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RESEARCH ARTICLE

Impact of subzero heat treatment on some mechanical properties of bimetals

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Abstract
Deep cryogenic (subzero) treatment (DCT) influence on the mechanical properties of bimetals used in the crushing industry has been examined and analyzed in the current study. Examinations include annealing at 800°C, DCT, tempering at 250°C, charpy impact test, optic microscope (OM) images analysis, scanning electron microscope (SEM) images analysis, X-RAY images analysis and hardness measurement as Rockwell C. Bimetals (2 set each, 1 set is 5 sample) are put to annealing at 800°C for 5 hours, then DCT is executed at -180°C for 24 hours. Tempering is followed out out at 250°C for 3 hours for 1 set. The impact toughness rates after DCT/Tempering and after DCT are found with the help of charpy impact tests. Hardness rates and metallography of test pieces are examined and compared. Noteworthy hardness and toughness rates are observed after DCT. It was also observed that after DCT/Tempering, hardness is reduced, but impact energy/toughness is increased. A clean microstructure has been observed after DCT in OMs and SEMs. X-RAY analysis also reveals a pure and clean chemical composition. The impact toughness rates of samples after DCT+Tempering are determined %20 more compared with the rates after DCT. Hardness rates decreases %10 after DCT+Tempering compared with the rates after DCT.

1. Introduction

Bimetals are promising structural metallic materials used in crushing industries owing to their noteworthy mechanical properties (1). They are developed in nearly last 4 decades, and became a serious alternative to high manganese steel alloys, esp. to the Hadfield steel (2). Because of their high wear resistance properties and impact strength, they are extensively used in recent years. In comparison to classical high-Mn (Hadfield Steel Mn: %12, hardness Rockwell C:48) steel, bimetals' advantages are being harder and tougher, and having longer life (3,4). They can be manufactured by two methods; in the first method is liquid–liquid casting (gravity method; conducted in this study) and second method is liquid–solid (mold-cavity preparation) configuration (5,6). Details are given in materials and method section.

To improve the mechanical properties and eliminate residual stresses, conventional heat treatment methods are applied after casting process (8). However, when high toughness and impact resistance is needed, an alternative but overcosting method, Deep Cryogenic Treatment (DCT) can be applied as well as conventional heat treatment. In DCT process; the metals have been brought down to almost -180°C from high temperatures (800-900°C), applying liquid Nitrogen for approximately 24 hours, then they can be subjected to tempering at approximately at 250°C and finally quenched in still air until room temperature (9,10).

Thanks to this method, high toughness and hardness values can be obtained. These properties are very significant for wear resistance and impact strength (11).

Conventional heat treatment process, shallow cryogenic treatment and mechanical properties of bimetals have been investigated previously by Z.Özdemir in his previous studies (12,13).

In cryogenic treatment (CT), ultra-cold temperatures are applied to materials to change the microstructure. A highly cost reduction and performance increase can be obtained. Down to -184°C temperatures can be used. The cryogenic process is an extension of heat treatment, and can improve specifications of the material. The basic CT process consists of a gradual cooling of the component until the defined temperature, holding it for a given time (freezing time), and then progressively leading it back to the room temperature. Shallow cryogenic treatment is to gradually cool the workpiece at about - 84°C and deep cryogenic treatment (DCT) is to cool the workpiece at about -184°C (8,10).

Significant studies have been made on the cryogenic treatment of metals and dissimilar metals up till now. Some of the considerable ones have been mentioned below.

M.Ş. Adin and M.Okumuş investigated the microstructure and mechanical Properties of dissimilar metal weld between AISI 420 and AISI 1018 steels, conducted tensile tests and measured the hardness values and achieved remarkable results (14). M.Ş.Adin studied the effect of cryogenic treatment on cutting tools in machining of AA7075 aerospace aluminium alloy (15) and mechanical properties of MIG and TIG welded dissimilar steel joints (16) in his recent investigations.

The scientific purpose of our study is to investigate the HCCI and LCCS bimetallic castings in terms of toughness, hardness and metallography, comparison after DCT and DCT+Tempering. The effect of DCT and DCT+Tempering process are compared and analyzed with regards to toughness and hardness.

2. Materials and methods

High alloy cast iron (17) and low alloy steel (18) are chosen for examinations (Table 1 and 2).

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Process consists of 5 steps:

a. Casting
b. HT/DCT/Tempering
c. Impact Tests,
d. OM/SEM/X-RAYs
e. Hardness Test.

