

Investigation of The Effect of Surface Hardening Process Applied to Crankshafts on Mechanical Properties

Yavuz SUN

Karabük University

Hayrettin AHLATÇI

Karabük University

To Cite This Chapter:

Sun, Y., & Ahlatci, H. (2025). Investigation of the effect of surface hardening process applied to crankshafts on mechanical properties. In H. Gokmese, S. Bulbul, & Y. Uzun (Eds.), *Innovative approaches in materials science and applications* (pp. 128–137). ISRES Book Series. ISRES Publishing.

Introduction

The crankshaft is the metal rod on which the engine pistons are mounted. The crankshaft converts the linear motion from the pistons into rotary motion using a simple formula, thus becoming the primary hub for all rotational power transmitted to the wheels. Nitriding is the diffusion of nitrogen onto the steel surface, resulting in the formation of a hard, highly wear-resistant layer on the material's surface. Every material has a nitriding capability. Nitriding increases corrosion resistance and fatigue strength in some steels (Polat et al., 2011; Winter et al., 2013; Chen et al., 2019).

Wear is one of the types of damage that reduces the operating efficiency of machine elements and increases production costs. With the advancement of technology from past to present, the operating tolerances of machine elements have decreased significantly, more complex and precise parts are needed, and damage investigations due to wear have become very important as a result of the necessity to work with low error in the aviation, space and defense fields (Castro et al., 2007; Whitney et al., 1986).

This study investigated the effects of gas nitriding on the mechanical properties of a crankshaft. For this purpose, the crankshaft was subjected to gas nitriding at 520°C for 15 hours. Following the gas nitriding process, hardness and microstructure characterization studies were conducted separately on unnitrided and nitrided samples. Wear tests on the examined samples were conducted in a reciprocating wear tester under loads of 20N, 40N, and 60N. The tests revealed that the nitriding process applied to the crankshafts resulted in an approximately 20% increase in the wear resistance of the examined samples.

Materials and Methods

Gas Nitration

The chemical composition of the crankshaft used in the studies is given in Table 1. The

nitriding process of the steels was carried out at the Manksan A.Ş. facilities. The process involved nitriding to prevent white layer formation. The nitriding process was carried out in the oven shown in Figure 1. under an ammonia atmosphere at 520°C for 15 hours.

Table 1

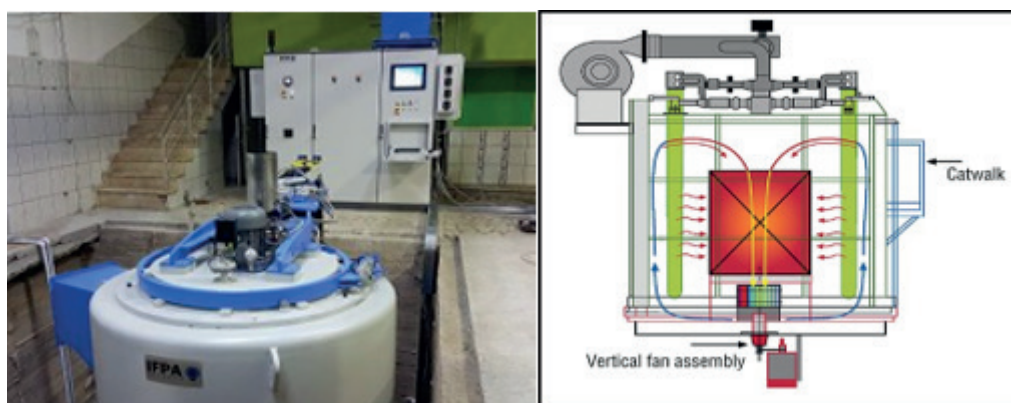
Chemical analysis results of the examined sample

C	Si	Mo	Cr	Mn	P	S
0,41	0,33	0,19	0,99	0,62	0,021	0,019

In the gas nitriding process, ammonia gas is introduced into the furnace. The system calculates the adequacy of the gas based on the furnace volume and the delivered gas flow. The furnace heats up to 520°C in approximately four hours. To achieve the Kn value, which depends on the amount of ammonia decomposition during all process steps, the system's temperature and gas flow are controlled. Additionally, the ammonia decomposer in the furnace breaks down the ammonia. When the temperature reaches 520°C, the nitriding process begins. Meanwhile, the ammonia released into the environment continues to decompose. After the nitriding process, the cooling fan is automatically activated, and the system cools to 100°C in approximately four hours. The entire nitriding process takes approximately 23 hours; however, the actual nitriding time is 15 hours, excluding the system's heating and cooling periods.

