BORIDE LAYER GROWTH KINETICS OF THE BORIDED HIGH ALLOYED COLD WORK TOOL STEEL

I. GUNES

Department of Metallurgical and Materials Engineering, Faculty of Technology, Afyon Kocatepe University, 03 200 Afyonkarahisar, Turkey
E-mail: *igunes@aku.edu.tr*

ABSTRACT

In this study, the case properties and diffusion kinetics of high alloyed cold work tool steel borided in Ekabor-2 powder were investigated by conducting a series of experiments at temperatures of 1123, 1173 and 1223 K for 2, 4 and 6 h. The boride layer was characterised by optical microscopy, X-ray diffraction technique and micro-Vickers hardness tester. X-ray diffraction analysis of boride layers on the surface of the steels revealed the existence of FeB, Fe_2B, CrB, Cr_2B and MoB compounds.

Depending on the chemical composition of substrates and boriding time, the boride layer thickness on the surface of the steel ranged from 13.14 and 120.82 μm. The hardness of the boride compounds formed on the surface of the steels ranged from 1806 to 2342 $HV_{0.05}$, whereas the Vickers hardness value of the untreated steels was 428 $HV_{0.05}$. The activation energy (Q) of the borided steel was 287.019 kJ/mol.

Keywords: boride layer, microhardness, kinetics, activation energy.

AIMS AND BACKGROUND

Boriding is a thermochemical surface hardening method which can be applied to practically any ferrous material, as well as some nonferrous materials (Mo, Nb, Ti alloys)[1–5]. The boriding process is applied in order to increase the hardness and the wear resistance of the surfaces of metals and alloys, and in order to retain these properties at high temperatures and increase erosion resistance. Therefore, studies on the properties of the borided layer have focused on the properties of hardness, wear and corrosion[6–14]. Boriding is mostly applied to iron-based alloys in industry. Nowadays the boriding process can be carried out in solid, liquid, gas and plasma media, between 700 and 1000°C for 1–10 h. The most useful boriding method is box boriding, which is easier to apply and more cost effective than other methods. The method applied during boriding, boron powder, type of borided material and process parameters are the factors which affect the shape of the boride layer and its mechanical properties.

The thickness of the boride layer formed on the surface of the metal by the boriding process is affected by the composition of the boriding medium, degree of purity, treatment temperature and time and metal composition subjected to boriding[15–19]. In general, the presence of alloying elements reduces the diffusivity of boron in the steel and consequently decreases the thickness of the borided layer. For example, while carbon, molybdenum and tungsten dramatically reduce the borided layer thickness, silicon, chromium and aluminum have moderate influence, and nickel, manganese and cobalt have only marginal influence[20].

In this study cold work tool steel was borided considering these advantages of pack boriding. Characterisation and growth diffusion of the obtained boride layer were calculated. The main objective of this study was to investigate the diffusion kinetics and the effect of process parameters, such as temperature, time and chemical composition, on the boride layers formed on cold work tool steel after powder pack boriding at different processing temperatures and times.

EXPERIMENTAL

Boriding and characterisation. The high alloyed cold work tool steel (Uddeholm Sleipner) essentially contained 0.90 wt.% C, 0.50 wt.% Mn, 7.80 wt.% Cr, 2.50 wt.% Mo and 0.50 wt.% V. The test specimens were cut into Ø 25×10 mm dimensions, ground up to 1000 G and polished using diamond solution. The boriding heat treatment was carried out in solid medium containing an Ekabor-2 powder mixture placed in an electrical resistance furnace operated at temperatures of 1123, 1173 and 1223 K for 2, 4 and 6 h under atmospheric pressure. The microstructures of polished and etched cross-sections of the specimens were observed under a Nikon MA100 optical microscope. The thickness of borides was measured by means of a digital thickness measuring instrument attached to an optical microscope (Nikon MA100). Thickness values given in the results section are averages of at least 15 measurements. The contour diagrams, showing the variation in boride layer thickness with respect to the boriding temperature and time, were plotted using the Sigma plot 12.5 program. The presence of borides formed in the coating layer was confirmed by means of X-ray diffraction equipment (Shimadzu XRD 6000) using Cu Kα radiation. The hardness measurements of the boride layer on each steel and unborided steel substrate were made on the cross-sections using a Shimadzu HMV-2 Vickers indenter with a 50 g load.

Kinetics. On the condition that boron diffuses and grows parabolically, the alteration of boride layer thickness with time can be described by the following equation:

$$x^2 = D\,t \qquad (1)$$

where x is the depth of the boride layer (mm); t – the boriding time (s); D – the growth rate constant that depends on the diffusion element (in this case boron) and the diffusion coefficient. It is a well-known fact that the main factor limiting the growth of a layer is the diffusion of boron into the substrate. It is possible to argue that the relationship between growth rate constant, D, activation energy, Q, and the temperature in Kelvin, T, can be expressed as an Arrhenius equation (equation (2)):

$$D = D_0 \exp(-Q/RT) \tag{2}$$

where D_0 is a pre-exponential constant; Q – the activation energy (J/mol); T – the absolute temperature (K), and R – the gas constant (J/mol K). The activation energy for the boron diffusion in the boride layer is determined by the slope obtained in the plot of ln D versus $1/T$, using equation (2). The formation rate of the boride layers was examined and kinetic equations and parameters were determined at a temperature range of 1123–1223 K for periods of 2–6 h.

RESULTS AND DISCUSSION

Characterisation of boride coatings. The cross-sections of the optical micrographs of the borided cold work tool steel at the temperature of 1123 and 1223 K for 2 and 6 h are shown in Fig. 1. As can be seen, the borides formed on the cold work tool steel substrate have a smooth morphology due to higher alloy content. It was found that the coating/matrix interface and matrix could be significantly distinguished and the boride layer had a columnar structure. Depending on the chemical composition of substrates and boriding time, the boride layer thickness on the surface of the steel ranged from 13.14 to 120.82 μm (Fig. 2).

