ACTA METALLURGICA SLOVACA
2025, VOL. 31, NO. 3, 167-170

RESEARCH PAPER

# Manufacture of briquettes from ball bearing steel pulverized metal waste without prior cleaning by cold pressing

*Vitaliy Kulikov*[1], *Erkenaz Baiseitova*[1*], *Svetlana Kvon*[1], *Aristotel Issagulov*[1], *Sholpan Tulegenova*[1], *Tatyana Kovalyova*[1], *Pavel Kovalev*[2]

[1]Karaganda Technical University named after Abilkas Saginov, Department of Nanotechnology and Metallurgy, Nursultan Nazarbayev Avenue No. 56, 100003, Karaganda, Kazakhstan
[2]NRU Peter the Great St. Petersburg Polytechnic University, Institute of Mechanical Engineering, Materials and Transport, Polytechnic street No.29B, 1940216Saint Petersburg, Russia

*Corresponding author: erkenaz-urist@mail.ru, tel.: +77713834688, Department of Nanotechnology and Metallurgy, Karaganda Technical University named after Abilkas Saginov, Nursultan Nazarbayev Avenue No. 56, 100003, Karaganda, Kazakhstan

Received: 17.07.2025
Accepted: 28.07.2025

## ABSTRACT

The article presents a study on the production of briquettes from bearing steel machining waste for use in secondary steelmaking. Cold compaction of pulverized ShH15 steel chips was carried out using a laboratory RP-50 hydraulic press with a maximum capacity of 500 kN. Through a series of experiments, the optimal composition of the briquetting mixture was established as 85% steel waste, 10% bentonite clay, and 5% liquid glass. The pressing parameters were optimized to improve the mechanical integrity of the briquettes. Thermal drying at 80 °C for 90 minutes, combined with a pressing force of 60 kN, resulted in the formation of structurally uniform briquettes with high compressive strength. These results demonstrate the effectiveness of the proposed method for converting uncleaned steel waste into a reusable metallurgical feedstock. These findings offer a novel solution for sustainable recycling of alloyed steel residues in industrial metallurgy.

**Keywords:** briquetting, bearing steel waste, cold pressing, bentonite binder, liquid glass

## INTRODUCTION

Increasing global competition, tightening environmental regulations, and the growing complexity of mineral resource extraction and processing demand enhanced technological standards across the metallurgical industry [1]. In this context, the modernization of existing production schemes and the development of innovative methods for processing both primary and secondary raw materials are critical to ensuring sustainable growth in metallurgical operations [2]. Modern high-intensity technologies not only impose stricter quality requirements on raw materials but also promote the integration of alternative and recycled inputs into the production chain.

Against the backdrop of limited supplies of low-sulfur coking coals and the ongoing intensification of metallurgical processes, complex ore–fuel composites—especially those subjected to pre-reduction—are becoming increasingly important. These materials improve the efficiency of smelting units and contribute to reducing the environmental footprint of metallurgical production.

At the same time, traditional technologies such as agglomeration and pelletizing have largely reached their technical and resource limitations. For example, the production of metallized agglomerates or mechanically robust pellets with elevated free carbon content remains a challenge under current technological conditions. Under these constraints, briquetting presents a promising alternative for transforming fine-grained waste and slag residues into dense, uniform ore–fuel briquettes suitable for metallurgical reuse [3,4].

Several researchers have thoroughly investigated the Parilak mechanisms of powder densification under varying conditions. For example, Pariľák et al. [5] developed a practical compaction model for metal powders subjected to cold pressing, identifying the principal factors that govern the densification process. In a similar vein Dragošek al. [6] examined the compaction behavior of the EN AW 6060 alloy, confirming that pressing parameters significantly influence the resulting mechanical properties. Furthermore, Kocisko et al. [7] explored different techniques of hot extrusion aimed at recycling aluminum chips, which directly contributes to the broader objective of improving secondary processing methods for metallic waste.

To ensure adequate mechanical strength in briquettes produced from steel machining waste, a set of experimental studies was carried out. These involved the selection and proportioning of binder components, determination of optimal mixing time based on particle size distribution, and optimization of pressing parameters to maximize compressive strength.

Based on the results, the optimal composition of the briquette mixture was determined as follows: 85% ShH15 steel chip sludge, 10% bentonite clay, and 5% liquid glass, with the total moisture content maintained below 5% by weight.

