Karabük Üniversitesi
Çelik Araştırma ve Geliştirme Dergisi
(JESRED)
e-ISSN: 2757 8224
Cilt 4, Sayı 1
Eylül 2023, 10-16
Araştırma Makalesi

Karabuk University
Journal of Steel Research and Development
(JESRED)
e-ISSN: 2757 8224
Volume 4, Issue 1
September 2023, 10-16
Research Article

Effect Of Temperature on Wear Behaviour Of 1.2344 and WP7V Hot Work Tool Steels

1.2344 ve WP7V Sıcak İş Takım Çeliklerinin Aşınma Davranışına Sıcaklığın Etkisi

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***Received**: 07/07/2023* ***Accepted**: 14/08/2023* ***Published Online:** 05/09/2023*

Abstract
Various grades of hot work tool steels are used in the manufacturing of hot-forming tools and molds. The tools and molds are exposed to high contact pressures combined with high temperature, causing severe tool failure during hot forming such as wear, and fatigue failure. Therefore, choosing the right quality tool steel is very important in the manufacture of tools and dies to avoid severe damage during hot forming. This study, it is aimed to compare the wear and mechanical properties of the heat-treated 1.2344 quality steel, which is widely used in hot-forming tools and moulds, and WP7V steel, which has been developed and patented by Dörrenberg and to offer a better alternative to 1.2344 quality steel. Samples were prepared from heat treated 1.2344 and WP7V hot work tool steels under the same conditions. Wear tests were conducted by using a pin-on-disc tribometer with 6 mm diameter 100Cr6 steel balls at 25°C- 400°C in a dry environment at 300rpm under a 20 N force load. The hardness of the samples was measured in HRC, and the microstructure of the samples was examined by a light microscope after metallographic preparation. The hardness values of WP7V hot work steel were higher. The results of wear tests revealed that the WP7V material could be a better alternative to 1.2344-grade steel with higher wear resistance in dry conditions.

Key Words
DIN 1.2344, WP7V, Wear Behaviour, Heat Treatment, Hardness, Microstructure

Özet
Sıcak şekillendirmede kullanılan takım ve kalıpların imalatında çeşitli kalitede sıcak iş takım çeliği kullanılmaktadır. Bu kalıp ve takımlar sıcak işlem sırasında yüksek sıcaklıkla bir araya gelen yüksek temas basınçlarına maruz kalır ve aşınma, yorulma gibi ciddi hasarlara uğrayabilir. Bu nedenle, sıcak şekillendirme sırasında meydana gelecek ciddi hasarların önüne geçilebilmesi için kalıp ve takımların imalatında doğru çelik kalitesi seçimi çok önemlidir. Bu çalışmada, sıcak şekillendirme takım ve kalıplarında yaygın olarak kullanılan ısıl işlem görmüş 1.2344 kalite çelik ile Dörrenberg tarafından geliştirilen ve patenti alınan WP7V çeliğin aşınma ve mekanik özelliklerinin karşılaştırılması ve 1.2344 kalite çeliğe daha iyi bir alternatif sunulması amaçlanmıştır. Isıl işlem görmüş 1.2344 ve WP7V sıcak iş takım çeliklerinden aynı şartlarda numuneler hazırlanmıştır. Aşınma testleri, kuru ortamda 300 rpm'de 20 N kuvvet yükü altında 25°C ve 400°C'de 6 mm çapında 100Cr6 çelik bilyeler ile disk-üzeri-pim aşınma cihazı kullanılarak gerçekleştirilmiştir. Numunelerin sertliği HRC cinsinden ölçülmüş, metalografik hazırlıktan sonra mikro yapıları ışık mikroskobu ile incelenmiştir. WP7V sertliği daha yüksek ölçüldü. Aşınma testlerinin sonuçları, WP7V malzemesinin kuru koşullarda daha yüksek aşınma direnci ile 1.2344 kalite çeliğe daha iyi bir alternatif olabileceğini ortaya koydu.

Anahtar Kelimeler
DIN 1.2344, WP7V, Aşınma Davranışı, Isıl İşlem, Sertlik, Mikroyapı

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Note: The abstract of this study has been presented as a paper at the 6th International Iron and Steel Symposium and published in the Proceeding Book. The full text of the study has been published in this issue of JESRED.