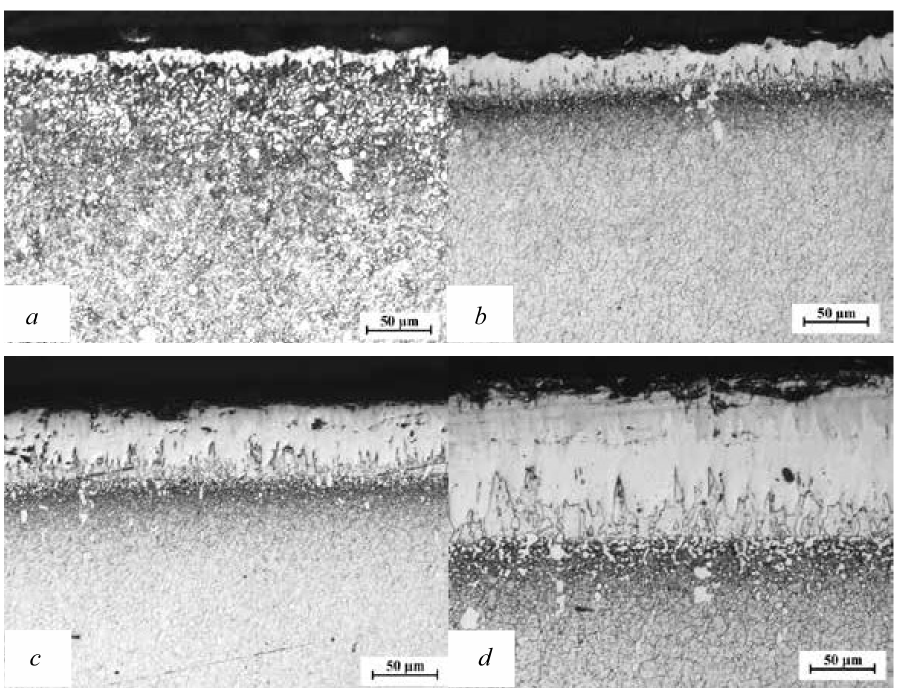

Fig. 1. Cross-sections of the borided cold work tool steel: 1123 K – 2 h (*a*); 1123 K – 6 h (*b*); 1223 K – 2 h (*c*), and 1223 K – 6 h (*d*)

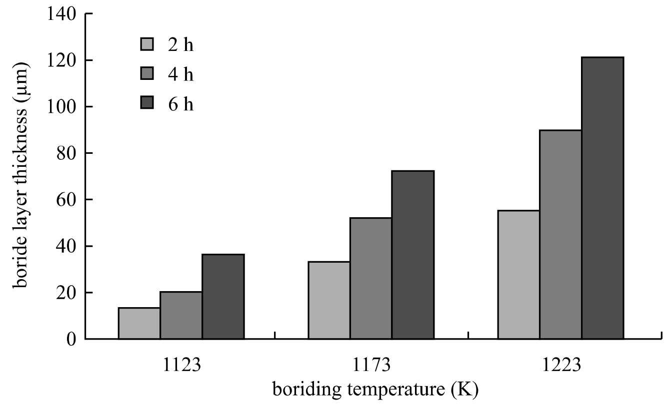

Fig. 2. Thickness values of boride layers with respect to boriding time and temperature

The amounts of C, Cr, Ni and Mo appear to be lower than that of iron in the boride layer because of less solubility. Thus, the deficiency of C, Cr, Mn and Mo results in a negative effect on the boride layer in terms of both thickness and morphology[21–24]. Efe et al. borided $31CrMoV_9$ and $34CrAlNi_7$ steels with Ekabor-2 boron powder at 1123–1223 K for 2–8 h and reported that some alloying elements (Cr, Ni) had a negative impact on the diffusion of boron atoms into the steel surface[25]. Gunes[13] borided gear steels with Ekabor-2 boron powder at 1123–1223 K for 2–6 h and obtained a 15–260 µm boron layer and alloying elements had an effect on both the morphology and the thickness of the boron layer.

In this study, the presence of borides was identified using XRD analysis (Fig. 3*a*–*d*). XRD patterns show that the boride layer consists of borides such as SB and S_2B (S = metal: Fe, Mo, Cr).

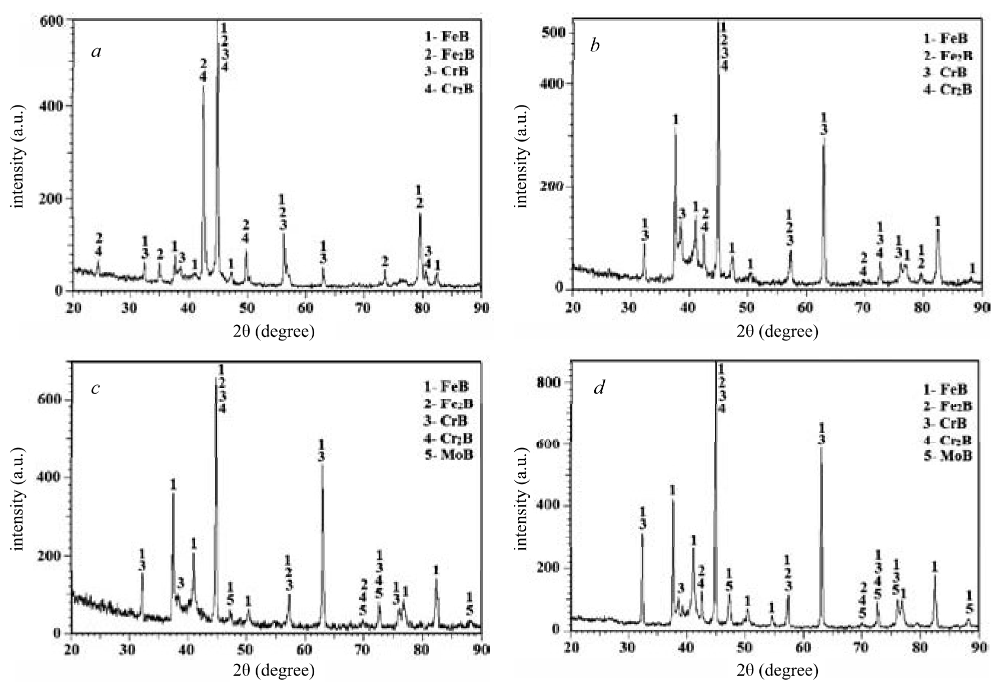

Fig. 3. X-ray diffraction patterns of borided cold work tool steel: 1123 K – 2 h (*a*); 1123 K – 6 h (*b*); 1223 K – 2 h (*c*); 1223 K – 6 h (*d*)

XRD results showed that boride layers formed on the cold work tool steel contained the FeB, Fe_2B, CrB, Cr_2B and MoB phases, respectively in Figs 3*a–d*. With increasing time and temperature, the Fe_2B phase content decreases and the FeB and CrB phases content increases for the steel. The boride layers mainly consist of intermetallic phases (FeB, Fe_2B, CrB and Cr_2B) as a result of diffusion of boron atoms from the boriding compound to the metallic lattice with respect to the holding time.

