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Texture Gradients in Shot Peened Ti-2.5Cu

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Abstract. Shot peening is a mechanical surface treatment having a deep impact on the materials which generates beneficial near-surface plastic deformation resulting in changes in peening texture characteristics. The present study aims to investigate the texture gradients in the solution treated (SHT) Ti-2.5Cu after shot peening with Almen intensity of 0.20 mmA. Due to a high transmission and a large beam cross-section of neutrons, texture analysis by neutron diffraction has become the standard method to investigate bulk textures. In contrary, the penetration depth of conventional X-rays is a relatively smaller than that of neutrons. Therefore, it is able to measure texture gradients in some hundred microns from the surface.

Introduction

Shot peening is a mechanical surface treatment; it provides industrial components with improved stress corrosion resistance, and improved fatigue life. This is based on the plastic deformation induced in near-surface by impacting a surface with shots. The changes in the surface state due to shot peening are, for examples, changes of the residual stresses, microstructures, hardness by work-hardening and dislocation density as shown in Fig. 1.

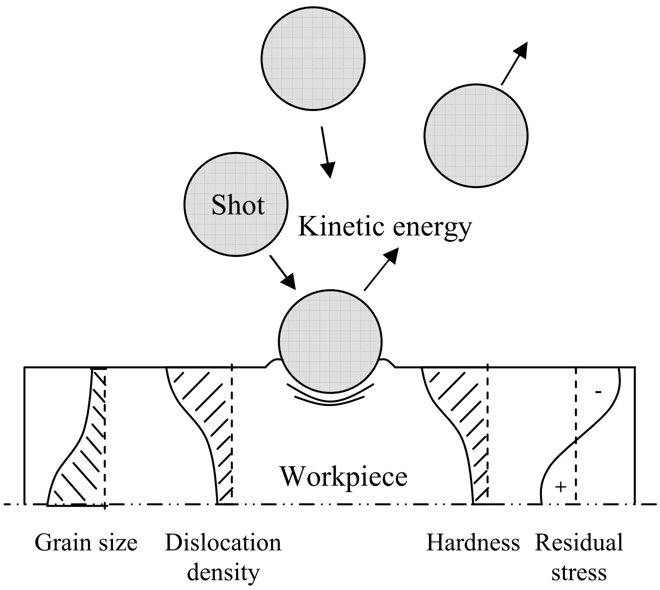


Fig. 1 Principle of shot peening process

The sever plastic deformation during shot peening lead to changes in the grain orientation so that characteristic peening textures occur in states initially free of textures or pre-existing texture may be changed by shot peening. It was found that the areas with high pole density observed in the cold rolling texture occur again with similar shape and extension after shot peening. However, shot peening reduces the intensity [1, 2]. As an example, electron backscatter diffraction (EBSD) has been used to investigate crystal lattice rotation caused by plastic deformation during high-strain rate laser shock peening in single crystal aluminum and copper samples. It was observed that for the Al (1-10) sample, the magnitude of rotation is ± 3° and covers a region around 35 µm across the shock line center on peened surface and reaches 40 µm below the surface. For the Cu (1-10) sample, the magnitude of rotation is ± 1.5° and the affected region is ± 20 mm on surface and 15 µm below the sample surface [3].

Due to the lack of literatures studying the effect of shot peening on the texture of titanium alloys, the main aim of the present study is to investigate the bulk texture and the texture gradient in the near-surface of shot peened Ti-2.5Cu by using neutron and conventional X-ray diffraction (XRD), respectively, to take in the account this effect on the shot peened surface properties. Due to a high transmission and a large beam cross section of neutrons for most materials, texture analysis by neutron diffraction has become the standard method to investigate bulk textures of different types of materials [4-6]. In contrary, the penetration depth of conventional X-rays is a relatively smaller than that of neutrons. Therefore, it is able to measure texture gradient in the near-surface of shot peened Ti-2.5Cu.

Material and Experiment

The Ti-2.5Cu alloy was received as 10 mm thick hot rolled plate. Specimens with the dimension of 20 x 20 x 10 mm^3 were cut. The conventional equated microstructure (Fig. 1) was achieved by solution heat treating (SHT) at 805 °C for 1 hr followed by water-quenching.

