

YÜZEY MÜHENDİSLİĞİ VE İLERİ KAPLAMA TEKNOLOJİLERİ

Levent Cenk KUMRUOĞLU
Garip ERDOĞAN



© Copyright 2021

Bu kitabın, basım, yayın ve satış hakları Akademisyen Kitabevi A.Ş.'ne aittir. Anılan kuruluşun izni alınmadan kitabın tümü ya da bölümleri mekanik, elektronik, fotokopi, manyetik kayıt ve/veya başka yöntemlerle çoğaltılamaz, basılamaz, dağıtılamaz. Tablo, şekil ve grafikler izin alınmadan, ticari amaçlı kullanılamaz. Bu kitap T.C. Kültür Bakanlığı bandrolü ile satılmaktadır.

ISBN

978-625-8037-44-9

Kitap Adı

Yüzey Mühendisliği ve İleri Kaplama Teknolojileri

Yazarlar

Levent Cenk KUMRUOĞLU

ORCID iD: 0000-0001-6420-3761

Garip ERDOĞAN

ORCID iD: 0000-0002-3924-9984

Yayın Koordinatörü

Yasin DİLMEN

Sayfa ve Kapak Tasarımı

Akademisyen Dizgi Ünitesi

Yayıncı Sertifika No

47518

Baskı ve Cilt

Vadi Matbaacılık

Bisac Code

TEC000000

DOI

10.37609/akya.893

GENEL DAĞITIM

Akademisyen Kitabevi A.Ş.

Halk Sokak 5 / A

Yenişehir / Ankara

Tel: 0312 431 16 33

siparis@akademisyen.com

www.akademisyen.com

İÇİNDEKİLER

BÖLÜM 1

YÜZEY MÜHENDİSLİĞİ

1.1. YüzeY İşlemler	3
1.1.1. YüzeY Kaplamalar	3
1.1.2. YüzeY Modifikasyonu	3
1.1.2.1. YüzeYin Kimyasal Bileşimi Değişmeden Yapılan Termal YüzeY Sertleştirme İşlemleri	4
1.1.2.1.1. Alevle YüzeY Sertleştirme	6
1.1.2.1.2. İndüksiyonla YüzeY Sertleştirme	8
1.1.2.1.3. Lazer ile yüzeY sertleştirme ve işleme	13
1.1.2.1.4. Elektron Işını ile YüzeY Sertleştirme	16
1.1.2.2. YüzeYin kimyasal bileşimini değiştirerek yapılan termokimyasal yüzeY sertleştirme işlemleri	16
1.1.2.2.1. Karbürleme	17
1.1.2.2.1.1. Katı ortamda karbürleme	18
1.1.2.2.1.2. Gaz karbürleme	20
1.1.2.2.1.3. Sıvı karbürleme	24
1.1.2.2.1.4. Plazma karbürleme	25
1.1.2.2.2. Nitrürleme	25
1.1.2.2.3. Karbo-Nitrürleme	26
1.1.2.2.4. Borlama	28
1.1.2.2.5. Plazma Borlama	30
1.1.2.2.6. Termo Reaktif Difüzyon (TRD)	33
1.1.2.2.7. YüzeY Mühendisliğinde Yaygın Kullanılan Tahribatsız Muayene Yöntemleri	35

BÖLÜM 2

PLAZMA BİLİMİ VE MÜHENDİSLİĞİ

2.1. Plazma Parametreleri	42
2.2. Plazma Türleri ve Uygulamaları	50
2.2.1. Glow Deşarj:	50
2.2.2. DC ve Puls DC Plazma Deşarj	54
2.2.3. Magnetron Uygulamaları	55
2.2.4. Radyo Frekansı (RF Diyot) Deşarj	59
2.2.5. Lazer ile İndüklenmiş Plazma (LIP) ve Lazer YüzeY Modifikasyonları	61

2.2.6. Ark deşarj yöntemi.....	65
2.2.7. Katodik Ark PVD Uygulaması.....	69
2.2.8. Plazma Nitrasyon Süreçleri ve Uygulamalar.....	86
2.2.8.1. Plazma Nitrasyon	86
2.2.8.2. Plazma Nitrasyon Uygulamaları 1 (Kam mili).....	89
2.2.8.3 Plazma Nitrasyon Uygulamaları 2 (Ektrüzyon Kalıbı)	98
2.2.3. Plazma Elektroliz ve Uygulamaları	99
BÖLÜM 3	
TERMAL SPREY TEKNOLOJİSİ	
3.1. Plazma Oluşum Süreçleri ve Plazma Jeti Üreteçleri	109
3.1.1. İlk Enerji Transferi: Elektron Gaz etkileşimleri.....	110
3.1.2. Termodinamik Etkileşimler	118
3.1.3. Taşınım Özellikleri	119
3.1.4. Kaplama oluşumu	121
3.2. Plazma Sprey ile Kaplama Uygulamaları	124
3.2.1. Aşınma Dirençli Kaplamalar	124
3.2.2. Gaz Türbinlerinde Uygulamalar	127
3.2.3. Biyomedikal Kaplama Uygulamaları	133
3.3. Sonuç ve Gelecek Değerlendirmesi.....	136
KAYNAKLAR.....	137