Microhardness measurements were carried out from the surface to the interior along a line in order to see the variations in the boride layer hardness, transition zone and matrix, respectively. The microhardness of the boride layers was measured at 10 different locations at the same distance from the surface and the average value was taken as the hardness.

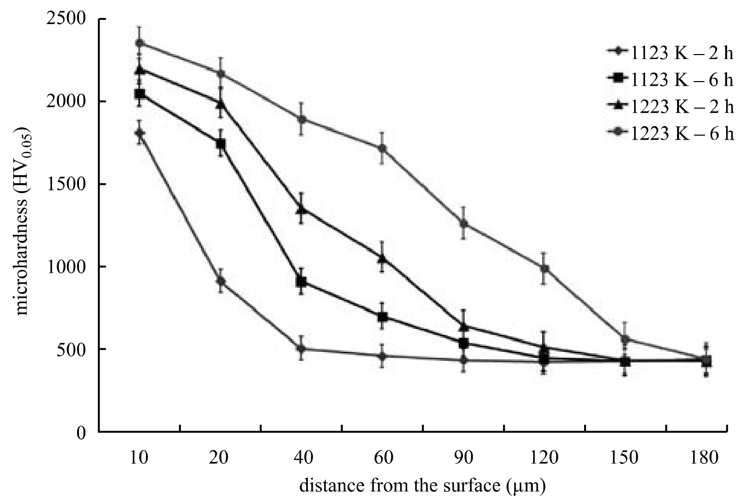

Fig. 4. Variation of hardness of borides formed on the surface of cold work tool steel from surface into interior

Microhardness measurements were carried out on the cross-sections from the surface to the interior along a line (Fig. 4). The hardness of the boride compounds formed on the surface of the steels ranged from 1806 to 2342 $HV_{0,05}$, whereas the Vickers hardness values of the untreated steels was 428 $HV_{0.05}$. When the hardness of the boride layer is compared with the matrix, boride layer hardness is approximately four times greater than that of the matrix.

Contour diagram showing boride layer variations due to boriding temperature and time is given in Fig. 5. Contour diagrams can be used for two purposes: (1) to predict the coating layer thickness with respect to the process parameters, namely time and temperature; (2) to determine the value of process time and temperature for obtaining a predetermined coating layer thickness[18,26]. The boride layer increased with the increase in boriding time and temperature in cold work tool steel.

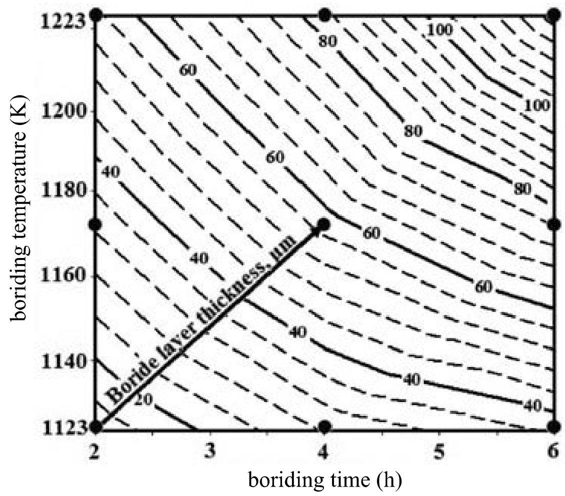

Fig. 5. Contour diagram and thickness values of boride layers with respect to holding time and test temperature

Kinetics. In this study, the effects of the processing temperature and boriding time on the growth kinetics of the boriding layer were also investigated. Kinetic parameters such as processing temperature and time must be known for the control of the boriding treatment and the growth rate constants were calculated using equation (1) (Fig. 6).

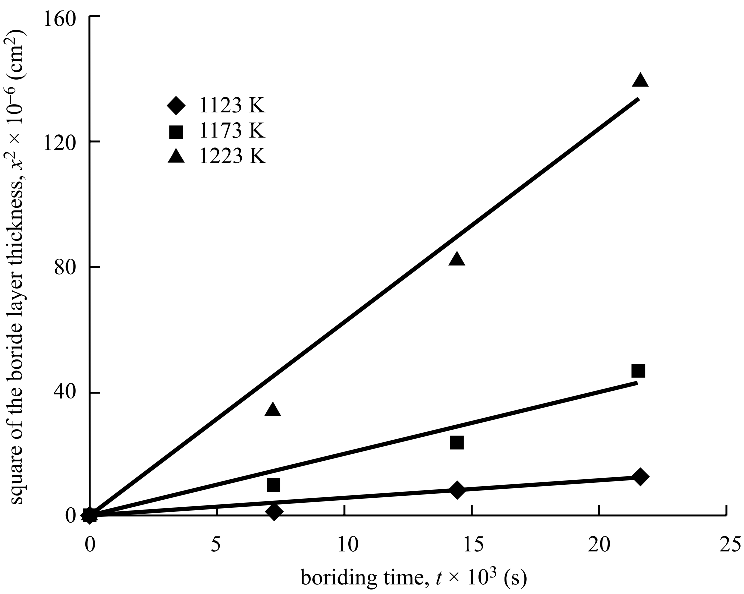

Fig. 6. Square of the boride layer thickness versus holding time in cold work tool steel

As a result, the effective growth rate constants with respect to boriding temperature are 1.38×10^{-10}, 4.27×10^{-10}, and 13.56×10^{-10} cm^2 s^{-1} for the cold work tool steel (Table 1). The plot of ln*D* versus 1/*T* exhibits a linear relationship (Fig. 7), and activation energy of 287.019 kJ/mol for the cold work tool steel was obtained from the slope of the straight lines.

Table 1. Growth rate constant (D) and activation energy (Q) as a function of boriding temperature and steel

Steels	Growth rate constant ($cm^2\ s^{-1}$) temperature (K) 1123	1173	1223	Activation energy (kJ/mol)
Cold work tool steel	1.38×10^{-10}	4.27×10^{-10}	13.56×10^{-10}	287.019

Activation energy values obtained in this study vary in accordance with the chemical composition of the steel. In steel with low carbon and alloying elements, activation energy decreases with the boride layer thickness increases at the boriding treatment. The values calculated in this study are compatible with the values reported in the literature as seen in Table 2 (Refs 9, 27–29). The present study gives the highest activation energy. It can be considered that carbon and alloying elements acted as a diffusion barrier, inhibiting the diffusion of active boron.