Figure 1

Gas nitriding furnace and its working principle

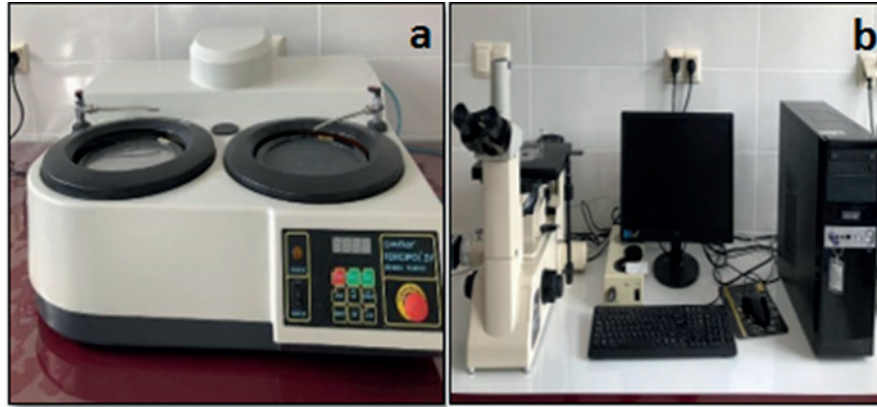


Microstructural And Mechanical Characterization

For metallographic processing, a 25x15x10 mm sample was cut from the crankshaft. The prepared samples were prepared for polishing by grinding to a 400-2500 mesh and polished with 3 micron Al₂O₃. Microstructure images were taken after etching with 3% nital. Microstructure images were taken longitudinally and in cross-section using a Nikon Eclipse 200 optical light microscope (Figure 2).

Figure 2

Sanding device (a) and optical microscope (b)



Hardness measurements were taken on the surface of nitrided crankshaft samples using a Vickers hardness tester at five different loads ranging from 0.20 to 5 kg. A picture of the test device is shown in Figure 3. During the test, hardness was measured at HV 0.5 using a diamond square pyramid with a 136° apex angle.

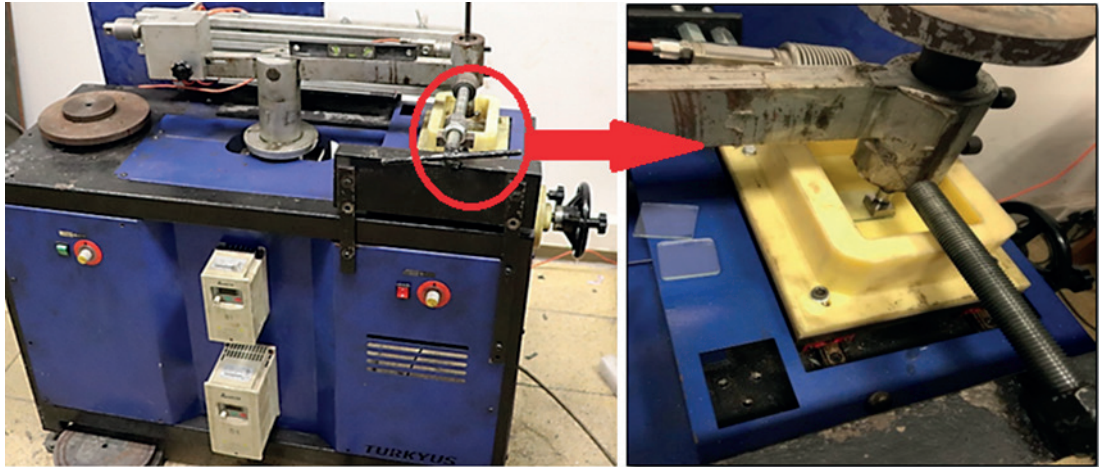
Figure 3

Vickers Hardness Tester



During the wear tests of the examined samples, 100Cr6 ball bearings and a 25x15x10 mm test sample were used as counter materials. The samples were designed to travel an average of 3 m under loads of 20N, 40N, and 60N. Dry-weather wear tests were conducted on the reciprocating wear device shown in Figure 4. Before and after the tests, the samples were weighed on an electronic scale with a precision of 0.0001 g, and the test results were evaluated according to weight loss. After the wear tests, the sample surfaces were examined with a scanning electron microscope (SEM) to determine the wear mechanisms, and surface roughness was measured with a profilometer.

