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ANALYSIS OF CAUSES OF PELLET MILL MATRIX WEAR BASED ON A SELECTED EXAMPLE

Summary

This paper presents selected results of an analysis of damage causes to pellet mill matrix. The tested pellet mill matrix was used for the traditional technological process of pellet production. The tests were carried out since matrix failure times were found out to be too short. In order to assess the causes of matrix damage, tests of chemical composition and hardness of the matrix material were performed as well as observation of microscopic points of wear, analysis in the area of parameters of the process of operation and general conditions of use of the pellet mill. Discrepancies between the chemical composition of the material of the pellet mill and the information contained in the DTR were observed. Attention was paid to a possible influence of heat treatment and operating parameters on its premature damage.
***Key words**: mill matrix, operational durability, chemical composition, heat treatment, parameters of external forces*

ANALIZA PRZYCZYN ZUŻYCIA MATRYCY GRANULATORA NA WYBRANYM PRZYKŁADZIE

Streszczenie

W artykule przedstawiono wybrane wyniki oceny przyczyn zniszczenia matrycy granulatora. Granulator, w którym pracowała oceniana matryca, wykorzystywany był do tradycyjnego procesu technologicznego produkcji peletów. Badania wykonano z uwagi na zbyt krótki okres bezawaryjnej pracy matrycy. W celu oceny przyczyn zniszczenia matrycy wykonano badania składu chemicznego oraz twardości materiału matrycy, dokonano obserwacji mikroskopowych miejsc zużycia oraz analizy w zakresie parametrów procesu eksploatacji oraz ogólnych warunków użytkowania granulatora. Stwierdzono rozbieżność składu chemicznego materiału granulatora od informacji zawartych w DTR. Zwrócono uwagę na ewentualny wpływ obróbki cieplnej oraz parametrów pracy na jego przedwczesne zniszczenie.
***Słowa kluczowe**: matryca granulatora, trwałość eksploatacyjna, skład chemiczny, obróbka cieplna, parametry wymuszeń zewnętrznych*

1. Introduction

According to many authors [4, 7, 9, 10, 12], among the basic matrix parameters there are:

- matrix clearance coefficient – the ratio between the area of openings and the working area of the matrix,
- diameter and length of matrix openings. The ratio between these values may fluctuate between 0.1 to 0.5 (depending on the material properties of the raw material subjected to the process of pressure agglomeration and the quality requirements of the obtained product),
- geometry of the inlet part of matrix openings.

According to Thomas et al. [20], matrix parameters influence both the course of the pelleting process and the quality of the final product. Pellet mill performance and energy consumption of the process are mainly connected with the length and diameter of the pressing channel of the matrix.

Fairfield [3] reports that the ratio between the length of the pressing channel and its diameter – called matrix compression ratio – is adjusted in relation to the susceptibility of fodder material to pelleting.

Laskowski [13] claims that in order to obtain pellets that would meet quality norms, matrices with a high compression ratio should be used for mixtures with high fat contents, whereas matrices with a low compression ratio should be used for mixtures characterized by a low susceptibility to forcing.

Channels in matrices are usually drilled in their inlet sections into a conical or parabolic shape, mainly in order to facilitate feeding of the material into the openings. The matrix geometries most commonly in use [5, 7] are presented in fig. 1.

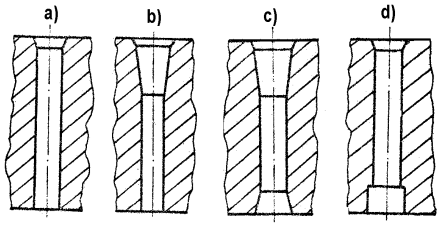


Fig. 1. The most commonly occurring matrix geometries [5, 7]: a) cylindrical segment with a cone, b) cylindrical segment with a double cone, c) cylindrical segment with a double cone and a cone at the outlet, d) cylindrical segment with a cone and a cylindrical (with a greater diameter) outlet

Rys. 1. Najczęściej spotykane geometrie otworów matrycy [5, 7]: a) cylindryczna część ze stożkiem, b) cylindryczna część z podwójnym stożkiem, c) cylindryczna część z podwójnym stożkiem i stożkiem na wyjściu, d) cylindryczna część ze stożkiem i cylindrycznym (o większej średnicy) wyjściem

On the basis of tests carried out by Poliščuk and Sokolova [5, 17], as well as research by Hejft [5, 7], it can be stated that increasing area around the inlet of fodder mixture into the opening has an impact on the increase in densifying pressures and the increase in density and kinetic durability of agglomerate.