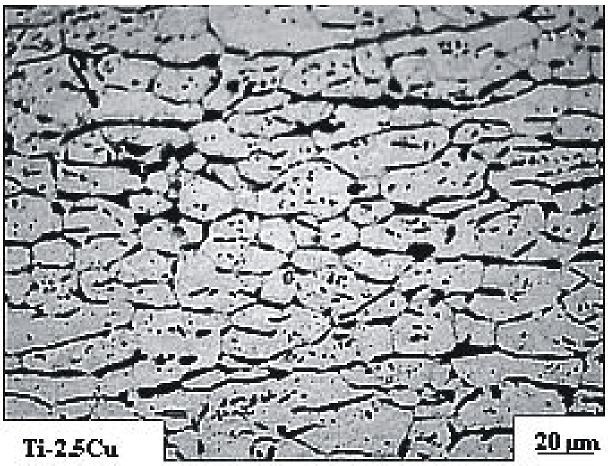


Fig. 2 Microstructure of the Ti-2.5Cu alloy, (SHT), average grain size ≈ 20 µm

Obviously, the microstructure of Ti-2.5Cu consists of α grains and stringers of the eutectoid component α + Ti_2Cu.

Threaded cylindrical tensile specimens were machined having gauge length and diameter of 25 and 5 mm, respectively. Tensile properties of Ti-2.5Cu are listed in Table 1.

E [GPa]	σ_y [MPa]	UTS [MPa]	e_u [%]	$\varepsilon_f = ln\ (A_o/A_f)$
105	520	610	14	0.62

Table 1 Tensile properties of Ti-2.5Cu (SHT)

Shot peening was done using cast steel (S330) having a hardness of 460 HV and an average shot diameter of 0.80 mm. All peening was performed to full coverage using Almen intensity of 0.20 mmA. Near-surface characteristics were determined after shot peening such as surface roughness, hardness, dislocation density and texture. Surface topography was determined by means of an electronic contact (stylus) profilometer instrument. Furthermore, microhardness HV0.1 was determined by means of a Struers Duramin tester using a force of 100 ponds and a loading time of 10 seconds. Three measurements were taken at each depth to construct the hardness-depth profiles.

The texture gradient and full width at a half maximum (FWHM) were measured by using conventional X-ray diffractometer (D-5000) at TU Clausthal, while the bulk texture was measured by applying the neutron diffraction using beamline TEX-2 [7] at the GKSS research center. The diffractometer parameters, which were used in this experiment, are listed in Table 2.

	Neutron diffractometer	X-ray diffractometer
Wavelength	1.332 Å	CoKα-radiation, λ = 1.789 Å
Monochromator	Cu (111)	
Detector	He-Single, 20 x 40 mm^2	Point detector (scintillation counter)
Slits sizes	Primary slit: 22 x 22 mm^2 Detector slit: 22 x 22 mm^2	Primary slit: ø 0.5 mm Detector slit: 6 x 16 mm^2
Sample environment	Eulerian cradle.	

Table 2 Parameters of neutron and X-ray diffractometers

Results and discussion

Hardness. The microhardness (Fig. 3) and FWHM (Fig. 4) depth profiles of shot peened Ti-2.5Cu clearly show maximum values at the surface followed by a gradual decrease towards the interior after shot peening with Almen intensity of 0.20 mmA. This is due to induced plastic deformation in near-surface within a depth of 250 µm approximately. Thus, it is expected that there are texture gradients up to 250 µm deep.