Table 1. Chemical composition of low carbon cast steel grade (%)

C	Si	Mn	P	Al	Cu	Cr
0,17	0,20	1,40	0,045	0,005	0,15	0,13
Ni	Mo	W	S	V	Fe	
0,06	0,01	0,001	0,042	0,05	rest	

Table 2. Chemical composition of high alloy cast iron grade G-X300CrMo27 (%)

C	Si	Mn	P	Al	Cu	Cr
3,10	0,398	0,822	0,002	-	0,135	21,8
Ni	Mo	W	S	V	Fe	
0,47	1,60	-	0,059	-	rest	

Chemical composition is shown in Tables 1 and 2. OM is carried out by Nikon Eclipse LV 150, SEM/X-RAY analysis has been carried out by FEI/Quanta 450 FEG, chemical analysis with BAIRD-DVG Spectrometer. Hardness rates are tested as Rockwell C (19).

2.1. Casting process

Gravity casting is conducted (high Cr-white cast iron Metal 2, low alloyed steel Metal 1) for casting of bimetal composite as shown in Fig.1. Liquid metal 1 (LAS) at 1580°C were poured into metal receiver 1 (fig. 1). The interface temperature has been measured by using thermocouple Pt-PtRh13. After appropriate temperature has been get, an activator boron and sodium mixture were dropped into metal 1 melt to prevent oxidation and get a permanent joint between 2 metals; right after that liquid metal 2 (high Cr white cast iron) at 1420°C were poured 2 (fig. 1).

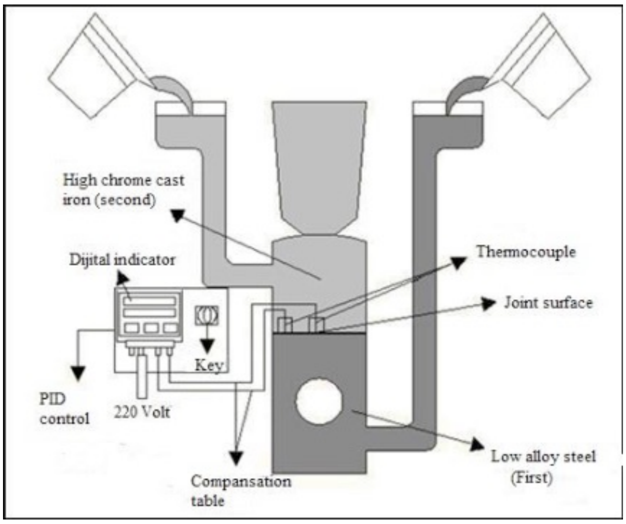

Figure 1. A schematic view of bimetal gravity casting process

All the samples have been prepared as Charpy Impact Test specimens in accordance with standard (20) before processes begin.

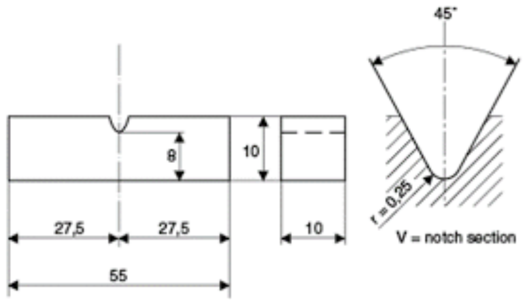

Figure 2. Charpy Impact Test Sample (20)

The velocity of pendulum is 5,2 m/s. and the beginning angle of pendulum is 150° in charpy impact tests (fig.3).

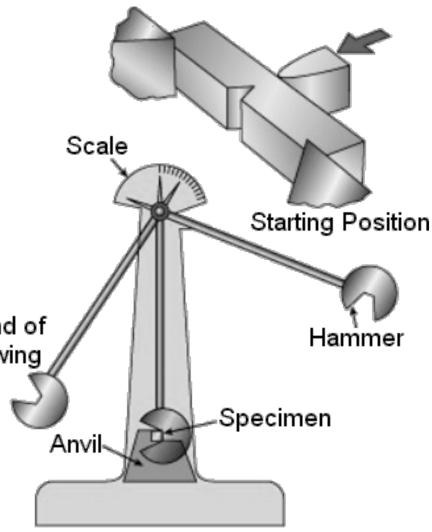

Figure 3. Charpy Impact Test Machine (20)

2.2. HT/DCT/Tempering Process

Annealing is executed to bimetals (2 layers, one of high alloy cast iron and the other layer low alloy steel) which are shown in figure 2 at 800°C for 5 hours (21).