According to research carried out by Andžjus [1], who analysed operational wear of matrix channels, the height of chamfer of inlet sections in typical openings should be from around 0.5 to 1 mm, at a cone angle of 45÷50° to 60°, respectively.

Grochowicz [4] reports that for materials difficult to densify, or high-thickness matrices, openings with a cylindrical or conical drilled outlet part are sometimes used.

Channels with a pronounced conical inlet of the calibrating section are used for mixtures that are relatively easy to pelletize as well as for briquetting grain materials [4, 13]. Lengthening the conical inlet up to halfway through the channel length, makes it possible to significantly reduce matrix thickness.

According to research carried out by Starosta [19] who focused on forcing dried plants through openings with a square cross-section, increasing the inlet cone angle above 20° is not justified. At more acute angles, an increase in densifying pressures is not accompanied by an adequate increase of briquette density.

According to Hejft and Obidziński [9], a pelleting and briquetting device, in the case of processing diverse raw materials, should be equipped with a set of matrices. This inconvenience may be minimized by using composite matrices [6, 8, 9]. At openings with greater diameters (exceeding 25-30 mm), replaceable sleeves may be used [16]; their use, however, reduces matrix compression ratio [9].

As reported by Chłopek et al. [2], matrices are made from alloy steels of the following types: X46Cr13, 20MnCr5, or 18NiCrMo5. When X46Cr13 steel is used, it is vacuum hardened and heat treated up to a hardness of 53-55 HRC on the surface and inside the core. 20MnCr5 and 18NiCrMo5 matrices are produced differently. They are case-hardened and hardened up to a hardness of 60-62 HRC down to depths of 0.8-1.2 mm. Matrices made from these steels show a greater hardness, in excess of 65 HB, during pelleting of raw materials. The condition of the working surface of the matrix is another important factor. According to Chłopek et al. [2], choosing a matrix requires the knowledge of the properties of the densified material and the final product.

Roughness of the working surface of matrix channels, which has a significant influence on the value of the coefficient of friction at contact with the raw material is another parameter whose the densification process and the quality of the obtained product depend on. As reported by Strijbos [13], the coefficient of friction depends on two dimensionless parameters: the particle-to-channel-wall hardness-ratio, and the average particle-diameter-to-wall-roughness ratio. Increasing the roughness results in increased resistances to forcing, energy consumption of the process, and decreased matrix life.

According to Pattersen and Kathman [13], chromium-nickel matrices, or those made from appropriate alloys that have polished openings, are characterized by lower values of the coefficient of friction and longer life.

The roughness of matrix openings decreases with the passing of matrix operation time as a result of the surface being re-polished by particles of the densified material [13, 14, 7, 4].

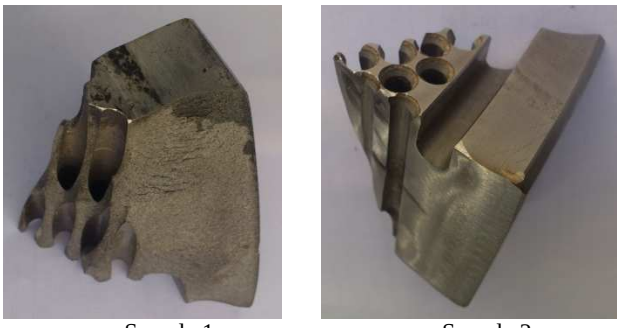
Matrices produced by renowned pellet mill manufacturers, before they are put into use, are lapped [15]. Lapping is a long-term process carried out by means of specially composed mixtures that contain plant material mixed with abrasive powder (e.g. electrocorundum) [15].

2. Aim of the research

The aim of the research was to assess the causes of premature damage of pellet mill matrices during the process of operation.

3. Research methodology

For laboratory tests, samples from a damaged matrix were used. These samples were taken from breakage points. Fig. 2 illustrates the materials collected for analyses. To facilitate the description of research results, the samples are marked as: Sample 1 and Sample 2.



Sample 1 Sample 2

Source: own work / Źródło: opracowanie własne

Fig. 2. Samples taken from breakage pints of a damaged matrix

Rys. 2. Próbki pobrane z miejsc przełomów zniszczonej matrycy

In order to assess the causes of matrix damage, the following tests were performed: chemical composition of the matrix material, hardness of the matrix material throughout the matrix thickness, as well as macro- and microscopic analyses of characteristic places; metallographic specimens of structures were also prepared and subjected to observation.

