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THE USE OF COMPUTER IMAGE ANALYSIS IN DETERMINING MATERIAL FLOW IN THE ROLLER PRESS DURING COMPACTING OF FINE-GRAINED MATERIAL

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Abstract

Mechanisms of fine-grained material flow in a roller press are a constant subject of research. The proper transfer of feed in the feeder has a significant influence on the correct course of the compaction and consolidation process, product quality, and the intensity of wear of the forming components. A few mathematical models of compaction process have been put forth, but they are focused mainly on loads in the compacting unit and consolidated material properties. During compaction the loose material properties including the Young module, the external and internal friction coefficient, and the side pressure coefficient change continuously. Therefore visualisation tests were carried out to survey the flow of material in a compaction unit equipped with rollers with a flat working surface and gravity feeder. Using the NI Vision Builder program, the recorded video observations were analyzed and the medium speed distribution of the material in the feeder was determined. The results were presented in the form of graphs and compared with one another, specifying the relationship between the material speed distribution and the press operation parameters.

Key words: Compaction, Agglomeration, Roller press, Consolidation, Fine-grained materials

1. INTRODUCTION

Pressure agglomeration is one of the essential methods used to consolidate powdery and fine-grained materials. Whenever possible, in the case of mineral materials and selected production waste materials, this process is carried out in roller presses (Bembenek, 2017a). Likewise it has undeniably gained recognition in the chemical (Flore et al., 2009; Kosturkiewicz et al., 2017, Hryniewicz & Bembenek, 2017), pharmaceutical (Kleinebudde, 2004), energy (Borowski & Hycnar, 2013) and food industries. The major advantages of this type of machines include their constant operability with relatively low demand for energy and a longer life span of moulding components as compared to other briquetting machines (e.g. screw or stamping machines) or pressurised granulators (Bembenek, 2018). In roller presses the feed is consolidated in a compaction zone. This consists of elements that come in direct contact with the material, i.e. working rollers, feeder, and side sealings. In most cases, the working surfaces provided on both rollers to mould briquette at a given moment are mirror images of each other. In the case of hard-to-briquette materials, however, working surfaces are best differentiated; so an asymmetrical compaction unit is preferably employed in such circumstances (Bembenek, 2017b). The working surface on each roller can also be flat. This type of ring is the cheapest to manufacture. The smooth working surface is used to produce a consolidated material in the shape of a flat ribbon. This kind of agglomeration can also be a part of a dry granulation process (Hryniewicz et al., 2011). This is one of the processes of pressure agglomeration in which granules with a defined grain fraction can be obtained from fine-grained material. Dry granulation is carried out in two steps (Gara, 2015; Kosturkiewicz et al., 2017). The first is properly preparing the powdered material followed by consolidating it under pressure. The second one is crushing the product of consolidation and classifying it.

The correct flow of material in the compaction zone makes the roller press operate properly, because it reduces the unit energy consumption and allows the user to achieve high product efficiency along with its proper mechanical durability (Bembenek & Romanyshyn, 2018). During compaction the loose material properties including the Young module, the external and internal friction coefficient, and the side pressure coefficient change continuously. Therefore the visualisation tests were carried out to survey the flow of material in the compaction unit equipped in the gravity feeder. Using the NI Vision Builder program, the video recordings collected were analyzed and the medium speed distribution of the material in the gravity feeder zones was determined. The research was aimed at understanding the character of material flow in the feeder. It has a significant influence on the correct course of the compaction and consolidation process, the product quality, and the intensity of the wear of the working components.

