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Quality Steel Production Research Based on the Introduction of Deoxidation Technology

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Abstract— *Deoxidation is one of the important technological operations of the steel production process, the main tasks of which are to reduce the concentration of oxygen dissolved in the melt and the most complete removal of the resulting deoxidation products from the melt. In metallurgical practice, more and more often, when deoxidizing steel, the so-called. complex deoxidizers, which are alloys of several elements with a high affinity for oxygen, allowing deoxidizing steel deeper than traditional ferroalloys and obtaining a more favorable metal structure with high mechanical properties by modifying non-metallic inclusions. The essence of complex deoxidation is to increase the reactivity of elements due to more favorable energy conditions, under which the reactions of interaction of elements with oxygen dissolved in liquid steel proceed more fully.*

Keywords— metallurgy, ferrous metallurgy, steel, smelting, furnace, deoxidation, secondary aluminum waste, electromotive force analysis, express analysis.

1. INTRODUCTION

The quality of the metal can be improved by reducing harmful impurities, gases, non-metallic inclusions in it. To improve the quality of the metal, they use: processing with synthetic slag, vacuum degassing of metal, electroslag remelting (ESR), vacuum arc remelting (VAR), metal remelting in electron-arc and plasma furnaces, etc [1,2].

Vacuum degassing is carried out to reduce the content of gases in the metal due to a decrease in their solubility in liquid steel at reduced pressure and non-metallic inclusions [3,4,5,6].

The evacuation of steel is carried out in a ladle, when pouring from a ladle into a ladle, when pouring into a mold [7].

For evacuation in a ladle, a ladle with liquid steel is placed in a chamber closed with a sealed lid. Vacuum pumps create a vacuum to a residual pressure of 0.267 ... 0.667 kPa. When the pressure is reduced, hydrogen and nitrogen are released from liquid steel. Floating gas bubbles capture non-metallic inclusions, as a result of which their content in steel is reduced. The strength and ductility of the steel are improved [8,9,10,11].

It is effective to carry out vacuuming in a ladle before deoxidation with strong deoxidizers - silicon and aluminum. The carbon of the metal reacts with oxygen, the carbon monoxide is pumped out, and with it nitrogen and hydrogen are pumped out. As a result, the metal is deoxidized without the formation of non-metallic inclusions and degassed [12,13,14].

When evacuating a stream of metal when pouring from a ladle into a ladle, an empty ladle is installed in a vacuum chamber, air is evacuated. A second ladle with metal is fed to the chamber. The metal from the upper ladle is poured through the funnel into the lower one, while the vacuum in the chamber is not broken. Getting into a rarefied space, the jet breaks up into small droplets. Degassing in a fragmented jet vacuum is more efficient than vacuuming metal in a ladle [15,16,17,18,19,20].

For high-quality and some high-alloy steels, ingot casting is used in vacuum. A two-piece chamber is used. A dried mold is placed in the lower part, an intermediate ladle is hermetically installed on the plate in the upper part. Air is pumped out of the chamber, metal is poured into the tundish and casting begins. The degree of degassing depends on the residual pressure [21]. Gases are removed not only from the ingot, but also from the metal jet flowing in vacuum. A significant reduction in the hydrogen content (up to 60 ... 70%) ensures the production of steel insensitive to flocs, which simplifies the process of producing large forgings. Ingots obtained in this way are characterized by improved mechanical properties, but their cost increases significantly [22,23,24,25].

The deoxidation process of steel is very complex. It is usually described by a mechanism of four successive steps [26].

1) Dissolution and homogenization of the deoxidizer in the steel melt in order to direct the deoxidation reaction towards the formation of oxides.

2) Stimulation of the formation of critical nuclei of deoxidation products in a homogeneous environment.

3) Performing the actual deoxidation by increasing the amount of reaction products.

4) Separation of deoxidation reaction products by flotation from the melt in order to increase the purity of the steel.

This four-step deoxidation mechanism results in the requirements for the properties and quality of deoxidizers in order to obtain the most pure steel from the end user [26,27,28].

The deoxidizing agent must be in a form that allows it to dissolve easily in the melt. Pure elements such as silicon, aluminum and titanium are difficult to dissolve in steel due to the dense oxide film on the surface. Therefore, they are used in the form of ferroalloys, which do not have problems with dissolution in liquid steel [29,30,31,32,33].

To facilitate the process of nucleation of deoxidation products, the melt is pretreated with aluminum. In this case, surfaces are formed between aluminum oxide and steel, on which nuclei of other deoxidizers are more easily formed [34,35].

The growth of deoxidation reaction products depends on the type of deoxidizer. Liquid particles are easier to coalesce than solid particles. Therefore, they tend to carry out deoxidation with the formation of a liquid reaction product [36].

Deoxidizers are added in the form of their ferroalloys or pure metals. Aluminum is added as a shot, and carbon is added as graphite or anthracite [37,38].

Deoxidation with silicon alone is very effective with the formation of solid SiO_2 particles. Deoxidation with manganese alone gives liquid reaction products, but is not entirely effective [39]. When these two deoxidizers are used together, the product of deoxidation with manganese is first formed - a liquid slag of the FeO-MnO type, which captures the solid product of deoxidation by silicon - SiO_2 particles [40,41]. The resulting product in this case is a slag of the Fe-MnO-SiO_2 type, in which the activity of silicon and magnesium oxides is much lower than when they act separately. This increases the efficiency of these deoxidizers in reducing the oxygen content of the steel [42,43].

The combined use of manganese and silicon is added to the melt in a certain ratio. Manganese and silicon are used in a ratio of 7: 1 to 4: 1 to obtain a thin film of liquid slag as a deoxidation reaction product. The Fe-Mn ferroalloy is added first, followed by the Fe-Si ferroalloy [44,45,46].

Aluminum is a very effective deoxidizer, since aluminum oxide Al_2O_3 is a much more stable oxide than SiO_2, MnO and others. However, the Al_2O_3 oxide remains solid even at the casting temperature of the steel and therefore it is not used alone if a high degree of oxygen removal from the steel is required [47,48,49].

Aluminum is usually combined with manganese and silicon to give the alumina a chance to bond with the thin liquid slag.

Boron, zirconium, titanium are also strong deoxidizers. The degree of deoxidation achieved with 8% silicon can be achieved by adding as little as 0.7% boron or 0.1% titanium or 0.002% aluminum or 0.0003% zirconium [50,51,52].

