrasive material in the orifice. The amount of the abrasive agent depends on the linear speed of the feeder, the inner diameter of the orifice "d" and the distance between the conveyor belt and the head of the orifice "h" (Fig. 3). According to the assumptions, the linear speed of the feeder can be adjusted in the range between 0.8 and 3.6 m/min. The width of the belt is 12 mm.

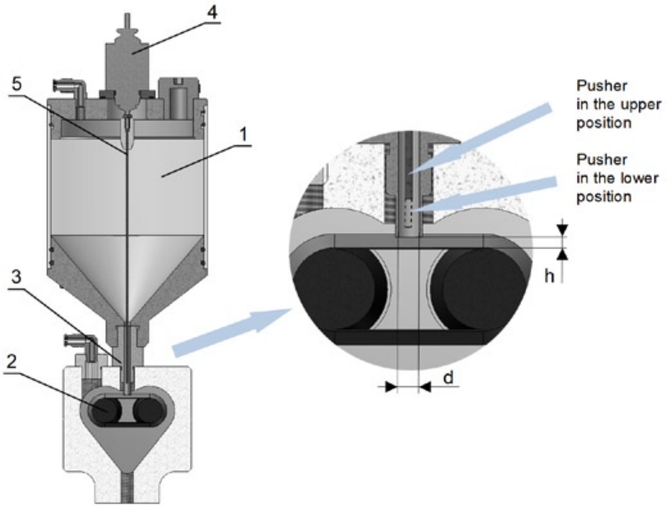

Fig. 3. Dosing system developed: 1 – abrasive agent feeder, 2 – conveyor belt, 3 – orifice, 4 – electromagnet, 5 – pusher

4. Research methodology

In order to verify the designed dispenser module in the laboratory environment, a research methodology and a test stand were developed. The acceleration method enabling initial recognition of the impact of the vibration frequency of the pusher and the speed of the conveyor on the accuracy and efficiency of the dosing process was used. In order to reduce the experimental work, the authors carried out tests only for extreme values of the vibration of the electromagnet and for eight different linear speeds of the feeder available in the full range of adjustment. Test parameters are presented in Table 2.

The tests were conducted using a laboratory model of the developed feeder (Fig. 4). Alumina with a grain size of 50μm, as recommended by ASTM G 76, was used as the abrasive. An important element affecting the accuracy of the dosage is the moisture of the abrasive. In order for this parameter to be set at the exactly same level, the abrasive was subjected to thermal stabilisation.

The abrasive was heated up in the thermal chamber for one hour at the temperature of 150°C, and then for two hours, it was cooled down to 70°C. After processing in the thermal chamber, the erodent was placed in a hermetic container, where it further cooled down to room temperature. The abrasive material prepared in that way was used for tests only once. For each sample, the same amount of the abrasive, i.e. 1.5 kg, was put in the feeder.

Table 2. Parameters of tests on the dosing module

No.	Description	Parameters
1	Type of the abrasive	alumina 50μm
2	Temperature of the abrasive	20°C
3	Pusher vibration frequency	1.5; 15 Hz
4	Feeder speed	0.8; 1.2; 1.4; 1.8; 2.2; 2.6; 3; 3.6 m/min
5	Number of tests for defined speeds of the feeder	10
6	Single test time	1 min

5. Test results

When the feeder's operation is at the minimum linear speed of 0.8 m/min and the frequency of vibrations of the pusher is at 1.5 and 15 Hz, the dosing process was recorded using a quick vision technique. The recording system was composed of a Phantom V310 camera with a Sigma 24-70 F2.8 lens, and a panel LED illuminator. Two