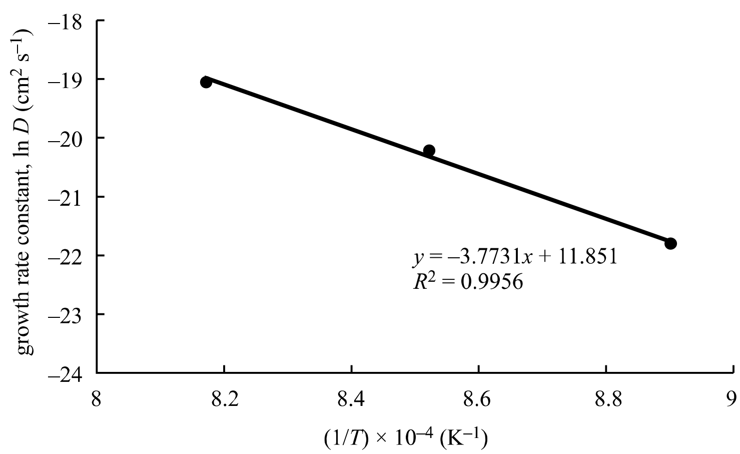

Fig. 7. Growth rate constant versus the processing temperature in cold work tool steel

Table 2. Comparison of activation energy for diffusion of boron with respect to the different boriding media and steel

Steel	Temperature range (K)	Boriding medium	Activation energy (kJ/mol)	References
AISI 1040, P20	1073–1223	pack	168, 200	9
AISI 304, H13	1073–1223	salt bath	253, 244	27
AISI 52100	1123–1223	pack	269	28
AISI 8620	973–1073	plasma paste	100	29
High alloyed cold work tool steel	1123–1223	pack	287.019	present study

CONCLUSIONS

The following conclusions may be derived from the present study:

Boride types formed on the surface of the cold work tool steel have columnar structure.

Depending on the process time, temperature and chemical composition of substrates the depth of the boride layer ranged from 13.14 to 120.82 μm.

The multiphase boride coatings that were thermochemically grown on the cold work tool steel were constituted by the FeB, Fe_2B, CrB, Cr_2B and MoB phases.

The surface hardness of the borided cold work tool steel was in the range of 1806 to 2342 $HV_{0.05}$, while for the untreated steel substrate it was 428 $HV_{0.05}$.

Activation energy of 287.019 kJ/mol for cold work tool was determined.

REFERENCES

1. G. V. LEVCHENKO, A. B. SYCHKOV, A. M. NESTERENKO, V. L. PLYUTA: Formation Features of Highly Resistant Carbide and Boride Coatings Prepared by a Two-stage Method. Metallurgist, **57** (3–4), 237 (2013).
2. C. BINDAL, A. H. UCISIK: Characterization of Borides Formed on Impurity-controlled Chromium-based Low Alloy Steels. Surf Coat Tech, **122**, 208 (1999).
3. M. USTA, I. OZBEK, C. BINDAL, A. H. UCISIK, S. INGOLE, H. LIANG: A Comparative Study of Borided Pure Niobium, Tungsten and Chromium. Vacuum, **80**, 1321 (2006).
4. G. KARTAL, S. TIMUR, M. URGEN, A. ERDEMIR: Electrochemical Boriding of Titanium for Improved Mechanical Properties. Surf Coat Tech, **204**, 3935 (2010).
5. L. QIN, K. YANG, C. LIU, B. TANG: Enhanced Plasma Boriding with Molybdenum Using Double Glow Plasma Surface Alloying Technique. Mater Lett, **82**, 127 (2012).
6. M. KEDDAM: A Kinetic Model for the Borided Layers by the Paste-boriding Process. Appl Surf Sci, **236**, 451 (2004).
7. M. KEDDAM, R. CHEGROUNE: A Model for Studying the Kinetics of the Formation of Fe_2B Boride Layers at the Surface of a Gray Cast Iron. Appl Surf Sci, **256**, 5025 (2010).
8. I. GUNES: Kinetics of Borided Gear Steels. Sadhana, **38**, 527 (2013).
9. C. BINDAL, A. H. UCISIK: Characterization of Boriding of 0.3% C, 0.02% P Plain Carbon Steel. Vacuum, **82**, 90 (2008).
10. I. GUNES, A. DALAR: Effect of Sliding Speed on Friction and Wear Behaviour of Borided Gear Steels. J Balk Tribol Assoc, **19** (3), 325 (2013).
11. I. USLU, H. COMERT, M. IPEK, O. OZDEMIR, C. BINDAL: Evaluation of Borides Formed on AISI P20 Steel. Mater Design, **28**, 55 (2007).
12. S. TAKTAK: Some Mechanical Properties of Borided AISI H13 and 304 Steels. Mater Design, **28**, 1836 (2007).
13. I. GUNES: Wear Behaviour of Plasma Paste Boronized of AISI 8620 Steel with Borax and B_2O_3 Paste Mixtures. J Mater Sci Technol, **29**, 662 (2013).
14. M. TABUR, M. IZCILER, F. GUL, I. KARACAN: Abrasive Wear Behavior of Boronized AISI 8620 Steel. Wear, **266**, 1106 (2009).
15. M. ERDOGAN, I. GUNES, A. DALAR: Investigation of Corrosion Behavior of Borided Gear Steels. T Indian I Metals, **67**, 291 (2014).
16. L. G. YU, K. A. KHOR, G. SUNDARARAJAN: Boride Layer Growth Kinetics during Boriding of Molybdenum by the Spark Plasma Sintering (SPS) Technology. Surf Coat Tech, **201**, 2849 (2006).
17. K. GENEL: Boriding Kinetics of H13 Steel. Vacuum, **80**, 451 (2006).
18. M. BEKTES, A. CALIK, N. UCAR, M. KEDDAM: Pack-boriding of Fe-Mn Binary Alloys: Characterization and Kinetics of the Boride Layers. Mater Charact, **61**, 233 (2010).
19. O. OZDEMIR, M. A. OMAR, M. USTA, S. ZEYTIN, C. BINDAL, A. H. UCISIK: An Investigation on Boriding Kinetics of AISI 316 Stainless Steel. Vacuum, **83**, 175 (2009).