The use of deoxidizers other than carbon leads to the formation of liquid or solid products in the form of a dispersed phase in the steel melt. Since these oxides are lighter than steel, they rise to the surface of the melt and can be removed as slag [53]. Usually, particles with a radius of less than 10-3 cm are not able to rise to the surface of the melt; particles with a radius of more than 10-2 cm are almost completely removed from the melt. To effectively remove particles, steps are taken to coalesce them into larger particles [54,55,56].

2. EXPERIMENTAL PART OF THE RESEARCH

2.1. Materials

The main materials studied in this study are liquid steel obtained in the final smelting stage [57].

As a deoxidizer for the study, we chose aluminum slag from the process of secondary melting of aluminum scrap from the "Uzbek Plant for the Processing of Scrap, Scrap Metal" [58,59,60]. At the beginning of the process of steel deoxidation, it was carried out in enlarged laboratory conditions: by screening out foundry slag and shavings and cakes from water leaching of the plant's salt slag. Salt slag, crushed to +10 mm, leaching with hot water 4 - 5 times by stirring, settling and decanting, after which it was subjected to appropriate drying. Fractions were used - 0.315, + 0.24, - 0.14 mm in a ratio of 4:3:1, ensuring the homogeneity of the salt slag. The chemical composition of the charge components is shown in Table 1.

Table 1. Chemical composition of the charge components for steel deoxidation

Material name	Components									
	Cu	SiO_2	Al_{metal}	Al_2O_3	CaO	MgO	Fe	FeO	Fe_3O_4	S
Screenings of foundry slag	0,8	26,7	15,1	45,9	2,9	2,0	-	5,8	-	-
Screening shavings	1,7	31,1	12,7	34,5	4,2	2,8	9,2	-	-	-
Cake	1,1	8,5	13,1	48,8	1,6	-	-	3,6	-	-

2.2. Research methodology

At the Tashkent State Technical University, a method has been developed for the express determination of the activity (concentration) of dissolved oxygen directly in the liquid metal [61,62,63].

The developed technique for determining the activity of a position is based on measuring the EMF of a galvanic cell. The galvanic circuit consists of two electrodes (standard and investigated with variable oxygen activity), a solid oxide electrolyte with ionic conductivity (MgO), and current collectors closed to a measuring device.

The magnitude of the EMF arising in this circuit is determined in accordance with the Nernst equation.

$$E = \frac{RT}{nF} \ln \frac{a_0}{a_0^{(c)}}$$

where n is the transfer number of the potential-determining process, F is the Faraday number, a0 is the oxygen activity in the studied melt, a_o (c) is the reference oxygen activity [64].

Iron saturated with carbon was used as an electrode, the oxygen activity in which in the temperature range 1570 - 1650 ° C is constant and equal to 0.0004 [65]. The value of n for magnesium oxide - MgO in the studied temperature range is constant and equal to 2.

The oxygen concentration is calculated from the measured value of oxygen activity for iron-carbon melts:

$$[O] = \frac{a_0}{f_0^{(c)}}$$

where $f_0^{(c)}$ – the oxygen activity coefficient for carbons is a value that can be determined from the graphs in Fig. 2.

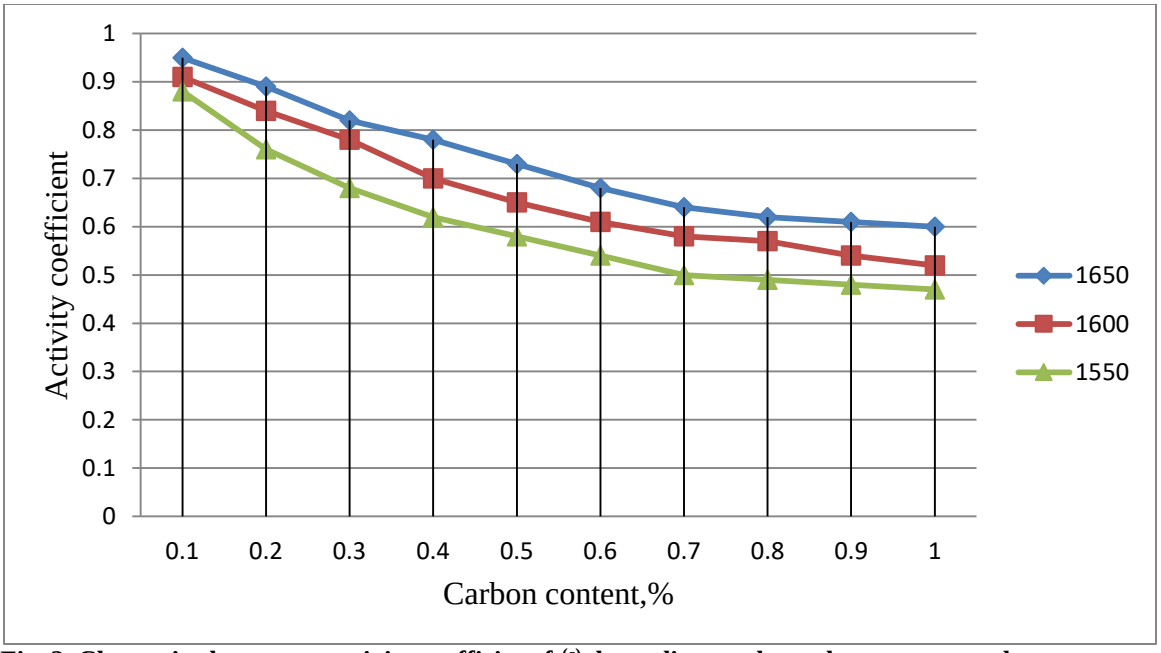


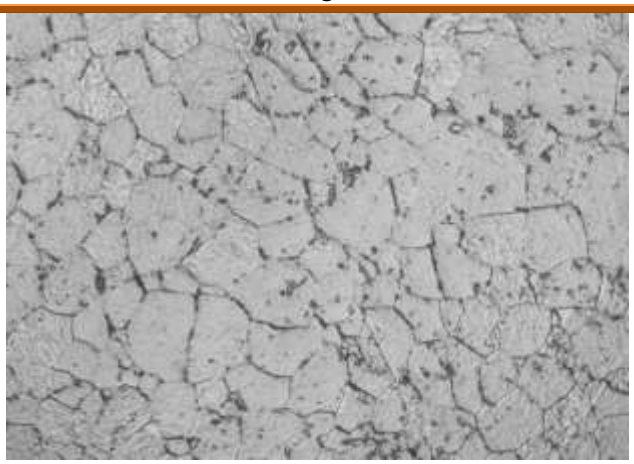
Fig. 2. Change in the oxygen activity coefficient $f_0^{(c)}$ depending on the carbon content and temperature

In this work, an attempt is made to fill this gap to some extent and to compare the use of metallographic and scanning electron microscopes for the study of metal alloys used in industry [66,67,68]. The analysis was performed using a MICRO-200 metallographic microscope and a Philips SEM 515 scanning electron microscope [69,70,71].