2. CURRENT KNOWLEDGE ABOUT MATERIAL FLOW IN ROLLER PRESS

The fine-grained material pressure agglomeration process involves pressures up to hundreds of MPa (Hryniewicz, 1997; Lecompte et al., 2005; Yehia, 2007). It can be divided into two stages. At the first stage, during which the packing of particles of the material is rearranged, relatively high compaction rates are obtained under small external forces. At the second stage, the particles are consolidated together and a semi-continuous body is formed. In that case, much lower compaction rates are obtained under high values of external forces (Johanson, 1965; Hryniewicz, 1997). At both stages, the loose material properties including the Young module, the external and internal friction coefficient, and the side pressure coefficient change continuously. This variability does not allow the proper modeling and simulation of fine-grained material transfer and consolidation processes in the roller press by means of the currently available advanced computer tools. A few mathematical models of compaction process have been put forth e.g. Johanson (1965), Katashinskii (1966) or Hryniewicz (1997), but they are mainly focused on predicting press operating parameters e.g. pressure and forces (Bindhumadhavan et al., 2005; Lecompte et al., 2005; Hryniewicz et al., 2011) and material properties after consolidation e.g. the density of ribbon (Zinchuket et al., 2004; Peter et al., 2010). The real flow of fine-grained material in the compaction zone is hard to model. Presently only visualisation tests can provide this information (Janewicz & Kosturkiewicz, 2006; Loginov et al., 2001; Loginov et al., 2015; Bembenek, 2017b). They are especially applicable in the case of gravity feeders, since the feed transfer and the process parameters are predictable for forced flow feeders. The results of test conducted by Janewicz & Kosturkiewicz (2006), Loginov et al. (2001), Loginov et al. (2015), Bembenek (2017b) described only the generalized flow character of fine-grained material depending on the working surface used in the compacting unit. Moreover, this work was done using a compacting unit equipped with rollers with forming cavities. Only in the work described by Krok et al. (2014) can the velocity distribution of the fine-grained material during the consolidation in a roller press equipped with smooth forming rollers be found. Unfortunately, the operating parameters of the device with which the experiments were carried out, (i.e. roller diameter 260mm, roller width 36 mm, peripheral speed of the rollers of 0.08 m/s, the 10 mm gap between rollers) did not correspond to the actual conditions for this type of process in industrial conditions. This was the rationale for carrying out visualization tests in which the operating parameters were set at a level similar to the industrial parameters. The test results were evaluated using image analysis methods.

3. MATERIALS AND EXPERIMENTAL PROCEDURE

The research tests employed the application of a press with rolls measuring 450 mm in diameter by 76 mm wide, marked with the symbol LPW 450. The compacting unit was equipped in a set of two flat rings and a gravity feeder (figure 1). The transparent front wall in the hopper was installed. Two model materials were used for the visualisation tests–calcium hydroxide and fine-grained hard coal–which were selected to obtain maximum contrast between the materials. The feed was arranged in the gravity feeder alternately in layers with a thickness of about 20 - 30 mm up to a height of approximately 200 mm. The experiment was recorded from the moment when the press drive system was turned on until the material was completely discharged from the feeder. The image recorder was installed about 1 m away from the compaction unit and the rollers were accelerated to a speed of 0.1 m/s, 0.2 m/s, 0.3 m/s. The tests were performed with a gap measuring either 5 or 8 mm between the rollers. The flow of material for each configuration of roller speed and gap was repeated three times, totaling 18 experiments (table 1). The video recording was performed with the Nikon D5000 camera equipped with the Nikkor 18-105 VR lens with image stabilization. The recording was made with a resolution of 640x424 pixels and an image rate of 24 images per second and then analyzed in NI Vision Builder program. In order to use Vision Builder in the research, the recordings were processed to 8 images per second, resulting in a total of 70 to 200 movie images in each sample.