To cite this article: *Volkan Karakurt et al., Effect of Temperature on Wear Behaviour Of 1.2344 and WP7V Hot Work Tool Steels, Journal of Steel Research and Development, 4(1), 10-16.*

1. Introduction

Tool steels, which are the most important material group of high-quality steels, are used in hot, warm, and cold forming processes of many materials from metal to plastic as tool materials [1]. In addition, their high toughness, wear resistance, strength, corrosion resistance, and enhanced softening resistance at high temperatures make these materials the most desirable for many industrial applications [1]. As the focus of the industrial sector shifts towards the use of new, light-in-weight, special materials with high mechanical properties, the requirements for tool properties are also changing. Additionally, the demand for tools with high wear resistance is increasing as well. With the hardening and tempering heat treatments applied to tool steels, the mechanical properties of these materials are significantly improved. Along with their improved mechanical properties, the service life of tool steels is also economically important [2]. Damages such as wear, and fatigue directly affect the production economy by reducing the life of the mold and causing interruption of production. L. Lavtar et al. stated that mold costs generally constitute about 10% of the total costs, but unexpected mold damages increase this rate much higher than 30% [3]. On the other hand, the wear of the material on the tool surface determines the tool's production costs and economic working life. Therefore, a high-performance tool material should have properties such as good heat resistance, strength, toughness, ductility, hardness, and especially wear resistance [4-5].

Tools and melds used in hot metal forming operate under conditions such as high temperatures, high contact pressures and impact loading, and abrasive wear of work material. Therefore, the tool material needs to have very good mechanical properties along with wear resistance properties [9-12]. Although various types of damage occur in tools used in hot forming due to a very complex combination of thermal, mechanical, chemical and tribological loads they are exposed to, wear damage has an important place among them. Accordingly, the wear resistance of tool material as a first step can be used as a criterion in tool material selection [6-8]. The 1.2344-grade tool steel is a standard material used as tool material in hot forming processes such as extrusion tools, forging molds, aluminium injection molds, hot cutting blades, and plastic molds. WP7V is secondary hardenable alloyed special tool steel developed and patented by Dörrenberg with enhanced toughness, compressive strength, and wear resistance at high temperatures.

In this study, the possibility of using DörrenBerg patented WP7V tool steel instead of 1.2344 (X40CrMoV5-1) tool steel, which is generally used for hot work applications, was investigated. For this purpose, the dry environment wear behaviour of two steels at room temperature and high temperature (400 °C) was compared. The materials used in the study were heat treated under the same conditions. Afterward, microstructure and hardness measurement studies were carried out.

2. Material And Method

2.1. Material

1.2344 and WP7V quality hot work tool steels used in the experimental studies were supplied by SAĞLAM METAL A.Ş. The chemical compositions of 1.2344 and WP7V hot work tool steels are presented in Table 1.

Table 1. The chemical compositions of hot work tool steels 1.2344 and WP7V

Material	C	Cr	Mo	V
1.2344	0.40	5.30	1.40	1.00
WP7V	0.50	7.80	1.50	1.50

2.2. Heat Treatment of Materials

Heat treatments of 1.2344 and WP7V hot work tool steels were carried out in a Schmetz brand vacuum furnace at Sağlam Metal. After vacuuming, the furnace was heated to 1040°C process temperature. High-pressure nitrogen was used for cooling. Then, tempering was performed to obtain the desired hardness and to relieve the stress in the steels. The steps of the heat treatment process are shown in Figure 1.