3. RESULTS AND DISCUSSION

3.1. Microstructural analysis of the composition of steel obtained after deoxidation

The quality of the product obtained after adding a sufficient amount of a deoxidizer to molten steel and several technological parameters was analyzed by determining the oxygen activity according to the proposed method. The results of the analysis of the microstructure of the obtained steel after deoxidation are shown in Fig. 3.



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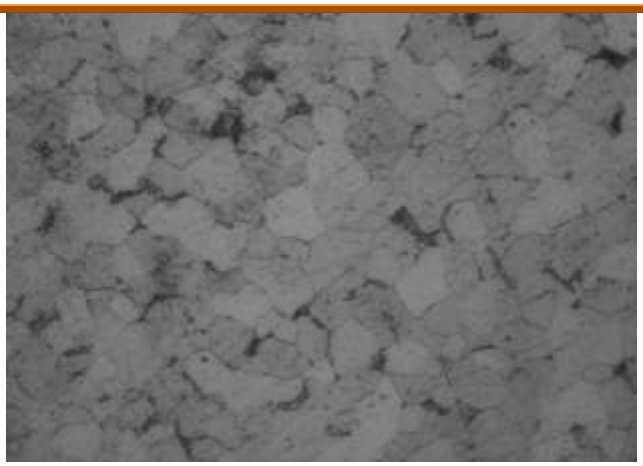

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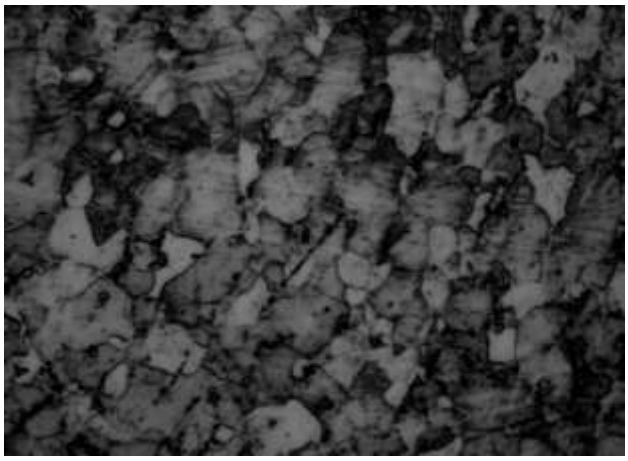

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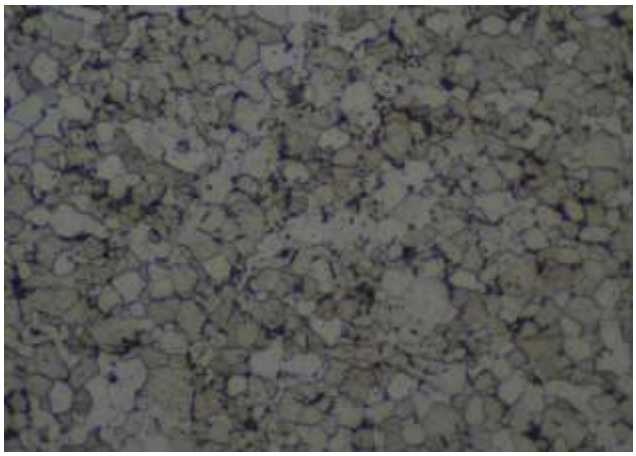

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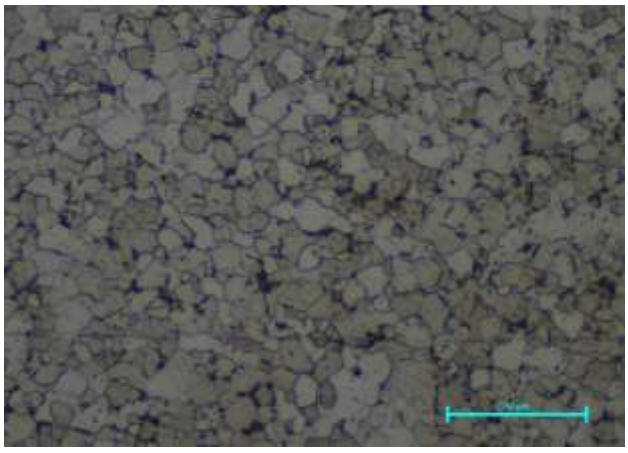

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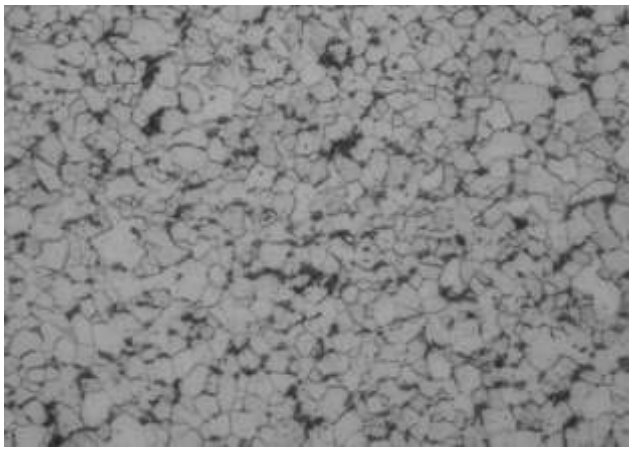

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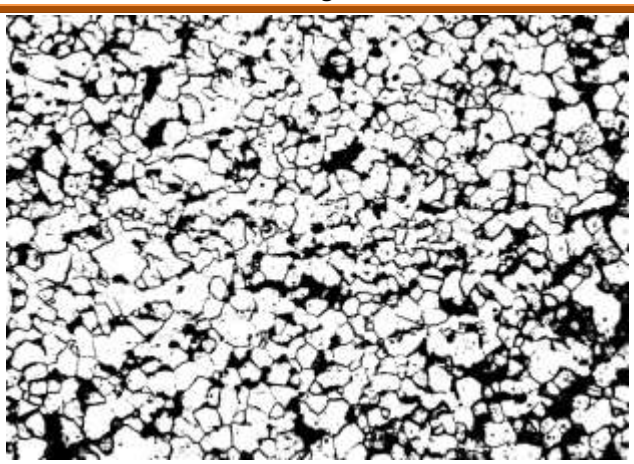