After annealing, DCT is carried out at -180°C for 24 hours. After DCT, tempering is executed for 1 group (5 samples) at 250°C for 5 hours and the second group (5 samples) have been restored to room temperature (Fig.4). (22).

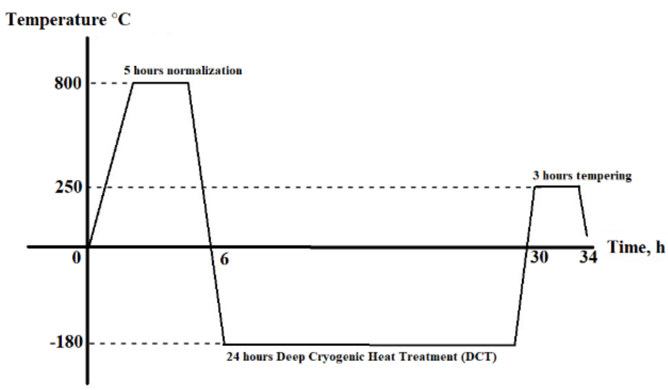

Figure 4. Overall HT/DCT/Tempering Process

2.3. Charpy Impact Tests

Impact tests are executed in accordance with the ASTM E23-02 “Standart Test Methods For Notched Bar Impact Testing Of Metallic Materials” (20). Test pieces are taken from bimetal castings and set before DCT/Tempering and DCT separately as seen in figure 5.

The results at table 3 and 4 have been obtained and the samples are observed as in figure 6 after tests.

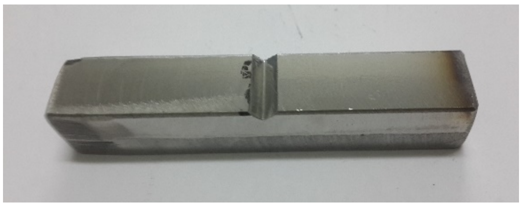

Figure 5. Charpy Impact Test Sample

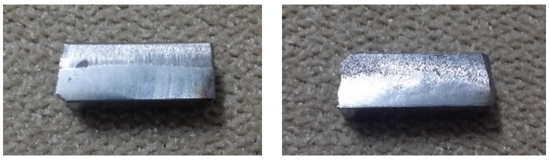

Figure 6. Charpy Impact Test Sample (after test)

Table 3. Charpy Impact Test Results (after DCT)

Energy (J.)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
LCS	4,6	4,9	5,4	5,3	5,4
HCCI	9,5	9,1	9,2	8,7	8,5

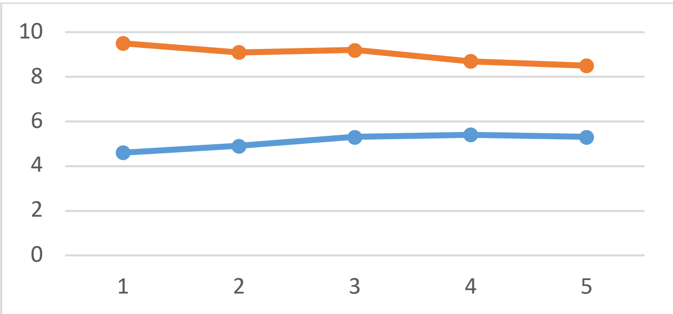

Figure 7. Charpy Impact Tests Fracture Energy as Joule, Orange is High Cr Cast Iron, Blue is Low Alloy Steel (after DCT)

Table 4. Charpy Impact Test Results (after DCT/Tempering)

Energy (J.)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
LCS	5,4	6,2	6,4	6,8	6,0
HCCI	12,3	11,8	12,4	12,7	11,5

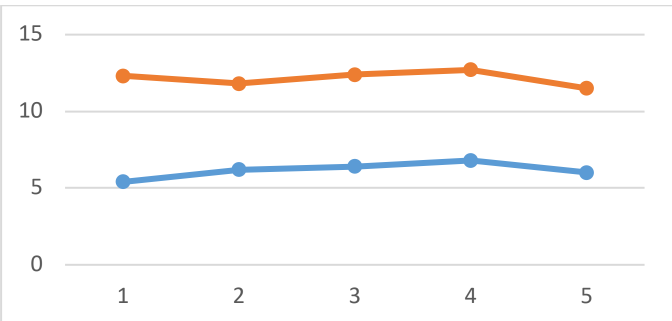

Figure 8. Charpy Impact Tests Fracture Energy as Joule, Orange is High Alloy Cast Iron, Blue is Low Alloy Steel (after DCT/Tempering)

The toughness rates are increased 20 % after DCT+Tempering as seen in figure 8 and 9.

