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Received: 2018-01-22 ; Accepted: 2018-03-07

AGGLOMERATION PROCESS OF POST-PRODUCTION TOBACCO WASTE

Summary

The paper presents the research results of the agglomeration process of post-production tobacco waste arising during the cigarette production process at British-American Tobacco in Augustów. The agglomeration process tests were carried out on the SS-3 station with the "open compaction chamber-compacting piston" working system, having an open chamber with a diameter of 8 mm. Investigations of agglomeration of post-production tobacco waste were carried out according to the Hartley experiment plan PS/DS-P: Ha4, where the input values were: waste moisture (9, 12 and 15%), process temperature (60, 80 and 100°C), mass of the sample (0,3; 0,6 and 0,9 g) and the matrix hole length (37, 42 and 47 mm). During the tests, the susceptibility to compacting the tested tobacco waste was determined by determining the maximum pressures for agglomerating the raw material and the obtained granulate density. On the basis of the conducted tests, it was found that the tested tobacco waste is a material characterized by high compaction susceptibility, as it was evidenced by the obtained low values of maximum compaction pressures during its compaction. Moisture content of tobacco waste and the process temperature are the parameters having the greatest impact on the values of maximum compaction pressures and the density of granules obtained from tobacco waste. The most advantageous temperature range for carrying out the agglomeration process of tobacco waste from the point of view of the work system load is 60-70°C. The high granulate density obtained during the tests (733,3-1313,32 kg·m^{-3}) is a very advantageous feature of the product.
***Key words**: agglomeration, post-production tobacco waste, agglomeration pressures, granulate density*

PROCES ZAGĘSZCZANIA POPRODUKCYJNYCH ODPADÓW TYTONIOWYCH

Streszczenie

W pracy przedstawiono wyniki badań procesu zagęszczania poprodukcyjnych odpadów tytoniu powstałe w trakcie procesu produkcyjnego papierosów w British-American Tobacco w Augustowie. Badania procesu zagęszczania przeprowadzono na stanowisku SS-3, z układem roboczym „otwarta komora zagęszczania-tłok zagęszczający", z komorą otwartą o średnicy 8 mm. Badania zagęszczania poprodukcyjnych odpadów tytoniu przeprowadzono według planu eksperymentu Hartleya PS/DS-P: Ha4, gdzie wielkościami wejściowymi były wilgotność odpadów (9, 12 i 15%), temperatura procesu (60, 80 i 100°C), masa zagęszczanej próbki (0,3; 0,6 i 0,9 g) oraz długość otworu w matrycy (37, 42 i 47 mm). W trakcie badań określono podatność na zagęszczanie badanych odpadów tytoniowych przez określenie maksymalnych nacisków zagęszczających surowiec oraz gęstości uzyskanego granulatu. Na podstawie przeprowadzonych badań stwierdzono, że badane odpady tytoniowe są materiałem charakteryzującym się wysoką podatnością na zagęszczanie, o czym świadczą uzyskane niewielkie wartości maksymalnych nacisków zagęszczających w trakcie jego zagęszczania. Wilgotność odpadów tytoniowych i temperatura procesu to parametry mające największy wpływ na wartości maksymalnych nacisków zagęszczających i gęstości granulatu otrzymanego z odpadów tytoniowych. Najkorzystniejszy zakres temperatury prowadzenia procesu zagęszczania odpadów tytoniowych z punktu widzenia obciążenia układu roboczego to zakres 60-70ºC. Uzyskana w trakcie badań wysoka gęstość granulatu (733,3–1313,32 kg·m^{-3}) jest bardzo korzystną cechą otrzymanego produktu.
***Słowa kluczowe**: zagęszczanie, poprodukcyjne odpady tytoniowe, naciski zagęszczające, gęstość granulatu*

1. Introduction

Poland, after Italy, is the second largest European tobacco producer [3]. The volume of tobacco harvest from 2012 amounted to 31,6 thousand tonnes, and for 2013, 39,5 thousand tonnes [3].

Tobacco waste is one of the post-production waste produced in agri-food processing plants, classified in the nuisance waste group.

