Competition:

Section: «Scientific-methodical and scientific-technical works»

Title: Positron annihilation spectroscopy studies of defects induced by surface mechanical treatments

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Description:

The knowledge on the impact of the given surface treatment process is important from the practical point of view. Management of the production process, preparing better quality parts of machines and devices, protection from corrosion, and limiting of the wear need this kind of knowledge. In the current cycle of studies, we investigated the influence of different treatment parameters on defect structure formed beneath the affected surface in so called subsurface zone. A two processes named blasting and sliding, were detailed described. A few aspects of their applications, i.e. in dental prosthetics, and their influence on oxidation and radiation resistance, was discussed. The cycle of work appears as a part of activities performed at Dzhelepov Laboratory of Nuclear Problems and as the main techniques use positron annihilation spectroscopies methods.

Surface mechanical treatment such as blasting, cutting, sliding and machining introduce changes in microstructure on the surface but also below it. The subsurface zone is characterized by different physical and mechanical properties relative to the specimen interior. The surface treatment process led to the creation of several kinds of structural defects with unknown distributions and occupied depths. Their occurrence is revealed in changes in strength, ductility, and microhardness. Corrosion can also be connected with defects. Moreover, faster wear of materials starts at the atomic level and can affect the lifetime of the material. The studies of the subsurface zone are usually performed using conventional engineering methods such as microhardness tests and other analytical techniques like as electron microscopy, or X-ray diffraction. These methods provide broad characteristics; however, plastic deformations occurring during treatment generate structural defects which are largely undetected by the methods mentioned above. Open-volume defects such as vacancies and their clusters are relatively simple to be observed using positron annihilation spectroscopy.

Blasting:

Blasting is a treatment process involving bombarding the surface with small abrasive particles. This process is used for cleaning surfaces of metallic products but also for its decoration and improving its texture. Blasting can be characterized by many process parameters such as angle, pressure, size, or type of abrasive particles and process duration. Thus, changes generated on and below the surface can be strongly dependent on these features. Every single abrasive particle can be treated as a bullet launched on the surface. The impact of the hit depends on particle mass and its velocity likewise the direction of the collision angle. Essentially, the bigger particles and higher compression of air used to propel the blasting material cause the higher deformations of the subsurface zone. The direction of the blasting nozzle is also very important. Small collision angles generate a smaller concentration of defects beneath the blasted surface; however, strong surface erosion was also observed in this case. Performed studies proved that erosion increases for small sandblasting angles.

Sliding:

When two bodies are in sliding contact, the load at the surface is supported by asperities. The asperities undergo elastic or plastic deformation as soon as they are in contact. High stress concentration in these regions can lead to damage and thus also crack initiation. The asperity region is the source of dislocations that lead to stress concentration in the subsurface zone. It is not excluded that the impacts between asperities cause propagation of deformation to large depths from the worn surfaces. That is the deformation observed at a depth of hundreds of micrometers from the surface. The size of the asperities is on the order of a micrometer or less; however, the subsurface zone range is hundreds of micrometers. This zone contains crystalline defects generated during sliding, which accompany the deformation, and their concentration decreases with increasing depth from the worn surface. The mechanism of subsurface zone generation is still poorly understood. Nevertheless, the collection of new experimental data for various metals and alloys can help get to know it.

Applications:

The oxide layer present on the metal surface has a great influence on prosthetics and oxidation resistance. Commonly used tooth implants have a two-layer structure. The outer veneer layer, which ensures aesthetic, is built from weak ceramics or composite connected with a strong supporting core made of ceramics or metal alloys on the metal–veneer bond strength. Base metal alloys are formed by elements that are able to be passivated, especially chromium. These oxides and organic contaminants are mostly removed through blasting. One of the challenges in Cr containing alloys is controlling the excessive formation of chromium oxide that results in lower bond strength between base metals and veneer. After sandblasting, some abrasive particles remain and adhere to the blasted surface and can positively influence the adhesion properties of a material. The influence of blasting parameters and material hardness on alumina retention was discussed in the presented works. Similarly, also other surface treatments influence the oxide structure in the surface and affect other material properties. The oxidation behavior of Ni-based superalloys changes as a result of grounding and polishing. On a polished surface, a multilayered oxide scale was found consisting of NiO, Cr_2O_3, and internal zone of Al_2O_3, while on the ground surface, mainly protective Al_2O_3 formation was observed. It was shown that, by the simple surface mechanical preparation method, the alloy could be moved from the region of alumina formation into chromia forming alloys. Then, in the case of studied Ni-based superalloys, polishing showed a negative effect in terms of high temperature oxidation behavior.