A detailed description of the preparation steps—including component selection, mixing, proportioning, and cold pressing—is provided in the following section.

## MATERIAL AND METHODS

Prior to defining the processing parameters for briquetting metal machining waste, a review of existing approaches to the compaction of fine metallic swarf was carried out [8,9]. Briquetting is essentially a physical–mechanical process designed to consolidate fine particles into dense structures with the aid of binders, ensuring sufficient mechanical integrity and compatibility with downstream metallurgical applications, particularly in smelting operations [10].

The experimental studies were conducted at the International Center for Materials Science of Karaganda Technical University using dedicated laboratory equipment. A hydraulic press of the RP-50 type, capable of exerting pressures up to 500 kN, was used for compaction, and a Nobertherm-3100 furnace was employed for post-processing heat treatment.

The briquetting feedstock consisted of fine-grained ShH15 bearing steel chips, a by-product generated during the machining of inner and outer rolling elements at the KZM Parchomenko production facility in Karaganda, Kazakhstan. The moisture content of the collected steel waste ranged from 10% to 15%, consistent with typical production batches. The chemical composition of the powder was analyzed using an SPAS-05 optical emission spectrometer. The resulting composition included 1.29% carbon, 2.00% chromium, and a slightly elevated sulfur content (0.07%), likely introduced by surface contaminants. Oxygen content was measured at 1.46%, which is attributed to residual moisture and surface oxidation of fine particles during storage. The oxygen content was estimated by optical emission spectroscopy using an SPAS-05 spectrometer. Overall, the chemical characteristics are within the expected range defined by EN ISO 683-17 standards for wear-resistant bearing steels.

DOI: https://doi.org/10.36547/ams.31.3.2228

**Table 1** – Chemical composition of powdery ShH15 steel compared to EN ISO 683-17 standard, wt.%

| Material | Content of elements | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Fe | C | S | Si | Mn | Cr | O | P |
| Powdery ShH15 steel chips | 94.58 | 1.29 | 0.07 | 0.30 | 0.30 | 2.00 | 1.4–6 | 0.012 |
| Steel (EN ISO 683-17)* | 94.51–97.38 | 0.95–1.05 | ≤0.02 | 0.17–0.37 | 0.20–0.40 | 1.30–1.65 | ≤2.00 | ≤0.025 |

**Table 1** (continued): Additional alloying elements in ShKh15 steel

| Material | Content of elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Al | Ni | Cu | Sb | V | Nb | Ti |
| Powdery ShH15 steel chips | 0.021 | 0.034 | 0.029 | 0.004 | 0.002 | 0.001 | 0.003 |
| Steel (EN ISO 683-17)* | ≤0.050 | ≤0.050 | ≤0.050 | ≤0.050 | ≤0.050 | ≤0.050 | ≤0.050 |

** Standard values according to EN ISO 683-17:2014 "Heat-treatable steels, alloy steels and free-cutting steels – Part 17: Ball and roller bearing steels".*

A particle size distribution analysis of the steel chip sludge was performed using a Retsch sieve analyzer. The results indicated that approximately 70% of the particles were within the 0–0.6 µm range, while about 25% were in the 0.7–3.0 µm range. Particles exceeding 1 mm in size accounted for less than 5% of the total mass. A similar granulometric analysis of the bentonite clay revealed that the majority of its particles also fell within the 0–0.7 µm range, with around 20% falling between 0.7 and 1.0 µm.

The briquette components were prepared in varying proportions, with steel chip sludge (ShH15) comprising 75–80% of the total mass, bentonite clay 10–20%, liquid glass 5–10%, and water content limited to 5%. Mixing was carried out using laboratory-scale runners for 1.5 to 2 minutes to ensure homogeneity prior to pressing (**Table 2**).