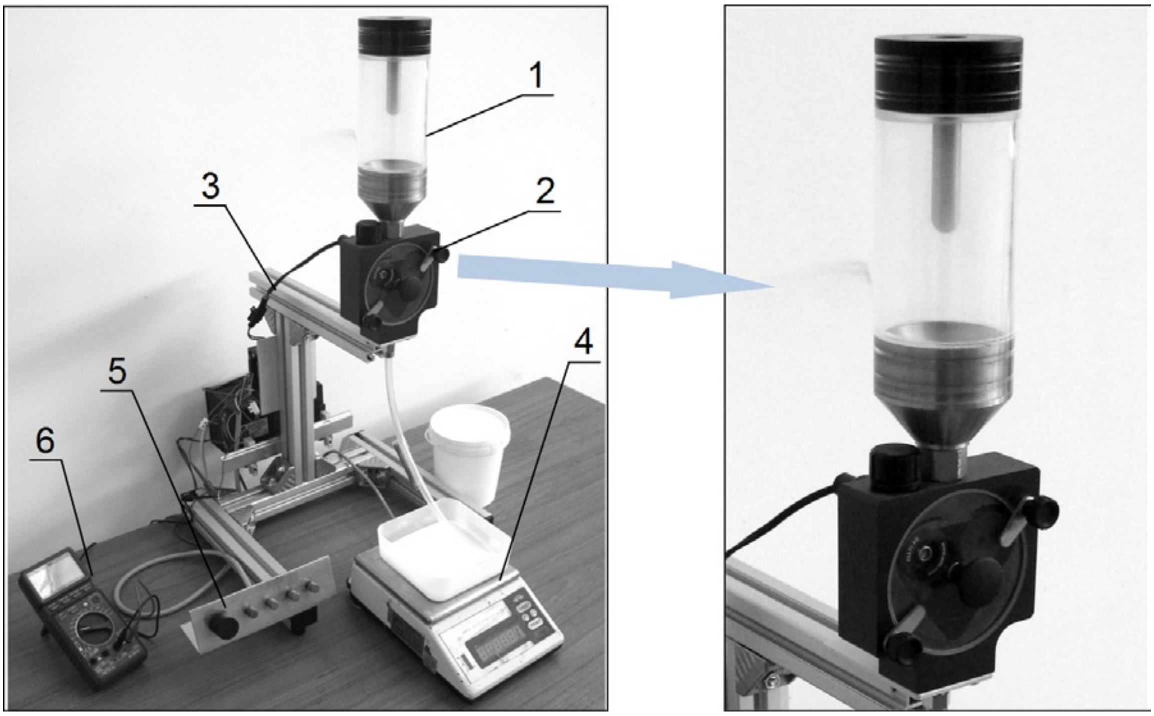

Fig. 4. Laboratory model of the feeder 1 – abrasive feeder, 2 – conveyor belt, 3 – support frame, 4 – scales, 5 – control panel, 6 – digital meter

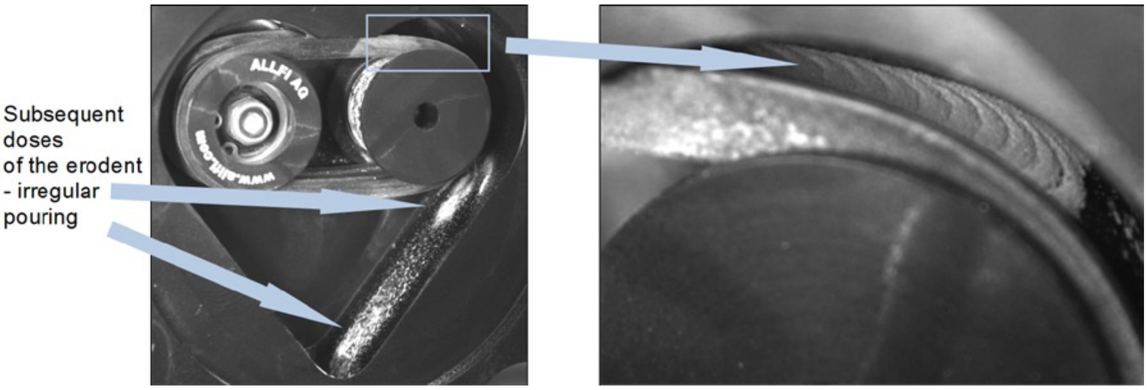

Fig. 5. Image recorded for the stream of the abrasive: a) after the release from the conveyor belt, b) on the conveyor belt (pusher's vibration frequency of 1.5 Hz, recording speed 300 fps, exposure time 2000 µs).