Figure 4
Reciprocating wear device



Characterization Results and Discussion

The microstructure images of the steel examined before and after nitriding are given in Table 2. An examination of the figure reveals tempered martensite phases in the pre-nitridation microstructure. An examination of the post-nitridation microstructure images (Table 2) reveals a more equiaxed grain structure. This is thought to be due to the nitriding process being carried out at 520°C and then slowly cooling to 100°C over 4 hours.

Table 2
Optical Microscope (LOM) and Scanning Electron Microscope (SEM) images of the examined alloys

	Non-nitrided	Nitrided
LOM		
SEM		

As mentioned in the literature, the low amount of strong nitride formers such as Cr and

Mo in the chemical composition of the crankshaft sample and the complete absence of V in the chemical analysis play a major role in the absence of a diffusion layer. The average thickness of the white layer seen in Figure 5 was measured as 23 μm . The SEM images shown in Figure 6 also support this view.

Figure 5

Optical microscope image of the nitriding layer.

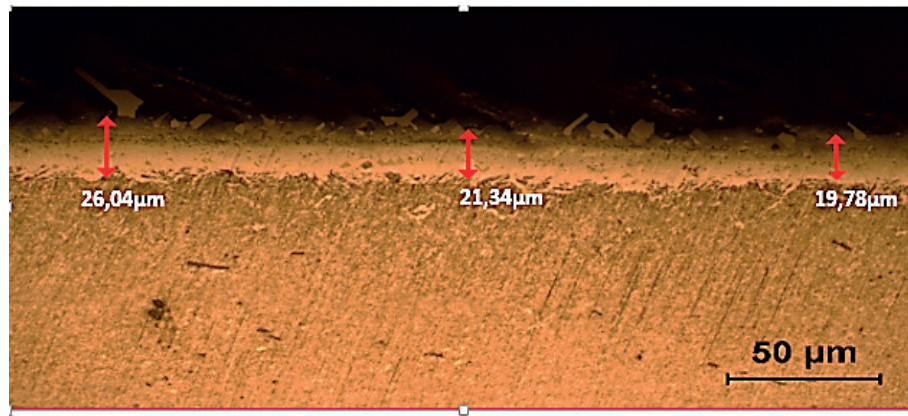
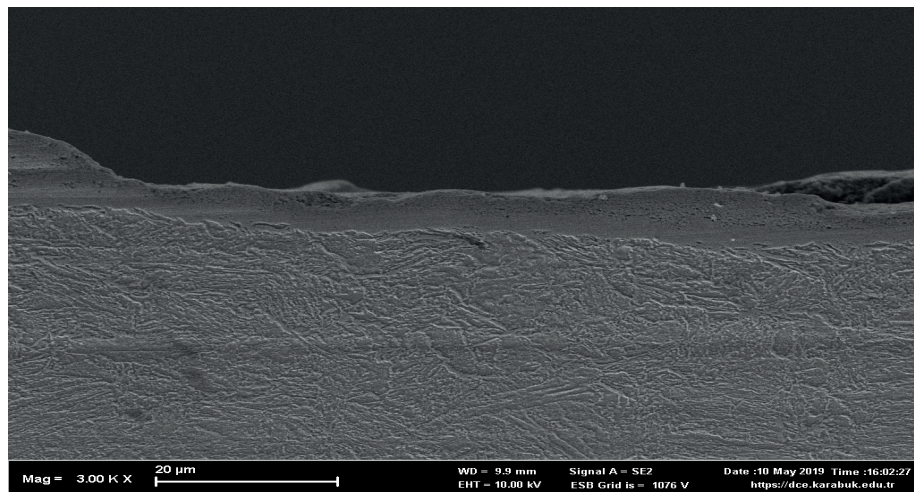


Figure 6

SEM image of the nitriding layer.