In Poland there are several factories of cigarettes (including British-American Tobacco in Augustów) and all of them have a problem with managing tobacco waste [5, 6].

According to Piotrowska-Cyplik and others [14] these wastes have a different consistency - depending on their place of production in the technological system of cigarette production. According to Piotrowska-Cyplik and others [15], they are including shreds of tobacco leaves, shavings and dust of varying graininess (from dozen μm to 1 mm). According to many scientific studies [1, 4], they are very useful for natural use and can be developed in various ways.

The cheapest way to develop post-production tobacco waste consists in their direct use as a fertilizer [16]. However, this method is not indicated for technical reasons, i.e. dusting during transport, susceptibility to wind erosion, difficulties in accurate sowing and mixing with soil [16].

As reported by Piecuch and colleagues [13], another way of managing this waste consists in the briquetting or granulation process, reducing the volume of waste arisen and eliminating the problem of their dusting to the atmosphere [6, 9].

Piotrowska-Cyplik and others [14, 15, 16] and Stachowiak and others [17] propose the process of composting tobacco waste as a beneficial alternative for management of this waste.

Post-production tobacco waste is also used as a component of lightweight construction concretes [12] or for obtaining flavonoids and rutin [2].

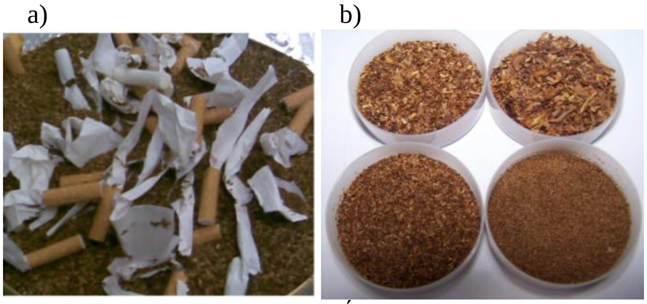
2. Aim of the study

The purpose of this work was to determine the suitability of tobacco waste obtained during the cigarette production process at British-American Tobacco in Augustów as a future, eco-friendly solid fuel in the form of granules.

3. Materials and methods

Tobacco waste (Fig. 1) produced during the cigarette production process at British-American Tobacco in Augustów was used as the research material.

a) b)



Source: own work / Źródło: opracowanie własne

Fig. 1. View of the tested tobacco waste: a) after production, b) cleaned and divided into fractions
Rys. 1. Widok badanych odpadów tytoniowych: a) po produkcji, b) oczyszczonych i podzielonych na frakcje

During the agglomeration process examination, the susceptibility to compacting the tested tobacco waste was determined by determining the maximum compaction pressures and the density of the obtained granulate.

The compaction process tests were carried out on the SS-3 test stand (Fig. 2), with the "open compaction chamber–compacting piston" working arrangement, presented in the works [7, 8, 10, 11]. To control the process temperature, a heating band 6 (applied to the open compaction chamber 7) was used, which was coupled with the temperature controller 3. Material agglomeration was performed using a piston 5 equipped with a tensometric sensor 4 allowing registration of forces acting on the piston 5.

Investigations of agglomerating post-production tobacco waste were carried out according to the Hartley experiment plan PS/DS-P: Ha4, where material, process and construction parameters were the input quantities:

- $x_1 = w_o$ - waste moisture content (9, 12 and 15%),
- $x_2 = t_p$ - process temperature (60, 80 and 100°C),
- $x_3 = m_p$ - sample weight (0,3; 0,6 and 0,9 g),
- $x_4 = l_m$- matrix hole length (37, 42 and 47 mm).

The granulometric distribution of tobacco waste was determined using a laboratory shaker LPz-2e by Multiserv Morek in accordance with the methodology presented in [10] using a set of 7 sieves with the following dimensions of a square mesh side: 4 mm, 2 mm; 1 mm; 0,5 mm; 0,25 mm, 0,125 mm and 0,063 mm.