2.4. Microstructure after DCT and after DCT/Tempering (OM/SEM/X-RAYs)

The microstructural examination of all the specimens has been carried out for validating the transformations occurred in the surface of the specimens after DCT and DCT/Tempering.

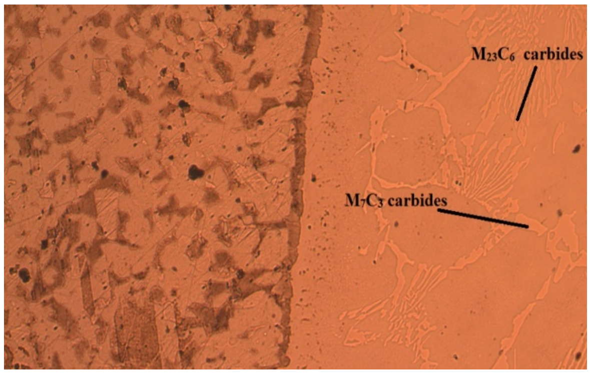

Figure 9. OM After DCT/Tempering (400 X)

Carbides affect the toughness and hardness in bimetals (Fig.9).

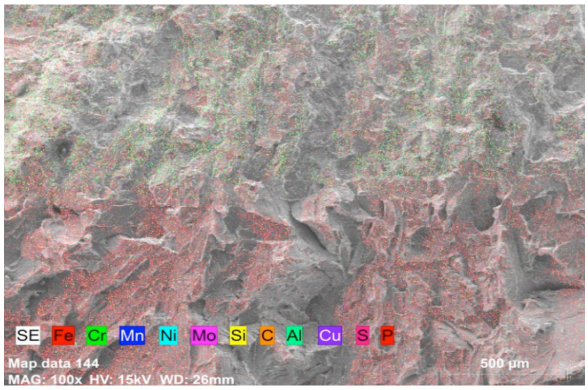

Figure 10. X-Ray After DCT/Tempering (full structure)

A successful casting of bimetal is obtained as seen in figure 10.

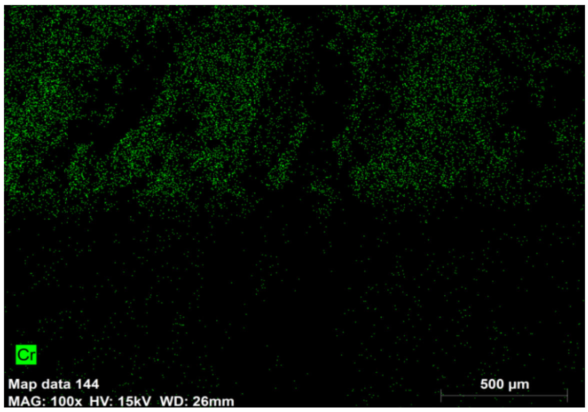

Figure 11. X-Ray After DCT/Tempering (Chromium)

Chromium content is dispersed equally and homogeneous in the high Cr cast iron side of bimetal (fig.11).

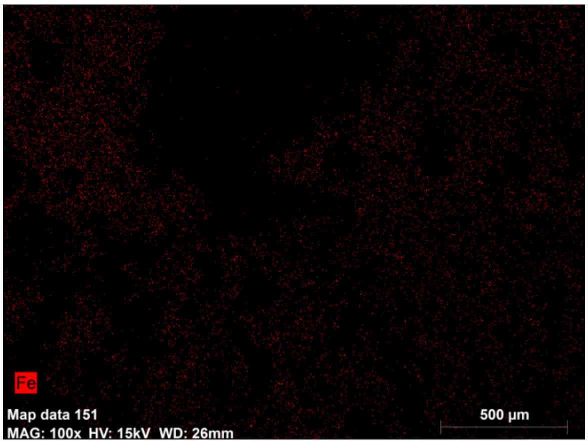

Figure 12. X-Ray After DCT/Tempering (Ferrite)