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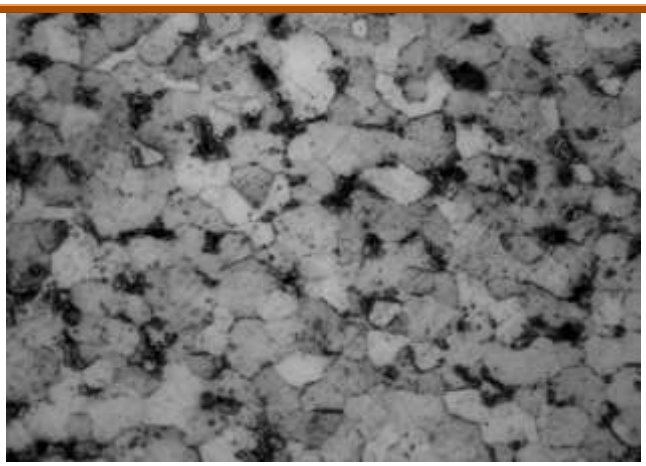

h

Fig. 3. Several photographs of steel microstructures obtained after using metallic aluminum as a deoxidizer

Microstructural analysis makes it possible to assess the nature of the distribution of carbides in the alloy matrix, the homogeneity of the structure, the presence of a carbide or ferrite network, etc. It is impossible to carry out such an analysis based on the fracture pattern. It is also impossible to obtain information on the state of the carbide phase - the uniformity of the distribution of carbides in the alloy matrix, their uniformity in size, the presence or absence of a carbide network or local accumulations. There is also no information about the presence of nonmetallic inclusions, which is one of the most important issues of the quality of such steels [72,73]. At the same time, raster micrographs perfectly illustrate the quality of the metal by the nature of the fracture, but they only answer the question: yes or no, good or bad? In this case, scanning microscopy cannot and cannot name the reason for the unsatisfactory quality of steel. This is prevented by the large depth of field, which reveals too many details, behind which it is almost impossible to highlight the main thing. In fig. 3 shows photographs of the steel structure taken from a section after etching onto the microstructure using metallographic (magnification 3000) and scanning microscopes.

From the point of view of analyzing the structure for compliance or non-compliance with GOST, as well as the analysis of carbide inhomogeneity and structure as a whole, a scanning electron microscope cannot be used in this case. A typical example is the study of the precipitation of cementite along the boundaries of the pearlite phase, which significantly reduces the impact toughness of carbon steel. The microstructure photograph (Fig. 3, a) clearly shows cementite bands along elongated pearlite colonies (indicated by arrows). In steel with a high level of properties, such effects are absent. In this case, metallographic analysis unambiguously and reliably fixes the structure and explains the relationship with properties. A micrograph obtained with a scanning electron microscope does not provide such a possibility (Fig. 3, b). The fractogram of the fracture is characterized by rather smooth surfaces with a rivulet pattern and well-defined grain boundaries, which indicates brittle intergranular fracture, passing by cleavage along the grain boundaries. But the type of fracture does not indicate the specific features of the structure that are the cause of the reduced properties. In this case, it is impossible to distinguish between ferrite, pearlite and cementite at a fracture. Therefore, information on the nature of the fracture of samples with different properties confirms only the test result, but does not name the structural reason responsible for the decrease in properties. In this regard, microstructural analysis has no alternative. In microstructural analysis, the method of illumination is essential. Streaks of cementite were initially detected using darkfield lighting. An example of a successful application of a scanning microscope for analyzing the structure of a wire for a steel cord is shown in Fig. 3, p. Since the quality of the wire is directly related to the inter-plate spacing in pearlite, scanning microscopy is the most effective research technique, especially considering the dispersion of the eutectoid structure. At high resolution, the plates of the pearlite structure in steel (St. 70, 80) are distinguished quite well, and in black and white colors. A black-and-white image of a scanning electron microscope makes it possible to obtain almost immediately a binarized image (two colors - black and white), which makes it possible to develop software for automatic quality control of a wire in a factory [4]. Since the computer analysis of the images is based on the brightness of different phases, the metallographic image of the structure (Fig. 3e) is difficult to use for automatic control of the eutectoid due to the richness of the shades of gray.

3.2. Analysis of some technological parameters of steel after deoxidation

The grain size of the various phases in the microstructure of a steel is important for studying the mechanical properties of this steel. If the size of the grains formed as a result of phase separation in a certain area of the steel is small, this steel is considered to be stronger than others. The fact that the black lines between the phases formed in the microstructure are evenly distributed also increases its strength. However, the thinner these lines separating the ferrite zones, the better. Since these linear zones are composed of cementite, we all know that cementite is not resistant to elongation and therefore degrades the properties of steel. The results of

the experiment are shown in tables 2 and 3. But this approach to the study of steel is not enough. In addition, the strength of the steel and the degree of its elongation must be determined experimentally.

Table 2. Results of measurements of grain size [µm]

Element	A source	Field ID	Phase	Grain ID	Grain size	Area	Equiv. Diameter
1	Freeze	6	Ferrite	1	4	8930,10	106,63

Table 3. Statistics of grain size measurements

Statistics	Ferrite	Units
Grain size G:	3,5	
Method:	Planimetric method	
Standard:	ISO 643(2012)	
Field ID:	6	
Number of grains:	0,5	
Grain area		
Average:	17860,2	µm^2
Minimum:	8930,1	µm^2
Maximum:	8930,1	µm^2
Standard. off:	12629,1	µm^2
95% Trust. interval:	-113501,5	µm^2
Relative accuracy:	-636	%

In fig. 4 depicts a tensile diagram of mild steel recorded with a special device on a testing machine.

At the initial stage of loading to a certain point A, the tension diagram is an inclined straight line, which indicates the proportionality between load and deformation - the validity of Hooke's law. The load at which this proportionality is not yet violated is denoted in the diagram by F and is used to calculate the proportionality limit:

$$\sigma_{nu} = \frac{F_{nu}}{A_0} \quad (1)$$

Where A_0 is the cross-sectional area of the sample before testing.