It should also be mentioned that a surface treatment can lead to nanocrystallization. The treated material is subsequently annealed and the produced nanosize grains improve surface properties. Introduced dislocations are the basis of this process. Hence, the above can be regarded as the additional field of surface treatment application. It has been proven that the grain boundaries in the irradiated polycrystalline material can influence defects concentrations because they act as sinks where created defects disappear. Therefore, grain size refinement was proposed as a solution for enhanced resistivity of nuclear materials under extreme irradiation conditions. In other words, the usability of such materials is extended without affecting their mechanical properties (i.e. strength and ductility). Nuclear materials have to withstand neutron irradiation for many years. The irradiation damages created by long time neutron exposition can be replaced by irradiation with heavy ions. The implantation range of such ions is limited to several µm depths. The typical nanostructured area obtained by mechanical surface treatment significantly exceeds the range of the heavy ions. It means that fundamental microstructures changes caused by neutron degradation can be performed in a thin nanostructured surface prepared by easily applicable mechanical methods and heavy ions irradiation. Mechanical surface treatments allow one to get grain size in the surface region in wide ranges up to sizes even not available for typical methods exploiting high-pressure, like high pressure torsion, hydrostatic extrusion, equal channel angular pressing, etc. This gives the possibility to study an irradiation degradation of nanostructured metals and also the application of surface treatments as a finishing method for enhanced surface radiation resistance.

Highlights:

- Surface mechanical treatments can be used as an effective tool for the modification of the surface. They cause plastic deformations and introduce different types of defects below the subsurface zone. These defects depend on the material and mainly consist of mixture of dislocations and monovacancies or vacancies clusters. [1-15]
- The defect concentration decrease with the depth and depends on treatment parameters and material properties, i.e., hardness. The total thickness of subsurface zone:
  - for blasting increase with pressure, size of abradant and the impact angle; [1-9]
  - for sliding increase with the load. [11-14]
- The roughness of the sandblasted surface increases with the blasting impact angle, size of abradant, pressure. However, the impact of blasting time is imperceptible. [1-9]
- Nitrogen atmosphere during annealing provides insufficient protection from the formation of layers below the stainless steel surface. Blasting erodes these layers. [1]
- The erosion process during the 60-s sandblasting under 0.1 MPa pressure cannot completely remove metal oxides from the dental alloys and higher compression of air 0.4 MPa is needed to clean the surface. [8]
- The deposition of alumina blasting particles depends on material hardness. A shallow deposition is noted for hard metals, i.e., dental alloys, and deep Al_2O_3 retention in soft metals i.e., copper. [4, 8]
- The cavitation erosion process can be monitored using positron annihilation spectroscopy methods. The incubation period of the cavitation process can be used as a non-polluting surface modification technique that replaces blasting. [10]
- Surface preparation influences the oxidation behavior of Ni-based alloys. In the case of Ni-based alloys, polishing showed a negative effect in terms of high temperature oxidation behavior. [15]
- The surface mechanical treatment can lead to nanocrystalization. Nanostructuration of Ti obtained using blasting can reduce the amount of irradiation vacancy clusters almost twice compared to coarse grain samples. The disappearance of vacancy clusters after annealing at 200 ˚C indicates the promising self-healing property of Ti. [9]
- The defect profile in the subsurface zone of pure silver exposed to dry sliding contains monovacancies up to the depth of 110 μm, beyond vacancies associated with dislocations and undamaged regions are present. The total depth of the subsurface zone is more than 300 μm and it is hardly affected by the applied load. [14]
- Subsurface zone in pure niobium samples exposed to dry sliding revealed the defect depth profile extended in the range from 70 to 140 μm depending on the applied load from 5 to 50 N. No vacancy clusters were noted. [13]
- For pure Zr exposed to dry sliding, complex defect distributions are observed. Close to the worn surface only dislocations are present; at a certain depth the vacancy clusters occur, with the depth increase, their size decreases. Further from the worn surface again dislocations are present. [11, 12]

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Papers:

1. P. Horodek,, J. Dryzek, A.G. Kobets, M. Kulik, V.I. Lokhmatov, I.N. Meshkov, O.S. Orlov, V. Pavlov, A.Yu. Rudakov, A.A. Sidorin, K.Siemek, S.L.Yakovenko, Slow positron beam studies of the stainless steel surface exposed to sandblasting Acta Physica Polonica A 125 (2014) 714, doi:10.12693/APhysPolA.125.714, Impact Factor: 0.643;
2. P.Horodek, M.K. Eseev, A.G. Kobets, Studies of stainless steel exposed to sandblasting, Nukleonika, 60 (2015) 721, doi:10.1515/nuka-2015-0129, Impact Factor: 0.941;
3. P. Horodek, K. Siemek, J. Dryzek, A.G. Kobets, M. Wróbel, Positron annihilation and complementarny studies of stainless steel exposed to sandblasting at different angles, Tribol. Lett. 64 (2017) 30; doi:10.1007/s11249-017-0813-0, Impact Factor: 3.193;
4. P.Horodek, K. Siemek, J. Dryzek, M. Wróbel, Positron Annihilation and Complementary Studies of Copper Sandblasted with Alumina Particles at Different Pressures, Materials 10 (2017) 1343; doi:10.3390/ma10121343, Impact Factor: 3.623;
5. S. Kurdyumov, K. Siemek, P. Horodek, Positron annihilation spectroscopy studies of bronze exposed to sandblasting at different pressure, J. Phys.: Conf. Ser. 791 (2017) 012029 doi:10.1088/1742-6596/929/1/012029, Impact Score: 0.55;
6. K.Skowron, K.Siemek, Positron annihilation spectroscopy studies of sandblasted copper, Acta Physica Polonica B Proceedings Supplement 11 (2018) 4 doi:10.5506/APhysPolBSupp.11.795, Impact Score: 0.38;
7. P.Horodek, K.Siemek, J.Dryzek, M. Wróbel, Impact of abradant size on damaged zone of 304 AISI steel characterized by positron spectroscopy, Metallurgical and Materials Transacions A 50 (2019) 1502, doi:10.1007/s11661-018-5067-4, Impact Factor: 2.625;
8. K. Siemek, M. Kulik, M. K. Eseev, A. G. Kobets, M. Wróbel, O. S. Orlov, A. A. Sidorin, Surface and subsurface defects studies of dental alloys exposed to sandblasting, Acta Metallurgica Sinica (English Letters) 32 (2019) 1181, doi:10.1007/s40195-019-00884-5, Impact Factor: 2.090;
9. K. Siemek, P. Horodek, V.A. Skuratov, J. Waliszewski, A. Sohatsky, Positron annihilation studies of irradiation induced defects in nanostructured titanium, Vacuum 190 (2021) 110282, doi:10.1016/j.vacuum.2021.110282, Impact Factor: 2.906;
10. K.Siemek, M.K.Eseev, P.Horodek, A.G.Kobets, I.V.Kuziv Defects studies of nickel aluminum bronze subjected to cavitation, Applied Surface Science 546 (2021) 149107, doi:10.1016/j.apsusc.2021.149107, Impact Factor: 6.182;
11. J. Dryzek, K. Siemek, Formation of subsurface zone induced by sliding wear in zircionium studied by positron lifetime spectroscopy, Tribol. Lett. 64 (2016) 15; doi:10.1007/s11249-016-0747-y, Impact Factor: 3.193;
12. J. Dryzek, P. Horodek, Slow positron beam studies of zirconium exposed to dry sliding, Journal of Physics: Conference Series, 791 (2017) 012020, Impact Score: 0.55;
13. J. Dryzek, P. Horodek, Positron Annihilation Studies of the Near-Surface Regions of Niobium before and after Wear Treatment, Tribology Letters, 65 (2017) 117, doi: 10.1007/s11249-017-0902-0**,** Impact Factor: 3.193;
14. J.Dryzek, K.Siemek, Positron Annihilation Studies of Subsurface Zone Created during Friction in Pure Silver, Tribology Transactions 62 (2019) 658, doi:10.1080/10402004.2019.1600769, Impact Factor: 1.511;
15. W. Nowak, K. Siemek, K. Ochał, B.Kościelniak, B. Wierzba Consequences of different mechanical surface preparation of Ni-base alloys during high temperature exposure, Materials 13 (2020) 3529, doi:10.3390/ma13163529, Impact Factor: 3.623;

Конкурс:

Раздел: «Научно-методические и научно-технические работы»

Название: Исследования дефектов методом аннигиляционной спектроскопии позитронов после механической обработкой поверхности

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Статьи:

1. P. Horodek,, J. Dryzek, A.G. Kobets, M. Kulik, V.I. Lokhmatov, I.N. Meshkov, O.S. Orlov, V. Pavlov, A.Yu. Rudakov, A.A. Sidorin, K.Siemek, S.L.Yakovenko, Исследование поверхности нержавеющей стали после пескоструйной обработки медленным позитронным пучком Acta Physica Polonica A 125 (2014) 714, doi:10.12693/APhysPolA.125.714, Импакт-фактор: 0.643;
2. P.Horodek, M.K. Eseev, A.G. Kobets, Исследования нержавеющей стали после пескоструйной обработки, Nukleonika, 60 (2015) 721, doi:10.1515/nuka-2015-0129 Импакт-фактор: 0.941;
3. P. Horodek, K. Siemek, J. Dryzek, A.G. Kobets, M. Wróbel, Аннигиляция позитронов и дополнительные исследования нержавеющей стали после пескоструйной обработки под разными углами, Tribol. Lett. 64 (2017) 30; doi:10.1007/s11249-017-0813-0, Импакт-фактор: 3.193;
4. P.Horodek, K. Siemek, J. Dryzek, M. Wróbel, Аннигиляция позитронов и дополнительные исследования меди, подвергнутой пескоструйной обработке с частицами оксида алюминия при различных давлениях, Materials 10 (2017) 1343; doi:10.3390/ma10121343, Импакт-фактор: 3.623;
5. S. Kurdyumov, K. Siemek, P. Horodek, Исследование бронзы аннигиляционной позитронной спектроскопией после пескоструйной обработки при разном давлении, J. Phys.: Conf. Ser. 791 (2017) 012029 doi:10.1088/1742-6596/929/1/012029, Импакт-фактор: 0;
6. K.Skowron, K.Siemek, Исследование меди после пескоструйной обработки с помощью аннигиляционной позитронной спектроскопии, Acta Physica Polonica B Proceedings Supplement 11 (2018) 4 doi:10.5506/APhysPolBSupp.11.795, Импакт-фактор: 0;
7. P.Horodek, K.Siemek, J.Dryzek, M. Wróbel, Влияние размера абразива на поврежденную зону из стали AISI 304, охарактеризованное методом позитронной спектроскопии, Metallurgical and Materials Transacions A 50 (2019) 1502, doi:10.1007/s11661-018-5067-4, Импакт-фактор: 2.625;
8. K. Siemek, M. Kulik, M. K. Eseev, A. G. Kobets, M. Wróbel, O. S. Orlov, A. A. Sidorin, Исследования поверхностных и подповерхностных дефектов стоматологических сплавов, подвергнутых пескоструйной очистке, Acta Metallurgica Sinica (English Letters) 32 (2019) 1181, doi:10.1007/s40195-019-00884-5, Импакт-фактор: 2.090;
9. K. Siemek, P. Horodek, V.A. Skuratov, J. Waliszewski, A. Sohatsky, *Исследования аннигиляции позитронов в облученных дефектах в наноструктурированном титане*, Vacuum 190 (2021) 110282, doi:10.1016/j.vacuum.2021.110282, Импакт-фактор: 2.906;

10. K.Siemek, M.K.Eseev, P.Horodek, A.G.Kobets, I.V.Kuziv *Исследование дефектов никель-алюминиевой бронзы в условиях кавитации*, Applied Surface Science 546 (2021) 149107, doi:10.1016/j.apsusc.2021.149107, Импакт-фактор: 6.182;
11. J. Dryzek, K. Siemek, Образование подповерхностной зоны, вызванное износом скольжения в цирционе, изучено с помощью спектроскопии времени жизни позитронов, Tribol. Lett. 64 (2016) 15; doi:10.1007/s11249-016-0747-y, Импакт-фактор: 3.193;
12. J. Dryzek, P. Horodek, Исследование циркония при сухом скольжении на медленных позитронных пучках, Journal of Physics: Conference Series, 791 (2017) 012020, , Импакт-фактор: 0;
13. J. Dryzek, P. Horodek, Исследования аннигиляции позитронов в приповерхностных областях ниобия до и после износостойкости, Tribology Letters, 65 (2017) 117, doi: 10.1007/s11249-017-0902-0**,** Импакт-фактор: 3.193;
14. J.Dryzek, K.Siemek, Исследования аннигиляции позитронов в подповерхностной зоне, образовавшейся при трении в чистом серебре, Tribology Transactions 62 (2019) 658, doi:10.1080/10402004.2019.1600769, Импакт-фактор: 1.511;
15. W. Nowak, K. Siemek, K. Ochał, B.Kościelniak, B. Wierzba Последствия различной механической подготовки поверхности сплавов на основе никеля при высокотемпературном воздействии, Materials 13 (2020) 3529, doi:10.3390/ma13163529, Импакт-фактор: 3.623;