Determination of the granulate density was carried out (after 24 hours from the moment of compaction) by measuring the height and diameters of the granulate with the accuracy of ± 0,02 mm and determining its mass by a laboratory weight WPS 360 with an accuracy of ± 0,001 g. Density was calculated as the ratio of the mass of granules to the sum of their volume.

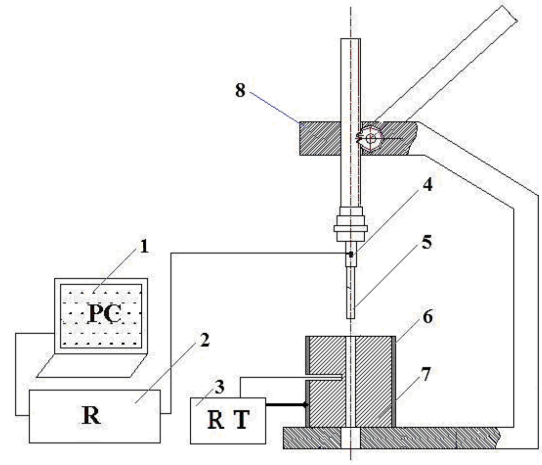


Fig. 2. Scheme of the modernized SS-3 station [7, 8, 10, 11]: 1 - computer, 2 - *Spider 8* multi-channel recorder, 3 - temperature controller, 4 - tensometric sensor, 5 - compacting piston, 6 - heating band, 7 - compaction chamber, 8 -press
Rys. 2. Schemat zmodernizowanego stanowiska SS-3: 1 - komputer, 2 - rejestrator wielokanałowy Spider 8, 3 - regulator temperatury, 4 - czujnik tensometryczny, 5 - tłok zagęszczający, 6 - opaska grzejna, 7 - komora zagęszczania, 8 - praska

Determination of the moisture content of raw materials (tobacco waste) before the agglomeration process was carried out according to PN-76/R-64752 using a moisture analyzer WPE 300S with an accuracy of 0,01%, in accordance with the methodology presented in [6, 7].

4. Results

The sieve analysis (Fig. 3) of post-production tobacco waste (after being cleaned of filters and tissue paper) made it possible to state that the highest percentage was in the fraction of 0,5 mm (61,84%), the fraction of 0,25 mm accounted for 16,62%, the 1 mm fraction was 16,29 and the fraction of 0,125 mm was 3,73%. The remaining fractions accounted for less than 5%.

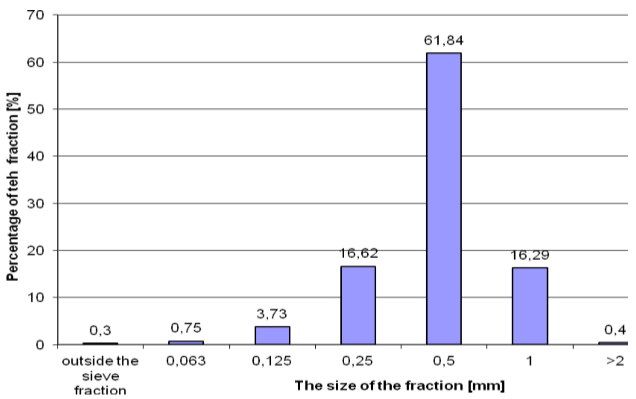


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Fig. 3. Granulometric distribution of post-production tobacco waste
Rys. 3. Rozkład granulometryczny poprodukcyjnych odpadów tytoniowych

Table 1 presents results of the research on the post-production tobacco waste agglomeration process in accordance with the Hartley PS/DS-P Ha4 experiment plan.