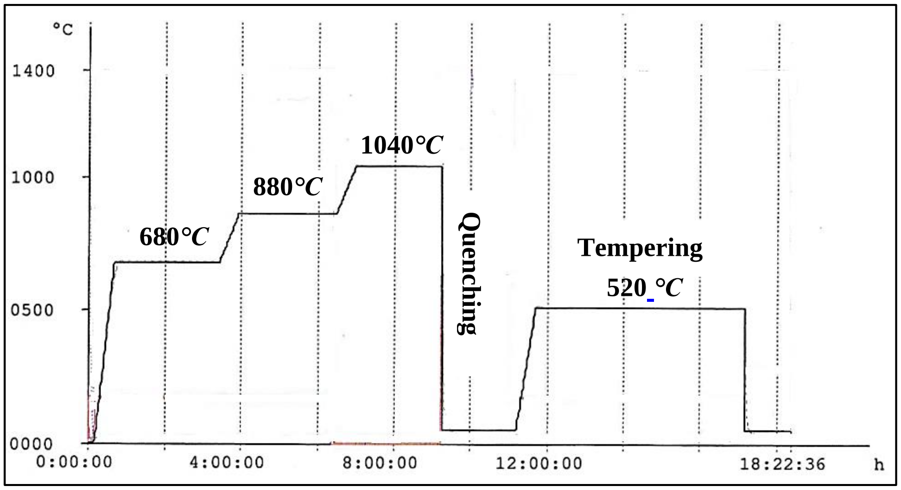


Figure 1. Hardening heat treatment process chart of 1.2344 and WP7V quality hot work tool steels

2.3. Microstructure Examination of Materials

Microstructure characterizations were conducted by using Nikon LV150N model optical microscope. The samples for metallographic examinations were grinded with sandpaper in the grid range of 200, 600, 800, 1000, 1200, and 2500, respectively. Then they were polished by using 9µm diamond suspension. Chemical etching of the samples was conducted by using the etchant of 3% Nital (HNO_3).

2.4. Hardness Measurements

The hardness of all samples was measured as Rockwell (C-Scale) in the QATM- QNESS 150R device. Hardness measurements were carried out by application of a preload of 10 kg followed by a 15-second major load of 150 kg. The average of 5 tests per sample was reported as the hardness of the samples.

2.5. Wear Test

Tests were performed on a Pin-On-Disc (POD) wear tester with a 100Cr6 steel ball. Square specimens (30 mm*30 mm*3 mm) were used for the wear test. The tests were carried out at room temperature (25°C-77°F) and high temperature (400°C-204.44°F) with a 300-rpm sliding speed and 1000 m sliding distance with a constant load of 20 N. Friction coefficient data were obtained from the device. Weight losses at the beginning and end of the test were measured with a 0.001 gr precision scale. The wear rates of hot work tool steels were calculated using the following formula with the weight (gr) loss data obtained with a precision scale.

$$Wa=\Delta G/ d\times M\times S \ (mm^3/Nm) \quad [1]$$

Wa: Wear rate (mm^3/Nm), ΔG: Weight loss (mg), M: Applied Load (FN) (N), S: Wear distance (m), d: Density (mg/mm^3) [13-15]. The wear test mechanism is shown in Figure 2.

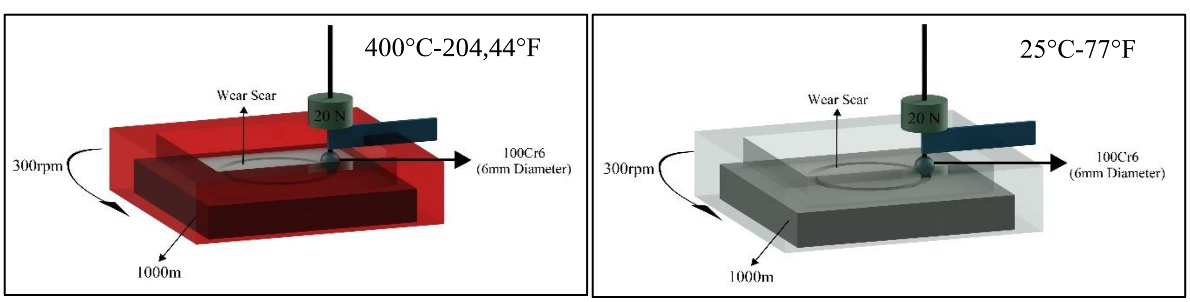


Figure 2. Room temperature and high-temperature wear device of 1.2344 and WP7V quality hot work tool steels

3. Results and Discussion

3.1. Wear Test Results

Figure 3 shows the hardness values of 1.2344 and WP7V hot work tool steels, which were hardened and tempered in the same conditions. As can be seen from the graph in Figure 3, the final hardness of WP7V hot work tool steel is 1.33 HRC higher than that of 1.2344. This increase in hardness can be attributed to the formation of complex carbides in the structure (see Table 3. WP7V 100X image).

