Investigation of the Properties of WC Layer Grown on the Nodular Graphite Cast Iron by Thermoreactive Diffusion Technique

Erçin YAKUT[1], and Serkan DAL[2]
[1]Turkish Standards Institute, Nevsehir, TURKEY
[2]Metallurgy and Material Engineering Department, Nevsehir Haci Bektas Veli University, Nevsehir, TURKEY

Corresponding author: Serkan DAL (e-mail: serkandal@nevsehir.edu.tr).

This research was produced from the first author's master's thesis.

Submitted on 12.06.2024, Revised on 01.07.2024, Accepted on 08.07.2024, Published online on 15.07.2024

ABSTRACT In this study, WC grown was investigated on the surface of spheroidal graphite cast iron, which has a high silicon content and is preferred due to its properties, using the Thermo Reactive Diffusion (TRD) method. For this purpose, a mixture of 45% Al_2O_3+45% FeW and 10% NH_4Cl was used as coating powder, and the GGG70 spheroidal graphite cast iron surface, which was the substrate material, was coated with the TRD method at 1000 °C for 4 hours and at 1100 °C for 2, 4 and 6 hours. The successfully obtained coated samples were sectioned and their coating morphologies, thicknesses and microhardness were examined. The phase structures formed on the coating surface were obtained by the X-Ray Diffraction method (XRD) and the WC layer assessed by optical microscope and micro-hardness testing. As a result of the study, the lowest coating thickness was obtained on the sample coated at 1000 °C for 4 hours. Although the highest coating thickness was obtained on the sample coated at 1100 °C for 6 hours, flaking began to occur in the 1100 °C for 6 h. As a result of the microhardness analysis, it was observed that the hardness of the coating layer was approximately 8 times higher (2080 Hv) than the substrate material.

KEYWORDS Cast iron, microhardness, TRD, WC coating.

1. INTRODUCTION

Nodular graphite cast irons; It is also called ductile, ductile or nodular cast iron. Nodular graphite cast iron takes its name from the graphite it contains, which exists in the form of spheres. Graphite taking its spherical form does not require additional heat treatment, and its main difference from gray cast iron is the geometry of graphite. First generation spheroidal graphite cast irons generally contain silicon (Si) in the range of 1.8-2.8%. New generation high silicon spheroidal graphite cast irons have a silicon content between 2.8-4.5%. An advantage of new generation cast irons is cost-effective machining due to lower tool wear[1]. Due to high silicon, new generation spheroidal graphite cast irons exhibit superior strength values compared to the old generation spheroidal graphite cast irons, which show similar elongation [1-2].

It is very important to give new properties to the materials used in industries and to carry out studies that extend their lifespan. These studies generally; mechanical, chemical, tribological etc. is carried out to improve its properties. Today, processes for improving material properties; The processes that examine the design of the surface and substrate material together and can economically provide features that these two cannot provide alone are called "Surface Engineering" as a science [3]. Surface engineering methods have attracted great attention thanks to the technical and economic advantages they provide. The reason for this is that some products that can meet technological requirements can only be obtained by coating processes or can be made economical in this way [4].

Thermo reactive diffusion (TRD) () method; It is a thermochemical technique that forms hard and highly wear-resistant layers such as carbide, nitride and carbo-nitride on the surface of steel materials [5]. The thermoreactive diffusion (TRD) technique was developed by Toyota company and T. Arai in 1968. TRD is also known as Toyota diffusion coating technique (TD) and thermal diffusion technique [6]. The name of the TRD method varies depending on the medium used; Such as Salt Bath, Fluidized Bed and Box Cementation Method [7]. High hardness, impact resistance and wear resistance can be achieved by TRD (Thermo Reactive Diffusion) processes [8]. The TRD coating method has advantages such as easy operation, affordable cost, uniform coating in rough areas, extension of mold life, reduction in lubricant use, and increase in product quality due to the increase in surface treatments and dimensional accuracy [9]. TRD method methods are affected by many variables [10]. Some of these parameters; diffusion temperature, diffusion time, amount of coating material, amount of activator, structure of the material, heat treatments. However, in order for the thermoreactive diffusion process to occur, it is very important that the C content of the material is at least 0.3% or greater [11].