KAYNAKLAR

1. Cionea, C. Microstructural Evolution Of Surface Layers During Electrolytic Plasma Processing. <http://hdl.handle.net/10106/4922>
2. Kumruoğlu, L. C. Elektrolitik plazma teknolojisi ile çeliklere uygulanan yüzey modifikasyon işlemleri - Ulusal Tez ve Araştırma Merkezi - Akademik Tezler ve Araştırmalar. (Sakarya Üniversitesi, Fen Bilimleri Enstitüsü, 2012).
3. Erdemir Yayınları. *Çelik Yüzeylerin Kaplanması*. (2006).
4. Wang, S.Q., Wei M.X., Zhao Y.T. Effects of the tribo-oxide and matrix on dry sliding wear characteristics and mechanisms of a cast steel, *Wear* Vol. 269, Issues 5-6, 19, July 2010, pp. 424-434.
5. V. N. Duradzhi, T. S. Lavrova, A. M. Mokrova Thermochemical treatment of steel in an electrolytic plasma 1986, Corpus ID: 92814970 Materials Science Thermochemical Treatment of Steel in an Electrolytic Plasma.
6. Yüksel M., *Malzeme Bilgisi*. (1998).
7. T Wierzchon, & T Burakowski. *Surface engineering of metals: principles, equipment, technologies* -. (content.taylorfrancis.com, 1998).
8. Ayhan Dayanç. Çelik ve Döküm Kam Millerinin Plazma Nitritleme İşlemi ile Tribolojik Özelliklerinin Artırılması. (Sivas Cumhuriyet Üniversitesi, 2017).
9. L. C. Kumruoğlu, Elektrokimya, Metalografi, Korozyon ve Plazma Elektrolizi Lisans ve Lisansüstü Dersleri Ders Notları.
10. Başaran, B., H. 2007, Saf demirin ethanolamine çözeltisi içerisinde elektrolitik plazma yöntemiyle yüzey sertleştirilmesi, (GYTE Mühendislik ve Fen Bilimleri Enstitüsü yüksek lisans tezi, 2007).
11. Ulutan M., AISI 4140 Çeliğinin Yüzey Sertleştirme İşlemleri ve Kaplama Yöntemleri Sonrası Mekanik Davranışlarının Araştırılması Doktora Tezi, (Eskişehir Osmangazi Üniversitesi, Fen Bilimleri Enstitüsü Makine Mühendisliği Anabilim Dalı, 2007).
12. Çelik, A., Alsan, A. & Karakan, M. Plazma İle Termokimyasal Yüzey İşlemleri. <https://www.mmo.org.tr/temmuz-2002/makale/makale-plazma-ile-termokimyasal-yuzey-islemleri>
13. Bhadeshia, H. & Honeycombe, R. *Steels: Microstructure and Properties*. (Butterworth-Heinemann, 2017).
14. Committee, A. I. H. *Metals handbook*. (ASM International, 1990).
15. Sheng, S. L., Liu, Q., Ma, Y. & Ren, J. Wear performance of laser surface hardened GCr15 steel. *J. Wuhan Univ. Technol.-Mater Sci Ed* **25**, 84–88 (2010).
16. El-Labban, H. F., Abdelaziz, M. & Mahmoud, E. R. I. Laser Surface Melting of carbon Steel: Part II: Effect of Laser Beam Power on Microstructural Features and Surface Hardness.
17. Wang, C.-C. & Hwang, J.-R. Surface hardening of AISI 4340 steel by electron beam treatment. *Surf. Coat. Technol.* **64**, 29–33 (1994).
18. Luk, S. F., Leung, T. P., Miu, W. S. & Pashby, I. Heating performance of electrolytic heat-treatment in aqueous solution by pulse current. *J. Mater. Process. Technol.* **63**, 833–838 (1997).
19. Suchánek, J. & Kuklík, V. Influence of heat and thermochemical treatment on abrasion resistance of structural and tool steels. *Wear* **267**, 2100–2108 (2009).
20. Grum, J. Comparison of different techniques of laser surface hardening. *J. Achiev. Mater. Manuf. Eng.* **24**, 9 (2007).