20. B. SELCUK, R. IPEK, M. B. KARAMIS, V. KUZUCU: An Investigation on Surface Properties of Treated Low Carbon and Alloyed Steels. J Mater Process Tech, **103**, 310 (2000).
21. A. K. SINHA: Boriding (Boronizing). ASM Handbook. J Heat Treat (OH, USA), 437 (1991).
22. I. OZBEK, C. BINDAL: Kinetics of Borided AISI M2 High Speed Steel. Vacuum, **86**, 391 (2011).
23. I. CAMPOS, G. RAMIREZ, U. FIGUEROA, J. MARTINEZ, O. MORALES: Evaluation of Boron Mobility on the Phases FeB, Fe_2B and Diffusion Zone in AISI 1045 and M2 Steels. Appl Surf Sci, **253**, 3469 (2007).
24. G. KARTAL, O. L. ERYILMAZ, G. KRUMDICK, A. ERDEMIR, S. TIMUR: Kinetics of Electrochemical Boriding of Low Carbon Steel. Appl Surf Sci, **257**, 6928 (2011).
25. G. C. EFE, M. IPEK, I. OZBEK, C. BINDAL: Kinetics of Borided 31CrMoV9 and 34CrAlNi7 Steels. Mater Charact, **59**, 23 (2008).
26. S. SEN, U. SEN, C. BINDAL: The Growth Kinetics of Borides Formed on Boronized AISI 4140 Steel. Vacuum, **77**, 195 (2005).
27. S. TAKTAK: A Study on the Diffusion Kinetics of Borides on Boronized Cr-based Steels. J Mater Sci, **41**, 7590 (2006).
28. Y. KAYALI, I. GUNES, S. ULU: Diffusion Kinetics of Borided AISI 52100 and AISI 440C Steels. Vacuum, **86**, 1428 (2012).
29. I. GUNES, S. ULKER, S. TAKTAK: Kinetics of Plasma Paste Boronized AISI 8620 Steel in Borax Paste Mixtures. Prot Met Phys Chem Surf, **49**, 567 (2013).

Received 21 June 2014
Revised 30 August 2014

Vol. 38 No 4A 2015

OXIDATION COMMUNICATIONS

Scientific Bulgarian Communications
Ltd., Co.

BORIDE LA
ALLOYED C

By: Gunes, I (Gur

OXIDATION COM
Volume: 38 Issu
Published: 2015
Document Type:
View Journal Im

OXIDATION COMMUNICATIONS

Impact Factor

0.489 *2015* **0.337** *5 year*

JCR® Category	*Rank in Category*	*Quartile in Category*
CHEMISTRY, MULTIDISCIPLINARY	**144 of 163**	**Q4**

Data from the 2015 edition of Journal Citation Reports

Publisher
SCIBULCOM LTD, PO BOX 249, 1113 SOFIA, BULGARIA

ISSN: 0209-4541

Research Domain
Chemistry

Close Window

Abstract

In this study, the
Ekabor-2 powder
1173 and 1223 K
diffraction techni
the surface of the

Depending on th
on the surface of
compounds form
hardness value o
was 287.019 kJ/mol.

Keywords

Author Keywords: boride layer; microhardness; kinetics; activation energy

KeyWords Plus: AISI 8620 STEEL; WEAR BEHAVIOR; GEAR STEELS; MECHANICAL-PROPERTIES; DIFFUSION KINETICS; PASTE MIXTURES; SURFACE; MOLYBDENUM; CHROMIUM; SPEED

Author Information

Reprint Address: Gunes, I (reprint author)

Afyon Kocatepe Univ, Fac Technol, Dept Met & Mat Engn, TR-03200 Afyon, Turkey.

Addresses:

[1] Afyon Kocatepe Univ, Fac Technol, Dept Met & Mat Engn, TR-03200 Afyon, Turkey

E-mail Addresses: igunes@aku.edu.tr

Publisher

SCIBULCOM LTD, PO BOX 249, 1113 SOFIA, BULGARIA

Categories / Classification

Research Areas: Chemistry

Web of Science Categories: Chemistry, Multidisciplinary

See more data fields

Cited References: 29

Showing 29 of 29 **View All in Cited References page** *(from Web of Science Core Collection)*

1. **Pack-boriding of Fe-Mn binary alloys: Characterization and kinetics of the boride layers** **Times Cited: 28**
By: Bektes, M.; Calik, A.; Ucar, N.; et al.
MATERIALS CHARACTERIZATION Volume: 61 Issue: 2 Pages: 233-239 Published: FEB 2010

2. **Characterization of borides formed on impurity-controlled chromium-based low alloy steels** **Times Cited: 73**
By: Bindal, C; Ucisik, AH
SURFACE & COATINGS TECHNOLOGY Volume: 122 Issue: 2-3 Pages: 208-213 Published: DEC 15 1999

3. **Characterization of boriding of 0.3% C, 0.02% P plain carbon steel** **Times Cited: 20**
By: Bindal, C.; Ucisik, A. H.
VACUUM Volume: 82 Issue: 1 Pages: 90-94 Published: SEP 12 2007

4. **Evaluation of boron mobility on the phases FeB, Fe2B and diffusion zone in AISI 1045 and M2 steels** **Times Cited: 42**
By: Campos, I.; Ramirez, G.; Figueroa, U.; et al.
APPLIED SURFACE SCIENCE Volume: 253 Issue: 7 Pages: 3469-3475 Published: JAN 30 2007

5. **Kinetics of borided 31CrMoV9 and 34CrAlNi7 steels** **Times Cited: 21**
By: Efe, Gooezde Celebi; Ipek, Mediha; Ozbek, Ibrahim; et al.
MATERIALS CHARACTERIZATION Volume: 59 Issue: 1 Pages: 23-31 Published: JAN 2008

6. **Investigation of Corrosion Behavior of Borided Gear Steels** **Times Cited: 4**
By: Erdogan, Muzaffer; Gunes, Ibrahim; Dalar, Alper
TRANSACTIONS OF THE INDIAN INSTITUTE OF METALS Volume: 67 Issue: 2 Pages: 291-297 Published: APR 2014

7. **Boriding kinetics of H13 steel** **Times Cited: 86**
By: Genel, K
VACUUM Volume: 80 Issue: 5 Pages: 451-457 Published: JAN 26 2006

