Arch. Metall. Mater. **68** (2023), 4, 1591-1595

DOI: https://doi.org/10.24425/amm.2023.146227

S. RAVAI NAGY[1], A.B. POP[1], M. NABIAŁEK[2], C. ALEXANDRU[3], A.M. ȚÎȚU[4*]

EXPERIMENTAL RESEARCH ON THE INFLUENCE OF ROUGHNESS OF THE MACHINED SURFACE OF A PART ON GALVANIZATION

The purpose of this scientific paper is to follow the influence of thermal galvanizing, as a technological process on the quality of the galvanized surface. The galvanizing technology used and studied involves at the end of the process, the removal of excess zinc from the surface by centrifugation. The zinc layer will be lower than that of simple immersion galvanizing. The measurements were performed following the roughness of the machined surface on a five-Section specimen – each Section being processed with a different cutting regime. The results were analyzed after each operation. The first measurements were made after the turning operation, followed by measurements made after pickling and fluxing and then after thermal galvanizing. Based on the results obtained, the aim was to set up a range of best roughness at which the galvanized part should have a commercial appearance and be made with a cost-effective cutting regime in terms of costs.

Keywords: Surface quality; turning; pickling; hot dip galvanizing; optimization

1.

Hot dip galvanization is the process of immersing iron or steel in a molten zinc bath to produce a corrosion-resistant multilayer coating of zinc-iron alloys and zinc metals. While the steel is immersed in zinc, a metallurgical reaction occurs between the iron in the steel and the hot-dip galvanization. Because this reaction is a diffusion process, the coating is formed perpendicular to all surfaces, creating a uniform thickness throughout the piece. Studies working on this topic have been confirmed in the literature. Among them are the works of Kuklik [1] and Kania [2], who are studying the problem of hot-dip galvanizing steel structures. The sustainability of the hot dip galvanizing process has been investigated by [3-6]. Najafabadi [7] states that hot dip galvanizing is one of the most common corrosion prevention techniques for steel. This widely available method extends the life of steel structures by up to 50 years. Similar studies belonged to Li [8], Deng [9], and Xie [10]. The corrosion resistance of the acrylic acid layer as measured by electrochemical tests was analyzed by [11]. In the study [12], we analyzed the effect of hot dip galvanizing on the fatigue strength of AISI4340 crude steel and AISI4340 ionic nitrides in the laboratory air atmosphere. The hot-dip galvanizing process has been in use since 1742 and has supplied long-term maintenance-free corrosion protection for decades at a reasonable cost. Hot-dip galvanizing has been used for generations to protect steel, but the galvanizing process continues to evolve with modern technologies and creative chemistry. The three main steps of the hot-dip galvanizing process are surface treatment, galvanization, and post-treatment, each of which is described in detail. The process is simple in nature, which is a clear advantage over other corrosion protection methods. The basic principle of galvanization is the galvanic protection of basic steel parts. Galvanic steel prevents the progression of corrosion with the help of a zinc layer. Therefore, the passivation of galvanic steel is based on the electrochemical relationship between steel and zinc. The elements of the world are ordered by an electrochemical matrix. This electrochemical matrix is decided by seeing the reducing and oxidizing capabilities of the element. In other words, the affinity of the elements for reduction and oxidation in turn decides the position of these elements.

Inspection of galvanized steel is a straightforward process. Zinc does not adhere to or react with dirty steel. Therefore, a vis-

---

[1] TECHNICAL UNIVERSITY OF CLUJ-NAPOCA, NORTHERN UNIVERSITY CENTRE OF BAIA MARE, FACULTY OF ENGINEERING – DEPARTMENT OF ENGINEERING AND TECHNOLOGY MANAGEMENT, 62A, VICTOR BABES STREET, 430083, BAIA MARE, MARAMURES, ROMANIA
[2] CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF PHYSICS, ARMII KRAJOWEJ 19 AV., 42-200 CZĘSTOCHOWA
[3] ELECTRO SISTEM, 4B, 8 MARTIE STREET, 430406, BAIA MARE, MARAMURES, ROMANIA
[4] "LUCIAN BLAGA" UNIVERSITY OF SIBIU, FACULTY OF ENGINEERING, INDUSTRIAL ENGINEERING AND MANAGEMENT DEPARTMENT, 10 VICTORIEI STREET, 550024, SIBIU, ROMANIA