The proportionality limit (σ) is the highest stress up to which there is a directly proportional relationship between the load and deformation. For St3, the proportionality limit is approximately equal to σ = 195 ... 200 MPa.

The OA zone is called the elastic zone. Only elastic, very slight deformations occur here. The data characterizing this zone makes it possible to determine the value of the elastic modulus E.

After reaching the proportionality limit, the deformation begins to grow faster than the load, and the diagram becomes curvilinear. In this section, in the immediate vicinity of point A, point B is located, corresponding to the elastic limit.
The results of the steel tensile experiment are shown in Table 4.

According to the results of physical and mechanical tests, this sample corresponds to the grade of rolled 280 in accordance with GOST 14918-2020. According to the results of chemical analysis, this sample does not correspond to the coating class 100. The results showed that the sample corresponds to the coating class 150 according to GOST 14918-2020.

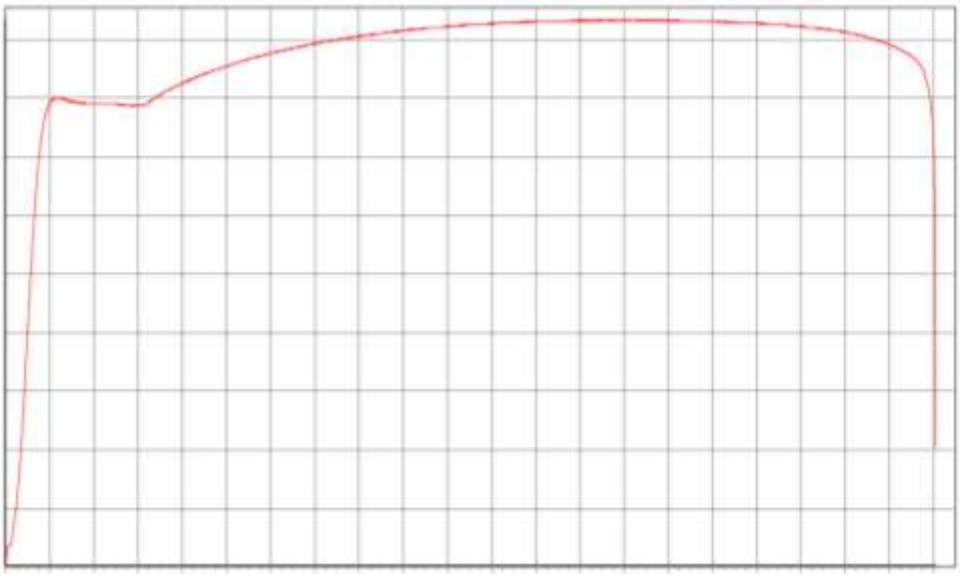

Fig. 4. Tension diagram of steel obtained after deoxidation

Table 4. Results of tensile tests of steel

Parameter name, measurement unit		Sample no.	Test results			Conformity statement
			Norm for ND	Fact		
Spherical hole depth, mm		1	-	9,0		-
Ultimate tensile strength σ, N / mm^2		1	-	455	454	-
Yield strength $\sigma_{0.2}$, N / mm^2		1	-	409	405	-
Elongation δ4,%		1	-	21,8	21,7	-
Bend at 180^o		1	No delamination	No delamination		Does not match
Mass of the coating applied on both sides of the rolled product, g / m^2, not less	Average of three samples	1	-	164		-
	One sample	1	-	162		-
Coating thickness on one side of the rolled product, μm, not less	Average of three samples	1	-	11,3		-
	One sample	1	-	11,0		-

4. CONCLUSION

Laboratory testing has shown good agreement between the results of determining the oxygen content by the EMF method and standard chemical analysis. This allows us to recommend this technique for industrial control of the oxygen content in the melt and operational control of the steel deoxidation process.

The results of various studies of the deoxidized steel have shown that the use of secondary aluminum slag, which is much cheaper as a deoxidizer in the final melting period, is cost-effective. As a result of this technology, the level of integrated use of metallurgical raw materials will increase and environmental protection will improve.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] Yusupkhodzhaev AA, Khudoyarov SR, Valiev Kh. R. Processing of secondary technogenic formations in ferrous metallurgy. - Tashkent: Tashkent State Technical University, 2014. - 140p.

[2] P. Duarte, H. Becerra. Production of high-carbon direct reduced iron (DRI) using Energiron DR technology. Ferrous metals, No. 6, 2016. P. 24 - 30.

[3] J. Schenck, H. B. Lyngen. Potential for effective application of direct reduction and smelting reduction processes in Europe. Ferrous metals, No. 2, 2017. P. 25 - 31.

[4] A. Klinger, A. Altendorfer, D. Bettinger, G. D. Hughes, A. A. Al-Husseini, D. R. Gupta. A new generation process optimization system for a direct iron reduction plant. Ferrous metals, No. 10, 2017, pp. 19 - 27.

[5] V. E. Roshchin, A. V. Roshchin. Electron mechanism of reduction processes in blast and ferroalloy furnaces. CIS Iron and Steel Review.№ 1, 2019. pp. 14 – 24.

[6] Vaclav Smil. Still the Iron Age: Iron and Steel in the Modern World. Woburn, United States. Butterworth-Heinemann Inc, 2016. P. 280.

[7] Pasquale Cavaliere. Ironmaking and Steelmaking Processes: Greenhouse Emissions, Control, and Reduction. Cham, Switzerland, Springer International Publishing AG, 2016. P. 466.

[8] K. V. Parmod. Steel Data Handbook. New Delhi, India, I K International Publishing House Pvt. Ltd, 2015. P. 240.

[9] Robert A. Battis. Technological Innovation and Economic Change in the Iron Industry, 1850-1920. London, United Kingdom, Taylor & Francis Ltd, 2018.P. 462.

[10] Snehanshu Pal, Anshuman Patra, Prabodh Ranjan Padhee. Process Modeling for Steel Industry. New Delhi, India, I K International Publishing House Pvt. Ltd, 2018. P. 212.

[11] Stan Henderson, Ken Royall. Barrow Steelworks: The Open Hearth Years 1880-1959.Ulverston, United Kingdom, Pixel Tweaks Publications, 2017.P. 96.

[12] Rafael Colas, George E. Totten. Encyclopedia of Iron, Steel, and Their Alloys. Washington, USA, CRC Press, 2016. P. 4038.