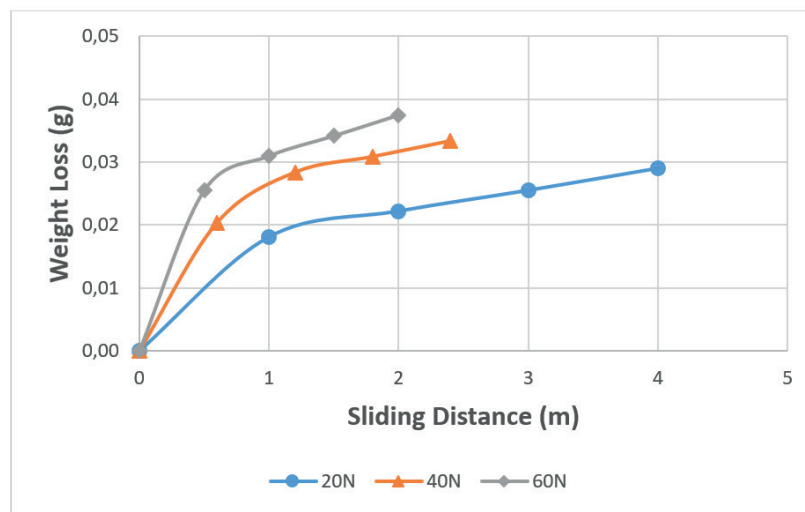


The average hardness value of the examined crankshafts without nitriding is 384 HV0.5. Table 3 shows the hardness values and indentation depths of the nitrided samples at different loads. A Vickers hardness indentation taken from the surface of the nitrided sample under a 5 kg load indicates that the indentation layer has passed through and reached the base material.

Table 3*Hardness results obtained from the nitriding layer*

Applied Load	Hardness	Trace Depth (μm)
0,20	741	4,52
0,50	549	8,30
1,00	471	12,69
5,00	416	30,09

In the study, wear tests were applied to nitrided and non-nitrided crankshafts under 20-60N loads and a sliding distance of 1-4 m. As a result of the wear test, weight losses were determined before and after the test using an electronic scale with a sensitivity of 0.0001 g (0.1 mg) and were proportional to the sliding distance. Figure 7 shows the weight loss graph for the non-nitrided material, while Figure 8 shows the weight loss graph for the nitrided sample.

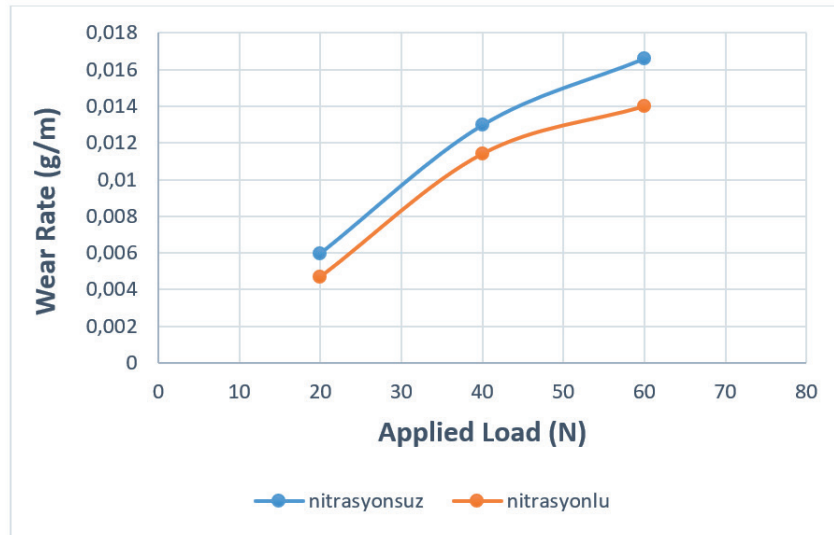
Figure 7*Weight loss graph of samples non-nitrided*

As seen in Figure 7, the non-nitrided samples experienced a weight loss that initially increased up to 1 meter and then varied linearly with the applied load and distance travelled. An examination of the weight loss graph of the nitrided samples (Figure 8) reveals a weight loss that varies linearly with the applied load and distance traveled. Examining these figures, it can be concluded that the nitrided samples exhibited less weight loss compared to the non-nitrided samples. The wear resistance of the sample increased by approximately 20% after the nitriding heat treatment. The wear behaviour of the examined crankshaft depends on the applied nitriding heat treatment, the applied load, and the hardness of the crankshaft. As a result, the hardness of the crankshaft increases, and therefore, its wear resistance also increases (Telesang et al., 2015; Uzun, 2002).