8. **EFFECT OF SLIDING SPEED ON FRICTION AND WEAR BEHAVIOUR OF BORIDED GEAR STEELS** **Times Cited: 19**
By: Gunes, I.; Dalar, A.
JOURNAL OF THE BALKAN TRIBOLOGICAL ASSOCIATION Volume: 19 Issue: 3 Pages: 325-339 Published: 2013

9. **Kinetics of plasma paste boronized AISI 8620 steel in borax paste mixtures** **Times Cited: 9**
By: Gunes, I.; Ulker, S.; Taktak, S.
PROTECTION OF METALS AND PHYSICAL CHEMISTRY OF SURFACES Volume: 49 Issue: 5 Pages: 567-573 Published: SEP 2013

10. **Wear Behaviour of Plasma Paste Boronized of AISI 8620 Steel with Borax and B2O3 Paste Mixtures** **Times Cited: 18**
By: Gunes, Ibrahim
JOURNAL OF MATERIALS SCIENCE & TECHNOLOGY Volume: 29 Issue: 7 Pages: 662-668 Article Number: 1005-0302(2013)29:7<662:WBOPPB>2.0.TX;2-# Published: JUL 2013

11. **Kinetics of borided gear steels** **Times Cited: 17**
By: Gunes, Ibrahim
SADHANA-ACADEMY PROCEEDINGS IN ENGINEERING SCIENCES Volume: 38 Issue: 3 Pages: 527-541 Published: JUN 2013

12. **Kinetics of electrochemical boriding of low carbon steel** **Times Cited: 42**
By: Kartal, G.; Eryilmaz, O. L.; Krumdick, G.; et al.

APPLIED SURFACE SCIENCE Volume: 257 Issue: 15 Pages: 6928-6934 Published: MAY 15 2011

13. **Electrochemical bonding of titanium for improved mechanical properties** Times Cited: 39
By: Kartal, G.; Timur, S.; Urgen, M.; et al.
SURFACE & COATINGS TECHNOLOGY Volume: 204 Issue: 23 Pages: 3935-3939 Published: AUG 25 2010

14. **Diffusion kinetics of borided AISI 52100 and AISI 440C steels** Times Cited: 34
By: Kayali, Yusuf; Gunes, Ibrahim; Ulu, Sinan
VACUUM Volume: 86 Issue: 10 Pages: 1428-1434 Published: APR 27 2012

15. **A model for studying the kinetics of the formation of Fe2B boride layers at the surface of a gray cast iron** Times Cited: 26
By: Keddam, M.; Chegroune, R.
APPLIED SURFACE SCIENCE Volume: 256 Issue: 16 Pages: 5025-5030 Published: JUN 2010

16. **A kinetic model for the borided layers by the paste-boriding process** Times Cited: 53
By: Keddam, M
APPLIED SURFACE SCIENCE Volume: 236 Issue: 1-4 Pages: 451-455 Published: SEP 15 2004

17. **Formation features of highly resistant carbide and boride coatings prepared by a two-stage method** Times Cited: 1
By: Levchenko, G. V.; Sychkov, A. B.; Nesterenko, A. M.; et al.
METALLURGIST Volume: 57 Issue: 3-4 Pages: 237-243 Published: JUL 2013

18. **Kinetics of bonded AISI M2 high speed steel** Times Cited: 30
By: Ozbek, I.; Bindal, C.
VACUUM Volume: 86 Issue: 4 Pages: 391-397 Published: NOV 11 2011

19. **Enhanced plasma bonding with molybdenum using double glow plasma surface alloying technique** Times Cited: 12
By: Qin, Lin; Yang, Kunkun; Liu, Chengsong; et al.
MATERIALS LETTERS Volume: 82 Pages: 127-129 Published: SEP 1 2012

20. **Electroluminescence properties of a PIN structure made by nearly stoichiometric a-SiCx:H active layer** Times Cited: 24
By: Sel, Kivanc; Akaoglu, Baris; Ozdemir, Orhan; et al.
VACUUM Volume: 83 Issue: 5 Pages: 813-818 Published: JAN 1 2009

21. **An investigation on surface properties of treated low carbon and alloyed steels (boriding and carburizing)** Times Cited: 52
By: Selcuk, B; Ipek, R; Karamis, MB; et al.
JOURNAL OF MATERIALS PROCESSING TECHNOLOGY Volume: 103 Issue: 2 Pages: 310-317 Published: JUN 15 2000

22. **The growth kinetics of borides formed on boronized AISI 4140 steel** Times Cited: 51
By: Sen, S; Sen, U; Bindal, C
VACUUM Volume: 77 Issue: 2 Pages: 195-202 Published: JAN 17 2005

23. Title: [not available] Times Cited: 130
By: SINHA AK
ASM HDB Volume: 4 Pages: 437 Published: 1991

24. **Abrasive wear behavior of boronized AISI 8620 steel** Times Cited: 69
By: Tabur, M.; Izciler, M.; Gul, F.; et al.
WEAR Volume: 266 Issue: 11-12 Pages: 1106-1112 Published: MAY 30 2009

25. **A study on the diffusion kinetics of borides on boronized Cr-based steels** Times Cited: 29
By: Taktak, Sukru
JOURNAL OF MATERIALS SCIENCE Volume: 41 Issue: 22 Pages: 7590-7596 Published: NOV 2006

26. **Some mechanical properties of borided AISI H13 and 304 steels** **Times Cited: 86**
By: Taktak, Sukru
MATERIALS & DESIGN Volume: 28 Issue: 6 Pages: 1836-1843 Published: 2007

27. **Evaluation of borides formed on AISI P20 steel** **Times Cited: 68**
By: Uslu, I.; Comert, H.; Ipek, M.; et al.
MATERIALS & DESIGN Volume: 28 Issue: 1 Pages: 55-61 Published: 2007

28. **A comparative study of borided pure niobium, tungsten and chromium** **Times Cited: 29**
By: Usta, Metin; Ozbek, Ibrahim; Bindal, Cuma; et al.
VACUUM Volume: 80 Issue: 11-12 Pages: 1321-1325 Published: SEP 7 2006

29. **Boride layer growth kinetics during boriding of molybdenum by the Spark Plasma Sintering (SPS) technology** **Times Cited: 26**
By: Yu, L. G.; Khor, Khiam Aik; Sundararajan, G.
SURFACE & COATINGS TECHNOLOGY Volume: 201 Issue: 6 Pages: 2849-2853 Published: DEC 4 2006

Showing 29 of 29 **View All in Cited References page**

BORIDE LAYER GROWTH KINETICS OF THE BORIDED HIGH ALLOYED COLD WORK TOOL STEEL

By: Gunes, I (Gunes, I.)