Studies have been conducted in the literature on the coating ability of many materials with various coating techniques. Gökçe and Çelik., 2022 carried out a study on the design of a mechatronic system for coating WC on stainless steel with the electro spark deposition method. At the end of their study, they achieved automatic coating in a faster time than manual coating and achieved the best efficiency under 100 grams of pressure [12]. In another study [13], studies were conducted on the growth kinetics of the WC-Fe layer formed on the surface iron during solid phase diffusion and measured the coating thicknesses for different coating temperatures and different times. As a result, the thickness of the reaction layer gradually increased with heat treatment times from 15 to 105 min at 1085 °C. In a similar study [14], the TiC coatability of spherical graphite cast iron in a salt bath was investigated by the TRD method. As a result, it was stated that a coating layer was formed at 850°C for 6 hours or more. Solak [15] investigated the VC coatability of Armox 500 armor steel using the TRD method in a salt bath. For coating thicknesses formed in 2, 4 and 6 hours at 950, 1000 and 1050°C; It was observed that the thickness and microhardness of the coating layer increased with increasing temperature and time [3]. In a study conducted in 2019; The VC coatability of the GGG70 cast iron surface was investigated using the pack cementation technique by keeping it at 850, 900, 950, 1000°C for 2 hours and 4 hours. It was observed that the coating had a homogeneous distribution for each temperature and time parameter, and the coating thickness increased with increasing temperature. As a result of micro abrasion tests, it was observed that the lowest friction coefficient value was obtained in the sample coated at a temperature of 0.16 to 900°C and for 2 hours.

In this study, WC coatability of new generation spheroidal graphite cast iron was investigated by thermoreactive diffusion method. For this purpose, samples were coated at different temperatures and times and the coating layers formed on the surface were examined. The morphologies and microhardness values of the resulting coating layers were examined.

2. MATERIALS AND METHOD

In this study, an attempt was made to coat the WC layer on the surface of new generation spherical graphite cast iron using the thermoreactive diffusion method. For this purpose, the new generation GGG70 cast iron substrate material, whose chemical composition is given in Table 1 [16], was first cut into 10*10*15 mm dimensions and each surface was sanded with 120, 400, 800 and 1000 mesh sandpaper respectively, and then the surfaces were washed and cleaned of dirt and residues with alcohol. . A mixture of 45% Al_2O_3+45% FeW and 10% NH_4Cl was added as coating powder into stainless steel crucibles and the samples were embedded in this powder. Before the crucibles were closed, they were coated with Al2O3 to prevent contact with air, and then their lids were tightly closed. The prepared crucibles were coated in a high temperature furnace (Carbolite CWF1200) at 1000 °C for 4 hours and at 1100 °C for 2, 4 and 6 hours. The heating rate was 15 °C/min from room temperature to coating temperature, and then the samples were cooled in an open air environment. After the surfaces of the coated samples were cleaned, they were sanded and polished with 3□m diamond abrasive. The microstructures of the samples, one surface of which was polished, were examined with Nikon MA 100 and Clemex (image analysis system). Phases were determined from the coating surfaces using the RIGAKU MINIFLEX 600 X-Ray Diffraction method (XRD). Additionally, Vickers microhardness tests were performed with the Future-Tech (FM 700) Microhardness device under a 25 gf load for 10 seconds. The results obtained are discussed.

Table 1
Elemental content of GGG70 nodular graphite cast iron sample [16]

	Wt%								
Material	C	Si	Mn	Cu	Cr	S	P	Mg	Fe
GGG70	3.47	2.41	0.17	0.07	0.03	0.01	0.02	0.05	Balance

3. RESULTS AND DISCUSSIONS

Figure 1 shows the optical microstructure photographs of the samples coated at 1000 °C for 4 hours and at 1100 °C for 2, 4 and 6 hours. First of all, when the sample in which the coating process was tried at 1000 °C for 4 hours (Figure 1.a) was examined, it was seen that a very thin layer was obtained. When the samples coated at 1100 °C were examined, it was seen that the thickness of the coating layer formed increased visibly compared to the coating at 1000 °C. In addition, as the coating time increased, the coating layer thickness increased, but as seen in Figure 1.d, in the sample coated for 6 hours, as the coating layer increased, flaking began to occur on the outer surfaces. Coating layers similar to the WC layer obtained by Zhong et al. [13] using W plate on gray cast iron were also observed in this study.