As the distance traveled during the wear test on crankshaft samples increases, weight loss increases. Wear rates were calculated by proportioning these weight losses to the sliding distance. Figure 9 shows the wear rate graph.

Figure 8

Wear rate graph depending on applied load



SEM images and EDX results of the worn surfaces of the non-nitrated and nitrided samples subjected to wear under 20 N and 60 N loads after the wear test are given in Tables 4 and 5, respectively. The samples subjected to wear under a 20 N load were relatively narrow and shallow in depth. The samples subjected to wear under a 60 N load were observed to have wider and deeper scars.

Figure 9

Weight loss graph of nitrided samples

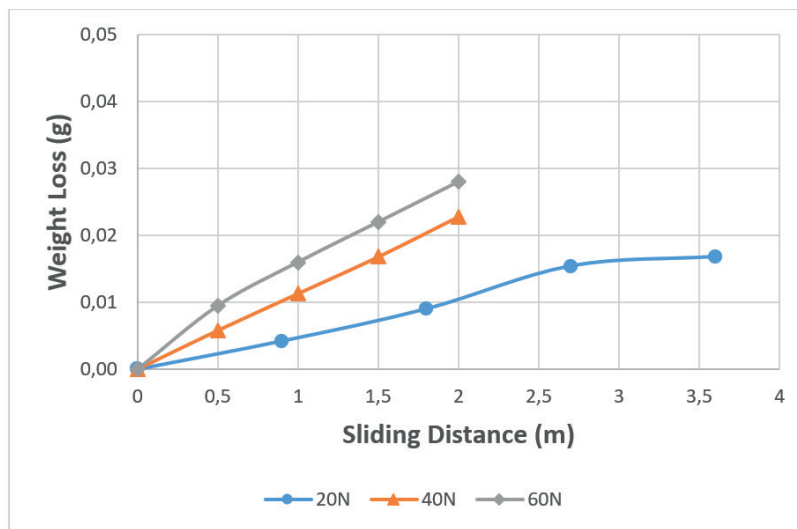


Table 4

SEM Image and EDX Results of Worn Surface for Non-Nitrided Samples

SEM

20 N

Selected Points	C	N	O	Na	S	Cl	Cr	Mn	Fe
1	13.68	2.27	42.36	0.73	0.08	0.12	0.12	0.56	40.08
2	3.70	0.65	0.27	0.10	0.02	0.17	0.26	1.03	93.80
3	14.43	1.36	37.86	0.75	0.20	0.47	0.17	0.00	44.75
4	59.65	12.28	22.10	1.91	0.88	0.90	0.00	0.56	1.72

SEM

60 N

Selected Points	C	N	O	Na	S	Cl	Cr	Mn	Fe
1	2.69	1.16	31.68	0.00	0.07	0.00	0.00	0.00	64.40
2	48.40	5.03	29.68	6.35	0.64	5.71	0.06	0.10	4.02
3	3.70	1.38	2.80	0.45	0.01	0.09	0.00	0.11	91.47
4	71.48	5.02	19.07	0.74	0.96	1.17	0.00	0.31	1.25

Table 5

SEM Image and EDX Results of Worn Surface for Nitrided Samples

SEM

20 N

EDS

Selected Points	C	N	O	Na	S	Cl	Cr	Mn	Fe
1	48.81	10.01	14.66	2.74	0.71	18.63	0.00	0.41	4.03
2	4.02	1.08	30.94	0.02	0.00	0.02	0.34	0.27	63.32
3	5.20	0.96	7.42	0.00	0.05	0.00	0.11	0.66	85.60
4	18.88	0.00	18.36	0.26	0.00	0.78	0.36	0.25	61.10

SEM

60 N

EDS

Selected Points	C	N	O	Na	S	Cl	Cr	Mn	Fe
1	8.80	2.70	44.47	0.27	0.00	0.53	0.23	0.00	43.01
2	17.73	2.55	3.22	0.23	0.04	0.38	0.03	1.65	74.17
3	58.55	13.50	21.33	0.61	0.77	1.84	0.44	0.00	2.97
4	2.95	0.76	11.19	0.00	0.00	0.08	0.17	0.63	84.21