Table 1. Results of the research on the post-production tobacco waste agglomeration process, in accordance with the Hartley PS/DS-P Ha4 experiment plan
Tab. 1. Wyniki badań procesu zagęszczania poprodukcyjnych odpadów tytoniu, zgodnie z planem eksperymentu Hartleya PS/DS-P Ha4

Independent variables					Dependent variables	
	$x_1=z_w$ [%]	$x_2=t_p$ [°C]	$x_3=m_p$ [g]	$x_4=l_m$ [mm]	Maximum agglomeration pressure [MPa]	Pellet density [kg·m^{-3}]
1	15	60	0,3	37	14,23	1206,9
2	9	100	0,3	37	14,02	1268,45
3	9	60	0,3	47	9,56	877,43
4	15	100	0,3	47	20,33	1074,72
5	15	60	0,9	37	17,76	1171,94
6	9	100	0,9	37	19,71	1228,82
7	9	60	0,9	47	1,95	733,3
8	15	100	0,9	47	19,98	1101,49
9	9	80	0,6	42	8,43	1180,31
10	15	80	0,6	42	18,18	1180,14
11	12	60	0,6	42	19,64	1201,18
12	12	100	0,6	42	19,84	1281,98
13	12	80	0,6	37	16,79	1251,58
14	12	80	0,6	47	22,79	1313,32
15	12	80	0,3	42	16,17	1276,76
16	12	80	0,9	42	24,77	1291,92
17	12	80	0,6	42	19,01	1268,05

Source: own work / Źródło: opracowanie własne

Fig. 4 presents the results of research on the influence of material and process factors (moisture content of waste and process temperature) as well as construction factors on the maximum agglomeration pressures obtained during compaction of post-production tobacco waste in the open chamber.

On the basis of the carried out tests (Fig. 4a and Table 1), it can be noticed that with increasing humidity of tobacco waste from 9% to about 12% and increasing the process temperature, the maximum agglomeration pressures increased. Further increase in humidity to 15% resulted in a decrease in the maximum agglomeration pressures. The increase in maximum agglomeration pressures along with the increase in material moisture and process temperature was caused by sticking the thickened material to the walls of the compaction chamber and the compacting piston (Fig. 4a), which was particularly visible in the temperature range of 60 - 80°C. The adhesion of the material to the walls of the compaction chamber and the compacting piston caused an increase in the transfer resistance and consequently the values of agglomeration pressures increased.

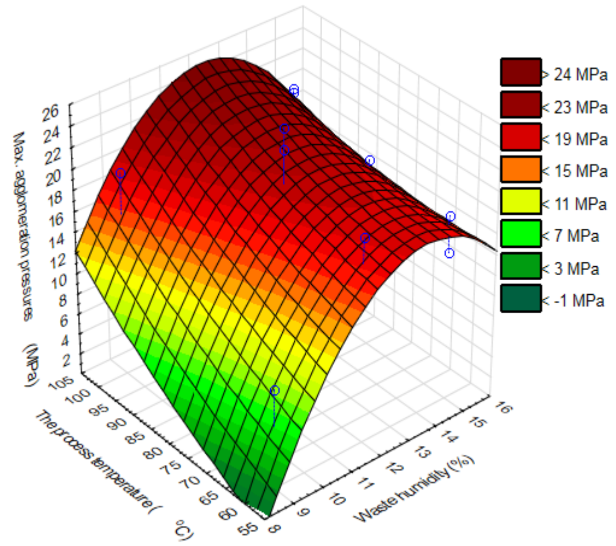
The increase in the material moisture content above 12% caused a decrease in agglomeration pressures due to an increase in the amount of liquid in the material which contacts with the die and the piston, that improved the lubricating properties of the compacted material and at the same time caused a decrease in agglomeration pressures.

The influence of process temperature t_p and material moisture on the maximum agglomeration pressures obtained during the compaction of tobacco waste in the open chamber is described by the following relationship:

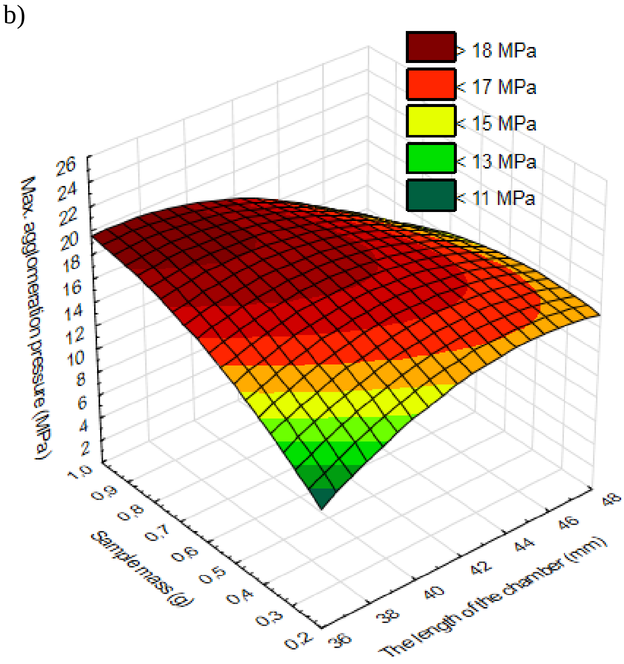
$$p_{max} = -117,1575 + 18,9578t_p + 0,2393w_o - 0,6423t_p^2 - 0,029t_pw_o + 0,0016w_o^2, \quad (1)$$

where:
p_{max} – maximum agglomeration pressures [MPa],
t_p – process temperature [°C],
w_o – moisture content of tobacco waste [%].

a)



b)



Source: own work / Źródło: opracowanie własne

Fig. 4. Influence of material, process and construction factors on the maximum agglomeration pressures obtained during the compaction of post-production tobacco waste in the open chamber: a) effect of humidity and process temperature, b) the impact of the sample mass and hole length in the matrix
Rys. 4. Wpływ czynników materiałowo-procesowych i konstrukcyjnych na maksymalne naciski zagęszczające uzyskane podczas zagęszczania poprodukcyjnych odpadów tytoniowych w komorze otwartej: a) wpływ wilgotności i temperatura procesu, b) wpływ masy zagęszczanej próbki i długości otworów w matrycy

Analyzing Fig. 4b. and Tab. 1., it can be seen that with increasing the die hole length from 37 mm to 42 mm, the maximum agglomeration pressures increased.

The increase in the maximum agglomeration pressures observed together with the increase of the compaction chamber length is caused by an increase of the compacted waste actual contact surface with the die surface, which results in increased frictional resistance and consequent increase in compaction pressures [12]. Increasing the mass of the compacted sample from 0,3 g to 0,6 g resulted in an increase in the maximum agglomeration pressures (Fig. 4b). The obtained test results (Fig. 4b and Table 1) show that the maximum agglomeration pressures were obtained with the mass sample also caused, similarly to increasing the hole length in the die, the increase of the contact surface of compacted waste with the matrix surface resulting in the increase of the amount of compacted waste in one agglomerating cycle. The greater amount of compacted waste increases the resistance of transporting compacted waste and consequently increases the agglomeration pressures. A further increase in sample weight from 0,6 g to 0,9 g caused a slight decrease in the agglomeration pressures. During the tests, it was found that at a mass of 0,9 g, it was necessary to pre-compact the waste entering the compaction chamber, because it was not fully contained in the compaction chamber. Initial compaction caused a reduction of the waste actual friction surface to the matrix surface which decreased the resistance values and in consequent decreased the agglomeration pressures (Fig. 4b). The obtained test results (Fig. 4b and Table 1) show that the highest maximum agglomeration pressures were obtained with the mass of sample 0,6 g and with the compaction chamber (matrix) length of 42 mm. The effect of the sample mass m_p and the compaction chamber (matrix) length l_m on the maximum agglomeration pressures during the compaction of tobacco waste in the open chamber is described by the following relationship:

$$p_{max} = -140{,}5402 + 77{,}6255 m_p + 6{,}5664 l_m - 11{,}8407 m_p^2 - 1{,}4317 m_p l_m - 0{,}0698\, l_m^2, \qquad (2)$$