**Table 2** Experimental dosage formulations of briquette components

| Sample | Shavings mass, g | Bentonite clay, g | Liquid glass, g | Water, g |
|---|---|---|---|---|
| 1A | 50 | 5 | 5 | 0.1 |
| 1B | 50 | 7.5 | 5 | 0.1 |
| 1C | 50 | 10 | 5 | 0.1 |
| 2A | 50 | 5 | 7.5 | 0.1 |
| 2B | 50 | 7.5 | 7.5 | 0.1 |
| 2C | 50 | 10 | 7.5 | 0.1 |
| 3A | 50 | 5 | 10 | 0.1 |
| 3B | 50 | 7.5 | 10 | 0.1 |
| 3C | 50 | 10 | 10 | 0.1 |
| 4A | 50 | 5 | 5 | 0.05 |
| 4B | 50 | 7.5 | 5 | 0.05 |
| 4C | 50 | 10 | 5 | 0.05 |
| 5A | 50 | 5 | 7.5 | 0.05 |
| 5B | 50 | 7.5 | 7.5 | 0.05 |
| 5C | 50 | 10 | 7.5 | 0.05 |
| 6A | 50 | 5 | 10 | 0.05 |
| 6B | 50 | 7.5 | 10 | 0.05 |
| 6C | 50 | 10 | 10 | 0.05 |

**Fig. 1** presents a comparative histogram showing the mass fractions of bentonite clay, liquid glass, and water used in the preparation of 18 laboratory-scale briquette samples (designated 1A–6C), produced under varying compositional regimes. In all cases, the amount of ShH15 steel powder was fixed at 50 g, while the proportions of binder components—bentonite clay (5–10 g), liquid glass (5–10 g), and water (0.05–0.1 g)—were systematically varied.

Each series (1 through 6) represents a distinct binder-to-solvent combination, enabling a comparative assessment of how formulation parameters influence the physical and mechanical behavior of the resulting briquettes. The histogram data provide insight into component ratios across all samples and form the basis for evaluating compressive strength, moisture resistance, and overall process ability. Evaluating the role of binder composition is crucial for optimizing briquette design and supporting the use of recycled feedstock in industrial-scale metallurgical operations.

A consistent increase in the amount of binder components is observed from subgroup A to C within each series: the bentonite content rises from 5 g to 10 g, and liquid glass increases in parallel from 5 g to 10 g. Additionally, there is a transition from higher moisture levels (0.1 g of water in series 1–3) to lower moisture content (0.05 g in series 4–6), intended to evaluate the influence of water on briquette strength.

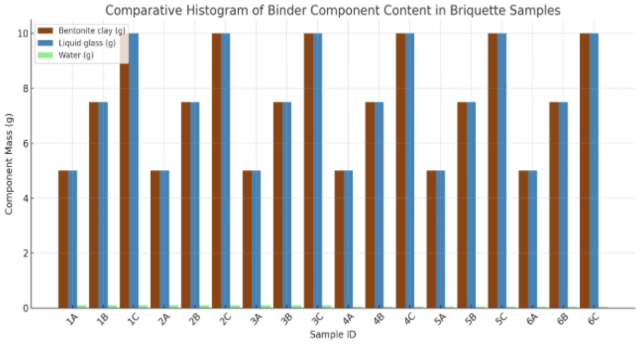

**Fig.1** Comparative histogram of binder component content in experimental briquette samples (Series 1A–6C). Each sample contains 50 g of ShKh15 steel chips. The composition varies by the proportions of bentonite clay (5–10 g), liquid glass (5–10 g), and water (0.05–0.1 g). The histogram illustrates trends in formulation design and provides a basis for analyzing the effect of mixture composition on the mechanical properties of the briquettes.

The graphical data enable a clear visualization of the formulation uniformity across all sample series and support the selection of an optimal composition—specifically sample 4C—based on a favorable combination of physical and mechanical properties.

During the initial phase of the experimental trials, briquetting was performed using a cylindrical die with a diameter of 20 mm (**Fig. 2**). Each sample was subjected to a static compression load of 60 kN. Following compaction, the briquettes were thermally dried in a SNOL laboratory furnace at 80 °C for 90 minutes. This temperature–time regime was chosen to promote uniform evaporation of moisture and stabilization of the internal structure without compromising the mechanical integrity of the briquette.

**Fig. 2** Laboratory Press Die and Forming Mold Assembly for Briquetting

In the subsequent stage of the experimental cycle, the fabricated briquettes were subjected to mechanical testing to evaluate their strength characteristics. The ultimate compressive strength was measured using an Instron-100 universal floor-standing testing machine, which ensures high accuracy under controlled static loading conditions. Additionally, surface hardness was assessed using a

Wilson-1150 hardness tester, specifically designed for precise determination of material surface strength across standardized scales. The summarized results of these mechanical tests are compiled and presented in **Table 3**.