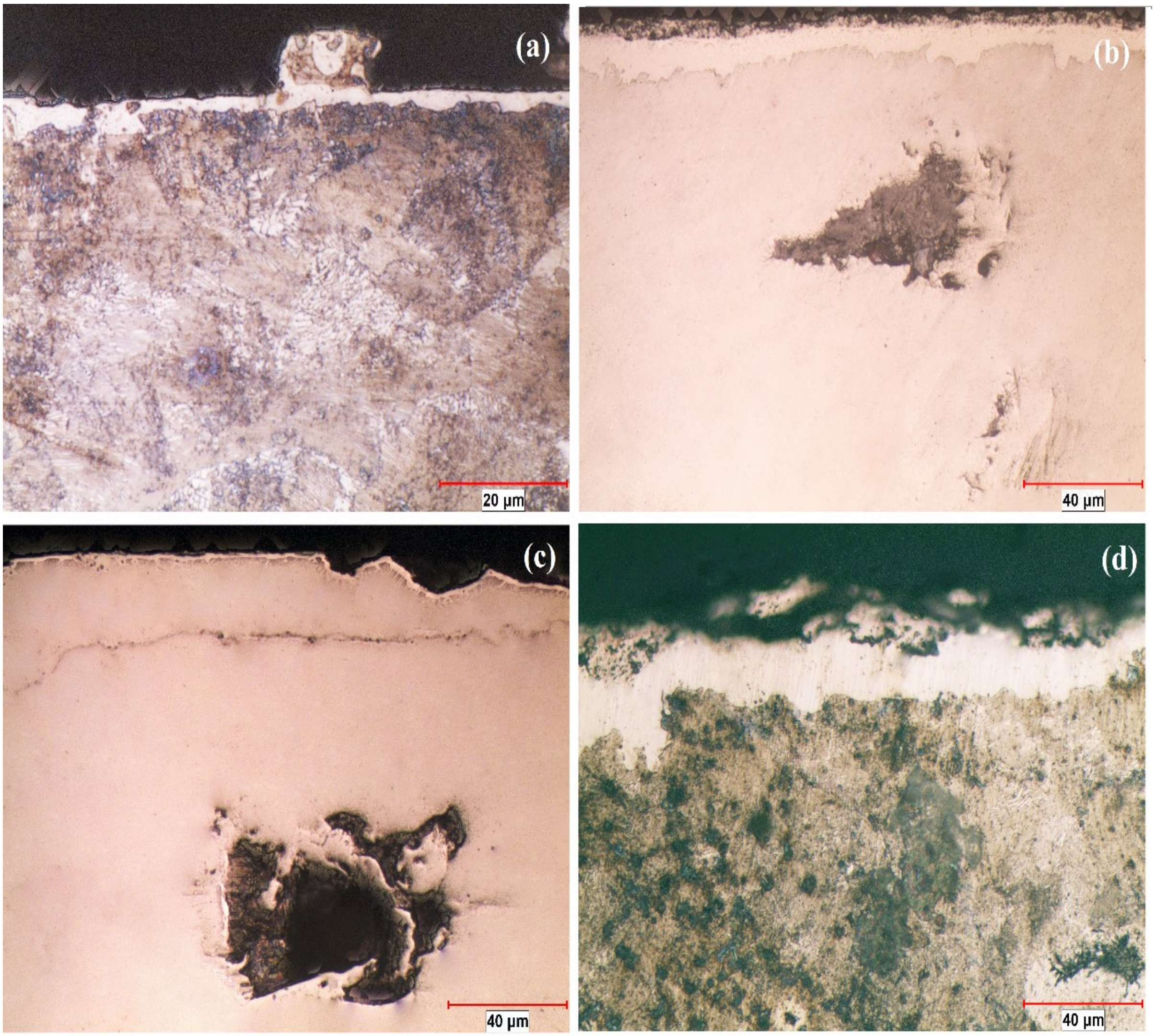

Figure 1. Optical microstructure images taken from samples coated with WC, (a) 1000 °C-4h, (b) 1100 °C-2h, (c) 1100 °C-4h, (d) 1100 °C-6h

Figure 2 shows the XRD graph obtained from the coating surface of the sample coated at 1100 °C for 4 hours. It can be seen from the diffraction peaks of the samples that a layer consisting of Fe [17], W [13, 17], FeW_3C [18], WC [13-19], Fe_2W [20] phases is formed. The most dominant peaks were observed between 2θ=35°-60°. Consistent with the literature [13], the first most dominant phase was the W phase in the (110) and (200) planes and the second most dominant phase was the WC phase in the (100) plane. As can be seen from the XRD graph, it is possible to say that the coating layer consists of WC and W phases, as seen in the optical microscope photographs shown in Figure 1. When the obtained coating layers were examined, as seen in Table 2, increasing the coating temperature by 100° caused the coating thickness to increase by approximately 21 microns. Additionally, when the samples are examined at 1100 °C, it is seen that the coating thickness increases as the coating time increases, as in the literature [13]. However, although the coating thickness increased in the sample obtained by the Thermo-reactive Diffusion (TRD) method at 1100 °C for 6 hours, cracks appeared on the outer surface, as seen in Figure 1.