[13] Sh.T. Khojiev, A.A. Yusupkhodjaev, D.Y. Aribjonova, G.B. Beknazarova, D.N. Abdullaev. Depletion of Slag from Almalyk Copper Plant with Aluminum Containing Waste // International Journal of Innovative Technology and Exploring Engineering, Volume-9, Issue-2, December 2019. P. 2831 – 2837.

[14] S.T. Matkarimov, A.A. Yusupkhodjaev, Sh.T. Khojiev, B.T. Berdiyarov, Z.T. Matkarimov. Technology for the Complex Recycling Slags of Copper Production // Journal of Critical Reviews, Volume 7, Issue 5, April 2020. P. 214 – 220. http://dx.doi.org/10.31838/jcr.07.05.38

[15] Sh.T. Khojiev, S.T. Matkarimov, E.T. Narkulova, Z.T. Matkarimov, N.S. Yuldasheva. The Technology for the Reduction of Metal Oxides Using Waste Polyethylene Materials // Conference proceedings of "Metal 2020 29th International Conference on Metallurgy and Materials", May 20 – 22, 2020, Brno, Czech Republic, EU. P. 971-978. https://doi.org/10.37904/metal.2020.3592

[16] A.A. Yusupkhodzhaev, Sh.T. Khozhiev, U.A. Akramov. Use of non-traditional reducing agents to expand the resource base of ojsc uzmetkombinat**.** Chernye Metally, 2021, 2021(4), pp.4–8. https://doi.org/10.17580/chm.2021.04.01

[17] A.A. Yusupkhodjaev, Sh.T. Khojiev, B.T. Berdiyarov, D.O. Yavkochiva, J.B. Ismailov. Technology of Processing Slags of Copper Production using Local Secondary Technogenic Formations// International Journal of Innovative Technology and Exploring Engineering, Volume-9, Issue-1, November 2019. P. 5461 – 5472.

[18] Sh.T. Khojiev, A.A. Yusupkhodjaev, D.Y. Aribjonova, G.B. Beknazarova, D.N. Abdullaev. Depletion of Slag from Almalyk Copper Plant with Aluminum Containing Waste // International Journal of Innovative Technology and Exploring Engineering, Volume-9, Issue-2, December 2019. P. 2831 – 2837. DOI: 10.35940/ijitee.B7200.129219

[19] Hojiyev Sh.T., Norqobilov Y.F., Raxmataliyev Sh.A., Suyunova M.N. Yosh metallurg [Matn]: savol-javoblar, qiziqarli ma'lumotlar va metallar ishlab chiqarish texnologik jarayonlari. – Toshkent: "Tafakkur" nashriyoti, 2019 . - 140 b. ISBN 978-9943-24-273-9

[20] Yusupxodjayev A.A., Mirzajonova S.B., Hojiyev Sh.T. Pirometallurgiya jarayonlari nazariyasi [Matn]: darslik. – Toshkent: "Tafakkur" nashriyoti, 2020. – 300 b. ISBN 978-9943-24-295-1

[21] Хожиев Ш.Т., Исмаилов Ж.Б., Очилдиев К.Т., Шукуров М.С., Махмудова О.О. Анализ возможных химических реакций при обеднении медных шлаков // "Студенческий вестник": научный журнал, № 6(104). Часть 4. Москва, Изд. «Интернаука», Февраль 2020 г. С. 38 – 41.

[22] Khojiev Sh.T., Abjalova H.T., Erkinov A.A., Nurmatov M.N. Study of methods for preventing copper loss with slags // "Студенческий вестник": научный журнал, № 6(104). Часть 4. Москва, Изд. «Интернаука», Февраль 2020 г. С. 71 – 74.

[23] Khojiev Sh.T., Erkinov A.A., Abjalova H.T., Abdikarimov M.Z. Improvement of the hydrodynamic model of the bubbling depletion of slag in the ladle // "Студенческий вестник": научный журнал, № 6(104). Часть 4. Москва, Изд. «Интернаука», Февраль 2020 г. С. 75 – 77.

[24] Raxmataliyev Sh.A., Hojiyev Sh.T. Xo'jalik chiqindilaridan toza kumushni ajratib olish usullari // Texnika yulduzlari, № 1, Toshkent: "ToshDTU", Mart, 2019. 104 – 107 b.

[25] Юсупходжаев А.А., Бердияров Б.Т., Хожиев Ш.Т., Исмоилов Ж.Б. Технология повышения комплексности использования стратегически важного сырья в цветной металлургии Узбекистана // Научно-практический журнал «Безопасность технических и социальных систем», № 1, Ташкент, Изд. «ТашГТУ», Декабрь, 2019. С. 12 – 21.

[26] Yusupxodjayev A.A., Hojiyev Sh.T., Ochildiyev Q.T. Gidrometallurgiya jarayonlari nazariyasi: amaliy mashg'ulotlar uchun uslubiy ko'rsatmalar. –Toshkent: ToshDTU, 2020. -132 b.

[27] Yusupxodjayev A.A., Hojiyev Sh.T., Ochildiyev Q.T. Gidrometallurgiya jarayonlari nazariyasi: laboratoriya ishlari uchun uslubiy ko'rsatmalar. –Toshkent: ToshDTU, 2020. -36 b.

[28] Abjalova Kh.T., Khojiev Sh.T. Intensification of the process of depletion the converter slag // Texnika yulduzlari, № 4, Toshkent: "ToshDTU", Dekabr, 2019. 59 – 63 b.

[29] Абжалова Х.Т., Хожиев Ш.Т. Обеднение шлаков кислородно-факельной печи Алмалыкского медного завода // Texnika yulduzlari, № 4, Toshkent: "ToshDTU", Dekabr, 2019. 53 – 58 b.

[30] Юсупходжаев А.А., Хожиев Ш.Т., Сайназаров А.М., Курбанов Б.Т. Современное состояние и перспективы развития автогенных процессов переработки сульфидных медных концентратов // Инновационное развитие науки и образования: сборник статей X Международной научно-практической конференции, Состоявшейся 10 марта 2020 г. в г. Пенза. – Пенза: МЦНС "Наука и Просвещение". – 2020. С. 20 – 24.