**Table 3** Strength test results of samples

| Sample Series | A (MPa) | B (MPa) | C (MPa) |
|---|---|---|---|
| 1 | 426 | 455 | 491 |
| 2 | 467 | 506 | 521 |
| 3 | 470 | 511 | 519 |
| 4 | 547 | 563 | 589 |
| 5 | 529 | 561 | 579 |
| 6 | 516 | 541 | 559 |

Among the tested formulations, sample 4C demonstrated the highest compressive strength. It was evident that an increase in moisture content led to a reduction in strength. This can be attributed to the swelling of bentonite particles under pressure, followed by evaporation during drying, which introduces porosity into the structure and decreases mechanical integrity. In terms of binder formulation, the most effective ratio was 2:1 (bentonite clay to liquid glass), which provided the strongest adhesive bonding between particles.

To identify the optimal drying conditions, a series of 18 tests was performed by varying the drying temperature (60–110 °C) and duration (60, 90, and 120 minutes). Water evaporation and compressive strength were recorded for each condition. The highest compressive strength—581 MPa—was achieved by drying at 80 °C for 90 minutes, which ensured effective moisture removal without degrading the binder. Drying at higher temperatures led to either minimal strength improvement or slight deterioration, likely due to over-drying and the onset of liquid glass vitrification. Similarly, shorter or extended drying times showed reduced effectiveness, confirming that 80 °C for 90 minutes is the most efficient regime.

In the second part of the study, the focus shifted to defining the optimal pressing and briquetting conditions for ShH15 steel grinding chips. To refine the drying regime, additional tests were conducted using a SNOL-67/350 furnace, where sample 4C was subjected to drying at temperatures between 50 and 100 °C. The mass of the briquettes was measured at 30-minute intervals to determine the water evaporation rate (**Table 4**).

**Table 4** Presents a comparative analysis of the standard and experimentally measured pressing pressures at selected briquette densities.

| Density, ρ (g/cm³) | Standard Pressing Pressure*, MPa | Experimentally Measured Pressure, MPa | Deviation, % |
|---|---|---|---|
| 1.0 | 10 | 10 | 0.0 |
| 2.0 | 20 | 20 | 0.0 |
| 3.0 | 30 | 30 | 0.0 |
| 4.0 | 40 | 40 | 0.0 |
| 5.0 | 50 | 45 | –10.0 |
| 6.0 | 60 | 55 | –8.3 |
| 7.2 | 50 (reference point) | 50 | 0.0 |
| 8.0 | 80 | 75 | –6.25 |

Based on the data presented in **Table 4**, the optimal drying parameters were confirmed to be 80 °C and 90 minutes. Excessive drying time resulted in the over-evaporation of moisture and partial glazing of the binder, which negatively affected structural strength. Conversely, insufficient time or temperature did not allow the binder to reach its full bonding potential.

## RESULTS AND DISCUSSION

Analysis of the data in **Table 3** shows that formulation 4C achieved the highest compressive strength—589 MPa—outperforming all other variants. This result is linked to the optimal binder ratio: 10 g bentonite clay, 5 g liquid glass, and low moisture (0.05 g), which together reduce porosity and ensure a dense, stable structure.

A comparison between series 1–3 and 4–6 confirms the influence of moisture: increasing the water content to 0.1 g (as in series 1–3) results in lower strength, despite similar binder ratios. This is due to bentonite swelling under pressure and the formation of voids during drying.

Within each series, increasing bentonite improves strength up to a saturation point—particularly at a 2:1 bentonite-to-glass ratio (variants B and C)—where a strong adhesive matrix forms, promoting uniform bonding between ShH15 steel particles.

**Fig. 3** presents the visual appearance of the briquettes. Samples with composition 4C showed the most uniform structure, smooth surface, and sharp edges, indicating optimal binder distribution. In contrast, other variants showed porosity and microcracks, consistent with their lower strength.

**Fig. 3** Sample of the obtained briquettes

The results confirm that not only the absolute content of each component, but also their ratio within the clay–glass–water system plays a critical role in determining the mechanical properties of the briquettes. Based on the comprehensive assessment of performance indicators, formulation 4C can be recommended as the optimal composition for further experimental trials and potential scale-up for semi-industrial and industrial applications.

Among the key performance metrics of a briquette is its compressive strength, which directly correlates with its handling and transport characteristics. Ideally, the density of the briquettes should approach that of molten steel, approximately 7.8 g/cm³, to ensure maximum compatibility in metallurgical melting processes.