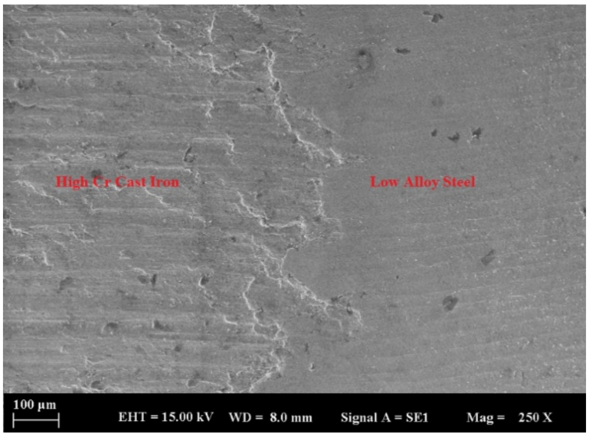

Figure 13. SEM After DCT/Tempering 250 X

A stable and homogeneous microstructure have been obtained after DCT/Tempering. The findings in SEM/X-Ray pictures also reveals a clean and homogeneous microstructure generally (fig. 9-13).

2.5. Hardness

Hardness rates are taken as Rockwell C from 3 different points of samples (19).

Table 5. Hardness Values

Hardness rates of bimetal after DCT		
Low Alloy Steel (HRc)	Interface (HRc)	High Alloy Cast Iron (HRc)
36.6, 37.4, 38.2	49.2, 53.2, 46.7	54.2, 56.5, 55.6
Hardness rates of bimetal after DCT/Tempering		
Low Alloy Steel (HRc)	Interface (HRc)	High Alloy Cast Iron (HRc)
32.3, 31.5, 31.2	42.1, 43.5, 43.3	52.5, 51.3, 50.7

3. Results and discussion

A remarkable and simultaneous grow in the hardness and toughness of the samples subjected to DCT when compared with the previous studies of writer (12,13). Neverthless, after tempering a small fall in hardness is observed. At the same time, a rise in the toughness values is seen obviously.

The SEM and OM images reveals a clear and perfect composition of bimetals (fig.6,10). X-Ray analyse shows also a perfect match and composition of high alloy cast iron and low alloy steel component (fig.7).

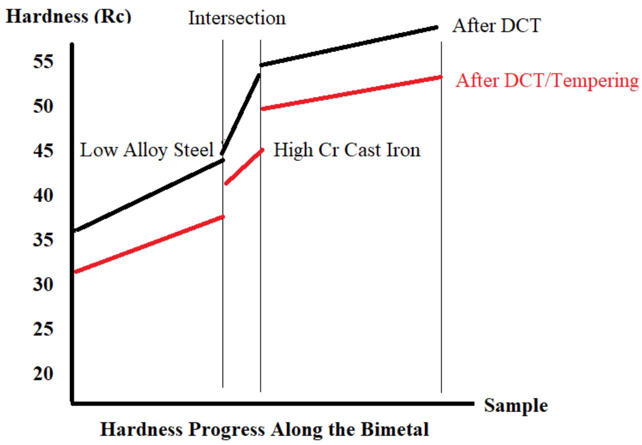

Figure 11. Hardness Progress

It has been observed that the hardness values and toughness values are increased simultaneously after DCT and DCT+Tempering compared with previous results (12,13).

After DCT; hardness rates and impact toughness of the bimetal increase at the same time. We can explain this phenomenon is affected greatly by the uniform distribution of components of the bimetal as seen in X-Ray images (fig.7,8,9).

No defects and casting faults has been observed, so the processes obtained noteworthy results. We can explain this feature is caused by the effect of carbon diffusion and the precipication of eutectic carbides esp. M_7C_3 and $M_{23}C_6$ carbides (fig.9).

In practice, there is a contradiction, that is; hard materials are resistant to abrasion, these materials are, at the same time, not resistant to impacts. This problem is overcome by bimetallic casting; the base part is tough enough to absorb impacts and the working layer is hard and also tough to resist wear and abrasion.

This result is obtained by eutectic carbides esp. M_7C_3 and $M_{23}C_6$ in high chromium cast iron microstructure (fig.9).

4. Conclusions

The study reveals below results in terms of DCT and DCT+Tempering:

1. A good joint and interface is obtained after casting process.
2. A homogeneous combination of two metals have been achieved.
3. It can be observed obviously that microstructure is stable and free from casting defects after DCT+Tempering.
4. Simultaneous increase in hardness and tuoghness after DCT
5. Tempering increases the toughness, sacrificing hardness.
6. A homogeneous distribution of elements is observed as seen in X-Ray analysis
7. Carbides provides a high toughness as well as high hardness related with the Cr amount in bimetal hard side.
8. The potentiality of deep cryogenic treatment of bimetallic castings is conducted and as a result increased toughness and hardness values are obtained as observed in impact tests and hardness rates.

