Applied Surface Science 327 (2015) 1–6

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Layer wise evolution of the Cu–Zn alloy microstructure after sandblasting

Yuriy N. Petrov, Mihail A. Vasylyev, Lidiya N. Trofimova, Irina N. Makeeva, Vera S. Filatova*

G.V. Kurdyumov Institute for Metal Physics, National Academy of Sciences of Ukraine, Ukraine

ARTICLE INFO

Article history:
Received 6 November 2013
Received in revised form
22 September 2014
Accepted 27 October 2014
Available online 18 November 2014

Keywords:
Transmission electron microscopy
Surface treatment
Sandblasting
Twins
Low stacking fault energy

ABSTRACT

This paper reports our recent studies on structural changes of a brass alloy (Cu–37Zn) after sandblasting. Investigation of the alloy foils using transmission electron microscopy (TEM) obtained at different distance from the treated surface. The existence of three structural surface layers after sandblasting was shown. The upper surface layer about 5 μm, corresponds to nano-crystalline state, the second one, consisting of nano-crystalline, ultra-microcrystalline and microcrystalline grains with FCC and orthorhombic structure mixture, occurs deeper than 5 μm and reaches the depth of 30 μm. The third layer can be attributed to the FCC disoriented cellular structure with multi-layer stacking-faults. The parameters characterizing changes of the nano-crystalline grains and polygonal structures are given. The role of the structural changes from one layer to another is discussed.

1. Introduction

It is well known that many properties of the metallic materials depend on the structure and properties of their subsurface region. Sandblasting as a surface treatment method is primarily used for surface cleaning and corrosion removal [1]. In this method, the sample surface is blasted repeatedly by high-speed sand particles, leading to the removal of the surface oxide layer and generation of the severe plastic deformation in the surface layer. In addition to removing the surface oxides, a compressive residual stress layer is often formed in the subsurface region. Microstructure changes due to severe plastic deformation have been reported by Valiev et al. [2]. The sandblasting provided repeated impacts on a surface at a high speed and generated high-density of dislocations. The resultant dislocations could be re-arranged under stress to form dislocation networks, leading to the formation of the nanocrystallites separated by diffuse grain boundaries. Annealing is necessary to diminish dislocations and sharpen the grain boundaries. As an example, Wang and Li reported that nanometer-sized grains were formed in the surface layer of the sandblasted and subsequently annealed 304 stainless steel [3,4] and brass [5]. The mean grain size was 20 nm and the grain size increased as the annealing temperature was raised. The nano-grains were randomly oriented as indicated by the selected area diffraction pattern. The thickness of the nano-crystalline layer or the layer affected by sandblasting was about 70 μm. The researches [3–6] demonstrate improvements in mechanical and electrochemical properties by nanocrystallization upon sandblasting. The high-density grain boundaries blocked the motion of the dislocations and also increased the yield point. As a result, hardness of the sandblast-annealed surface layer increased. However, the situation was different if the surface was treated by sandblasting only. In this case, sub-grains or cells formed in the sandblasted surface layer with diffuse boundaries; i.e. the dislocation network was caused by heavy deformation. In study [7] it was found that the sandblasted samples of commercially pure (CP) titanium exhibited an increase in fatigue strength by 11% over that of the untreated samples. Both sandblasting and sandblasting followed by a subsequent annealing step seemed to improve the corrosion properties of the CP titanium specimens.

Aluminizing is often used to improve steel's resistances to corrosion, oxidation and wear. Articles [8,9] report that the resistances of aluminized carbon steel to corrosion, wear and corrosive wear were considerably improved by the surface nanocrystallization treatment (a process combining aluminizing, sandblasting and recovery treatment). These improvements are attributed to the high-density grain boundaries, which accelerate atomic diffusion and thus passivating, block dislocation movement more effectively, and enhance

* Corresponding author. Tel.: +380 952808137.
E-mail address: tchudo55@hotmail.com (V.S. Filatova).

http://dx.doi.org/10.1016/j.apsusc.2014.10.162
0169-4332/

the passive films' adherence to the substrate. The passive film on the nanocrystalline surface also showed increased hardness and higher resistance to scratching.

Surface nanocrystalline of metals and alloys with Vickers' hardness below 2 GPa has been processed by sandblasting at room temperature and post-annealing. Fu and Li reported that nanocrystalline layer was generated onto the martensite steel by using sandblasting at 500 °C [10]. The average grain size is about 30 nm on the blasted surface, and deformed depth reaches about 70 mm. The surface nanocrystalline martensite steel by using sandblasting at high temperature has higher hardness and elastic deformation energy, and better wear resistance.

The 1Cr18Ni9Ti stainless steel was surface nanocrystallized successfully by the supersonic fine particles bombarding (SFPB) technology, and the surface hardness increased notably resulting from grain refinement and martensite phase transformation after the SFPB treatment [11]. The nanocrystalline surface layer with high hardness can reduce the adhesive wear and abrasive wear effectively. The higher surface activity of the nanocrystallized layer is helpful for forming oxide film during wearing, which can enhance its tribological properties in air. The wear damage of the original 1Cr18Ni9Ti steel is plastic deformation-induced adhesive wear and abrasive wear, while the dominant wear mechanisms of the SFPBed samples change to the coactions of fatigue wear, adhesive wear and abrasive wear.

The aim of the work is a detailed analysis of the mechanism of micro-structure state evolution on the depth of the modified layer in brass plate after sandblasting.