21. Bermúdez, M. D., Iglesias, P., Jiménez, A. E. & Martínez-Nicolás, G. Influence of sliding frequency on reciprocating wear of mold steel with different microstructures. *Wear* **267**, 1784–1790 (2009).
22. Luk, S. F., Leung, T. P., Miu, W. S. & Pashby, I. Development of electrolytic heat-treatment in aqueous solution. *J. Mater. Process. Technol.* **84**, 189–192 (1998).
23. Lee, M. K., Kim, G. H., Kim, K. H. & Kim, W. W. Effects of the surface temperature and cooling rate on the residual stresses in a flame hardening of 12Cr steel. *J. Mater. Process. Technol.* **176**, 140–145 (2006).
24. Davis J, D. J. Surface Engineering for Corrosion and Wear Resistance - CRC Press Book. Available at: <https://www.crcpress.com/Surface-Engineering-for-Corrosion-and-Wear-Resistance/Davis/p/book/9781907747663>. (Accessed: 25th October 2018)
25. L.C. Kumruoğlu, Isıl Yüzey Sertleştirme, , SCÜ, MMM, FBE Ders Notları,
26. Zeytin S.,Metallerin Isıl İşlemi SAU Ders Notları,. (1999).
27. <https://portal.tpu.ru/departments/laboratory/mnol-nk/Tab/17%20Localized%20Hardening.pdf> 2021
28. Saraçoğlu, M.H.,D2 çeliğinden üretilmiş ve değişik şarlarda plazma nitrülenmiş zımbaların aşınma davranışının incelenmesi. (Uludağ Üniversitesi Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, 2007., 2007).
29. AISI 4340, 4140, 8640, 5140, 1040, Katalog ve Stanart Bilgileri, İSTE, Metalurji Malzeme Böl. Kimyasal Metalurji, Ders Dökümanları
30. Jayanti S. Hardenability of Steel: 4 Factors | Metallurgy. Available at: <http://www.engineeringenotes.com/metallurgy/steel/hardenability-of-steel-4-factors-metallurgy/26025>. (Accessed: 29th October 2018)
31. Kandpal, B. C., Chutani, A., Gulia, A. & Sadanna, C. A Review On Jominy Test And Determination Of Effect Of Alloying Elements On Hardenability Of Steel Using Jominy End Quench Test. **1**, 7
32. Rawers, J. 2006 Nitrogen As A Friendly Addition To Steel. Journal ID: ISSN 1611-4442
33. Davis, J. R. *Surface Hardening of Steels: Understanding the Basics*. (ASM International, 2002).
34. Akım Beslemeli Paralel Rezonans İnverterli Bir İndüksiyonlu Isıtma Uygulaması. https://www.researchgate.net/Publication/236672860_Akım_Beslemeli_Paralel_Rezonans_Inverterli_Bir_Induksiyonlu_Isitma_Uygulaması. (Accessed: 25th October 2018)
35. Durukan, I., <http://etd.lib.metu.edu.tr/upload/12608879/index.pdf>
36. Islam, M. U. An overview of research in the fields of laser surface modification and laser machining at the Integrated Manufacturing Technologies Institute, NRC. *Adv. Perform. Mater.* **3**, 215–238 (1996).
37. Kaul, R., Ganesh, P., Tiwari, P., Nandedkar, R. V. & Nath, A. K. Characterization of dry sliding wear resistance of laser surface hardened En 8 steel. *J. Mater. Process. Technol.* **167**, 83–90 (2005).
38. Molian, P. A. Laser surface heat treatment of AISI 4340 steel: A microstructural study. *Mater. Sci. Eng.* **51**, 253–260 (1981).
39. Totten, G. E. *Steel Heat Treatment: Metallurgy and Technologies*. (CRC Press, 2006).

40. Bach, F.-W., Möhwald, K., Laarmann, A. & Wenz, T. *Modern Surface Technology*. (John Wiley & Sons, 2006).
41. Flores-Renteria, M. A., Ortiz-Dominguez, M., Simon-Marmolejo, I., Martinez-Martinez, L. E. & Zuno-Silva, J. Microstructural Characterization of Nitro-Boriding Coating on ARMCO® Pure Iron. *Microsc. Microanal.* **24**, 2240–2241 (2018).
42. Yasavol, N. & Mahboubi, F. The effect of duplex plasma nitriding-oxidizing treatment on the corrosion resistance of AISI 4130 steel. *Mater. Des.* **38**, 59–63 (2012).
43. Elliott, T. L. Surface hardening. *Tribol. Int.* **11**, 121–125 (1978).
44. Paul Johan Heintzberger. The Influence Of Carburising Temperature On The Case Depth And Properties Of Vacuum Carburised Precision Gears. (Faculty of Engineering, the Built Environment and Information Technology, University of Pretoria, 2017).
45. Zuno-Silva, J. *et al.* Kinetics of Formation of Fe₂B Layers on AISI S1 Steel. *Mater. Res.* **21**, (2018).
46. Anthymidis, K. G., Stergioudis, G., Roussos, D., Zinoviadis, P. & Tspas, D. N. Boriding of Ferrous and Non-Ferrous Metals and Alloys in Fluidised Bed Reactor. *Surf. Eng.* **18**, 255–259 (2002).
47. Lin, G. *et al.* Boronizing mechanism of cemented carbides and their wear resistance. *Int. J. Refract. Met. Hard Mater.* **41**, 351–355 (2013).
48. Şen, U. Küresel grafitli dökme demirlerin borlanması. (İTÜ, FBE, 1997).
49. Timur, S. *et al.* United States Patent: 8951402 - Ultra-fast boriding of metal surfaces for improved properties. (2015).
50. Barış M., Farklı Borlama Sürelerinin Transmisyon Çeliginde Abrasiv Asınma Davranışlarına Etkisinin İncelenmesi. (Teknoloji Eğitimi Gazi Üniversitesi Fen Bilimleri Enstitüsü, 2007).
51. Yang, H. P., Wu, X. C., Min, Y. A., Wu, T. R. & Gui, J. Z. Plasma boriding of high strength alloy steel with nanostructured surface layer at low temperature assisted by air blast shot peening. *Surf. Coat. Technol.* **228**, 229–233 (2013).
52. P. A. Dearnley, T. Farrell, And T. Bell, Developments in Plasma Boronizing, J. Materials For Energy Systems, Vol. 8, NO. 2, September 1986.
53. Eray Abakay. Termo-Reaktif Difüzyon (Trd) Yöntemi İle Çeliklerin Nb-Al-N Kaplanması. (T.C. Sakarya Üniversitesi Fen Bilimleri Enstitüsü, 2013).
54. İbrahim Fatih Kekik. Termo-reaktif difüzyon (TRD) tekniği ile Cr-Ti-N esaslı kaplamaların gerçekleştirilmesi ve özelliklerinin incelenmesi Investigation of Cr-Ti-N coatings on the steel surface by thermo-reactive diffusion (TRD) process. (SAÜ/ FBE/ Metalurji ve Malzeme Mühendisliği ABD, 2015).
55. Council, N. R. *et al.* *Plasma Processing of Materials: Scientific Opportunities and Technological Challenges*. (National Academies Press, 1991).
56. Proceedings, CAS - CERN Accelerator School: Plasma Wake Acceleration : Geneva, Switzerland, November 23-29, 2014. *CERN Document Server* (2017). doi:10.5170/CERN-2016-001
57. Hammett, G. Introduction to Plasma Physics. https://w3.pppl.gov/~hammett/courses/plasma-astro-10/Plasma_Intro_all_v16.pdf
58. Necla Yaman. Atmosferik Plazma Kullanılarak Sentetik Liflerinin Yüzeysel Özelliklerinin Değiştirilmesi Üzerine Bir Araştırma. (Ege Üniversitesi Fen Bil. Ens., 2008).