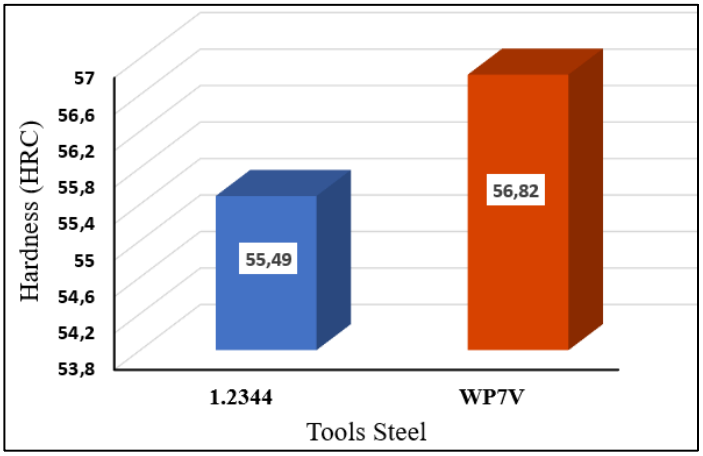
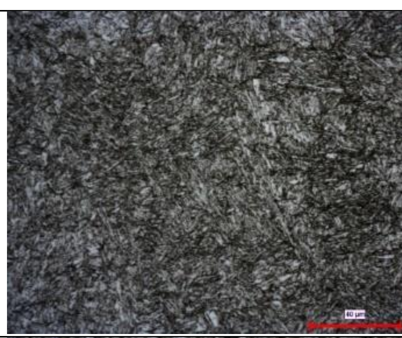


Figure 3. Rockwell C hardness values of hardened and tempered 1.2344 and WP7V hot work tool steels

3.2. Microstructure Inspections

The characteristic microstructures of hardened and tempered 1.2344 and WP7V hot work tool steel samples are shown in Table 2. A tempered martensite structure was formed in both types of steel however, a coarser martensite occurred in 1.2344 hot work tool steel structure than that of WP7V. In optical microscope images of WP7V steel (Table 2 100X), whitish particles were observed to precipitate in the matrix. It can be assumed that the particles precipitated in the matrix may be chromium carbide due to the high Cr content of WP7C steel.

Table 2. 50-100X microstructure images of vacuum heat treated 1.2344 and WP7V hot work tool steels

	1.2344	WP7V
50X		
100X		

3.3. Wear Test Results

Figure 4 shows the macro images of 1.2344 and WP7V hot work tool steels after the wear test at 25 and 400°C.

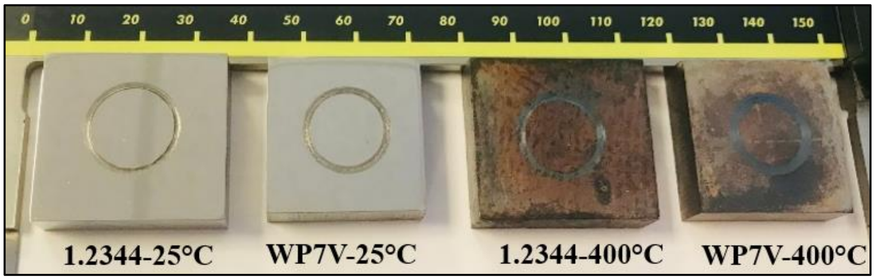


Figure 4. Macro images of 1.2344 and WP7V hot work tool steels after the wear test at 25 and 400°C.

The weight loss and wear rate results obtained in the wear test for 1000 m sliding distances at 25°C and 400°C are given in Figure 5 and Table 3. The weight losses of 1.2344 tool and WP7V steel at room temperature were 7.8 mg and 5.8 mg respectively. Accordingly, WP7V hot work tool steel wears 34% less at room temperature. In the wear test at 400°C, the weight losses of 1.2344 and WP7V hot work tool steels were 12.5 mg and 9.2 mg respectively. The loss of WP7V hot work tool steel was 35% less at high temperatures as well.

The wear rates of the samples were calculated by using the formula [1] and the results are given in Figure 5(b) and Table 3. The wear rate of 1.2344 hot work tool steel at room temperature is 4.9×10^{-4} mm^3/Nm, while WP7V hot work tool steel is 3.7×10^{-4} mm^3/Nm. The wear rate of WP7V hot work tool steel is 32% higher than 1.2344 hot work tool steel. The variation of the wear rate variation of the two steels was also obtained at 400°C in the same direction. The wear rate of WP7 hot work steel was 36% less than 1.2344. Having evaluated the test results of weight loss and wear rates it is seen that the hot work tool of WP7V steel revealed better wear resistance for both temperatures. The high wear resistance of WP7V hot work tool steel could be related to its microstructure and higher hardness than 1.2344.