[*] Coressponding author: mihail.titu@ulbsibiu.ro

ual inspection of the product can rigorously evaluate the quality of the coating. The thickness of the coating is usually evaluated using a magnetic thickness indicator. Testing and sampling requirements are included in the national or international standards associated with the product. A literature study by Gaderbauer [13], Reséndiz-Flores [14] and Vizureanu [15] addressing issues in this direction has been confirmed in the literature. If the noble metal is bound to a more active metal, that is, if the upper element is bound to the lower element, the corrosion rate of each element will change. Changing the rate of corrosion adversely affects noble and reactive elements. At the end of the coupling, the rate of corrosion of precious metals decreases, but the rate of corrosion of active metals increases. Therefore, when a precious metal and an active metal are combined, the precious metal is less likely to corrode. However, corrosion occurs in active metals faster than standard conditions.

The wide range of applications of galvanized steel can be seen as evidence of the benefits of galvanized steel. The most common advantages of galvanized steel can be illustrated as excellent prevention against corrosion, ease of surface modification, and excellent protection against mechanical damage. In addition, the cost-effective properties of the galvanizing process make it desirable for most sellers. The need for galvanized steel for regular maintenance is less than for regular carbon steel due to the zinc coating. Therefore, the long-term cost-effectiveness of galvanized steel can be regarded as a major factor in material choice. The preventive function of the zinc coating and the speed of the process can be seen as the main advantages of the galvanizing process. The hard layer of galvanized steel has a high resistivity to scratches and damage. For this paper, the purpose is to set up the effect of hot-dip galvanization on the quality of the surface treated by the hot galvanizing process.

By setting up the relationship between pre- and post-applied part roughness for hot galvanization, you can make recommendations for smallest part roughness during chipping. In other words, knowing the minimum roughness can set up the smallest advance in which a part is processed. Using forwards with values lower than the determined minimum advance increases the cost of machining without affecting the quality of the galvanized surface. As a result of the hot galvanizing technique, the particularly excellent quality surface obtained by cutting is destroyed, resulting in higher roughness. If the roughness is large, those values will decrease after applying hot galvanization. Throughout this paper, we look to set up best roughness intervals where galvanized parts have a commercial appearance and are made in a cost-effective cutting regime from a cost perspective (base time is possible). As small as possible). The topic approached is not specified in the literature. Manufacturing companies lacked communication at the level of the department that manages the processing of parts by cutting and the department that performs hot galvanization. The designer of the part sets up the quality of the galvanized surface only by showing hot galvanization. The curriculum of metallurgists does not describe the quality of the surface. The issues addressed are related to the hot galvanizing technique and the reactions that occur. Design engineers describe galvanization as an anticorrosion treatment. The technical engineers who set up the cutting technique do not use hot galvanization in their curriculum or are generally unrelated to surface coverage.

2. Research method

In the present study, the test piece was made by turning from a bar with a diameter of 25 mm, made of S275JO material. The Section s processed for the study have a length of 30 mm. Each Section was processed with a cutting regime in which the variable parameter is the advance (Fig. 1).

Fig. 1. The specimen processed by turning

The cutting parameters considered are the cutting speed: 1800 rmp and the feed: 0.14; 0.2; 0.32; 0.4; 0.6 mm/rev. The processing of the specimen was performed using the CNC lathe, HAAS TL-2. The cutting tool being a lathe knife with the characteristics: the body of the lathe knife – PVJBR2020K11