59. Kostov, K. G., Nishime, T. M. C., Castro, A. H. R., Toth, A. & Hein, L. R. O. Surface modification of polymeric materials by cold atmospheric plasma jet. *Appl. Surf. Sci.* **314**, 367–375 (2014).
60. Tamer Akan. Dc Glow Deşarj Plazmaları Ve Teknolojide Bazı Uygulamaları. (2016). doi:DOI: 10.13140/RG.2.1.3107.9287
61. <https://www.plasma-universe.com/plasma-classification-types-of-plasma/>.
62. Isaiah M., 2016aiaa Aviation 2016: Invited Sessionsession 264-Fd-60: Identifying The Impact Of Non-Equilibrium Mechanisms In Engineering Flows Aerospace Applications of NonEquilibrium Plasmadf.
63. [https://en.wikipedia.org/wiki/Plasma_\(physics\)#Temperature](https://en.wikipedia.org/wiki/Plasma_(physics)#Temperature).
64. Kayla Wiles. Treat cancer with cold plasma? Aerospace engineer helps bring first clinical trial. (2019).
65. Gerdes, T., Tap, R. & Willert-Porada, M. The Role Of High Pressure Plasma In Microwave Sintering Processes. in *Novel Materials Processing by Advanced Electromagnetic Energy Sources* (ed. Miyake, S.) 139–142 (Elsevier Science Ltd, 2005). doi:10.1016/B978-008044504-5/50027-1
66. Plasma - Applications of plasmas. *Encyclopedia Britannica* Available at: <https://www.britannica.com/science/plasma-state-of-matter>. (Accessed: 15th September 2019)
67. Kumruoglu, L. C., Becerik, D. A., Ozel, A. & Mimaroglu, A. Surface Modification of Medium Carbon Steel by Using Electrolytic Plasma Thermocyclic Treatment. *Mater. Manuf. Process.* **24**, 781–785 (2009).
68. Simon, A., Anghel, S. D., Papiu, M. & Dinu, O. Diagnostics and active species formation in an atmospheric pressure helium sterilization plasma source. *Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. At.* **267**, 438–441 (2009).
69. The atmospheric-pressure plasma jet: A review and comparison to other plasma sources.
70. Jeong, J. Y. *et al.* Etching materials with an atmospheric-pressure plasma jet. *Plasma Sources Sci. Technol.* **7**, 282–285 (1998).
71. Le, H. P. & Cambier, J.-L. Modeling of Inelastic Collisions in a Multifluid Plasma: Excitation and Deexcitation. *Phys. Plasmas* **22**, 093512 (2015).
72. Kumruoğlu, L.C, D., A. & Karaca, B. Plasma nitriding process of cast camshaft to improve wear resistance. (2019). doi:10.12693/APhysPolA.135.793
73. By, M. Practical Plasma For Thin-Film Deposition. *Hackaday* (2018). Available at: <https://hackaday.com/2018/04/11/practical-plasma-for-thin-film-deposition/>. (Accessed: 15th September 2019)
74. Kumruoğlu Levent Cenk, Özel Ahmet, Okumuş Sefer Cem. Surface Modification of Tantalum by Plasma Electrolytic Oxidation. *Frontier of Applied Plasma Technology*, 7(1) (Yayın No: 1496578). (2014).
75. M.S. Cebeci, L. C. Kumruoğlu. Investigation Of Dye Removal By Advanced Oxidation Electrolysis Discharge Method. *Çukurova İI. Uluslararası Multidisipliner Çalışmalar Kongresi 11.06.2019*
76. Levent Cenk KUMRUOĞLU. Steel Wire Cleaning By Electrolytic Plasma Method. *Çukurova I. Uluslararası Multidisipliner Çalışmalar Kongresi* (2018).
77. Kumruoğlu Levent Cenk, Özel Ahmet (2014). Electrolytic Plasma Surface Cleaning Of Industrial Metallic Components. *Acta Physica Polonica A*, 125, 379-381., Doi: 10.12693/APhysPolA.125.379.