2. Materials and methods of investigation

Alloy Cu–37Zn (mass %) with stacking fault energy (SFE) of about 15 mJ m^{-2}, was used to carry out the present investigation. X-ray diffraction analysis of the initial state of the alloy confirmed that it possessed FCC structure prior to sandblasting (not shown). Sample, 245 μm thick, was subjected to sandblasting. Al_2O_3 powder, 250 μm size, was delivered to the surface plate at 4 atm pressure during 20 s. Mean roughness was within 2.2–3 μm after sandblasting (SB).

The alloy structure was investigated by TEM using JEM-2000FXII electron microscope at accelerating voltage 200 kV. Dislocation structure evolution on the sandblasted surface and in depth of the sample was studied with a layer-by-layer analysis of the foil (cross-) section structure parallel to the treated surface at the following depths: 2.5, 5, 15, 30 and 60 μm. The layer was moved away by electrolytic polishing in electrolyte: acetic acid – 800 ml, Na_2CrO_4 – 160 g at the temperature 20 °C on Tenupol-3 device. When in the process of foil thinning the necessary thickness of the removing layer was achieved, one of its sides was closed with Teflon film, and polishing continued until a hole appeared. Crystalline structure of the chosen regions was defined by electron diffraction technique obtained with the help of different diameter selector diaphragms. Average parameters of the dislocation structure were determined by direct length and width measurements of nanocrystalline (NC), ultra-microcrystalline (UNC) and microcrystalline (MC) grains at 50 different sections of the investigated sample.

3. Results of investigation and discussion

An electron-microscopic investigation of the alloy foils, obtained at different distance from the treated surface, showed the existence of three structural layers. The upper treated surface layer of about 5 μm, corresponds to NC state with FCC structure. The second one, consisting of NC-, UMC-, MC-grains with FCC structure and with another structure, which cannot be indexed as FCC, occurs deeper than 5 μm and is observed up to 30 μm in depth. And, finally, third layer, consisting of UMC- and MC-structure elements with FCC structure, exists deeper into the sample (about 60 μm from the upper layers). The changes of the nano-grain parameters on the brass plate thickness in nanocrystalline layer after sandblasting is shown in Fig. 1.

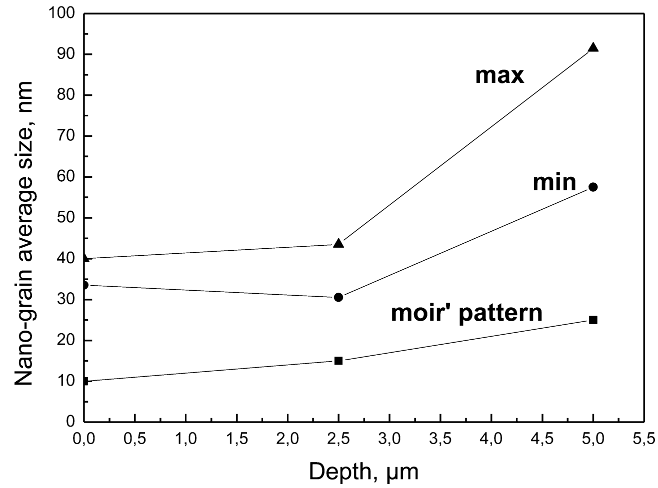

Fig. 1. Distribution of the nano-grain sizes and standard *s* distribution on the depth of Cu–Zn alloy plate: 1 – maximal nano-grain size; 2 – minimal nano-grain size; 3 – moiré pattern size.

The results of the electron microscopic investigation of the sandblasting influence on Cu–Zn alloy dislocation structure in the NC-structure layer are shown in Fig. 2. Typical microstructure of the plate surface is shown in Fig. 2a. It can be seen that the grains are mainly of the equiaxed shape. The respective diffraction pattern corresponds to a very fine structure and consists of the solid diffraction rings with a great number of point reflections, which are relatively uniform distributed. Nano grains in this layer are disoriented on large angles [12]. In less deformed alloy regions (at the depth about 2.5 μm) the degree of equiaxed nano grains is less (Fig. 1), and thin twins are sometimes observed inside of them (Fig. 2b). The alloy structure at the depth 5 μm is heterogeneous in the grain size (Fig. 1). Rings of micro diffractions correspond to the nano grain structure areas. Ultra thin deformation twins of different thickness are observed inside NC-grains, and the distance between them is in the range from 2.5 to 30 nm (Fig. 2c). Standard deviation *s* of the maximum average grain size is found in the range of sizes corresponding to UMC-grains, which give point-circular diffraction pattern and complex diffraction contrast in the bright field (Fig. 2d), what was studied with dark-field technique. Dark-field photomicrograph of the certain UMC-grain dislocation structure, obtained in the diffraction ring fragment (1 1 1), is shown at Fig. 2e. One of the split dislocation set, the distance between which is 2.5 nm, can be seen at the photograph. Hence, diffraction contrast in UMC-grain, observed in the bright field, is conditioned by two sets of split dislocations with different Burgers vectors but belonging to one glide plane.

It is necessary to note that round shape moiré patterns are present in the layer structure up to 5 μm depth against the NC-grain background, which usually arises at intergranular surface of two thin crystals at their superposition from tilt boundaries and twist boundaries, differing by a small angle of disorientation up to 10°. The sizes of moiré patterns turned to be comparable with nano-grain sizes as small as they are (Fig. 1). Moiré fringes are also registered at the points of micro-twin intersection and on the boundaries of overlapping thin grains, which are possibly of lens-like form.