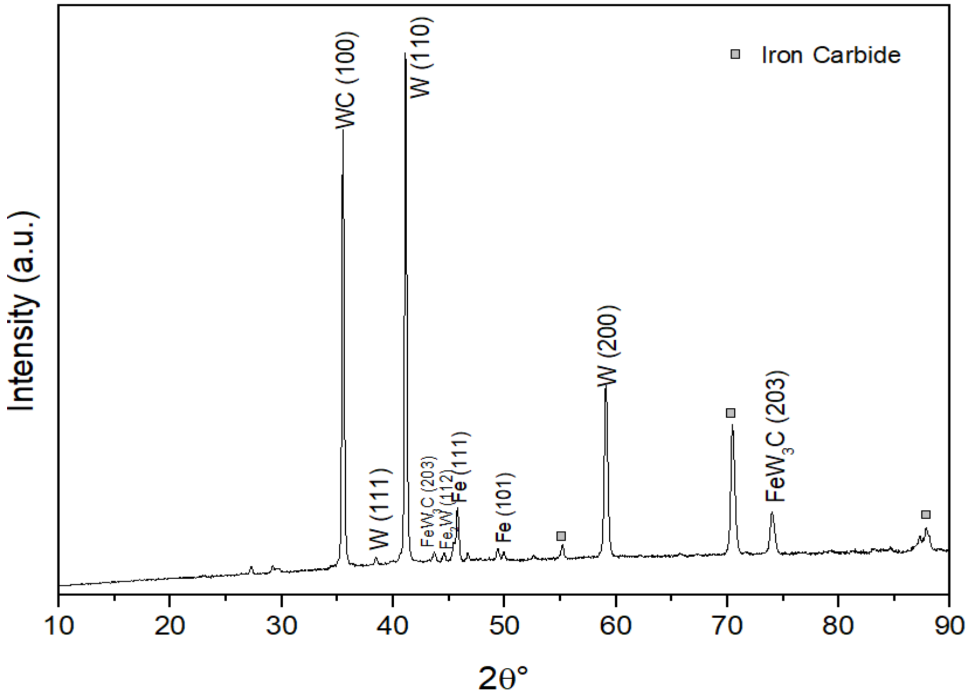

Figure 2. XRD analysis graph taken from the coating surface of the 1100 °C-4h sample