78. I Nasov, A. T. P. Surface Engineering Of Polymers, Case study: PVD coatings on polymers. (2013).
79. Tamer Akan. Dc Düşük Basınç Elektriksel Gaz Deşarjlar. (2016). doi:DOI: 10.13140/RG.2.1.3370.0725
80. <https://www.pfeiffer-vacuum.com/en/know-how/introduction-to-vacuum-technology/fundamentals/mean-free-path/#tab-1.6>.
81. Mean free path. *Wikipedia* (2019).
82. Plasma surface metallurgy : with double glow discharge technology -- Xu-Tec process (eBook, 2017)<http://www.worldcat.org/title/plasma-surface-metallurgy-with-double-glow-discharge-technology-xu-tec-process/oclc/1004951574>. (Accessed: 13th November 2018)
83. Yoshida, S., Hagiwara, K., Hasebe, T. & Hotta, A. Surface modification of polymers by plasma treatments for the enhancement of biocompatibility and controlled drug release. *Surf. Coat. Technol.* **233**, 99–107 (2013).
84. Bormashenko, E., Whyman, G., Multanen, V., Shulzinger, E. & Chaniel, G. Physical mechanisms of interaction of cold plasma with polymer surfaces. *J. Colloid Interface Sci.* **448**, 175–179 (2015).
85. Sneha Sama. Thermal plasma technology: The prospective future in material processing. *J. Clean. Prod.* **142** 2017 3131e3150 doi:<https://doi.org/10.1016/j.jclepro.2016.10.154>
86. John Harry. *Introduction to Plasma Technology: Science, Engineering and Applications*, DOI:10.1002/9783527632169
87. Bogaerts, A., Neyts, E., Gijbels, R. & van der Mullen, J. Gas discharge plasmas and their applications. *Spectrochim. Acta Part B At. Spectrosc.* **57**, 609–658 (2002).
88. Jun Chen, S. G. DC Glow Discharge in Axial Magnetic Field at Low Pressures. *Hindawi Advances in Mathematical Physics*
89. Varvara Efimova 2011 Study in analytical glow discharge spectrometry and its application in materials scienc. (Technische Universität Dresden). <https://d-nb.info/1067190775/34>
90. Wagenaars, E (Erik). Plasma breakdown of low-pressure gas discharges. (2006). doi:10.6100/ir614696
91. Garpman, S. Polarization Effects on Discrete Transitions in Light Alkali Atoms Calculated in the Linked Diagram Formalism. *Phys. Scr.* **12**, 295–304 (1975).
92. Andrew Somorjai. The ratio of enthalpy minus piezoelectric energy versus the sum of the 1st ionization atomic energy in N moles of an ideal gas in an isochoric process. https://www.researchgate.net/publication/276279085_The_ratio_of_enthalpy_minus_piezoelectric_energy_versus_the_sum_of_the_1st_ionization_atomic_energy_in_N_moles_of_an_ideal_gas_in_an_isochoric_process (2015).
93. Ken-ichi OUCHI. Science reports of the Research Institutes, Tohoku University. Ser. A, Physics, chemistry and metallurgy 4, 203-236, 195 The Chemical Reaction Induced by the Glow Discharge in Ammonia Gas. (1952). ISSN 00408808
94. Bogaerts, A. & Gijbels, R. Fundamental aspects and applications of glow discharge spectrometric techniques. *Spectrochim. Acta Part B At. Spectrosc.* **53**, 1–42 (1998).
95. Bogaerts, A. The glow discharge: an exciting plasma! *J. Anal. At. Spectrom.* **14**, 1375–1384 (1999).

96. Dugdale, R. A. The application of the glow discharge to material processing. *J. Mater. Sci.* **1**, 160–169 (1966).
97. N.Strauss H.K.Pulker , Plasma diagnostic of ion and plasma PVD processes Thin Solid Films Volume 442, Issues 1–2, 1 October 2003, Pages 66-73
98. Karthikeyan, S., Hill, A. E., Cowpe, J. S. & Pilkington, R. D. The influence of operating parameters on pulsed D.C. magnetron sputtering plasma. *Vacuum* **85**, 634–638 (2010).
99. Belkind, A. *et al.* Characterization of pulsed dc magnetron sputtering plasmas. *New J. Phys.* **7**, 90–90 (2005).
100. Corbella, C., Rubio-Roy, M., Bertran, E. & Andújar, J. L. Plasma parameters of pulsed-dc discharges in methane used to deposit diamondlike carbon films. *J. Appl. Phys.* **106**, 033302 (2009).
101. Kelly, P. J. & Arnell, R. D. Magnetron sputtering: a review of recent developments and applications. *Vacuum* **56**, 159–172 (2000).
102. Cansever, N. Manyetik Alanda Sıçratma Yönteminde Son Gelişmeler, https://www.mmo.org.tr/sites/default/files/8b3eff8baf56627_ek.pdf
103. *Handbook Of Physical Vapor Deposition (Pvd)Processing Film Formation, Adhesion, Surface Preparation and Contamination Control.* (NOYES UBLICATIONS Westwood, New Jersey, U.S.A. by Donald M. Mattox Society of Vacuum Coaters Albuquerque, New Mexico).
104. Salim Fatih DEMİR. CrN Kaplamalara Antibakteriyel Özellik Kazandırmak Amacıyla Ag ve pd Katkılandırılması. (İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, 2007).
105. Bai, X. Laser-induced plasma as a function of the laser parameters and the ambient gas 2014 INIS Vol 52 INIS Issue 7 https://inis.iaea.org/search/search.aspx?orig_q=RN:52015139
106. M. Naderia, *et al.* Laser-structured high performance PVD coatings. *Surface & Coatings Technology* doi:<https://doi.org/10.1016/j.surfcoat.2018.07.094>
107. Illmann, U., Ebert, R., Reisse, G., Freller, H. & Lorenz, P. Laser based chemical vapour deposition of titanium nitride coatings. *Thin Solid Films* **241**, 71–75 (1994).
108. Tuncay Turutođlu. Titanyum Yüzeýlerin Katodik Ark Alüminyum Plazması İle Alaşımlanması. (İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, 2013).
109. Kwok, C. T., Cheng, F. T. & Man, H. C. Laser surface modification of UNS S31603 stainless steel. Part II: cavitation erosion characteristics. *Mater. Sci. Eng. A* **290**, 74–88 (2000).
110. Angelastro, A., Campanelli, S. L., Casalino, G. & Ludovico, A. D. Optimization of Ni-Based WC/Co/Cr Composite Coatings Produced by Multilayer Laser Cladding. *Adv. Mater. Sci. Eng.* **2013**, 1–7 (2013).
111. Watanabe, I., McBride, M., Newton, P. & Kurtz, K. S. Laser surface treatment to improve mechanical properties of cast titanium. *Dent. Mater.* **25**, 629–633 (2009).
112. Laser Surface Modification of Alloys for Corrosion and Erosion Resistance | ScienceDirect. Available at: <https://www.sciencedirect.com/book/9780857090157/laser-surface-modification-of-alloys-for-corrosion-and-erosion-resistance>. (Accessed: 20th November 2018)
113. Chi, Y., Gu, G., Yu, H. & Chen, C. Laser surface alloying on aluminum and its alloys: A review. *Opt. Lasers Eng.* **100**, 23–37 (2018).