**Table 4** provides a comparative analysis between the standard theoretical values of pressing pressure and the experimental data obtained at various briquette densities. At a density of ρ = 7.2 g/cm³—recognized in industrial practice as a technologically optimal value—there was full agreement between the calculated and measured pressure (50 MPa), confirming the validity of the selected compaction regime. Minor deviations observed at higher density levels are attributed to increased compaction resistance and non-linear deformation behavior of the pulverized steel material under cold pressing conditions.

Achieving optimal compressive strength is essential to prevent briquette fractures. Substituting liquid glass with bentonite clay—while maintaining consistent pressing and drying parameters—resulted in improved strength, attributed to the wrapping effect of the clay and its strong adhesion capacity in a liquid glass medium [11].

An optimal binder content was identified at approximately 10%; exceeding this level leads to the formation of an excessively thick interparticle layer, which increases the brittleness of the final product [12]. The most energy-efficient pressing pressure for the combined binder system was 60 kN, as further increases in compaction force resulted in disproportionately high energy consumption without a corresponding gain in briquette strength, **Fig. 4**.

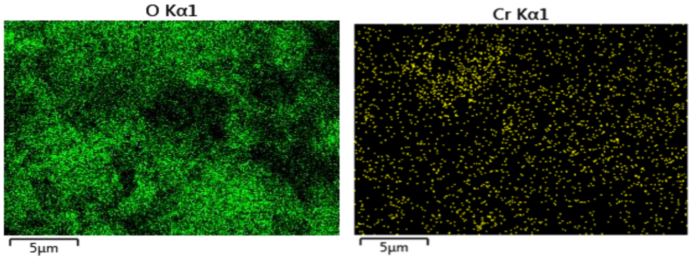

**Fig. 4** The distribution map of elements in the sample composition: ShH15 shavings 85%, liquid glass 5%, bentonite clay 10%

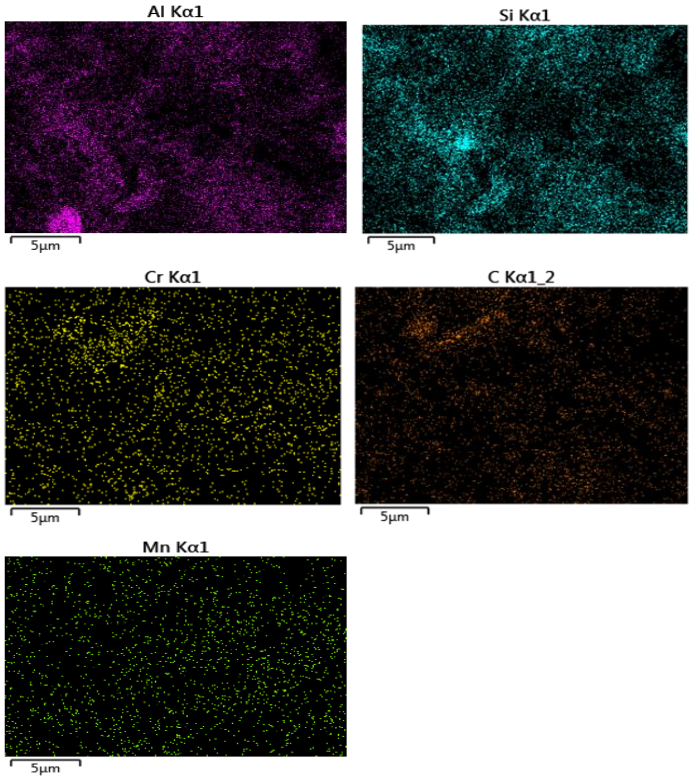

**Fig. 4 (continued).** Distribution map of chemical elements in the composition of the optimized briquette sample.

Overall, the findings of this study fully meet the objective of developing and validating a technologically feasible and economically viable method for processing metal machining waste without preliminary cleaning. The results contribute to the advancement of sustainable metallurgical technologies focused on resource efficiency, waste reduction, and improved recyclability of metal-containing secondary raw materials [13,14].