Tests of chemical composition were carried out by means of Thermo ARL Quantris emission spark spectrometer (fig. 3a). Microscope observations of breakage points and metallographic specimens were carried out by means of Hitachi S-3000N scanning microscope (fig. 3b) with an X-ray microanalysis module. Hardness tests were carried out by means of SHR-187.50 hardness tester.

Before commencing the tests, the samples were subjected to traditional machining. Appropriate surfaces were sanded and polished, then washed in ethyl alcohol and dried in an air stream. Thus pre-prepared samples, depending on the planned tests, underwent further preparatory procedures. After the samples were finally prepared, the planned analyses were performed.

a)

b)

Source: own work / Źródło: opracowanie własne

Fig. 3. View of: a) Thermo ARL Quantris emission spectrometer, b) Hitachi S-3000N scanning microscope
Rys. 3 Widok: a) spektrometr emisyjny Thermo ARL Quantris, b) mikroskop skaningowy Hitachi S-3000N

4. Research results

One of the issues of analysis was to determine the material that the matrix was made from. It was impossible to determine on the basis of the obtained documentation. Theoretical considerations were initially directed to 3H13 type material (X30Cr13, 1.4028), or a material with a similar chemical composition. Table 1 summarizes normative chemical composition of 3H13 material and, for comparison, test results of chemical composition of samples collected from the matrix.

Analysing the results shown in the table above, it can be stated that despite the similarity in chemical composition, the compared materials differ in the area of proportional contents of alloy elements. This pertains mainly to manganese, silicon, and sulphur. Additionally, chemical composition analysis made it possible to detect the presence of other elements (e.g. nickel), which are not covered by data included in the norms. In this context it is difficult to decide whether 3H13 is indeed the matrix material.

In relation to the analysed chemical composition, it is worth paying attention to the increased sulphur content. For martensitic steels, its content should not exceed 0.015%.

Tests of chemical composition carried out several times (three analyses for each of the samples) indicate that sulphur content in the material in question oscillates around 0.03%. The increased sulphur content manifests itself in its pronounced tendency to segregation. Sulphur is not iron soluble, and is present in steel in the form of iron and manganese sulphides. Its presence is undesirable, especially in the form of FeS. FeS forms low melt eutectics with austenite, which are the cause of heat cracking. Manganese sulphide is a refractory compound (melting point of 1620□C). It crystallizes in a higher temperature than iron. For this reason it is present in steel as isolated inclusions inside grains. In higher strength steels, manganese sulphides are the cause for lamellar cracking. In this context, the obtained results of chemical composition tests may be a cause for concern.

As far as heat treatment processes are concerned, the issue are mainly the course and parameters of the hardening process and its environment. Several adverse situations may be expected here. One of them is the appearance of hardening tensions. During steel hardening, type 1, 2, and 3 type residual stresses appear. Type 1 stresses (called heat stresses) appear as a result of the difference in cooling rates of the core and the surface of the hardened item (the range of impact of these stresses is comparable with the dimensions of the item). This means that if an inappropriate hardening procedure is performed, or if parameters recommendation as to the appropriate hardening process are compromised, then the probability of appearance of this type of stresses is the highest. In extreme cases, such stresses lead to hardening cracks. It is suspected that in the case of the analysed matrix either the procedure of customary hardening (the highest heat stresses) or an appropriate hardening procedure was performed, but the regime was insufficiently tight as far as recommendations and parameters are concerned. It can be added that in the case of heat stresses one of the methods of dealing with this problem is to carry out a procedure, e.g. graduated or interrupted hardening, that would allow to eliminate a large proportion of these stresses and obtain an adequate internal structure. Considering the untypical geometry of the hardened item (this mainly pertains to the rapid changes in thickness/cross-section between the mesh and the matrix rim – fig. 4a), it doubtlessly gives off temperature in a non-linear manner, which requires an appropriate hardening procedure to be chosen. In the case of customary hardening it would be rather difficult to avoid thermal stresses at such untypical item, whereas a failure to carefully select an appropriate hardening process may unconditionally lead to hardening cracks, as exemplified in the photograph shown in fig. 4b. The technologically problematic internal structure thus created is an additional element.