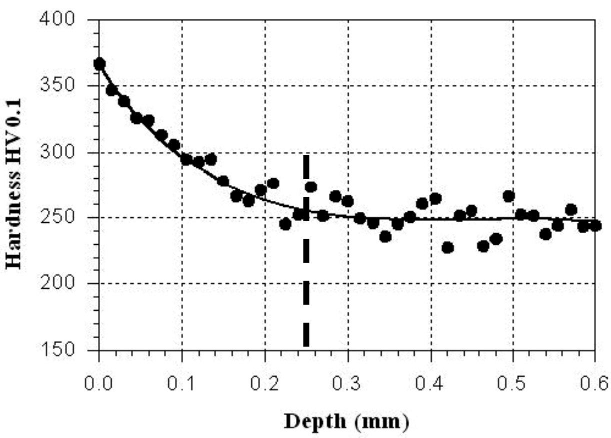


Fig. 3 Microhardness depth profile of shot peened Ti-2.5Cu

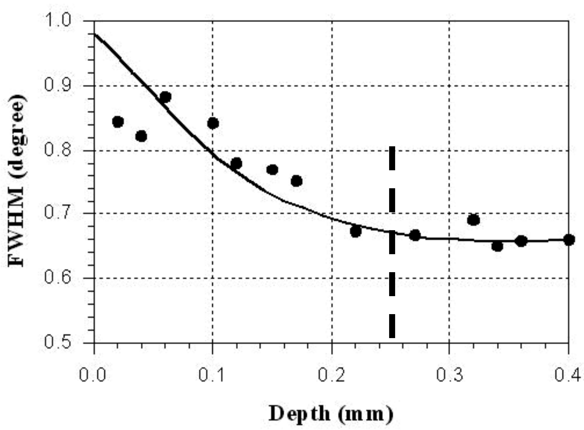


Fig. 4 FWHM depth profile of shot peened Ti-2.5Cu

Surface Topography. Roughness profiles of electropolished (EP) and shot peened (SP) specimens are illustrated in Fig. 5. As expected, the surface roughness (R_z = 5.42 µm) of shot peened Ti-2.5Cu is much higher than that of the electropolished reference (R_z = 0.36 µm). The shot peening-induced high surface roughness should be taken into account when using conventional X-ray diffraction and its shallow penetration to determine residual stresses or surface textures.

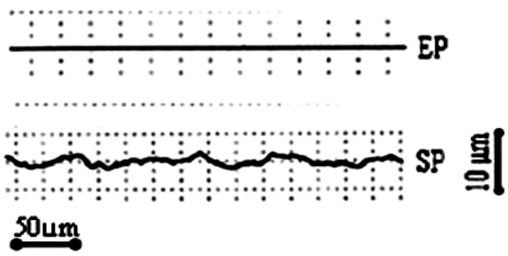


Fig. 5 Roughness profile of shot peened Ti-2.5Cu

Bulk Texture. The bulk texture of the hot-rolled (SHT) Ti-2.5Cu has been studied by using neutron diffraction in terms of the measured pole figures as shown in Fig. 6. Two texture components are

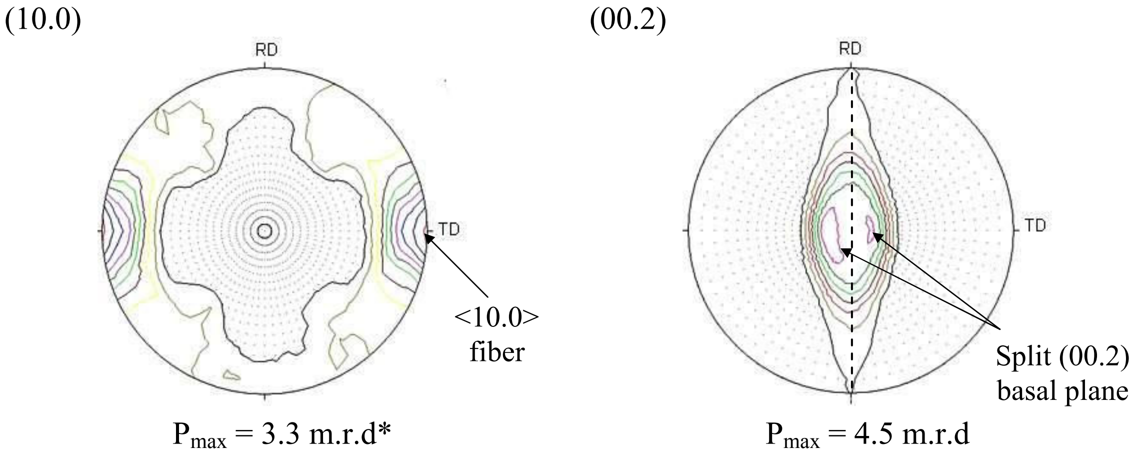


Fig. 6 Pole figures of the hot rolled Ti-2.5Cu measured by neutron diffraction
* m.r.d = multiples of random distribution

observed: (I) <10.0> fiber texture with the fibre axis in the transverse direction (TD), to this texture component, the (00.2) girdle like intensity distribution belongs. (II) Split (00.2) basal plane orientation in the normal direction with an angle of ±15° (c/a = 1.587), to this texture component, the orientation distribution 90° around ND in (10.0) pole figure belongs (dashed line in Fig. 6). The deviation from the perfect basal pole figure usually observed on cold-rolled commercially pure (CP) titanium is caused by a solid solution beta-eutectoid element (Cu). This is due to the finely dispersed second phase (Ti_2Cu) which is clearly visible in the microstructure (Fig. 2). The presence of a finely dispersed second phase within the grains has the effect of reducing the grain size and probably would be influential in the suppression of (11.2) twinning which plays an important role with (00.2) slipping to rotate the basal poles towards the TD in CP titanium. Moreover, a decrease in the critical resolved shear stress for basal slip could also be effective in producing this texture. Furthermore, it was investigated the effect of alloying elements on the lattice parameters and it is found that there was too little changes in lattice parameters to cause a pronounced effect on texture [8].