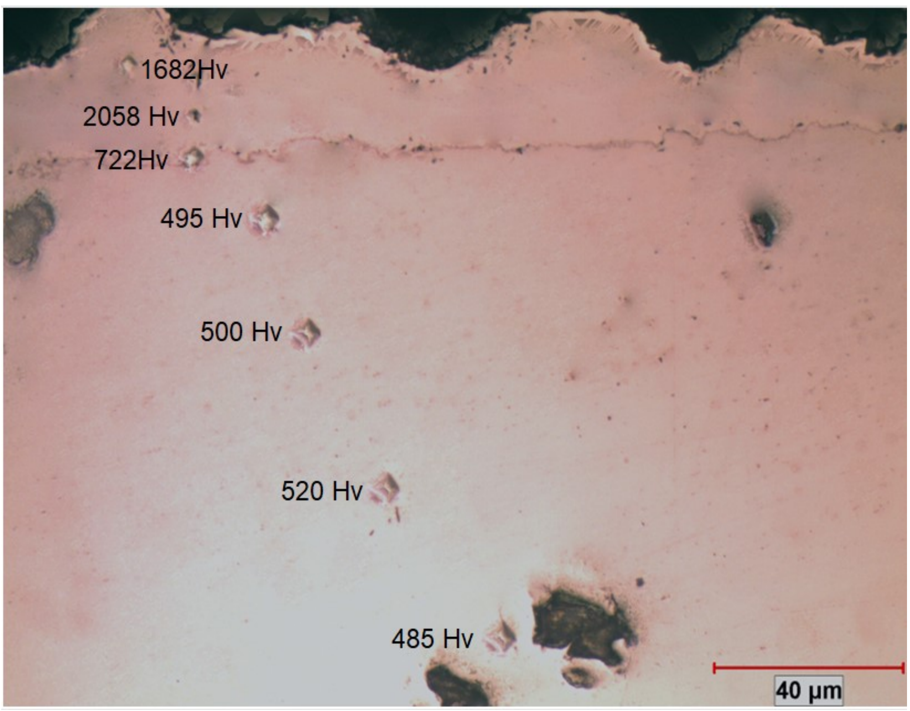

Figure 3. Optical microscope photograph of the microhardness trace profile of the sample obtained at 1000 °C for 4 hours

Table 2
Average coating thickness of samples

Samples	Average coating thickness(μm)
1000 °C-4h	2.90±0.71
1100 °C-2h	13.39±1.20
1100 °C-4h	24.13±1.92
1100 °C-6h	26.90±2.04

Figure 3 shows the vickers hardness measurement profiles taken from the cross-section of the sample coated at 1100 °C for 4 hours. It is clearly seen that the hardness values increase visibly from the substrate material to the coating layer. Figure 4. shows the microhardness distribution graph taken from all samples used in the study. It is seen that microhardness values increase from the substrate material to the coating layer in all samples. While the hardness value of GGG70 new generation spheroidal graphite cast iron used as the substrate material is approximately 280 Hv. The coating layer microhardness value reached approximately 2000 Hv. From this, it can be concluded that the hardness value on the surface of the substrate material increased approximately 8 times.

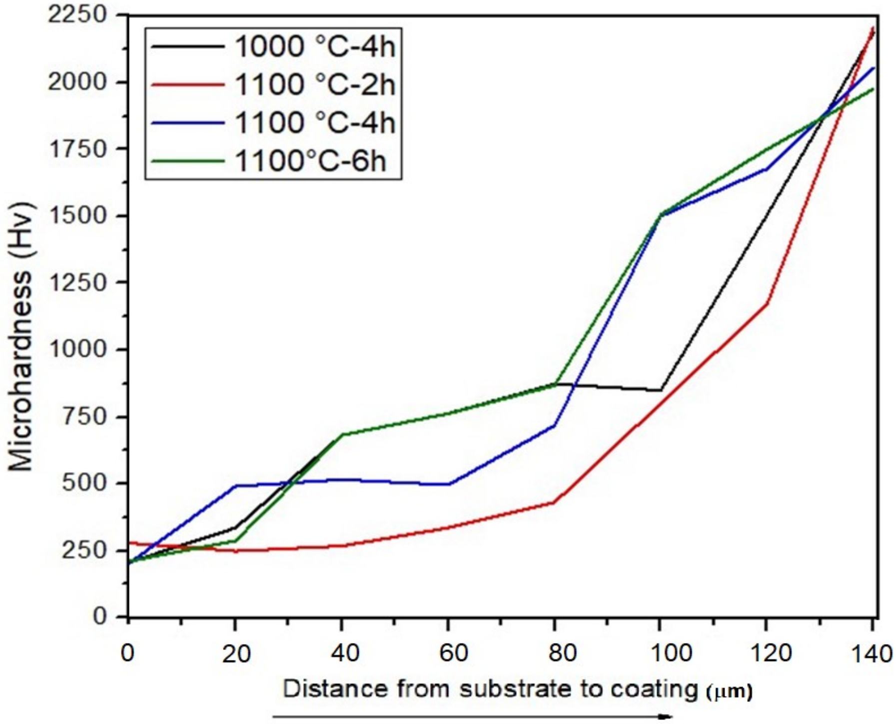

Figure 4. Microhardness value of samples

4. CONCLUSION

In this study, an attempt was made to obtain a WC coating layer on the surface of new generation spheroidal graphite cast iron using the Thermoreactive diffusion method and the following results were obtained.

- Coating layers were successfully obtained on all sample surfaces. Coating thicknesses increased with coating temperature and coating time. For the sample coated at 1100 °C for 6 hours, flaking started in the coating layer. In the sample coated at 1000 °C for 4 hours, the coating layer thickness was very low compared to other samples.
- It is seen that a layer consisting of Fe, W, FeW_3C, WC, Fe_2W phases is formed on the coating surface. In the XRD analysis, it was seen that the most dominant peak belonged to the W and WC phases.
- Microhardness values on the coating surface of all samples obtained increased approximately 8 times compared to the substrate material.