9. The impact toughness values after DCT+Tempering is determined approximately %20 more compared with the rates after DCT.
10. Hardness values decreases appriximately %10 after DCT+Tempering compared with the rates after DCT.

References

1. Zic, S., Dzambas, I., and Ikonic M., Possibilities of Implementing Bimetallic Hammer Castings in Crushing Industries, Metalurgija, **2009**, 48(1):51–54
2. Xiaofeng, X., Shengping, Y., Xiaoguang, Z. and Qiong, X., High Cr White Cast Iron/Carbon Steel Bimetal Liner by Lost Foam Casting with Liquid-liquid Composite Process, China Foundry, **2012**, 9(2):136–142
3. Xiao-Feng, X., Sheng-Ping, Y., Wei-Xin, Y., and Qiong X., HCWCI/Carbon Steel Bimetal Liner by Liquid-Liquid Compound Lost Foam Casting, **2012**, Journal of Iron and Steel Research, International, 19(0):13-19
4. Marukovich, E., Branovitsky, A., Na, Y., Lee J., Choi, K., Study on the possibility of continuous-casting of bimetallic components in condition of direct connection of metals in a liquid state, **2006**, Mater. Des. 27(10):1016–1026
5. Heijkoop, T., Sare, I., Cast-bonding—a new process for manufacturing composite wear products, **1989**, Cast Metals 2(3):160–168
6. Wrobel, T., Ni and Cr base layers in bimetallic castings. In: METAL, 20th Anniversary International Conference on Metallurgy and Materials, May 18–20, (Brno, Czech Republic), Tanger, **2011**: 758–764
7. Wrobel, T., Characterization of bimetallic castings with an austenitic working surface layer and an unalloyed cast steel base, J. Mater. Eng. Perform, **2014**, 23:1711–1717
8. ASM Handbook Volume 4, Heat Treating ASM Handbook, Volume 4A, Steel Heat Treating Fundamentals and Processes. ASM International, ISBN 978-1-62708-011-8, **2013**:382–386
9. Reddy, I., Rao, Dr. Y. S., Seshank, A.S.P and Inturi, V., Characterization and Performance Evaluation of HSS Cutting Tools under Deep Cryogenic Treatment, International Journal of Engineering and Science, **2015**,5(10):13-19
10. Prudhvi, K., and Lakshmi, V.V., Cryogenic Tool Treatment, Imperial Journal of Interdisciplinary Research (IJIR), **2016**
11. Yugandhar, T., Krishnan, P.K. Rao, C.V.B. and Kalidas, R., Cryogenic Treatment and Its Effect on Tool Steel, 6th International Tooling Conference, **2002**, 2:672-683
12. Özdemir, Z., Effect of Heat Treatment on the Impact Toughness of 'High-Chromıum Cast Iron – Low-Carbon Cast Steel' Bi-Metal Components, Metal Science and Heat Treatment, **2017**, 58: 738-741
13. Özdemir, Z., Shallow cryogenic treatment (SCT) effects on the mechanical properties of high Cr cast iron – low-carbon cast steel bimetallic casting, Int. J. Metalcast. **2020**
14. Adin M.Ş., Okumuş M., Investigation of Microstructural and Mechanical Properties of Dissimilar Metal Weld Between AISI 420 and AISI 1018 Steels, Arabian Journal for Science and Engineering, **2022**, 47:8341–8350
15. Adin, M.Ş., Performances of cryo-treated and untreated cutting tools in machining of AA7075 aerospace aluminium alloy, European Mechanical Science, **2023**, 7(2): 70-81
16. Adin, M.Ş., A parametric study on the mechanical properties of MIG and TIG welded dissimilar steel joints, Journal of Adhesion Science and Technology, 202
17. DIN EN 12513:2001, Abrasion Resistant Cast Irons, English Version of DIN EN 12513 (Foreign Standard) **2001**
18. ASTM A27M, Standard Specification for Steel Castings, Carbon, For General Application, **2006**
19. ASTM E18-02, Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials, **2004**
20. ASTM E23-02, Standart Test Methods for Notched Bar Impact Testing of Metallic Materials, **1982**
21. Totten, G.H., Steel Heat Treatment Metallurgy and Technologies, Second Edition, Portland State University of Portland, **2006**: 148-150
22. Jawahir, I.S., Attia, H., Biermann, D., Duflou, J., Klocke, F., Meyer, D., ... & Umbrello, D., Cryogenic manufacturing processes. CIRP annals, **2016**, 65(2): 713-736