Texture Gradients. The influence of shot peening on the local texture gradients in near-surface of Ti-2.5Cu has been investigated using the conventional X-ray diffractometer. The textures were measured at the surface before and after performing shot peening as shown in Fig. 7.

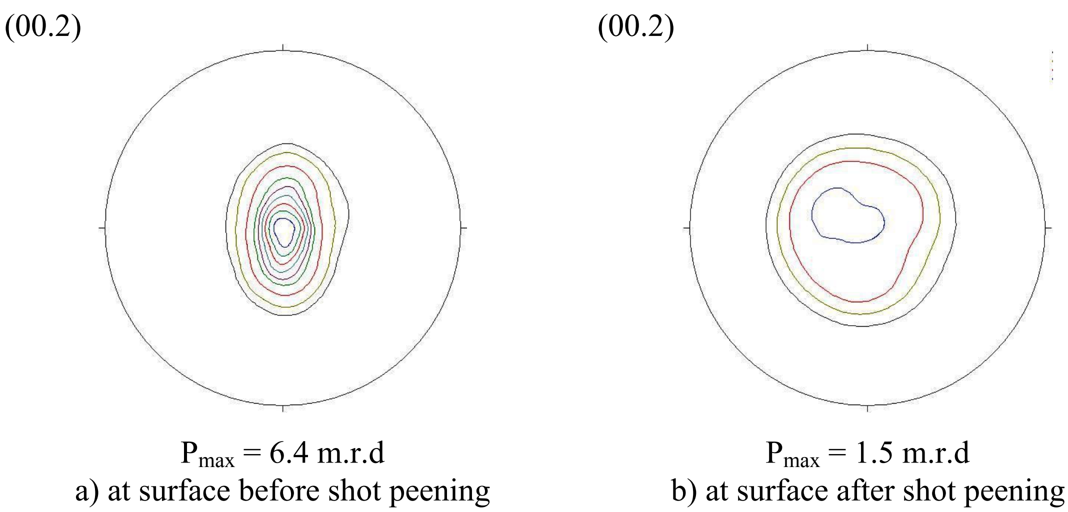
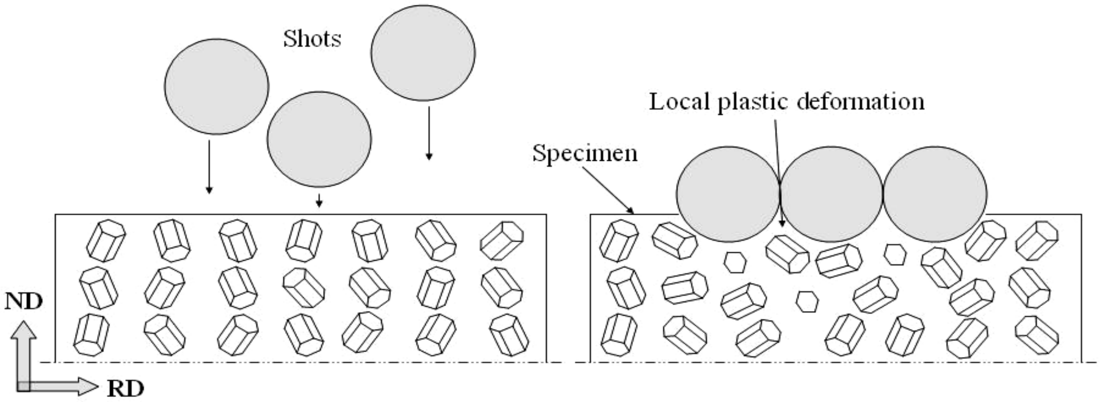


Fig. 7 Pole figures of Ti-2.5Cu at the surface before (a) and after (b) shot peening

It is observed that the (00.2) pole figures measured by both neutron (Fig. 6) and XRD (Fig. 7 – a) are slightly different because of different resolutions of both methods. Furthermore, it could be explained by the textures at the surface and the middle are different after rolling due the influence of friction between the roll and the surface of the plate which results in different flow rates and corresponding different strains. As seen in Fig. 7, the texture of the starting material at the surface is locally destroyed and a weak texture is produced (Fig. 7b) due to radial material flow caused by the shot impact normal to the surface as shown schematically in Fig. 8.