***Table 1**. The variation of test parameters and their names.*

		peripheral speed of the rollers, m/s		
		0.1	0.2	0.3
gap between rollers, mm	5	T1	T2	T3
	8	T4	T5	T6

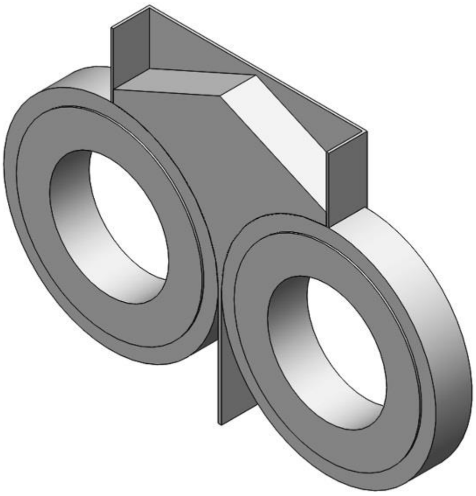

***Fig. 1.** Layouts of roller press compaction units with flat rings.*

To determine the velocity distribution of material in the press feeder, a special algorithm was developed in the Vision Builder program. The purpose of the algorithm was to find in individual areas the dividing line between materials (the boundaries between light and dark of the feed). Data of edge coordinate values from each image were then exported to Microsoft Excel. This enabled a calculation of the speed of layer boundaries movement in subsequent frames (1/8 second for every image change). The working area in which the material was located was divided into a mesh, organizing the compacting system into 74 fragments (figure 2a). The shape of the mesh was adjusted experimentally in this way to obtain only one layer boundary at a time while not being so small as to make it difficult to analyze the speed in the given area. The mesh parts which cover surfaces of contact material with the rollers were designed to be slightly smaller, because it was supposed that in these places the changes in the speed of the material would be different than in others. Each material boundary was delineated with markers mapping the limits of the black and white or white and black borders (figure 2b). On each subsequent image, after detecting the border, the program read and exported the coordinates of the marker's location. Based on the value of the vertical coordinate and the time of image duration velocity changes were calculated for vector in each area. All results were obtained in pixels per second and then were converted into real values in mm/s. Analysis was carried out from the moment the press was started until the feeder was empty.

As the algorithm works by looking for boundaries between white and black layers in areas, when there was no material in certain are-as, the coordinates of the marker locations were not recorded, as shown in figure 2d. Since there is no material in the upper area of the feeder, there are consequently no boundary markers. If in any area the algorithm did not find the dividing line between the layers (figure 2c), it did not pro-vide data for calculating the average speed in that area.

4. RESULTS AND DISCUSSION

Based on the data and calculations obtained from the tests, graphs were made in the GNU Image Manipulation Program (GIMP), showing the material velocity distribution in the roller press feeder. They are presented in a figures 3. Analyzing the obtained graphs, the variation of the speed values in individual zones of the feeder are noticed. Changes in the speed distribution during material flow at individual areas of the power supply, depending on the peripheral speed value of rollers and the set of gap between the rollers, are visible. The velocity distribution in subsequent areas is quite symmetrical, which corresponds to the use of two identical rollers in the process. In the case of tests conducted for the 5 mm gap, the maximum speed values were recorded at the level for T1 - 27.3 mm/s, T2 - 25.8 mm/s and for T3 23.7 mm/s. At the 8 mm gap, a significant increase in the maximum material velocity is visible.