## CONCLUSION

A comprehensive series of experiments validated the feasibility and technological efficiency of cold briquetting for untreated ShH15 steel machining waste. The optimal composition—85% steel chips, 10% bentonite clay [15,16], and 5% liquid glass—enabled the formation of mechanically durable briquettes, while simultaneously minimizing moisture-related defects and lowering compaction energy requirements. A briquette density of $\rho = 7.2\ \mathrm{g/cm^3}$, achieved under 50 MPa pressure, was shown to meet the performance thresholds adopted in industrial metallurgy.

The scientific novelty of this research lies in the development of a cold pressing protocol that eliminates the need for preliminary cleaning of high-carbon steel waste, while ensuring structural integrity through tailored binder optimization. Notably, the substitution of liquid glass with bentonite clay enhanced the cohesive strength of the briquettes without increasing binder consumption [17,18], which marks a significant advancement in sustainable binder systems.

In practical terms, this method enables the recycling of powdered bearing steel into high-density briquettes that are directly compatible with melting furnaces. The proposed process can be scaled for semi-industrial applications, offering both economic benefits and environmental advantages by reducing waste, improving resource utilization, and integrating circular economy principles into metallurgical operations.

**Acknowledgements:** This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan under grant BR24993020: "Development and implementation of technology for manufacture of complex alloyed steels with homogeneous structure due to synergistic effects on the melt."

## REFERENCES

1. T. Jarnerud, A.V. Karasev, P.G. Jönsson: Materials, 12(18), 2019, 2888. https://doi.org/10.3390/ma12182888
2. A. Razumov: Journal of Manufacturing Processes, 64, 2021, 1526–1535. https://doi.org/10.1016/j.jmapro.2021.02.025
3. A. Nazari: Materials Letters, 229, 2018, 301–305. https://doi.org/10.1016/j.matlet.2018.07.038
4. J. W. Murray: International Journal of Machine Tools and Manufacture, 169, 2021, 103803. https://doi.org/10.1016/j.ijmachtools.2021.103803
5. L. Parilak, E. Dudrova, R. Bidulsky, M. Kabatova: Powder Technology, 322, 2017, 447-460. https://doi.org/10.1016/j.powtec.2017.09.027
6. L. Dragošek, R. Kociško, A. Kováčová, R. Bidulsky, M. Škrobian: Acta Polytechnica, 55(5), 2015, 301-305. https://doi.org/10.14311/AP.2015.55.0301
7. R. Kočiško, R. Bidulský, L. Dragošek, M. Škrobian: Acta Metallurgica Slovaca, 20(3), 2014, 302–308. https://doi.org/10.12776/ams.v20i3.366
8. G. Ingarao: Journal of Manufacturing Systems, 68, 2023, 651–662. https://doi.org/10.1016/j.jmsy.2023.05.021
9. J.R. Duflou: CIRP Annals, 64, 2015, 37–40. https://doi.org/10.1016/j.cirp.2015.04.051 ouci.dntb.gov.ua
10. H. Amini Mashhadi, A. Moloodi, M. Golestanipour, E.Z.V. Karimi: Journal of Materials Processing Technology, 209, 2009, 3138–3142. https://doi.org/10.1016/j.jmatprotec.2008.07.020
11. R.Milford, et al.: Resources, Conservation and Recycling, 55, 2011, 1185–1195. https://doi.org/10.1016/j.resconrec.2011.05.021
12. W.H. Zhang, et al.: Resources, Conservation and Recycling, 125, 2017, 37–47. https://doi.org/10.1016/j.resconrec.2017.08.001
13. N.A. Babailov, Y.N. Loginov, L.I. Polyanskii, D.N. Pervukhina: Metallurgist, 62, 2018, 717–722. https://doi.org/10.1007/s11015-018-0713-z
14. T. Tokarski, M. Wędrychowicz, M. Wiewióra: Key Engineering Materials, 641, 2015, 24–29. https://doi.org/10.4028/www.scientific.net/KEM.641.24
15. O. Sariyev, et al.: Materials 18, 2023, 2608. https://doi.org/10.3390/ma18112608
16. L. Lohmeier, et al.: Steel Research International, 92(11), 2021, 2100210. https://doi.org/10.1002/srin.202100210
17. W. Chmura, J. Gronostajski: Journal of Materials Processing Technology, 106, 2000, 23-27. https://doi.org/10.1016/S0924-0136(00)00632-4
18. Z. Sherafat, M.H. Paydar, R. Ebrahimi: Journal of Alloys and Compounds, 487, 2009, 95-99. https://doi.org/10.1016/j.jallcom.2009.07.146