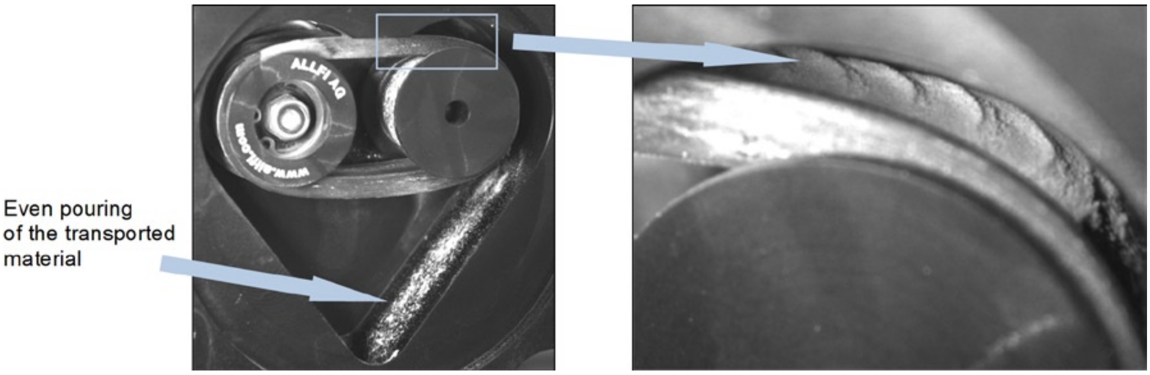

Fig. 6. Image recorded for the stream of the abrasive: a) after the release from the conveyor Belt, b) on the conveyor belt (pusher's vibration frequency of 15 Hz, recording speed 300 fps, exposure time 2000 µs).

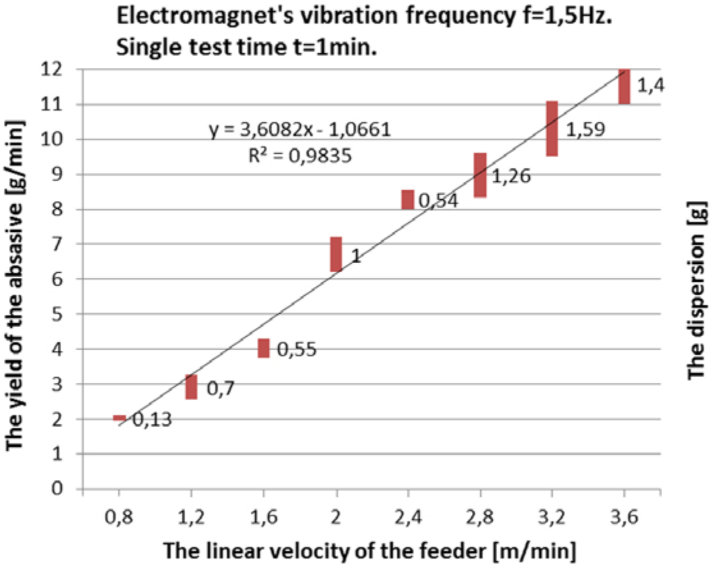

Fig. 7. Values of dispersion and the graph of abrasive consumption in the function of linear speed of the feeder

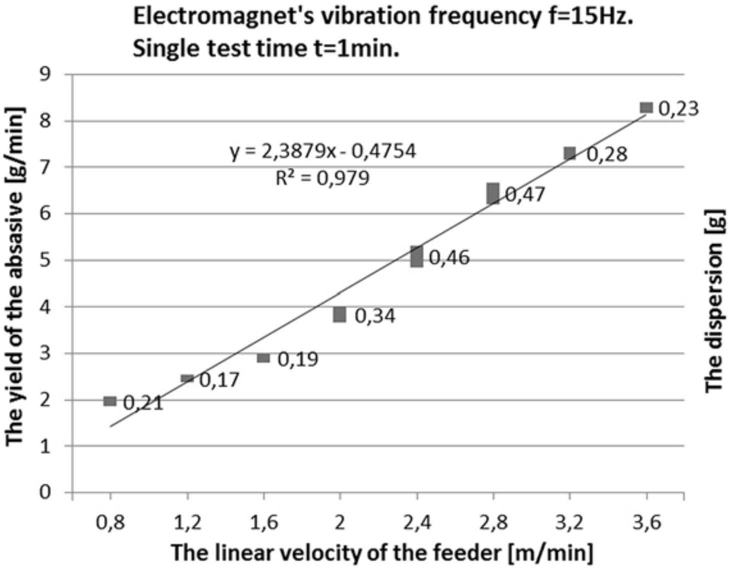

Fig. 8. Values of dispersion and the graph of abrasive consumption in the function of linear speed of the feeder

images were recorded. The first shows how alumina is deposited on the conveyor belt, and the other depicts the uniformity with which the erodent is dosed once it is removed from the belt. TEMA Motion software by SYSTEMS AB was used for image analysis. Based on its results, information about the influence of the frequency of the vibration of the pusher on the shape of the layer of the abrasive deposited on the moving conveyor belt was obtained.