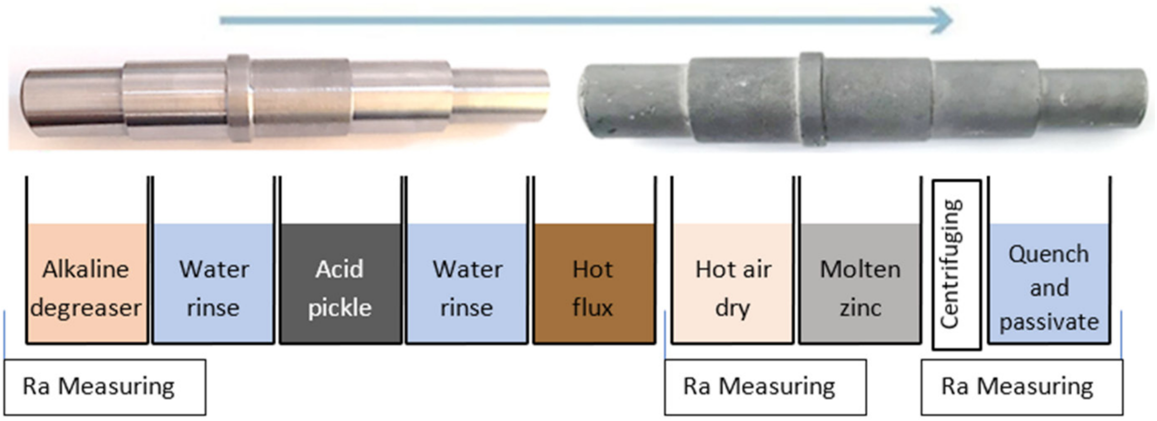


Fig. 2. Technological flow specific to thermal galvanizing

(Walter) (ISO 2936-2) and the cutting plate: VBMT110308-FP6, WPP20S (Walter Tiger tec). After machining, the part followed the technological flow specific to thermal galvanizing. Thus, the steps are shown in Fig. 2 and detailed below.

Degreasing, washing in alkaline solution. The solution used is Ferroclean 7135/1. The characteristics of the washing bath: temperature 50°C; PH 6.1; compressed air bubbling; holding time: 15 minutes.

- Water rinse in the pool with water – holding time: 10 min; compressed air bubbling.
- Pickling – it is made in a hydrochloric acid bath. The characteristics of the pickling bath: temperature 25°C; concentration of the bath: 29%, holding time: 20 minutes.
- Water rinse in the pool with water – holding time: 10 min; compressed air bubbling.
- Fluxing (preparation of the galvanizing surface and corrosion protection during the drying of the part) is performed in the basin by immersion. The solution used is based on zinc chloride (ZnCl2). The characteristics of the bath: temperature 45°C; PH 4.0; no bubbling; holding time: 5 minutes.
- Drying is performed in a closed enclosure heated by recirculating the air from inside. Dryer characteristics: temperature 80°C; with air recirculation; holding time: 40 minutes.
- Immersion in molten zinc: galvanizing basin temperature: 590°C; holding time: 5 min.
- Centrifuging.
- Passivation, oxidation in the pool with immersion water. Hold time: about 1-2 minutes.

3. Performance of measurements

The roughness measurement was performed with a TR200 device according to the key stages of the technology of obtaining a thermally galvanized part. Thus, the roughness was measured after each of the following operations: turning; pickling; completion of galvanizing. In the experiment the evaluation length is set to 4 mm.

TABLE 1

Characteristics of the TR-200 roughness meter used in the experiment

TR-200 Surface roughness tester	
	
Measuring system:	Metric
Display resolution:	0.001 µm
Range:	Ra, Rq: 0.005 µm – 16 µm
Pick-up measuring range:	±20 µm, ±40 µm, ±80 µm
Cut-off length:	0.25 mm / 0.8 mm / 2.5 mm/Auto
Evaluation length:	Ln = 1 … 5 cut-offs (selectable)
Tracing length:	Lt = (1 … 5 cut off) + 2 cut-off (selectable)

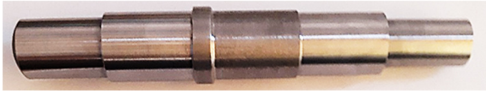
4. Conducting experiments and data collection

4.1. Turning processing

On a shaft type piece, 5 surfaces with different roughness's were processed by turning. The roughness of the surfaces after turning is centralized in TABLE 2 and evaluated in Fig. 3.