OXIDATION COMMUNICATIONS
Volume: 38 **Issue:** 1 **Pages:** 157-165
Published: 2015
Document Type: Article
View Journal Impact

Abstract

In this study, the case properties and diffusion kinetics of high alloyed cold work tool steel bonded in Ekabor-2 powder were investigated by conducting a series of experiments at temperatures of 1123, 1173 and 1223 K for 2,4 and 6 h. The boride layer was characterised by optical microscopy, X-ray diffraction technique and micro-Vickers hardness tester. X-ray diffraction analysis of boride layers on the surface of the steels revealed the existence of FeB, Fe2B, CrB, Cr2B and MoB compounds.

Depending on the chemical composition of substrates and bonding time, the boride layer thickness on the surface of the steel ranged from 13.14 and 120.82 mu m. The hardness of the boride compounds formed on the surface of the steels ranged from 1806 to 2342 HV0.05, whereas the Vickers hardness value of the untreated steels was 428 HV0.05. The activation energy (Q) of the borided steel was 287.019 kJ/mol.

Keywords

Author Keywords: boride layer; microhardness; kinetics; activation energy
KeyWords Plus: AISI 8620 STEEL; WEAR BEHAVIOR; GEAR STEELS; MECHANICAL-PROPERTIES; DIFFUSION KINETICS; PASTE MIXTURES; SURFACE; MOLYBDENUM; CHROMIUM; SPEED

Author Information

Reprint Address: Gunes, I (reprint author)

\+ Afyon Kocatepe Univ, Fac Technol, Dept Met & Mat Engn, TR-03200 Afyon, Turkey.

Addresses:

\+ [1] Afyon Kocatepe Univ, Fac Technol, Dept Met & Mat Engn, TR-03200 Afyon, Turkey

E-mail Addresses: igunes@aku.edu.tr

Publisher

SCIBULCOM LTD, PO BOX 249, 1113 SOFIA, BULGARIA

Categories / Classification

Research Areas: Chemistry

Web of Science Categories: Chemistry, Multidisciplinary

Cited References: 29

Showing 29 of 29 **View All in Cited References page** *(from Web of Science Core Collection)*

1. **Pack-boriding of Fe-Mn binary alloys: Characterization and kinetics of the boride layers** **Times Cited: 28**
By: Bektes, M.; Calik, A.; Ucar, N.; et al.
MATERIALS CHARACTERIZATION Volume: 61 Issue: 2 Pages: 233-239 Published: FEB 2010

2. **Characterization of borides formed on impurity-controlled chromium-based low alloy steels** **Times Cited: 73**
By: Bindal, C; Ucisik, AH
SURFACE & COATINGS TECHNOLOGY Volume: 122 Issue: 2-3 Pages: 208-213 Published: DEC 15 1999

3. **Characterization of boriding of 0.3% C, 0.02% P plain carbon steel** **Times Cited: 20**
By: Bindal, C.; Ucisik, A. H.
VACUUM Volume: 82 Issue: 1 Pages: 90-94 Published: SEP 12 2007

4. **Evaluation of boron mobility on the phases FeB, Fe2B and diffusion zone in AISI 1045 and M2 steels** **Times Cited: 42**
By: Campos, I.; Ramirez, G.; Figueroa, U.; et al.
APPLIED SURFACE SCIENCE Volume: 253 Issue: 7 Pages: 3469-3475 Published: JAN 30 2007

5. **Kinetics of borided 31CrMoV9 and 34CrAlNi7 steels** **Times Cited: 21**
By: Efe, Gooezde Celebi; Ipek, Mediha; Ozbek, Ibrahim; et al.
MATERIALS CHARACTERIZATION Volume: 59 Issue: 1 Pages: 23-31 Published: JAN 2008

6. **Investigation of Corrosion Behavior of Borided Gear Steels** **Times Cited: 4**
By: Erdogan, Muzaffer; Gunes, Ibrahim; Dalar, Alper
TRANSACTIONS OF THE INDIAN INSTITUTE OF METALS Volume: 67 Issue: 2 Pages: 291-297 Published: APR 2014

7. **Boriding kinetics of H13 steel** **Times Cited: 86**
By: Genel, K
VACUUM Volume: 80 Issue: 5 Pages: 451-457 Published: JAN 26 2006

8. **EFFECT OF SLIDING SPEED ON FRICTION AND WEAR BEHAVIOUR OF BORIDED GEAR STEELS** **Times Cited: 19**
By: Gunes, I.; Dalar, A.
JOURNAL OF THE BALKAN TRIBOLOGICAL ASSOCIATION Volume: 19 Issue: 3 Pages: 325-339 Published: 2013

9. **Kinetics of plasma paste boronized AISI 8620 steel in borax paste mixtures** **Times Cited: 9**
By: Gunes, I.; Ulker, S.; Taktak, S.
PROTECTION OF METALS AND PHYSICAL CHEMISTRY OF SURFACES Volume: 49 Issue: 5 Pages: 567-573 Published: SEP 2013

10. **Wear Behaviour of Plasma Paste Boronized of AISI 8620 Steel with Borax and B2O3 Paste Mixtures** **Times Cited: 18**
By: Gunes, Ibrahim
JOURNAL OF MATERIALS SCIENCE & TECHNOLOGY Volume: 29 Issue: 7 Pages: 662-668 Article Number: 1005-0302(2013)29:7<662:WBOPPB>2.0.TX;2-# Published: JUL 2013

11. **Kinetics of borided gear steels** **Times Cited: 17**
By: Gunes, Ibrahim
SADHANA-ACADEMY PROCEEDINGS IN ENGINEERING SCIENCES Volume: 38 Issue: 3 Pages: 527-541 Published: JUN 2013

12. **Kinetics of electrochemical boriding of low carbon steel** **Times Cited: 42**
By: Kartal, G.; Eryilmaz, O. L.; Krumdick, G.; et al.