It is observed that the wear rate and weight losses increase with increasing test temperature for both steels (Figure 5b). The lower strength values at high temperatures of steel could be seen as the root cause.

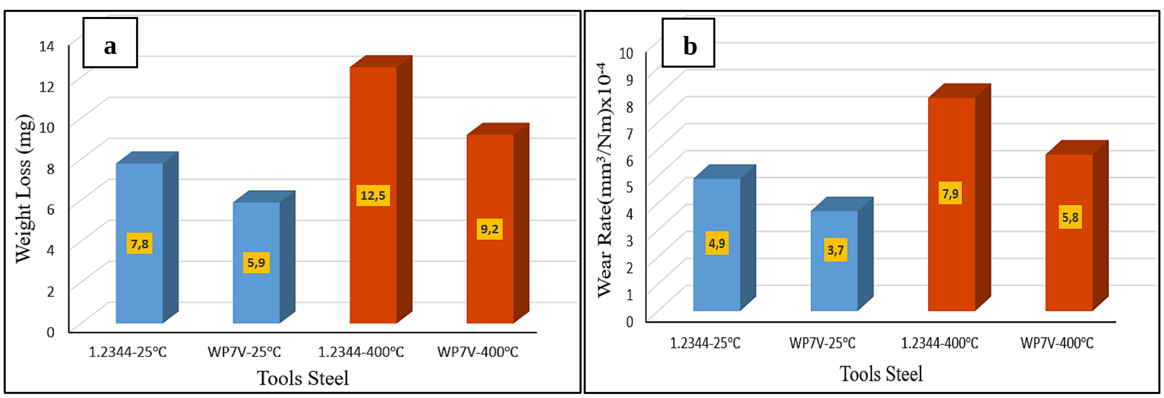


Figure 5. 1.2344 and WP7V quality hot work tool steels at 25 °C and 400 °C (a) Weight losses (b) Wear rates

Tablo 3. Weight loss and wear rate values of 1.2344 and WP7V quality hot work tool steels at 25 °C and 400 °C.

Tools Steel	Weight Loss (mg)	Wear Rate(mm3/Nm)
1.2344-25°C	7,8	4,9
WP7V-25°C	5,9	3,7
1.2344-400°C	12,5	7,9
WP7V-400°C	9,2	5,8

In Figure 6, the friction coefficient values of the materials are given. The average coefficient of friction of both hot work steels decreased significantly with increasing temperature. The friction coefficients of 1.2344 and WP7V hot work tool steels at room temperature (25°C) were 0.788 and 0.768 while they were 0.416 and 0.458 at 400°C respectively. The friction coefficient of WP7V material measured at both temperatures was lower than 1.2344 steel. The lower coefficient of friction of WP7V steel makes it a more suitable material for high-temperature applications.

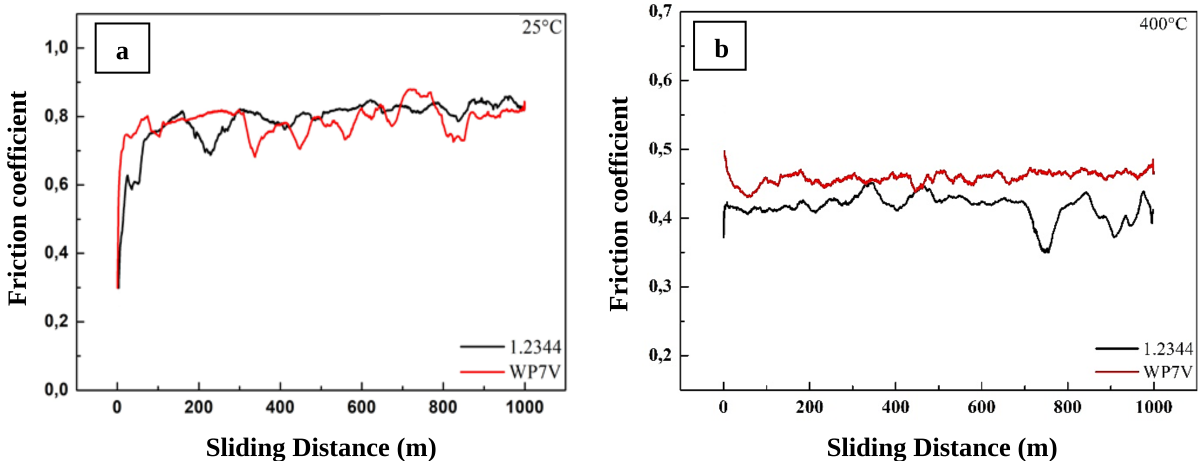


Figure 6. Friction coefficient values of 1.2344 and WP7V quality hot work tool steels at (a) 25 °C and (b) 400 °C