114. Bhatt, G. G., Patel, A. L., Desai, M. S. & Panchal, C. J. Laser induced damage studies on Al₂O₃, SiO₂, and MgF₂ thin films for anti-reflection coating application in high power laser diode. 4 (2013).
115. Basak, S. & Akiladevi Durairaj. Carbon Nanotubes (CNTs) Production, Characterisation and Its Applications. *Int. J. Adv. Pharm. Sci.* **1**, 187–195 (2010).
116. Levent Cenk KUMRUOĞLU, C. O. Laser ile Kesimin Termal Etkileri. *Metal Dünyası* (2004).
117. Miraoui, I., Boujelbene, M. & Zaied, M. High-Power Laser Cutting of Steel Plates: Heat Affected Zone Analysis. *Adv. Mater. Sci. Eng.* **2016**, 1–8 (2016).
118. Laser Cutting <http://www.laserk.com/newsletters/papercut.html>. (Accessed: 21st November 2018)
119. Gizem OKTAY. Katodik Ark Fbb Yöntemi İle Ti6al4v Altlık Malzemesi Üzerine Kaplanmış Magnezyumun Morfolojisine Bias Geriliminin Etkisi. (İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, 2007).
120. André Anders. Cathodic Arc Plasma Deposition, www.osti.gov/servlets/purl/810482
121. Andre Anders, D. M. S. Review of cathodic arc deposition technology at the start of the new millennium. *Surface and Coatings Technology* **133/134** 2000 78 Ž 190
122. Kenosistech. Sputtering and Cathodic Arc technology. Available at: <http://www.kenosistec.com/en/PVD%20sputtering%20cathodic%20arc.php>. (Accessed: 11th September 2019)
123. Akan, T. & Ekem, N. Anot Metali Buharlarında Plazma Üreten Yeni Teknik, Termyonik Vakum Ark (TVA).
124. Chun, S.-Y., Lee, S.-J., Lee, C.-H. & Chayahara, A. Nanometer-Ranged Metallic Coatings By Noble Pulsed Cathodic Arc Deposition. *Novel Materials Processing by Advanced Electromagnetic Energy Sources* (ed. Miyake, S.) 83–86 (Elsevier Science Ltd, 2005). doi:10.1016/B978-008044504-5/50017-9
125. Simoni, J. & Daligault, J. First-Principles Determination of Electron-Ion Couplings in the Warm Dense Matter Regime. *Phys. Rev. Lett.* **122**, 205001 (2019).
126. Acree Tech Inc. Cathodic Deposition,. Available at: <http://www.acreetech.com/index.php/pvd-technology/cathodic-arc-deposition>. (Accessed: 11th September 2019)
127. Bdiscom-Cathodic-Arc-Deposition-Application-Bulletin-rev1.pdf.
128. What Do Injection Molders Find Superior About A TiN Coating? / North East Coating Technologies. Available at: <http://www.northeastcoating.com/products/pvd-coating/coatings>. (Accessed: 11th September 2019)
129. Al₂O₃ thin films deposition by reactive evaporation of Al in anodic arc with high levels of metal ionization | Elsevier Enhanced Reader. doi:10.1016/j.surfcoat.2018.12.065
130. Kumruoğlu, L.C. Gence. T. PVD Kaplama Uygulamaları ve operasyonel kademeleri içeren Artema PVD Talimatları. (2019).
131. Abadias, G. *et al.* Review Article: Stress in thin films and coatings: Current status, challenges, and prospects. *J. Vac. Sci. Technol. A* **36**, 020801 (2018).
132. Thornton, J. Influence of apparatus geometry and deposition conditions on the structure and topography of thick sputtered coating, *J. Vac. Sci. Technol.*, Vol. 11, 666-670. (1974).