[31] S.T. Matkarimov, A.A. Yusupkhodjaev, Sh.T. Khojiev, B.T. Berdiyarov, Z.T. Matkarimov. Technology for the Complex Recycling Slags of Copper Production // Journal of Critical Reviews, Volume 7, Issue 5, April 2020. P. 214 – 220. http://dx.doi.org/10.31838/jcr.07.05.38

[32] Юсупходжаев А.А., Хожиев Ш.Т., Мирзажонова С.Б. Анализ состояния системы в металлургии. Монография. – Beau Bassin (Mauritius): LAP LAMBERT Academic Publishing, 2020. P. 189. ISBN 978-620-2-52763-7

[33] Modern Scientific Researches in Metallurgy: from Theory to Practice: monograph / Shokhrukh Khojiev (Ed.). - Beau Bassin (Mauritius): LAP LAMBERT Academic Publishing, 2020. P. 154. ISBN 978-613-9-47121-8

[34] Hojiyev Sh.T., Mirsaotov S.U. Oltin ishlab chiqarishda eritmani zararli unsurlardan tozalash usullari // "Ilm-fan taraqqiyotida zamonaviy metodlarning qo'llanilishi" mavzusidagi ilmiy onlayn konferensiya to'plami, Toshkent, 27-iyun, 2020. 442 – 446 b.

[35] Khojiev Sh.T., Kadirov N.A., Obidov B.M. Development of Alternative Fuel Production Technology by Recycling Polyethylene Bags up to 40 Microns Thick // Proceedings of an international scientific and technical online conference on "Challenges and Prospects Innovative Technics and Technologies in the Security Sphere Environment", Tashkent, September 17-19, 2020. P. 274 – 276.

[36] Khojiev Sh.T. Improving Environmental Protection as a Result of Non-ferrous Metallurgy Industry Waste Recycling // Proceedings of an international scientific and technical online conference on "Challenges and Prospects Innovative Technics and Technologies in the Security Sphere Environment", Tashkent, September 17-19, 2020. P. 278 – 280.

[37] Хожиев Ш.Т. Разработка эффективной технологии извлечения меди из конверторных шлаков// Journal of Advances in Engineering Technology, Vol.1(1), Sept, 2020. P. 50 – 56.

[38] Sh.T. Khojiev, A.A. Yusupkhodjaev, M. Rakhmonaliev, O.O'. Imomnazarov. Research for Reduction of Magnetite after Converting // Kompozitsion materiallar, Toshkent, 2019, №4. P. 54 – 55.

[39] Hojiyev Sh.T., Mirsaotov S.U. Tarkibida yaroqli uglerod saqlagan maishiy chiqindilarni metallurgiya sanoatiga maqsadli yo'naltirish// "Ishlab chiqarishga innovatsion texnologiyalarni joriy etish va qayta tiklanadigan energiya manbalaridan foydalanish muammolari" mavzusidagi Respublika miqyosidagi ilmiy-texnik anjumanining materiallari to'plami, Jizzax, 18-oktabr, 2020. 21 – 27 b.

[40] Hojiyev Sh.T., Mirsaotov S.U. Innovatsion texnologiya orqali metallurgiya sanoati chiqindisini qayta ishlash// "Ishlab chiqarishga innovatsion texnologiyalarni joriy etish va qayta tiklanadigan energiya manbalaridan foydalanish muammolari" mavzusidagi Respublika miqyosidagi ilmiy-texnik anjumanining materiallari to'plami, Jizzax, 18-oktabr, 2020. 329 – 336 b.

[41] Хожиев Ш.Т. Экономическая эффективность использования местных и альтернативных энергетических ресурсов для снижения расхода природного газа на металлургических предприятиях // Материалы республиканской научно-технической конференции «Инновационные разработки в сфере науки, образования и производства – основа инвестиционной привликательности нефтегазовой отрасли» в г. Ташкент, 3 ноября 2020 г. С. 413 – 416.

[42] Khojiev Sh.T., Matkarimov S.T., Narkulova E.T., Matkarimov Z.T., Yuldasheva N.S. The Technology for the Reduction of Metal Oxides Using Waste Polyethylene Materials // Conference proceedings of "Metal 2020 29th International Conference on

Metallurgy and Materials", May 20 – 22, 2020, Brno, Czech Republic, EU. P. 971-978. https://doi.org/10.37904/metal.2020.3592

[43] Hojiyev Sh.T., Berdiyarov B.T., Mirsaotov S.U. Mis ishlab chiqarishning chiqindisiz texnologiyasini ishlab chiqish muammolari // "Zamonaviy kimyoning dolzarb muammolari" mavzusidagi Respublika miqyosidagi xorijiy olimlar ishtirokidagi onlayn ilmiy-amaliy anjumani to'plami, Buxoro, 4-5 dekabr, 2020. 26 – 28 b.

[44] Berdiyarov B.T., Hojiyev Sh.T., Mirsaotov S.U. Rangli metallurgiya chiqindilarini qayta ishlashning dolzarbligi // "Zamonaviy kimyoning dolzarb muammolari" mavzusidagi Respublika miqyosidagi xorijiy olimlar ishtirokidagi onlayn ilmiy-amaliy anjumani to'plami, Buxoro, 4-5 dekabr, 2020. 61 – 62 b.

[45] Khojiev Shokhrukh, Berdiyarov Bakhriddin, Mirsaotov Suxrob. Reduction of Copper and Iron Oxide Mixture with Local Reducing Gases. Acta of Turin Polytechnic University in Tashkent, 2020, Vol.10, Iss.4. P. 7-17.

[46] Alamova G.Kh., Khojiev Sh.T., Okhunova R.Kh. Current State Of Copper Smelting Slags And Their Processing: A Review. Central Asian Journal of Literature, Philosophy and Culture, 2021, 02(02). P. 49-55.

[47] Alamova G.Kh., Khojiev Sh.T., Okhunova R.Kh. Comparative Estimation of the Efficiency of Various Materials in the Reduction of Magnetite in Slag Melt. International Journal for Innovative Engineering and Management Research, 2021, 10(03). P. 191-196. doi: 10.48047/IJIEMR/V10/I03/45

[48] Hojiyev Sh.T., Mirsaotov S.U., Ergasheva M.S. Metall oksidlarini amminotermik tiklashning ba'zi termodinamik jihatlari // UzACADEMIA: scientific-methodical journal, Vol. 2, Issue 1(12), 2021. P. 6-16.