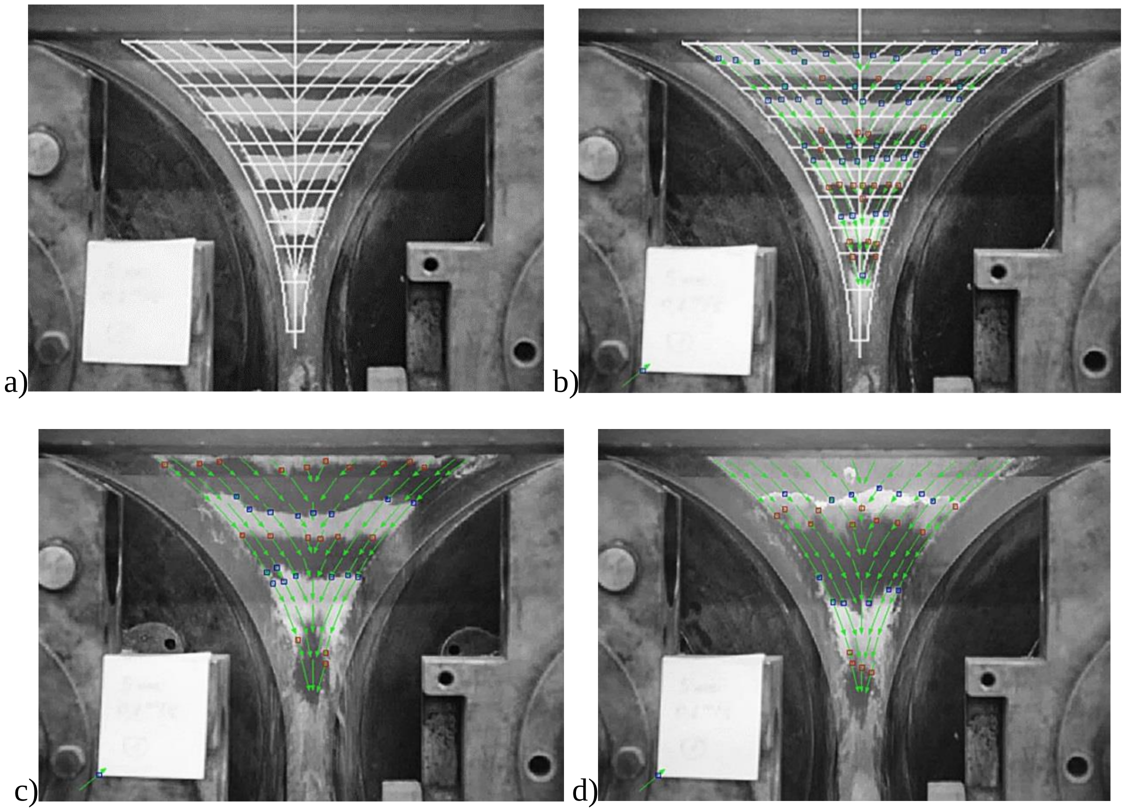

Fig. 2. Images of compaction unit: a) with mesh, b) vectors on a border of material layers, c, d) during the analyses.