133. Thin Film Growth Through Sputtering Technique and Its Applications Edgar Alfonso, Jairo Olaya and Gloria Cubillos. in *Crystallization – Science and Technology*
134. Barna, P. B. & Adamik, M. Fundamental structure forming phenomena of polycrystalline films and the structure zone models. *Thin Solid Films* **317**, 27–33 (1998).
135. Freund, L. B. & Suresh, S. *Thin Film Materials: Stress, Defect Formation and Surface Evolution*. (Cambridge University Press, 2004).
136. Karabacak, T. Thin-film growth dynamics with shadowing and re-emission effects. *J. Nanophotonics* **5**, 052501 (2011).
137. Mukherjee, S. & Gall, D. Structure zone model for extreme shadowing conditions. *Thin Solid Films* **527**, 158–163 (2013).
138. St. Braun, Th. Foltyn, L. van Loyen, M. Moss, and A. Leson: Multi-component EUV multilayer mirrors, Proc. SPIE 5037 (2003) Multi-component EUV multilayer mirrors,.
139. Sputter Deposition of Complex Alloy Thin Films. Bert Braeckman. Proefschrift tot het behalen van de graad van Doctor in de Wetenschappen: Fysica - PDF. Available at: <https://docplayer.net/51559238-Sputter-deposition-of-complex-alloy-thin-films-bert-braeckman-proefschrift-tot-het-behalen-van-de-graad-van-doctor-in-de-wetenschappen-fysica.html>. (Accessed: 19th September 2019)
140. Sheeja, D., Tay, B. K., Leong, K. W. & Lee, C. H. Effect of film thickness on the stress and adhesion of diamond-like carbon coatings. *Diam. Relat. Mater.* **11**, 1643–1647 (2002).
141. D. A. G.Pareja. Influence of Substrate Pre-treatments on the Residual Stresses and Tribo-mechanical Properties of PVD coatings. (Technische Universität Dortmund, Institute of Materials Engineering, 2014).
142. Makhlof, A. S. H. & Aliofkhazraei, M. *Handbook of Materials Failure Analysis with Case Studies from the Chemicals, Concrete and Power Industries*. (Butterworth-Heinemann, 2015).
143. Aninat, R. *et al.* Addition of Ta and Y in a hard Ti-Al-N PVD coating: Individual and conjugated effect on the oxidation and wear properties. *Corros. Sci.* **156**, 171–180 (2019).
144. Genel, K. İyon Nitrülenmiş AISI 4140 Çeliğin Yorulma ve Krozyonlu Yorulma Davranışı. (İ.T.Ü. Fen Bilimleri Enstitüsü, İstanbul., 2000).
145. Trabzon, L. İ., M. C. & Tosun, M. Plazma Nitrüleme İşleminin 316L Ostenitik Paslanmaz Çeliğinin Malzeme Özelliklerine Mikro Ve Nano Etkisi. *Mühendis ve Makina* **53**,
146. Yetim, A.F. Biyomalzeme olarak kullanılan AISI 316L paslanmaz çelik ve Ti6Al4V alaşımının plazma ile nitrüleme davranışı, Ti-DLC ince film kaplama ile karşılaştırılması, (Atatürk Üniversitesi Fen Bilimleri Enstitüsü, (Yüksek Lisans Tezi), 64s,).
147. *Heat Treating. ASM International*,. **Vol. 4**, (ASM Handbook, 1991).
148. MICHALSKI, J. D.C. glow discharge in a gas under lowered pressure in ion nitriding of Armco iron. *J. Mater. Sci. Lett.* 1411–1414 (2000).
149. Kumruoğlu, L.C. Dayanç. A. & Karaca., Improvement of tribological properties of steel camshaft by plasma nitriding. *Acta Physica Polonica A* **135**, (2019).
150. Kumruoglu, L.C. Production of Mg-3Al Based Composites Reinforced with Ti6Al4V Particles. *Acta Physica Polonica A* (2014). doi:DOI: 10.12693/APhysPolA.125.432