TABLE 2

Surface roughness after turning

	Speed of rotation 1800 rev/min				
	Cutting feed mm/rev				
	0.14	0.6	0.4	0.32	0.2
					
	Section 1	Section 2	Section 3	Section 4	Section 5
Ra	0.596	5.447	4.939	2.965	1.659
	0.662	5.298	5.098	3.037	1.469
	0.631	5.339	5.44	3.12	1.454
	0.574	5.281	5.182	2.942	1.49
	0.564	5.452	5.465	3.064	1.558
	0.685	5.352	4.978	2.578	1.279
	0.663	5.242	5.207	2.731	1.503

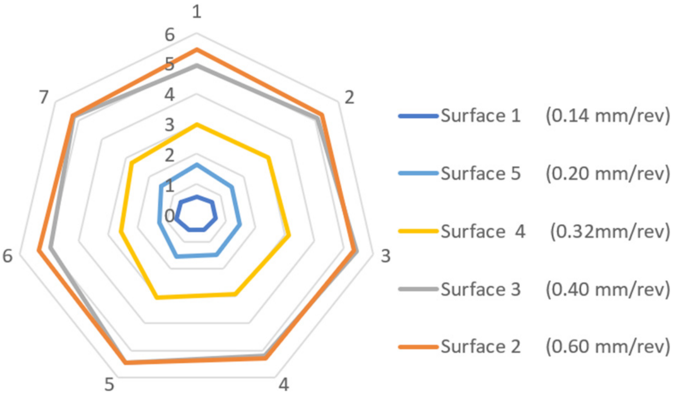


Fig. 3. Roughness sizes after turning on the circumference of the Sections

4.2. Pickling

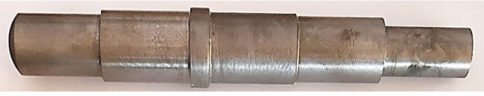
The turned parts followed the technological flow of galvanizing which provides before the actual galvanizing and a pickling. The surface roughness's after the pickling operation are shown in TABLE 3 and evaluated in Fig. 4. Gloves were used when managing the part during the roughness measurement to avoid contamination of the pickled surfaces.

4.3. Thermal galvanizing

The pickled and measured pieces were immersed in the zinc bath, followed by a centrifugation to remove the excess zinc.

TABLE 3

Surface roughness after pickling

					
	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
Ra	0.63	5.499	4.789	2.416	1.624
	0.649	5.125	4.512	2.593	1.865
	0.581	5.311	4.407	2.672	1.73
	0.797	6.196	4.818	2.773	1.57
	0.802	5.105	4.905	2.708	1.316
	0.678	5.356	5.006	2.61	1.414
	0.746	5.263	4.86	2.359	1.67

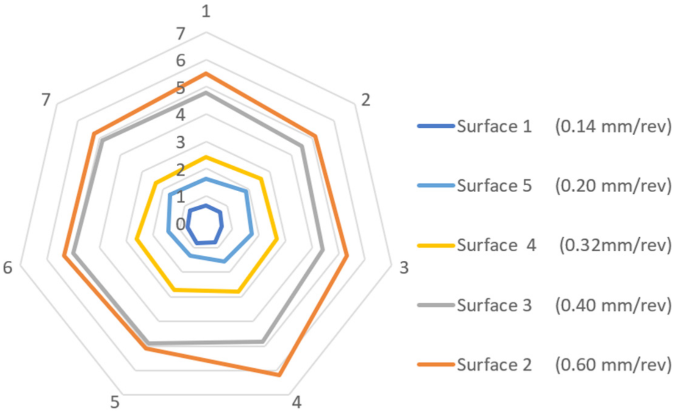


Fig. 4. Roughness sizes after pickling on the circumference of the Sections

The surface roughness's after the galvanizing (and centrifuging) operation are shown in TABLE 4 and evaluated in Fig. 5. The measurement of roughness on the circumference of the Section s was performed in 7 positions at equal distances from each other after turning and after pickling. After galvanizing, the measurement of roughness on the circumference of the Section s was performed in 8 positions with equal distances between them.

TABLE 4

Surface roughness after galvanizing

					
	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
Ra	1.965	3.182	3.318	2.446	1.841
	2.103	2.823	2.94	1.974	1.825
	1.72	5.509	2.91	2.21	1.939
	1.33	4.602	2.711	2.067	1.859
	1.426	4.28	2.683	2.251	2.419
	2.318	5.67	3.742	2.354	2.549
	2.294	5.287	3.725	2.991	1.834
	2.357	4.396	3.326	2.055	2.121