Table 1. The test results of chemical composition
Tab. 1.Wyniki analiz składu chemicznego

	C	Mn	Si	P	S	Ni	Cr	Cu	Mo	V	Al	Sn	Co	Ca
Sample	[% mass]													
3H13	0.25-0.36	<1.5	<1.0	<0.04	**0.015**	-	12.0 -14.0	-	-	-	-	-	-	-
Chemical composition of samples														
	C	Mn	Si	P	S	Ni	Cr	Cu	Mo	V	Al	Sn	Co	Ca
Sample 1	0.32	0.81	0.29	0.002	**0.032**	0.35	12.7	0.04	0.03	0.05	0.01	0.002	0.005	0.003
Sample 2	0.34	0.80	0.30	0.003	**0.028**	0.37	12.7	0.04	0.03	0.05	0.008	0.002	0.007	0.003

Source: own work / Źródło: opracowanie własne

a)

b)

Source: own work / Źródło: opracowanie własne

Fig. 4. View of damaged matrix: a) illustration of change in cross-section geometry, b) hardening crack (marked with a loop)

Rys. 4. Widok zniszczonej matrycy: a) ilustracja zmiany geometrii przekroju, b) pęknięcie hartownicze (oznaczone pętlą)

Parameters of the hardening process influence shaping of the internal structure. Their inappropriate configuration may be the cause of appearance of, for example, a greater quantity of residual austenite, which in connection with FeS leads to creation of low melt eutectics, which are the cause of heat cracking.

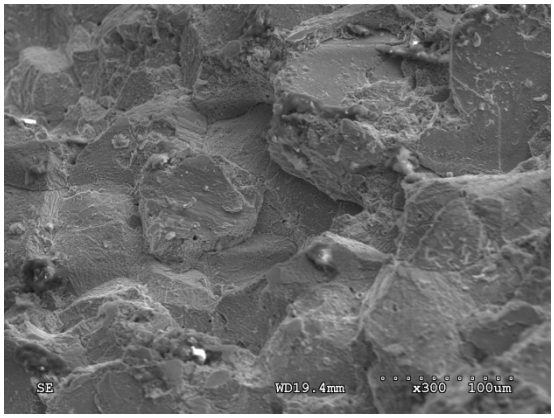


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Fig. 5. Clearly visible "empty spots" at grain borders (surface of sample breakage)

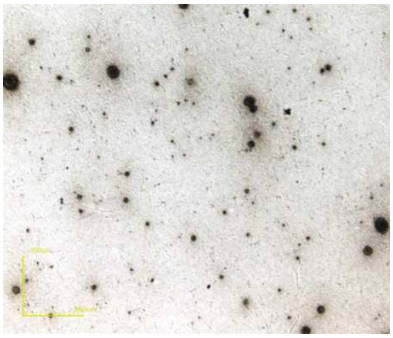
Rys. 5. Widoczne wyraźne „puste miejsca" na granicy ziaren (powierzchnia przełomu próbki)

Intercrystalline and pitting corrosion may be another result of inappropriate heat treatment. Intercrystalline corrosion is the result of liberation of chromium carbides from austenite, which lodge at the borders of steel grains thus causing chrome depletion of border areas. As a result of chromium content dropping below 13 %, border areas become not resistant to corrosion. Corrosion advances through places locally chrome depleted – between grains (crystals). Fig. 5 clearly shows individual separated from one another, which may be the result of intercrystalline corrosion.

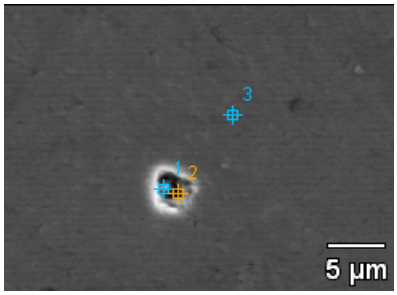
The data compiled in the table in fig. 6c may be an exemplary situation of local chrome depletion. In fig. 6b, points 1, 2, and 3 mark the spots of chemical composition analysis, included in the table. All three markers (fig. 5b) were set on characteristic "holes". Marker 3 was set above the same hole that was marked with the black circle in fig. 6b. These holes are a very possible result of pitting corrosion.