4. Results

In this study, microstructure, hardness, wear behaviour at room temperature and high temperature (400°C) of 1.2344 and WP7V hot work tool steels were investigated after hardening and tempering processes. The results obtained are summarized below:

- The structure observed after heat treatment in 1.2344 and WP7V hot work tool steels was a tempered martensite structure.
- It was suggested that WP7V hot work tool steel contained carbide particles in the tempered martensitic matrix.
- The final hardness of WP7V hot work tool steel was 1.33 HRC higher than 1.2344.
- The results of wear tests carried out at room temperature and 400°C revealed that the wear resistance of WP7V hot work tool steel is higher than 1.2344 at both test temperatures.
- It was observed that the wear resistance decreased (the wear rate increased) with increasing test temperature for both steels.
- The friction coefficient of WP7V hot work tool steel was lower than 1.2344 steel at both temperatures,
- From the wear test results, it was concluded that WP7V hot work tool steel with higher wear resistance and lower friction coefficient is preferable for applications where 1.2344 steel is used.

5. Reference

Koçak H. , 2019, *Takım Çelikleri*, 10.Ed., Bolokur Teknik Yayıncılık A.Ş.

Roberts, G. ., Krauss, G., & Kennedy, R. (1998). *ASM International: Tool Steels.* (5th ed., pp.1-120), OH.

L. Lavtar, T. Muhič, G. Kugler, M. Terčelj, *Eng. Fail. Anal.* 18 (2011) 1143–1152.

A. Gåård, *Tribol. Int*. 57 (2013) 251–256.

V. Leskovšek, B. Šuštaršič, G. Jutriša, J. Mater. *Process. Technol*. 178 (2006) 328–334.

J.A. Schey, Tribology in Metalworking: Friction, Lubrication and Wear, ASM, Ohio, 1984.

O. Barrau, C. Boher, C. Vergne, F. Rezai-Aria, Investigations on friction and wear mechanisms of hot forging tool steels, Proceedings of 6th International Tooling Conference, Karlstad, Sweden, 2002, pp. 95–111.

P.H. Hansen, Analysis of wear distribution in forging dies(PhD. thesis) Technical University of Denmark, Lyngby, 1990.

G.A. Roberts, R. Kennedy, G. Krauss, Tool Steels, ASM international, 1998.

M.X. Wei, S.Q. Wang, L. Wang, X.H. Cui, K.M. Chen, Effect of tempering conditions on wear resistance in various wear mechanisms of H13 steel, Tribol. Int. 44 (7–8) (2011) 898–905.

C. Mueller, I. Schruff, Steel selection contributing to wear reduction of forging dies, 2016, pp. 124–130.]

N.B. Dhokey, Effect of tempering and cryogenic treatment on wear and mechanical properties of hot work tool steel (H13), Materialstoday Proceedings Volume 43, Part 5, 2021, Pages 3006-3013

M. Tabur, “Bor Karbür Kaplanmış AISI 8620 ve Hardox 400 Çeliklerinin Abrasiv Aşınma Davranışlarının İncelenmesi”, Ph.D. Thesis, Gazi University Institute of Science and Technology, Ankara, (2008).

M. İzciler, “Yüksek krom alaşımlı dökme demirlerin farklı sıcaklıktaki abrasiv aşınma davranışına alaşım katkı oranının ve ısıl işlem şartlarının etkileri”, Ph.D. Thesis, Fırat University, Institute of Science and Technology, Elazığ, 50-122, (1997).

H.Çelik, “Kaynak edilebilen kobalt ve demir esaslı alaşımların yüksek sıcaklıktaki aşınma davranışları”, PhD Thesis, Istanbul Technical University, Institute of Science and Technology,İstanbul, 3-35, (1992)].