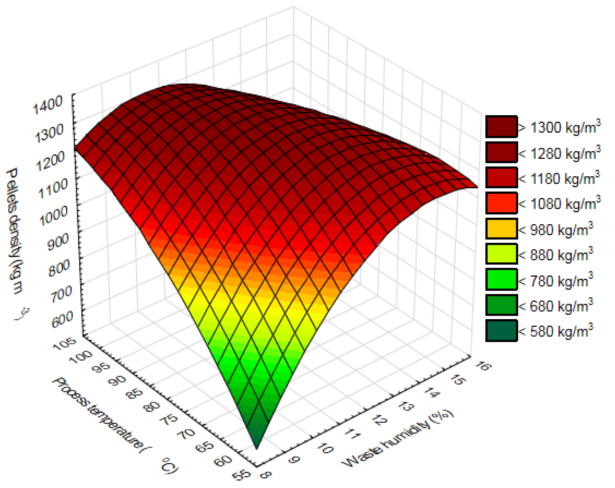
where:

p_{max} – maximum agglomeration pressures [MPa],
m_p – sample mass [g],
l_m – compaction chamber (matrix) length [mm].

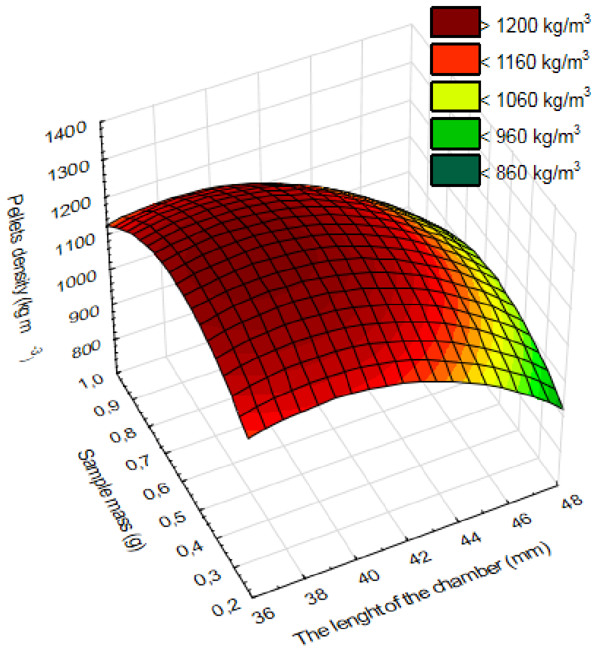
Table 1 and Fig. 5 present the results of research on the influence of material and process factors on the density of granules obtained during the agglomeration of post-production tobacco waste in the open chamber.

Analyzing Fig. 5a and Tab. 1, it can be seen that as the humidity of the tobacco waste and process temperature increased, the granulate density increased. The granulate density reached the highest values during the humidity increase to about 12% and at a process temperature of about 80°C. The increase in the compacted material moisture content from 9 to 12% improves the compacting properties of various tobacco waste fractions during the agglomeration process at elevated temperature. The increasing amount of moisture causes the formation of more viscous liquid, which causes the compacted waste to stick together and after the compaction process and the granulate cooling, creates a permanent structure which increases the granulate density. Further humidity (above 12%) and process temperature increase results in a decrease in agglomerate density. This happens due to moisture evaporation which takes place during the compaction process. This trend increases with increasing the temperature. High compaction pressures cause water to escape from the inside to the outside of the granulate, which reduces the granulate density.

a)



b)



Source: own work / Źródło: opracowanie własne

Fig. 5. The influence of material and process factors on the density of granules obtained during the agglomeration of post-production tobacco waste in the open chamber: a) the effect of humidity and process temperature, b) the impact of the sample mass and matrix hole length

Rys. 5. Wpływ czynników materiałowo-procesowych i konstrukcyjnych na gęstość granulatu uzyskanego podczas zagęszczania poprodukcyjnych odpadów tytoniowych w komorze otwartej: a) wpływ wilgotności i temperatura procesu, b) wpływ masy zagęszczanej próbki i długości otworów w matrycy

Thus, the most favorable value of humidity changes along with the increasing of the process temperature (Fig. 5) and as the temperature rises the most favorable process humidity decreases.

The influence of process temperature t_p and compacted waste humidity on the obtained granulate density during the compaction of tobacco waste in the open chamber is described by the following relationship:

ρ_g = -4585,9907 + 545,9131t_p + 58,9341w_o - 14,562t_p^2 - 2,2691$t_p w_o$ - 0,1743w_o^2, (3)
where:
ρ_g – granulate density [kg·m^{-3}],
t_p – process temperature [°C],
w_o – moisture content [%].