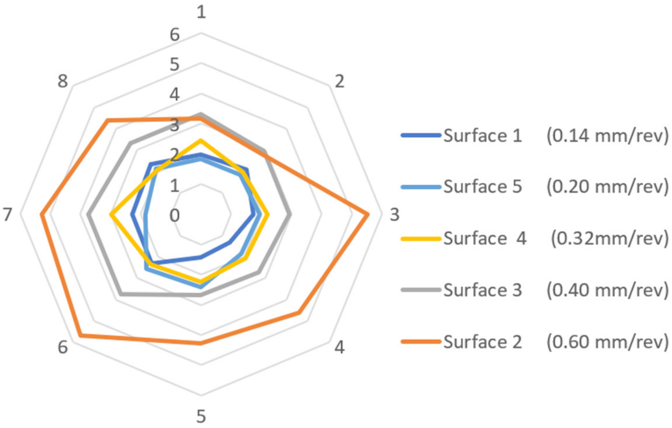


Fig. 5. Sizes of roughness after galvanizing on the circumference of the Sections

5. Results and discussions

The roughness on the circumference of the Section s processed by turning is constant. This aspect can also be seen in Fig. 1. The points are at equal distances from the center of the graph. The roughness on the circumference of the pickled Section already shows an elongation. Given that on each Section we can find this aspect is the result of the position of the piece in the pickling bath. The roughness of the part is influenced by the position of the specimen in the pickling bath. The displacement of material during pickling is not constant over the entire circumference of the workpiece surface. The value of roughness after pickling increases in the case of fine surfaces Ra = 0.6, Ra = 1.5 (Section 1 and 5) and for surfaces with higher roughness after turning, after pickling the values of roughness decrease (Fig. 4). The chipped roughness is marked with blue, and after pickling and fluxing the roughness is represented with orange. After thermal galvanizing (immersion in molten zinc followed by centrifugation) we find a variation of the roughness on the circumference of the part (Fig. 3). We consider this variation to be due to the centrifugation of the parts after removing them from the zinc bath. Following the thermal galvanizing, we notice an increase of the roughness's at Section s 1 and 2 and at Section s 3, 4 and 5 a decrease. Next, in Fig. 6 and TABLES 5 and 6 are presented and summarized a series of findings about the conduct of experiments and obtaining measured data.

TABLE 5

Average roughness on sections depending on the operation

	Surface 1	**Surface 5**	**Surface 4**	**Surface 3**	**Surface 2**
	0.14 mm/rev	**0.2 mm/rev**	**0.32 mm/rev**	**0.4 mm/rev**	**0.6 mm/rev**
Operation	Ra [µm]				
Turning	0.625	1.487	2.92	5.187	5.344
Pickling + Flux	0.698	1.598	2.59	4.757	5.408
Galvanized (hot dip)	1.939	2.048	2.294	3.169	4.469

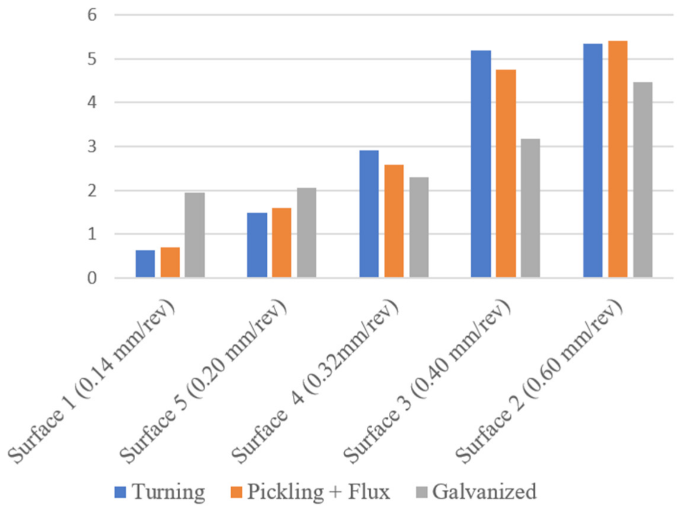


Fig. 6. Variation of roughness according to the first roughness and the current operation

TABLE 6

Percentage changes in the roughness of the chipped surface after galvanizing

	Surface 1	Surface 5	Surface 4	Surface 3	Surface 2
	0.14 mm/rev	0.2 mm/rev	0.32 mm/rev	0.4 mm/rev	0.6 mm/rev
Operation	Ra [μm]				
Turning	0.625	1.487	2.92	5.187	5.344
Galvanized (hot dip)	1.939	2.048	2.294	3.169	4.469
Percentage variation	+210.20%	+37.73%	–21.43%	–38.90%	–16.67%

If, after turning, the chipped surfaces have roughness's within the ranges Ra = 0.6 ... 2.9, after thermal galvanizing the Ra roughness's around 2 microns. Based on the earlier observations we can say that the parts should NOT be processed with a roughness less than Ra = 1.6 if they are hot dip galvanized. At roughness's Ra = 5.34; Ra = 5.20; Ra = 2.92 obtained by cutting we find a decrease in roughness after galvanizing. Hot zinc fills the gaps in the profile.