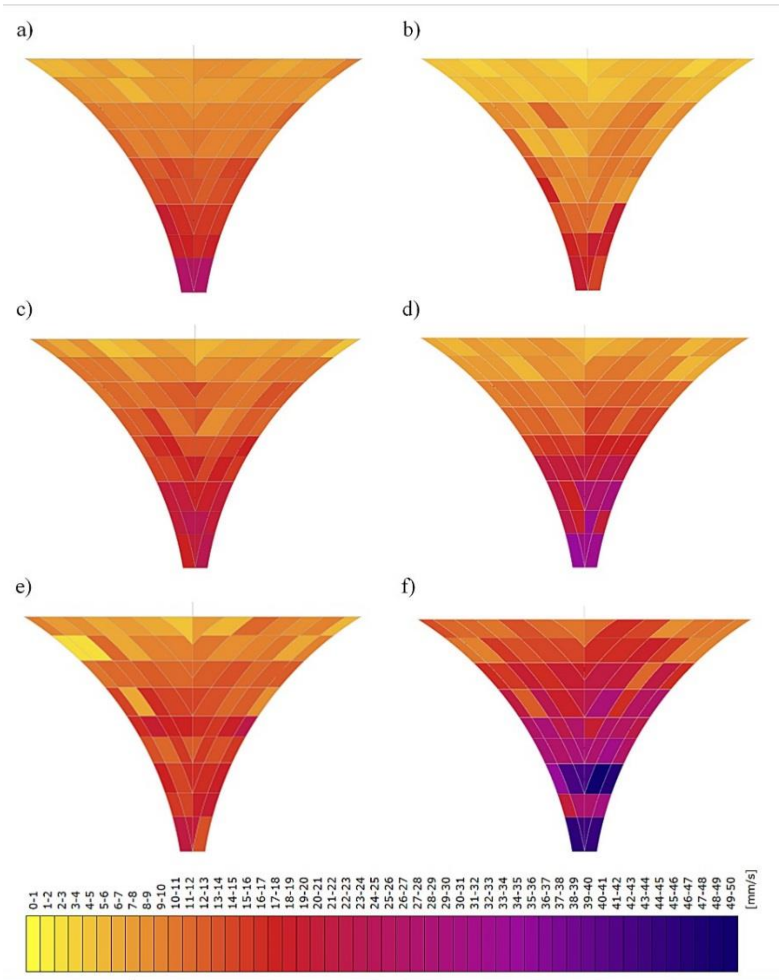

Fig. 3. A summary of graphics presenting the results for a given a)test T1, b) test T4, c) test T2, d) test T5, e) test T3, f) test T6.

Contrary to the 5 mm gap setting, it increases with increasing peripheral speed of the rollers, for T4 - 20.5 mm/s, for T2 - 36 mm/s, and for T3 – 47 mm/s. The maximum speed values can be observed in the zone of the smallest roller gap. The velocity in individual zones decreases going up from the zone of minimum gap of the rollers. Increasing the peripheral speed of the rollers results in aligning of the material flow velocity in individual zones. For the 5 mm gap with the smallest roller speed, the material in the upper area moves below half of the maximum speed. Values close to the maximum were recorded only in the lowest layers of material. The process is much slower than in the T2 and T3 tests. Roller speed change to 0.2 m/s increases material speed in higher layers. At the speed of 0.3 m/s for the 5 mm gap, the velocity distribution in most of the test area is fairly even. The material in the upper layers reaches average speeds similar to the lower layers.

Contrary to predictions, it is impossible to clearly distinguish the layer adjacent to the rollers, which moves much faster than the middle layers. Comparing tests T1 and T4, in which the speed of the rollers was the same, and the width of the gap between the rollers was different, it is seen that widening the gap did not increase the maximum speed of the material. The minimum and maximum speed is lower by 34.6% and 24.8%. The material velocity distribution changed considerably. With the larger gap, more of the higher material layers reach values close to 50% of the maximum value and more of the lower layers reach speeds close to the maximum. The speed distribution in the W4 variant is much more uneven. The distribution of speed values for tests T2 and T5 is similar, but more constant in the case of the wider gap. A similar number of lower layers reach speeds greater than 50% of maximum values. The minimum values for both cases are similar, and the maximum value of the speed when increasing the gap increased by 39.6%. The speed distributions in the T3 and T6 tests are very similar. Speed changes between layers are smooth and most of the material reaches speeds close to half the maximum speed. The difference can be seen in the minimum and maximum speed values, which increased significantly with the increase of the gap - the maximum speed increased by almost 100%, and the minimum 243.7%. Considering that the velocity distribution in almost all material zones is even. Increasing the gap width had a positive effect on the speed distribution of the process.