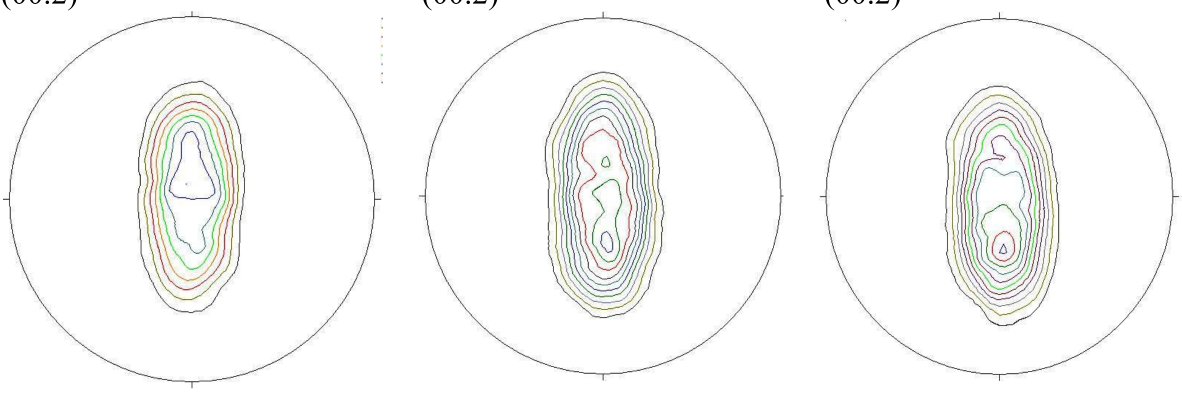


a) before shot peening b) after shot peening

Fig. 8 Scheme illustrating the destroyed texture due to shot peening (ND = normal direction, RD = rolling direction)

The wider distribution of the pole at the surface, shown in Fig. 7b, is mainly caused by the weak (randomized) texture. Also it could be explained by the wavy profile produced at the surface due to the spherical shots.

The crystallographic textures in near-surface layers of shot peened Ti-2.5Cu as measured by XRD are illustrated in Fig. 9.



P_{max} = 4.5 m.r.d
a) at depth of 120 µm

P_{max} = 5.7 m.r.d
b) at depth of 220 µm

P_{max} = 6.1 m.r.d
c) at depth of 340 µm

Fig. 9 Pole figures of shot peened Ti-2.5Cu at 120 µm (a), 220 µm (b) and 340 µm (c) in depth

Apparently, there are differences in the pole figures depending on the distance from the surface. It is observed that the sharpness of the basal poles increases within the depth (P_{max} = 4.5 and 5.7 m.r.d at the depths of 120 and 220 µm, respectively) as illustrated in Fig. 9a&b. This is due to a lower plastic deformation than that at the surface (P_{max} = 1.5 m.r.d) as illustrated in Fig. 7b. Furthermore, when the depth increases, the basal poles are oriented towards the RD to be almost similar to the basal poles measured by neutron as a bulk texture (Fig. 3). For comparison, texture was measured in the region having no influence of the plastic deformation (deeper than 250 µm), shown in Fig. 9 c. It is observed that the basal pole density (P_{max} = 6.1 m.r.d) at depth of 340 µm is almost as same as that at the surface (P_{max} = 6.4 m.r.d) but the distribution of the poles is slightly elongated towards RD, which proves that there were texture gradients in the as-received rolled sheet before performing the shot peening process.

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Conclusion

The near-surface texture in the solution treated Ti-2.5Cu is changed by shot peening due to radial material flow caused by the shot impact normal to the surface. These local texture changes might affect surface and near-surface properties, such as the resistance to fatigue cracks nucleation and micro-cracks growth. Furthermore, it is observed a split (00.2) basal plane orientation in the normal direction with an angle of ±15° towards the transverse direction which is nearly similar to CP titanium with the c/a ratio of 1.587 (<1.633). However, additions of copper lead to <10.0> fiber component with the fibre axis in the transverse direction due to the finely dispersed second phase (Ti_2Cu) and a fine grain size.

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