REFERENCES

[1] W. Stets, H. Löblich, G. Gassner, P. Schumacher. ‘Solution Strengthened Ferritic Ductile Iron: Properties, Production and Application’ *8th International Journal of Metalcasting*, 2014

[2] H. Lin, T. Lui, L. Chen., ‘Effetct Of Silicon Content On Intergranular Embrittlement Of Ferritic Spheroidal Graphite Cast Iron Suffered From Cyclic’ *Materials Transactions*. 44, 2003

[3] Duran, S., “"Investigation of VC coatability of GGG70 cast iron surface with pack cementation technique", *Nevşehir Hacı Bektaş Veli University Institute of Science and Technology, Master's Thesis*, Nevşehir, 2019.

[4] Ertem, M., “"Examination of microstructural properties of hardox 400 steel coated with niobium carbide-boron (NbC-B) by thermoreactive diffusion method and evaluation of wear behavior by Taguchi method", *Batman University Institute of Science, Master's Thesis*, Batman, 2021.

[5] Yıldırım, Y.B., “"Investigation of microstructural properties of medium carbon steel coated with ferro titanium by thermoreactive diffusion (TRD) method", *Fırat University Institute of Science, Master's Thesis*, Elazığ, 2016.

[6] Kandıran, M., “Investigation of the coating ability of GGG70 cast iron surface with wear-resistant CrC”, *Fırat University Institute of Science, Master's Thesis*,Elazığ, 2017.

[7] Abakay, E., “"Nb-Al-N coating of steels by thermo-reactive diffusion (TRD) method", *Sakarya University Institute of Science and Technology Master's Thesis*,Sakarya, 2013.

[8] Pehlivan, E., “Investigation of the coating ability of spheroidal graphite cast iron surface with TiBC layer”, *Nevşehir Hacı Bektaş Veli University Institute of Science and Technology, Master's Thesis*,Nevşehir, 2017.

[9] Yılmaz, E., “"Iron aluminide coating of steels by thermoreactive diffusion method", *Sakarya University Institute of Science, Master's Thesis*, Sakarya, 2008.

[10] Civil, M., “Investigation of CrVC coatability of GGG70 cast iron surface with pack cementation technique”, *Nevşehir Hacı Bektaş Veli University Institute of Science and Technology, Master's Thesis*, Nevşehir, 2019.

[11] Buytoz, S., Yılmaz, B., July 2019, Investigation of microstrucutural properties of TiC coating obtained by termoreactive diffusion process on AISI4140 steel, *Fırat University Journal of Engineering Sciences* 31(2), 473-480, 2019.

[12] Gökçe, B., Çelik, H.E., “Design of a Mechatronic System for Coating WC on Stainless Steel with Electro Spark Deposition Method”, *JournalMM*, 3(1), 20-32, 2022.

[13] Zhong, L., Zhang, X., Wang, X., Xu, Y., Wu, H., Fu, Y., “Growth kinetics of WC-Fe layer formed at the surface iron during solid-phase diffusion”, *CeramicsInternational*, 42, 16941–16947, 2016.

[14] Ferveren, Ç, “"Investigation of TiC coatability of spheroidal graphite cast iron by TRD method in salt bath", *Nevşehir Hacı Bektaş Veli University Institute of Science and Technology, Master's Thesis*, Nevşehir, 2021

[15] Başar, M., “"Investigation of VC coatability of Armox 500 armor steel by TRD method in salt bath", *Nevşehir Hacı Bektaş Veli University Institute of Science and Technology, Master's Thesis*,Nevşehir, 2021

[16] Dal S. Investigation on the Effect of Coating Temperature on the Properties of NbC Layer Coated with Pack Cementation Technique on GGG70 Nodular Graphite Cast Iron Surface. *J. Mater. Mechat. A.* 2023;4(2):598-607.

[17] Haglund, J., Fernandez-Guillermet, F., Grimvall, G., Korling, M., *Phys. Rev. B: Condens. Matter*, 48, 11685, (1993));

[18] Pollock, Stadelmaier., Metall. Trans., 1, 767, (1970)

[19] Metcalfe, A.E., J. Inst. Met., 73, 591, (1947)

[20] H.Arnfelt & A.Westgren, Jernkontorets Ann., 119, 185, (1935)