6. Conclusions and further research directions

In the case of surfaces with a roughness higher than Ra = 2.9 microns obtained by cutting following thermal galvanizing, their roughness decreases significantly (TABLE 6). In the case of surfaces with a roughness less than Ra = 2.9 microns obtained by cutting following thermal galvanizing, its roughness increases significantly (TABLE 6). Following the study, we found that, in terms of the quality of the galvanized surface, the cutting regime must be with advances greater than 0.32 mm/rev. The use of advances of less than 0.32 mm/rev is not justified because the roughness of the surface obtained by cutting after galvanizing will increase. This results in unjustified cutting costs or higher manufacturing costs. For the subsequent research activity, new fields of study are opened that can be approached: repeating experiments to substantiate observations; study of the influence of the quality of the galvanized surface / the roughness of the chipped surface on the corrosion resistance; determining the thickness of the zinc layer / the diffusion depth of zinc depending on the roughness of the part after cutting; determining the influence of the position of the part during the galvanizing technology on the zinc layer and its roughness; dimensional changes of the part depending on the thermal galvanizing operations; verification of the influence of the roughness of the galvanized part on the corrosion resistance of the zinc layer; the amount of zinc taken up by the part depending on the surface roughness before galvanizing. As a conclusion one can say that through this study, we set up a lower limit of the roughness of the part processed by cutting. Completing the study could also set up an upper limit of roughness when the amount of zinc on the surface will be too thick.

REFERENCES

[1] V. Kuklík, J. Kudlacek, Hot-dip galvanizing of steel structures, Butterworth-Heinemann (2016).

[2] H. Kania, J. Mendala, J. Kozuba, M. Saternus, Materials **13** (18), 4168 (2020).

[3] Z. Yu, J. Hu, H. Meng, Frontiers in Materials **7**, 74 (2020).

[4] A. Al-Negheimish, R.R. Hussain, A. Alhozaimy, D.D.N. Singh, Construction and Building Materials **274**, 121921 (2021).

[5] G. Ferraz, B. Rossi, Engineering Failure Analysis **118**, 104834 (2020).

[6] J.D. Hernández-Betancur, H.F. Hernández, L.M. Ocampo-Carmona, Journal of Cleaner Production **206**, 755-766 (2019).

[7] E.P. Najafabadi, A. Heidarpour, S. Raina, Thin-Walled Structures **164**, 107744 (2021).

[8] Z. Li, H. Peng, Y. Liu, J. Wang, X. Su, Transactions of the Indian Institute of Metals **75** (2), 397-406 (2022).

[9] Y.G. Deng, H.S. Di, R.D.K. Misra, Journal of Materials Research and Technology **9** (6), 14401-14411 (2020).

[10] Y. Xie, A. Du, X. Zhao, R. Ma, Y. Fan, X. Cao, Surface and Coatings Technology **337**, 313-320 (2018).

[11] Y. Fan, H. Yang, H. Fan, Q. Liu, C. Lv, X. Zhao, M. Yang, J. Wu, X. Cao, Materials **13** (10), 2340 (2020).

[12] S.Y. Sirin, International Journal of Fatigue **123**, 1-9 (2019).

[13] W. Gaderbauer, M. Arndt, T. Truglas, T. Steck, N. Klingner, D. Stifter, J. Faderl, H. Groiss, Surface and Coatings Technology **404**, 126466 (2020).

[14] E.O. Reséndiz-Flores, G. Altamirano-Guerrero, P.S. Costa, A.E. Salas-Reyes, A. Salinas-Rodríguez, F. Goodwin, Metals **11** (4), 578 (2021).

[15] P. Vizureanu, Metalurgia International **14** (5), 5-9 (2009).