151. Kumruoglu L.C., Üstel, F., Özel, A. & Mimaroglu, A., A. Micro Arc Oxidation of Wire Arc Sprayed Al-Mg6, Al-Si12, Al Coatings on Low Alloyed Steel. *Engineering* (2011). doi:doi:10.4236/eng.2011.37081
152. Davis, J. R. *Handbook of Thermal Spray Technology*. (ASM International, 2004).
153. Guns for Thermal Spray - Oerlikon Metco. Available at: <https://www.oerlikon.com/metco/en/products-services/coating-equipment/thermal-spray/spray-guns/>. (Accessed: 14th November 2018)
154. Herman, H., Sampath, S. & McCune, R. Thermal Spray: Current Status and Future Trends. *MRS Bull.* **25**, 17–25 (2000).
155. Li, M. & Christofides, P. D. Computational study of particle in-flight behavior in the HVOF thermal spray process. *Chem. Eng. Sci.* **61**, 6540–6552 (2006).
156. Qunbo, F., Lu, W. & Fuchi, W. Modeling influence of basic operation parameters on plasma jet. *J. Mater. Process. Technol.* **198**, 207–212 (2008).
157. Villafuerte, J. Current and future applications of cold spray technology. *Met. Finish.* **108**, 37–39 (2010).
158. Heimann, R. B. *Plasma Spray Coating*. (Wiley-VCH, 2008).
159. *Modern Surface Technology*. (John Wiley & Sons, 2006).
160. Davis, J. R. *Handbook of Thermal Spray Technology*. (ASM International, 2004).
161. Pawłowski, L. *The science and engineering of thermal spray coatings*. (John Wiley & Sons, 2008).
162. Trelles, J. P., Pfender, E. & Heberlein, J. V. R. Modelling of the arc reattachment process in plasma torches. *J. Phys. Appl. Phys.* **40**, 5635–5648 (2007).
163. Portal - Startseite Plasmaquelle Typ TRIPLEX. Available at: <http://www.unibw.de/eit2/Forschung/schwerpunkte/plasmaquellen-entwicklung/plasmaquelle-typ-triplex>. (Accessed: 2nd November 2014)
164. Marqués, J. L., Forster, G. & Schein, J. Multi-electrode plasma torches: Motivation for development and current state-of-the-art. *Open Plasma Phys. J.* **2**, 89–98 (2009).
165. Muggli, F. A., Molz, R. J., McCullough, R. & Hawley, D. Improvement of Plasma Gun Performance using Comprehensive Fluid Element Modeling: Part I. *J. Therm. Spray Technol.* **16**, 677–683 (2007).
166. Bobzin, K. *et al.* Modelling and diagnostics of multiple cathodes plasma torch system for plasma spraying. *Front. Mech. Eng.* **6**, 324–331 (2011).
167. Dyshlovenko, S., Pawlowski, L., Pateyron, B., Smurov, I. & Harding, J. H. Modelling of plasma particle interactions and coating growth for plasma spraying of hydroxyapatite. *Surf. Coat. Technol.* **200**, 3757–3769 (2006).
168. Dyshlovenko, S., Pateyron, B., Pawlowski, L. & Murano, D. Numerical simulation of hydroxyapatite powder behaviour in plasma jet. *Surf. Coat. Technol.* **179**, 110–117 (2004).
169. Herman, H. Plasma-sprayed Coatings. *Sci. Am.* **259**, 112–117 (1988).
170. Fauchais, P., Montavon, G. & Bertrand, G. From Powders to Thermally Sprayed Coatings. *J. Therm. Spray Technol.* **19**, 56–80 (2010).
171. Heimann, R. B. *Ceramics science and technology*. (Wiley-VCH, 2013).
172. Yuanzheng, Y., Youlan, Z., Zhengyi, L. & Yuzhi, C. Laser remelting of plasma sprayed Al₂O₃ ceramic coatings and subsequent wear resistance. *Mater. Sci. Eng. A* **291**, 168–172 (2000).

173. Fauchais, P. Understanding plasma spraying. *J. Phys. Appl. Phys.* **37**, R86–R108 (2004).
174. Li, M., Shi, D. & Christofides, P. D. Modeling and control of HVOF thermal spray processing of WC–Co coatings. *Powder Technol.* **156**, 177–194 (2005).
175. Hu, C. *et al.* SiC Coatings for Carbon/Carbon Composites Fabricated by Vacuum Plasma Spraying Technology. *J. Therm. Spray Technol.* **21**, 16–22 (2012).
176. Pu, H. *et al.* Ablation of vacuum plasma sprayed TaC-based composite coatings. *Ceram. Int.* **41**, 11387–11395 (2015).
177. Singh, V. P., Sil, A. & Jayaganthan, R. Wear of Plasma Sprayed Conventional and Nanostructured Al₂O₃ and Cr₂O₃, Based Coatings. *Trans. Indian Inst. Met.* **65**, 1–12 (2012).
178. Chuanxian, D., Bingtang, H. & Huiling, L. Plasma-sprayed wear-resistant ceramic and cermet coating materials. *Thin Solid Films* **118**, 485–493 (1984).
179. DeMasi-Marcin, J. T. & Gupta, D. K. Protective coatings in the gas turbine engine. *Surf. Coat. Technol.* **68–69**, 1–9 (1994).
180. Thermal Spray Abradable Coatings. <https://www.gordonengland.co.uk/abradable.htm>. (Accessed: 28th January 2019)
181. Thermal barrier coating. *Wikipedia* (2018). https://en.wikipedia.org/wiki/Thermal_barrier_coating
182. Clarke, D. R. & Phillipot, S. R. Thermal barrier coating materials. *Mater. Today* **8**, 22–29 (2005).
183. Lima, R. S. & Marple, B. R. Nanostructured YSZ thermal barrier coatings engineered to counteract sintering effects. *Mater. Sci. Eng. A* **485**, 182–193 (2008).
184. Mauer, G., Jarligo, M. O., Rezanka, S., Hospach, A. & Vaßen, R. Novel opportunities for thermal spray by PS-PVD. *Surf. Coat. Technol.* **268**, 52–57 (2015).
185. Sakarya Üniversitesi | Termal Sprey Araştırma ve Uygulama Laboratuvarı, Uygulamaları. <http://teslab.sakarya.edu.tr/tr/icerik/10666/41948/hakkimizda>. (Accessed: 29th January 2021)
186. http://medicoat.com/wp-content/uploads/2013/09/medical_coating.jpg. (Accessed: 29th January 2021)
187. Kobayashi, A., Yano, S., Kimura, H. & Inoue, A. Fe-based metallic glass coatings produced by smart plasma spraying process. *Mater. Sci. Eng. B* **148**, 110–113 (2008).