Fig. 6a illustrates small dark spots with dimensions of several to several hundred micrometers. They may be a result of both fine-dispersive liberations and intercrystalline and pitting corrosion. Fig. 7 presents an example view of a metallographic specimen with focal points of pitting corrosion – the photograph was taken from literature [11]. Areas of pitting corrosion appearing on this specimen are very similar to the dark spots observed in fig. 6a.

a)



b)



c)

All. elem. cont., [% mass}	**C**	**O**	**Si**	**S**	**Cr**	**Mn**	**Fe**	**Cu**
Place of analysis								
Point 1	1.06	0.84	0.27	0.86	**7.48**	-	40.48	49.01
Point 2	0.39	0.22	0.09	0.19	**13.60**	-	84.40	1.12
Point 3	0.96	0.27	0.34	-	**14.37**	0.76	83.30	-

Source: own work / Źródło: opracowanie własne

Fig. 6. Results of microscope observations of samples: a) corroded specimen, b) place of quality analysis of chemical composition, c) quality analysis results of chemical composition of places marked in fig. 5b

Rys. 6. Wyniki obserwacji mikroskopowych próbek: a) zgład trawiony, b) miejsce analizy jakościowej składu chemicznego, c) wyniki analizy jakościowej składu chemicznego miejsc zaznaczonych na rys. 6b

Fig. 7. Pitting corrosion [11]
Rys. 7. Korozja wżerowa [11]

As far as pitting corrosion is concerned, it can be stated that at a chromium content of 10 % and more, a thin layer of chromium and iron oxides with a thickness in the order of Å, the so-called passive layer, appears on the surface of steel. This layer is characterized by a compact structure, consistent with the base, causing abrupt increases in chemical potential, i.e. corrosion resistance. The layer protects from corrosion in a manner similar to e.g. paint coating. The passive layer must be capable of regeneration in case of mechanical damage to the surface. At locally lower chromium contents, the oxide layer appears is porous and consistent with the base to a small extent, which results in the corrosive agent having access to the surface of steel and corrosion to develop. Material damage which is completed in this kind of situation is stress pitting corrosion occurring when local damage to the passive layer takes place, and the layer does not regenerate, and at simultaneous action of external loads. The result of such corrosion is damage shown in fig. 8.

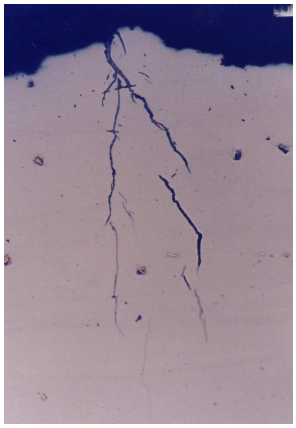


Fig. 8. Corrosion stress cracking [11]
Rys. 8. Korozyjne pęknięcie naprężeniowe [11]

It can be added that the performed macroscopic observations allowed to identify a corroded structure on working surfaces and in breakage points of the matrix (fig. 9).

After analysing the presented material, a final thought occurs. If it is assumed that operation and use of the pellet mill/matrix was in accordance with the rules of the technological process, then the issue of pellet mill operation could not have influenced such a rapid matrix damage.

It is assumed that hardening microcracks developed at the stage of heat treatment. As a result of the process of matrix operation, a gradual, yet accelerated, phenomenon of propagation of microcracking developed, which spread throughout the whole volume of the material. The appearance of iron and manganese sulphides in the structure of material could be an aspect that aggravates microcracking. At the same time, the phenomena of intercrystalline and pitting corrosion could occur. The moment of the carrying cross-section of the matrix was too small to transfer the loads from the technological process, matrix damage ensued.

Source: own work / Źródło: opracowanie własne

Fig. 9. Corrosion on working surfaces of the matrix
Rys. 9. Korozja na powierzchniach roboczych matrycy

5. Conclusions

The performed analysis of the technological process, the obtained information, the collected photographic documentation, and the analysis of the obtained test results allowed to formulate the following conclusions:

1. Assuming that the technological process was realized in the appropriate manner (as far as the parameters, processed materials, operation, and use of the pellet mill/matrix were concerned), it is impossible to damage the matrix during a 7-day operation cycle, unless there are other, hidden factors that led to it.
2. A discrepancy in the chemical contents between the analysed samples and the 3H13 steel.
3. Results of chemical composition tests provided information about an increased sulphur content in materials of the analysed samples. Its presence is undesirable, especially in the form of FeS, as binds with austenite to form low melt eutectics, which cause heat cracking. An additional element includes the possibility of creation of sulphides of manganese, which occurs in steel as isolated inclusions inside grains, this being the cause of lamellar cracking.
4. The most probable cause of matrix cracking is an inappropriate process of its heat treatment or inappropriate parameters of this process. Negligence in this area may result in, among others, hardening cracks, or pitting and intercrystalline corrosion, which lead to a complete damage to the material. The aforementioned high sulphur content should also be remembered as it creates compounds that lead to heat cracking.

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