At the vibration frequency of 1.5 Hz, the dosing process was uneven. Fig. 5a presents a discontinuous, pulsating character of the pouring of the abrasive agent from the transporter. The layer of the abrasive deposited on the conveyor belt was not uniform, and sections in the form of husks and with clearly visible borders could be observed (Fig. 5b). Each dose, when slipping off the conveyor belt, fell individually and was separated on the border of each section, which disrupted the uniform character of the dosing process. The dosage had a pulsating character.

With an increase in the pusher's vibration frequency to 15 Hz, the abrasive formed a more uniform layer than at low frequencies (Fig. 6b). Despite visible disparities in the deposition of the material, there was no unacceptable effect of segmentation. The dosing process ran continuously, evenly, and with no interference (Fig. 6).

Consecutive tests were performed to determine the accuracy and repeatability of the dosing of the abrasive material in the full range of the linear speed of the feeder. For each of selected velocities, a number of measurements were carried out according to Table 2. For each speed of the feeder, the value of the dispersion of the mass flow rate of the transported substance was determined. The values of dispersion for selected velocities at the vibration frequency of the pusher of 1.5 Hz are presented in Fig. 7.

For the dispersion values presented in Fig. 7, mean values were calculated; and based on them, an abrasive yield chart was created in the function of feeder speed. Approximation was performed using a linear speed with correlation index $R^2=0.9835$.

After that a series of tests were conducted for pusher's vibration frequency of 15 Hz. Fig. 8 presents the value of the dispersion determined based on 10 test series for selected linear velocities of the feeder.

Fig. 8 presents the chart of the yield of the abrasive as a function of speed of the feeder for mean values of the dispersion. The approximation chart takes the form of a linear function with a correlation coefficient $R^2 = 0.979$.

6. Analysis of the results

The analyses conducted by the authors indicate that the pusher's vibration frequency influences the precision of the dosing of the abrasive agent.

At a low frequency of 1.5 Hz, the layer of the abrasive material on the conveyor belt is heterogeneous, and the supply of the erodent is not regular and has pulsating character. Together with the increase in the frequency of vibration of the pusher, the results of tests become dispersed, and the dispersion varies between 0.13 to 1.59 g, which exceeds the values permitted by normative tests. The greatest dispersion is visible for the highest velocities of the feeder. When the vibration frequency of the pusher increased to 15 Hz, the dispersion was smaller, and as a result, the accuracy and precision of the dosing process improved. The layer of the abrasive material in this case had a regular, uniform structure, and nothing interfered the dosing process negatively influencing its uniformity. The higher the value of the pusher's vibration frequency, the lower the difference between the minimum and the maximum value of the dispersion in the full range of linear velocities of the feeder. The observed dispersion between 0.17 and 0.47 g constitutes 2 to 5.5% of the maximum performance of the dosing process. For the frequency of 15 Hz, the approximation function is characterised by a high correlation index, which means that the dosing process can be more precisely described by the functional relationship in the control system of the device for erosive wear tests. The increase in the frequency is equivalent to the drop in the efficiency of the abrasive dosage at identical values of the linear speed of the feeder.

7. Summary

In laboratory tests on erosion processes, an even dosage of the erodent is extremely important. Precise dosing of the abrasive agent enables accurate control over test parameters and repeatable reconstruction of the wear of structural and functional materials. In the dosing device developed by the authors of the article, the element that plays an important role is the electromagnet with an oscillating pusher preventing the clogging of the orifice.

Laboratory tests on the feeder system developed indicated that the frequency of the vibrations of the pusher affects the accuracy and uniformity of the dosing process. At the frequency of 1.5 Hz, the maximum value of the dispersion is about ± 0.8 g/min, which significantly exceeds the range of ± 0.5 g/min as defined in the ASTM G 76 standard. On the other hand, at the frequency of 15 Hz, there was a decline in the value of the dispersion to ± 0.24 g/min.

The study confirmed a significant influence of the frequency of vibration of the pusher on the precise dosing of alumina with the particle size of 50 µm. Increasing the frequency of vibration resulted in the higher accuracy, repeatability, and uniformity of the dosing process and led to the reduction in the consumption of the abrasive agent.

Further tests on the feeder will be performed for the frequency of vibration between 1.5–15 Hz with the view of full characterisation of the dosing process.

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