Analyzing Tab. 1 and Fig. 5b, it can be seen that as the holes in the die increase from 37 mm to 47 mm, the density of the obtained granulate increases. The increase in the density of granulate along with the increase in length results from the longer residence time of tobacco waste in the densification chamber, which increases the changes occurring in the concentrated waste while they are in the compaction chamber. This directly affects the increase in their density.
As the research results show (Tab. 1 and Fig. 5b), increasing the mass of the sample from 0,3 g to 0,6 g resulted in an increase in the granulate density. The increase in granulate density along with the increase in the mass of the compacted waste was caused by the increase in the compacted waste contact area with the matrix surface following the increase of the compacted waste amount in one compacting cycle. The greater amount of compacted waste increases the resistance of transferring compacted waste and consequently increases the compaction pressures, which in turn increases the granulate density. In addition, the obtained granulate has a layered structure (consists of consecutive portions thickened consecutively (Fig. 6).

Source: own work / Źródło: opracowanie własne

Fig. 6. View of the granulate (obtained with the parameters: l_m = 42 mm and m_p = 0,6 g) with visible dividing lines resulting from backfilling of subsequent raw material samples
Rys. 6. Widok granulatu (otrzymanego przy parametrach: l_m = 42 mm oraz m_p= 0,6 g) z widocznymi liniami podziału wynikającymi z zasypywania kolejnych próbek surowca

The less it is present in the granule of the subdivision area, the obtained granulate has a higher density. As the weight of the sample increases, the surface area of the granulate decreases, thus increasing its density.

A further increase in the sample weight from 0,6 g to 0,9 g resulted in a slight decrease in the granulate density.

This decrease is due to the fact that the 0,9 g sample mass did not fully fit into the thickening chamber and had to be pre-compacted. It resulted in a reduction in the friction surface of the tobacco waste by the die walls, a slight decrease in the agglomeration pressures and, as a consequence, a decrease in the granulate density. The obtained test results (Fig. 5b and Tab. 1) show that the highest granulate density (1313,32 kg·m^{-3}) was obtained at the mass of the compressed sample of 0,6 g and with a compaction chamber length of 47 mm.

The effect of sample mass m_p and compaction chamber (matrix) length l_m on the granulate density obtained during the compaction of tobacco waste in the open chamber is described by the following relationship:
ρ_g = -3743,20 + 243,92m_p + 1106,54l_m - 3,12m_p^2 -3,55$m_p l_m$ - 846,47 l_m^2, (4)
where:
ρ_g - granulate density [kg·m^{-3}],
m_p – sample mass [g],
l_m - compaction chamber (matrix) length [mm].

The obtained granulate from post-production waste can be successfully used as a solid fuel in prosumer installations.

5. Conclusions

Based on the conducted research, the following conclusions were formulated:
1. Agglomerated post-production tobacco waste is a material characterized by a high compaction susceptibility, as evidenced by the obtained low values of maximum agglomeration pressures during its compaction.
2. Moisture content of tobacco waste and process temperature are the parameters having the greatest impact on the values of maximum agglomeration pressures and the granules density obtained from tobacco refuse.
3. The most favorable temperature range for conducting the process of compacting tobacco waste from the point of view of the work system load is 60-70°C.
4. The high granulate density (733,3-1313,32 kg·m^{-3}) obtained during the tests is a very advantageous feature of the obtained product.
5. The highest granulate density values were achieved (1313,32 kg·m^{-3}) during the increase of humidity to about 12% and at process temperature around 80°C, with a mass sample of 0,6 g and a compaction chamber (matrix) length of 47 mm.
6. The obtained granules made of tobacco refuse (post-production waste from the British American Tobacco Plant in Augustów) can be used as a future solid fuel.

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This study was financed by the Ministry of Science and Higher Education of the Republic of Poland as a research project S/WBIŚ/2/2015.