In nitrated samples, under low and high loads, mild adhesion fracture marks were observed, and fine grooves formed at the location marked with the arrow in Table 5 (20N). In non-nitrated samples, under high loads, fragments broke off from the surface in the circled area (60N) in Table 4, and coarse grooves formed at the location marked with the arrow indicate excessive fracture. While deep and wide grooves formed after abrasion in the non-nitrated sample (Table 4) under a 60N load, finer grooves were

observed in the nitrided sample marked with the arrow in Table 5. Furthermore, under a 60N load, localized abrasive tearing and ruptures occurred in the nitrided sample, and it was determined that an oxide film had formed on the surface following this localized abrasion test. The formation of the oxide film increased wear resistance. The formation and propagation of surface cracks with a high degree of fracture at high loads are symptoms of fragment breakage resulting from the formation and propagation of severely fractured surfaces (Uma et al., 1999; Wang et al., 2020; Qiang et al., 2000).

Acknowledgement

This study was supported by Karabük University Scientific Research Projects Coordination with the project code FDT-2019-2104. The authors would like to thank the KBÜ-BAP unit for their financial support. They would also like to thank Emre Küçük for his contributions.

References

- Castro, G., Fernández-Vicente & A., Cid, J., 2007. “Influence of The Nitriding Time in The Wear Behavior of An AISI H13 Steel During A Crankshaft Forging Process” *Wear*, 263, 1375–1385.
- J-M. Winter & J. Kalucki, 2013. “Gas Nitriding and Gas Carburizing of Steels”, Volume 4A, *Steel Heat Treating Fundamentals and Processes*, J. Dossett and G.E. Totten, editors, *ASM Handbook*, pp. 647-679.
- Li WH, Chen HL & Yang SQ., 2009. “Surface Integrity Research on Barrel Finishing of Crankshafts” *Key Engineering Materials*, pp.655–660.
- Qiang Y. H., Ge S. R. & Xue Q. J., 2000. “Microstructure and Tribological Properties of Complex Nitrocarburized Steel”, *J. Mater. Process. Technol.* 101: 180.
- Ş. Polat, Ş. H. Atapek & H. Topaç, 2011. “Gaz Nitrasyon ile Yüzeyleri Sertleştirilmiş AISI 4140 ve DIN 1.2344 Çeliklerinde Mikroyapısal Karakterizasyon”, *6 th International Advanced Technologies Symposium (IATS'11)*, Elazığ, Turkey.
- Telasang, G., Dutta Majumdar, J., Padmanabham, G. & Manna, I., 2015. “Wear and Corrosion Behavior Laser Surface Engineered AISI H13 Hot Working Tool Steel”, *Surface and Coatings Technology* 261, 69–78.
- Uma Devi M., Chakraborty T. K. & Mohanty O.N. 1999. “Wear Behaviour of Plasma Nitrided Tool Steels”, *Surface and Coatings Technology*, 116–119: 212-221.
- Uzun H., 2002. “Borlama İle Yüzeyleri Sertleştirilen Çeliklerin Aşınma Ve Korozyona Karşı Dayanımları”, Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Makina Mühendisliği Anabilim Dalı, Isparta.

- Whitney WJ Jr & Schwab BE., 1986. “Crankshaft Surfaces: Finishing Methods, Surface Characterization and Their Influence on Wear”, *Wear* ; 108: 345–356.
- Z. Wang, B.X. Huang, H. Chen, C.Z. Wang, J. Ma & X.C. Zhao, 2020. “The Effect of Quenching and Partitioning Heat Treatment on the Wear Resistance of Ductile Cast Iron”, *J. Mater. Eng. Perform.*, 29 (7), pp. 4370-4378.

About The Authors

Yavuz SUN is a Professor of Metallurgical and Materials Engineering at Karabuk University. I have a Master’s and doctoral degree in Metallurgical and Materials Engineering from İstanbul Technical University. His main areas of interest are iron and steel alloys, non-ferrous metals, casting technology, and composite materials.

Email : ysun@karabuk.edu.tr, **ORCID**: 0000-0002-7336-5591

Hayrettin AHLATCI is a Professor of Metallurgical and Materials Engineering at Karabuk University. I have a Master’s and doctoral degree in Metallurgical and Materials Engineering from İstanbul Technical University. His main areas of interest are mechanical behaviors of materials, corrosion and wear behaviors, casting technology, and composite materials.

Email : hahlatci@karabuk.edu.tr, **ORCID**: 0000-0002-6766-4974

Similarity Index

The similarity index obtained from the plagiarism software fort his book chapter is 9 %.