APPLIED SURFACE SCIENCE Volume: 257 Issue: 15 Pages: 6928-6934 Published: MAY 15 2011

13. **Electrochemical bonding of titanium for improved mechanical properties** **Times Cited: 39**
By: Kartal, G.; Timur, S.; Urgen, M.; et al.
SURFACE & COATINGS TECHNOLOGY Volume: 204 Issue: 23 Pages: 3935-3939 Published: AUG 25 2010

14. **Diffusion kinetics of borided AISI 52100 and AISI 440C steels** **Times Cited: 34**
By: Kayali, Yusuf; Gunes, Ibrahim; Ulu, Sinan
VACUUM Volume: 86 Issue: 10 Pages: 1428-1434 Published: APR 27 2012

15. **A model for studying the kinetics of the formation of Fe2B boride layers at the surface of a gray cast iron** **Times Cited: 26**
By: Keddam, M.; Chegroune, R.
APPLIED SURFACE SCIENCE Volume: 256 Issue: 16 Pages: 5025-5030 Published: JUN 2010

16. **A kinetic model for the borided layers by the paste-boriding process** **Times Cited: 53**
By: Keddam, M
APPLIED SURFACE SCIENCE Volume: 236 Issue: 1-4 Pages: 451-455 Published: SEP 15 2004

17. **Formation features of highly resistant carbide and boride coatings prepared by a two-stage method** **Times Cited: 1**
By: Levchenko, G. V.; Sychkov, A. B.; Nesterenko, A. M.; et al.
METALLURGIST Volume: 57 Issue: 3-4 Pages: 237-243 Published: JUL 2013

18. **Kinetics of bonded AISI M2 high speed steel** **Times Cited: 30**
By: Ozbek, I.; Bindal, C.
VACUUM Volume: 86 Issue: 4 Pages: 391-397 Published: NOV 11 2011

19. **Enhanced plasma bonding with molybdenum using double glow plasma surface alloying technique** **Times Cited: 12**
By: Qin, Lin; Yang, Kunkun; Liu, Chengsong; et al.
MATERIALS LETTERS Volume: 82 Pages: 127-129 Published: SEP 1 2012

20. **Electroluminescence properties of a PIN structure made by nearly stoichiometric a-SiCx:H active layer** **Times Cited: 24**
By: Sel, Kivanc; Akaoglu, Baris; Ozdemir, Orhan; et al.
VACUUM Volume: 83 Issue: 5 Pages: 813-818 Published: JAN 1 2009

21. **An investigation on surface properties of treated low carbon and alloyed steels (boriding and carburizing)** **Times Cited: 52**
By: Selcuk, B; Ipek, R; Karamis, MB; et al.
JOURNAL OF MATERIALS PROCESSING TECHNOLOGY Volume: 103 Issue: 2 Pages: 310-317 Published: JUN 15 2000

22. **The growth kinetics of borides formed on boronized AISI 4140 steel** **Times Cited: 51**
By: Sen, S; Sen, U; Bindal, C
VACUUM Volume: 77 Issue: 2 Pages: 195-202 Published: JAN 17 2005

23. Title: [not available] **Times Cited: 130**
By: SINHA AK
ASM HDB Volume: 4 Pages: 437 Published: 1991

24. **Abrasive wear behavior of boronized AISI 8620 steel** **Times Cited: 69**
By: Tabur, M.; Izciler, M.; Gul, F.; et al.
WEAR Volume: 266 Issue: 11-12 Pages: 1106-1112 Published: MAY 30 2009

25. **A study on the diffusion kinetics of borides on boronized Cr-based steels** **Times Cited: 29**
By: Taktak, Sukru
JOURNAL OF MATERIALS SCIENCE Volume: 41 Issue: 22 Pages: 7590-7596 Published: NOV 2006

26. **Some mechanical properties of borided AISI H13 and 304 steels** Times Cited: 86
By: Taktak, Sukru
MATERIALS & DESIGN Volume: 28 Issue: 6 Pages: 1836-1843 Published: 2007

27. **Evaluation of borides formed on AISI P20 steel** Times Cited: 68
By: Uslu, I.; Comert, H.; Ipek, M.; et al.
MATERIALS & DESIGN Volume: 28 Issue: 1 Pages: 55-61 Published: 2007

28. **A comparative study of borided pure niobium, tungsten and chromium** Times Cited: 29
By: Usta, Metin; Ozbek, Ibrahim; Bindal, Cuma; et al.
VACUUM Volume: 80 Issue: 11-12 Pages: 1321-1325 Published: SEP 7 2006

29. **Boride layer growth kinetics during boriding of molybdenum by the Spark Plasma Sintering (SPS) technology** Times Cited: 26
By: Yu, L. G.; Khor, Khiam Aik; Sundararajan, G.
SURFACE & COATINGS TECHNOLOGY Volume: 201 Issue: 6 Pages: 2849-2853 Published: DEC 4 2006

Showing 29 of 29 View All in Cited References page

TÜBİTAK » ULAKBİM » CABİM

İBRAHİM GÜNEŞ, [IBRAHIM(45551), 0,00 TL] [**Yayın Teşvik (UBYT)**]

Üyelik İşleri -- [**Yayın Teşvik (UBYT)**] -- **Belge Sağlama (BS)** -- **Çık**
Dergi Listesi -- Yeni Başvuru -- Başvuru Durumları -- 2013 Yılı UBYT Programı Arama Motoru -- Yardım (Sıkca Sorulan Sorular)

ULUSLARARASI BİLİMSEL YAYIN TEŞVİK PROGRAMI
UBYT [anahtar: OXIDATION COMMUNICATIONS, Yayın Yılı: 2017]

1993 yılında sadece müsbet ilimlere verilmek üzere başlatılmış olan UBYT programı 2006 yılında sosyal ve beşeri alanlardaki yayınlara da teşvik verilmeye başlanması ile devam etmiştir. 2016 yılında ise Araştırmacı Teşviği ve Danışman Teşviği olmak üzere iki ayrı teşvik uygulaması işe sürdürülmektedir.

Danışman Teşvik Uygulaması:

Araştırmacı Teşvik Uygulaması:

2015 yılı UBYT Programı Uygulama Esasları

Başvuru için TIKLAYINIZ.

Dergi Adı ya da ISSN Numarası: OXIDATION COMMUNICA 2017 Dergi Tara

Taranan: `**OXIDATION COMMUNICATIONS**, Yayın Yılı: **2017**'

1 kayıt

ISSN	Yayın Adı	Puanı	Teşvik Miktarı
0209-4541	OXIDATION COMMUNICATIONS	0.02	500 TL

Sayfalar: [1]