5. CONCLUSIONS

Summing up the conclusions from this inquiry, it is concluded that in each case increasing the peripheral speed of the rollers in the compacting process positively affects the material speed distribution, lowering the difference of material speeds and moving the speed in each area closer to the maximum throughout the feeder. At low roller speeds, only the lowest material layers reach high values and most of the material moves at close to minimum speeds. No specific zones in the central areas and in areas close to the rollers in the feeder, like in the briquetting process, were noticed where the material flows with a lower/higher speed in relation to other areas. Speed changes occur mainly in the vertical axis and usually concern the entire horizontal layer of material. Thus, when using smooth rollers in a roll press, the material moves evenly with respect to the vertical axis, and changes in the press parameters affect the material movement in its entire volume. From the research conducted, it is concluded that changes in the parameters of the compacting process (gap width, peripheral speed of the rolls) do not always result in the improvement of the velocity distribution of the compacted material. Only with appropriate configuration of both the gap width and the peripheral speed that it is possible to obtain a specific effect in the process (eg. increasing the maximum value or improving the velocity distribution in the whole material). At the same time, as is seen from the above observations, in some cases the change of only one of the parameters brings a positive effect of increasing the maximum value or increasing the speed of higher (middle) material layers. Following the analysis, several conclusions were drawn to improve the quality of future visualisation research. First of all, the camera should be completely motionless during all attempts, which would eliminate calibration errors to real units between samples as well as errors in matching the mesh in each test. It would also be worth exploring different types of materials to see if the type of material is related to the speed distribution. Testing of the algorithm’s operation in Vision Builder drew attention to the fact that it is unnecessary to research how the material in the power supply is built up, nor does the material layout in the power supply actually matter. The material may be randomized in such a way that the boundaries between areas of contrasting colors are visible (they do not have to be parallel layers, and their thickness and accuracy are not important for this type of examination). It is also not known what effect the use of two different materials in the test had on the research had on. Perhaps a better result would be an analysis of compaction flow of one type of material, part of which will be dyed a contrasting color.

REFERENCES

Bembenek, M., 2018, *Innowacje w konstrukcji i zastosowaniu pras walcowych*, Rozprawy, Monografie – Akademia Górniczo-Hutnicza im. Stanisława Staszica, 337, Wydawnictwa AGH, Kraków (in Polish).

Bembenek, M., 2017a, Badania i perspektywy nowych obszarów stosowania pras walcowych, *Przemysł Chemiczny*, 96, 9, 1845-1847.

Bembenek, M., 2017b, Experimental analysis of consolidated material flow through a roller press with a non-symmetrical compaction unit, *Journal of Machine Construction and Maintenance*, 2, 117-122.

Bembenek, M., Romanyshyn, T., 2018, Operation of Briquetting Roller Presses with an Asymmetrical Compaction Unit, *Journal of Machine Construction and Maintenance*, 2, 53-59.

Bindhumadhavan, G., Seville, J.P.K., Adams, M.J., Greenwood, R.W., Fitzpatrick, S., 2005, Roll compaction of a pharmaceutical excipient: Experimental validation of rolling theory for granular solids, *Chemical Engineering Science*, 60, 3891 -3897.

Borowski, G., Hycnar, J.J., 2013, Utilization of Fine Coal Waste as a Fuel Briquettes, *International Journal of Coal Preparation and Utilization*, 33, 4, 194-204.

Flore, K., Schoenherr, M., Feise, H., 2009, Aspects of granulation in the chemical industry, *Powder Technology*, 189, 327-331.

Gara, P., 2015, Badania procesu dwustopniowej granulacji drobnoziarnistych odpadów, *Przemysł Chemiczny*, 9, 1509-1511 (in Polish).

Hryniewicz, M., 1997, *Metoda doboru pras walcowych oraz opracowania założeń do ich modernizacji lub konstrukcji*, Rozprawy, Monografie – Akademia Górniczo-Hutnicza im. Stanisława Staszica, 58, Wydawnictwa AGH, Kraków (in Polish).

Hryniewicz, M., Bembenek M., 2017, Analysis of the producibility of mineral fertilizers from industrial waste, *Journal of Research and Applications in Agricultural Engineering*, 62, 1, 43-47.

Hryniewicz, M., Gara, P., Bembenek, M., 2011, Modelowanie rozkładu nacisku jednostkowego w procesie kompaktowania materiału sypkiego, *Automatyka*, 15, 2, 175-182 (in Polish).

Janewicz, A., Kosturkiewicz, B., 2006, *Wizualizacja grawitacyjnego dozowania nadawy do prasy walcowej*, Monografie Wydziału Inżynierii Mechanicznej i Robotyki AGH, 32, 241-248 (in Polish).