[49] Khojiev S.T., Nuraliev O.U., Berdiyarov B.T., Matkarimov S.T., Akramov O'.A. Some thermodynamic aspects of the reduction of magnetite in the presence of carbon // Universum: технические науки: электрон. научн. журн., Часть 3, 3(84), 2021. P. 60-64. DOI - 10.32743/UniTech.2021.84.3-4

[50] Khojiev Sh.T., Berdiyarov B.T., Alamova G.X., Abjalova H.T. Application of Energy-Saving Technology in The Smelting of Copper Sulfide Concentrates in Autogenous Processes // International Journal of Academic and Applied Research, 5(3), 2021. P. 30-33.

[51] Shokhrukh Khojiev, Bakhriddin Berdiyarov, Dilfuza Yavkochiva, Jahongir Abduraimov. Study of the Factors Influencing the Decoppering Process of Non-Ferrous Metallurgy Slags: A Review // International Journal of Academic and Applied Research, 5(3), 2021. P. 84-93.

[52] Ergasheva M.S., Mirsaotov S.U., Khojiev Sh.T. Use of Zinc Plant Clinker as a Reducing Agent in The Processing of Copper Slags // European Scholar Journal, Vol. 2, Issue 3, 2021. P. 218-222.

[53] Shokhrukh Khojiev, Mirzaabdulla Nurmatov. Methods of Using Secondary Energy Resources in Industry // International Journal of Academic and Applied Research, 5(4), 2021. P. 87-96.

[54] Shokhrukh Khojiev, Bakhriddin Berdiyarov, Alisher Samadov, E'tibor Narkulova. New Technology for Decreasing Copper Content in Dump Slags: A Review // International Journal of Academic and Applied Research, 5(4), 2021. P. 212-220.

[55] Khasanov A.S., Berdiyarov B.T., Khojiev Sh.T., Abdullaev D.N., Ergashev J.K. New Technological Solutions to Reduce the Copper Content in the Slags of the Oxygen-Flare Smelting of Sulfide Copper Concentrates // International Journal of Academic and Applied Research, 5(4), 2021. P. 206-211.

[56] Shokhrukh Khojiev, Dilnoza Fayzieva, Sukhrob Mirsaotov, E'tibor Narkulova. New The Main Trends in the Integrated Processing of Waste from Mining and Metallurgical Industries // International Journal of Engineering and Information Systems, 5(4), 2021. P. 182-188.

[57] Shokhrukh Khojiev, Bakhriddin Berdiyarov, Ibrokhim Gulomov, Mukhammadali Mamatov. The Current State and Development of the Integrated Use of Technogenic Waste // International Journal of Engineering and Information Systems, 5(4), 2021. P. 189-194.

[58] Shokhrukh Khojiev, Sukhrob Mirsaotov, Javokhir Khamroev, Shamshod Khamroqulov. Development of Promising Technologies in the Production of Non-Ferrous Metals and Improvement of Existing Technologies // International Journal of Academic Multidisciplinary Research, 5(4), 2021. P. 356-361.

[59] Yusupkhodjaev A.A., Khojiev Sh.T., Khayrullayev P.A. Technology for the complex processing of wastes of non-ferrous metallurgy // Proceedings of International Conference on Integrated Innovative Development of Zarafshan Region: Achievements, Challenges and Prospects, Navoi, November 28, 2019. P. 129 – 135.

[60] А.А. Юсупходжаев, Ш.Т. Хожиев, У.А. Акрамов. Использование нетрадиционных восстановителей для расширения ресурсной базы ОАО «Узметкомбинат» // Черные металлы, апрель 2021, № 4 (1072). С. 4 – 8. DOI: 10.17580/chm.2021.04.01

[61] Alamova G.Kh., Khojiev Sh.T. Economic efficiency of using secondary energy resources in the industry // Texnika yulduzlari, 2021, №1-2. P. 294 – 298.

[62] Alamova G.Kh., Khojiev Sh.T. Improving properties of molten copper slags // Texnika yulduzlari, 2021, №1-2. P. 301 – 305.

[63] Alamova G.X., Hojiyev Sh.T. Mis boyitmalarining issiqlik berish xususiyatini oshirish // Texnika yulduzlari, 2021, №1-2. 305 – 310 b.

[64] Alamova G.X., Hojiyev Sh.T. Metallurgik jarayonlarni matematik modellashtirish muammolari // Texnika yulduzlari, 2021, №1-2. 314 – 317 b.

[65] Sh.T. Khojiev, M.S. Ergasheva, Sh.F. Khamroqulov, J.O'. Khamroev. The Current State of Copper Metallurgy and Its Raw Material Base // IJEAIS, 5(5), 2021. P. 7-14.

[66] T.P. Karimova, Sh.T. Khojiev, M.S. Saidova, N.Q. Bakhodirova. To Prevent the Loss of Copper with Slag during the Casting of the Converter Slag // IJEAIS, 5(5), 2021. P. 15-22.

[67] B. Berdiyarov, Sh. Khojiev, Sh. Rakhmataliev, M. Suyunova, N. Rasulova. Modern Technologies of Aluminum Production // IJEAIS, 5(5), 2021. P. 100-105.

[68] Sh. Mukhametdjanova, Sh. Khojiev, Sh. Rakhmataliev, I. Avibakirov, M. Mamatov. Modern Technologies of Copper Production // IJEAIS, 5(5), 2021. P. 106-120.

[69] Sh. Rakhmataliev, Kh. Sultonov, Sh. Khojiev, A. Abdukholiqov. Modern Technologies of Gold Production // IJEAIS, 5(5), 2021. P. 121-131.

[70] Khojiev Sh.T., Berdiyarov B.T., Kadirov N.A., Obidov B.M. and Turan M.D. (2021) Utilization of household waste-based solid fuel // Technical science and innovation: Vol. 2021: Iss.1. P. 168-176.

[71] L.T. Makhsudova, Sh.T. Khojiev, G.J. Shamaribkhodjaeva, N.K. Annakulova. The Practical Importance of the Use of Innovative Educational Technologies in the Teaching of Technical Sciences // IJAPR, 5(6), 2021. P. 55-63.

[72] Berdiyarov B.T., Khojiev Sh.T. Thermodynamic analysis of reduction of oxidized copper compounds in a slag phase // Kompozitsion materiallar, 2021, №4. P. 39 – 43.

[73] Toshpulatov D.D., Khojiev Sh.T., Berdiyarov B.T. Analysis of Non-Ferrous Metallurgy Waste Processing Capacity // IJEAIS, 5(11), 2021. P. 41-50.