Johanson, J.R., 1965, A Rolling Theory for Granular Solids, *Journal of Applied Mechanics*, 32, 4, 842-848.

Katashinskii, V.P., 1966, Analytical determination of specific pressure during the rolling of metal powders, *Soviet Powder Metallurgy and Metal Ceramics*, 5 (10), 765-772.

Kleinebudde, P., 2004, Roll compaction/dry granulation: pharmaceutical applications, *European Journal of Pharmaceutics and Biopharmaceutics*, 58, 317-326.

Kosturkiewicz, B., Janewicz, A., Hryniewicz, M., 2017, Granulacja dwustopniowa nawozów mineralnych, *Przemysł Chemiczny*, 96, 9, 1873-1876 (in Polish).

Krok, A., Peciar, M., Fekete, R., 2014, Using the DPIV optical technique to measure the velocity of powder material in the space between the rollers in a roll compactor, *Powder Technology*, 262, 131-141.

Lecompte, T., Doremus, P., Thomas, G., Perier-Camby, L., Le Thiesse, J.C., Masteau, J.C. Debove, L., 2005, Dry granulation of organic powders—dependence of pressure 2D-distribution on different process parameters, *Chemical Engineering Science*, 60, 3933-3940.

Loginov, Yu. N., Babailov, N.A., Pervukhina, D.N., 2015, Physical modeling of roller pressing with asymmetric effects on compacted material, News of higher educational institutions, *Black Metallurgy*, 58, 186-191 (in Russian).

Loginov, Yu. N., Bourkine, S. P., Babailov, N. A., 2001, Cinematics and volume deformations during roll press briquetting, *Journal of Materials Processing Technology*, 118, 151-157.

Peter, S., Lammens, R.F., Steffens, K.J., 2010, Roller compaction/Dry granulation: Use of the thin layer model for predicting densities and forces during roller compaction, *Powder Technology*, 199, 165-175.

Yehia, K.A., 2007, Estimation of roll press design parameters based on the assessment of a particular nip region, *Powder Technology*, 177, 148-153.

Zinchuk, A.V., Mullarney, M. P., Hancock, B.C., 2004, Simulation of roller compaction using a laboratory scale compaction simulator, *International Journal of Pharmaceutics*, 269, 403-415.

WYKORZYSTANIE KOMPUTEROWEJ ANALIZY OBRAZU DO OKREŚLANIA PRZEPŁYWU MATERIAŁU DROBNOZIARNISTEGO W STREFIE ROBOCZEJ PODCZAS KOMPAKTOWANIA W PRASIE WALCOWEJ

Streszczenie

Mechanizmy przepływu materiału drobnoziarnistego w prasie walcowej są ciągłym przedmiotem badań. Właściwy transfer surowca w podajniku ma znaczący wpływ na prawidłowy przebieg procesu zagęszczania i aglomeracji, jakość produktu oraz intensywność zużycia elementów formujących. Znanych jest kilka modeli matematycznych procesu zagęszczania, jednak ich głównym zadaniem jest określenie obciążeń w układzie zagęszczania oraz parametrów materiału po scaleniu. Podczas zagęszczania właściwości materiału sypkiego w tym moduł Younga, współczynnik tarcia zewnętrznego i wewnętrznego oraz współczynnik nacisku bocznego zmieniają się w sposób ciągły. Było to podstawą do przeprowadzenia eksperymentów wizualizacyjnych w celu zbadania przepływu materiału w układzie roboczym prasy walcowej wyposażonej w podajnik grawitacyjny. Przy pomocy programu NI Vision Builder zanalizowano otrzymane nagrania wideo i wyznaczono rozkład prędkości średnich materiału w podajniku. Opracowane wyniki przedstawiono w formie wykresów i porównano między sobą, wyszczególniając zależności pomiędzy rozkładem prędkości materiału a parametrami pracy prasy.

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