Determination of polycrystal diffraction elastic constants of Ti-2.5Cu by using in situ tensile loading and synchrotron radiation

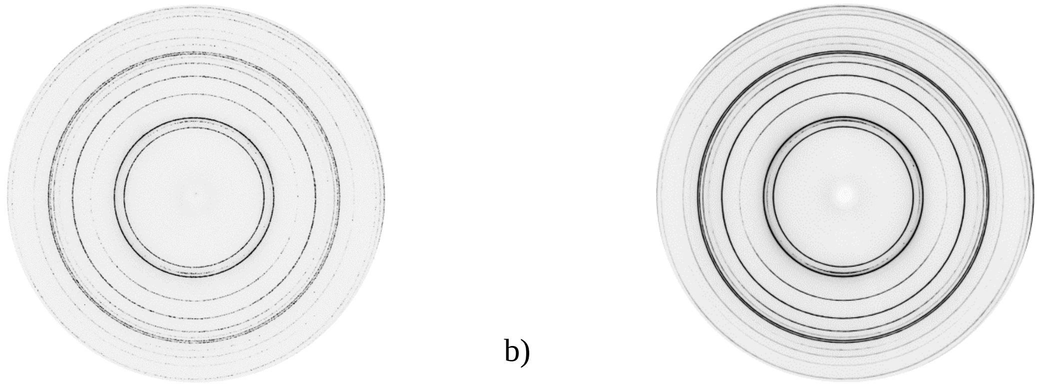
H.-G. Brokmeier[1,2], E. Maawad[1], Z. Zhong[2], M. Salih[2], N. Al-Hamdany[2], B. Schwebke[2], N. Schell[1]

[1]Helmholtz-Zentrum Geesthacht, Max-Plank-Str. 1, D-21502 Geesthacht, Germany
[2]Institute of Materials Science and Engineering, Clausthal University of Technology, Agricolastr. 6, D-38678 Clausthal-Zellerfeld, Germany

Ti-2.5Cu or IMI 230 (ASM) is used in the annealed condition as sheets, forgings and extrusions for fabricating component such as bypass ducts of gas turbine engines. In order to enhance the fatigue performance of this alloy, mechanical surface treatments such as shot peeing or ball-burnishing can be applied [1]. This beneficial influence is often explained by by the process-induced high dislocation densities hindering crack nucleation at the surface and compressive residual stresses which retard micro-cracks growth from the surface. Since residual stress evaluation is one of the important stages to interpret the fatigue behavior, it is necessary to precisely measure compressive and balancing tensile residual strains generated after applying mechanical surface treatments [2] and experimentally determine diffraction elastic constants (DEC's) which could be different compared with theoretical ones using elastic stiffness matrix of single crystals based on some models such as Reuss, Voigt and Kröner. This difference could be explained by the influence of crystallographic texture [3] and alloying elements [4]. The present experiment aimed to determine the DEC's of Ti-2.5Cu. The experimental and theoretical DEC's-values are compared in the present report.

The in situ tensile test was carried out at room temperature at PETRA III with a strain rate of 5 x 10^{-4} S^{-1}. The loading axis was parallel to the rolling direction (RD). A universal testing machine, by which sample can be loaded up to 20 kN, was installed at the HEMS side station (Beamline P07B). Monochromatic incident beam has a size of 0.5 x 0.5 mm^2 and a wavelength of 0.1422 Å. The diffracted beam, Debye–Scherrer cone, was registered on the MAR345 detector with a pixel size of 100 μm that was located perpendicular to the beam. The distance between the sample and the area detector was 1147 mm. The Ti-2.5Cu alloy was received as a 10 mm thick rolled plate. A tensile specimen was cut from this plate with a diameter of 5.04 mm and a gauge length of 25.90 mm. Due to relatively coarser grains in the rolling plane, the detector image shows discontinuous Debye-Scherrer rings (Fig. 1a) which could produce poor results due to insufficient grain statistics, Therefore, the tensile sample was plastically loaded up to 10.75 kN (just above the yield point of 10 kN) for grain refinement (Fig. 1b). This resulted in change in the grain and sample size. Accordingly, the new diameter and gauge length are 5.00 mm and 26.20 mm, respectively.

The lattice strain for each reflection ($\varepsilon_{(hkl)}$) can be calculated by $\varepsilon_{(hkl)} = (d_{(hkl)} - d_{0(hkl)})/ d_{0(hkl)}$, where $d_{0(hkl)}$ is a reference lattice spacing. The DEC's ($S_1 = - \nu_{(hkl)}/E_{(hkl)}$ & $1/2\ S_2 = (1+ \nu_{(hkl)})/ E_{(hkl)}$) are needed to calculate residual stresses from strains and they are dependent on lattice plane-dependent Young's modulus ($E_{(hkl)}$) and Poisson's ratio ($\gamma_{(hkl)}$) for each reflection (hkl). The slope of linear fitting of macrostress vs. lattice strain for reflection (hkl) gives $E_{(hkl)}$. Macrostress-lattice strain diagram (in the loading direction) is illustrated in Fig. 2. As seen, a linear fitting was used by using Origin software to determine the slopes of different reflections. Obviously, the (10.0) plane was elastically deformed more than the (00.2) plane under the same loading condition, since the resistance to elastic deformation dramatically increases in the most closely packed crystallographic direction (i.e., perpendicular to {00.l} planes). Accordingly, the basal plane (00.2) has the greatest lattice plane-dependent Young's modulus $E_{(00.2)}$ or the smallest DECs (S_1 & ½ S_2) as listed in Table 1. The relation between $E_{(hk.l)}$ and lattice plane angles with respect to the basal plane is represented in Fig. 3. The result indicates that the $E_{(hk.l)}$ gradually decreases with increasing the inclination angle of lattice planes with respect to the basal plane. Accordingly, the anisotropy factor ($E_{(00.2)}$/ $E_{(10.0)}$) for that polycrystalline Ti-2.5Cu alloy is about 1.14, while this factor is about 1.40 for single crystal titanium depending on the relation between c-axis and loading axis.



a) b)

Figure 1: Detector image taken for non-deformed tensile sample (a) and plastically deformed tensile sample at 10.75 kN ((just above the yield point at 10 kN)) (b).

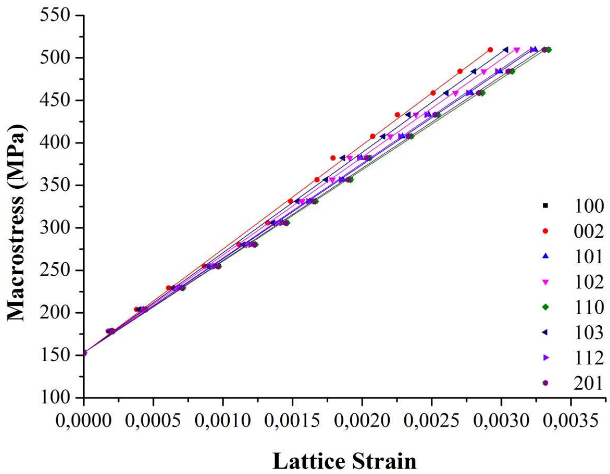


Figure 2: Macrostress-lattice strain diagram (in the loading direction).

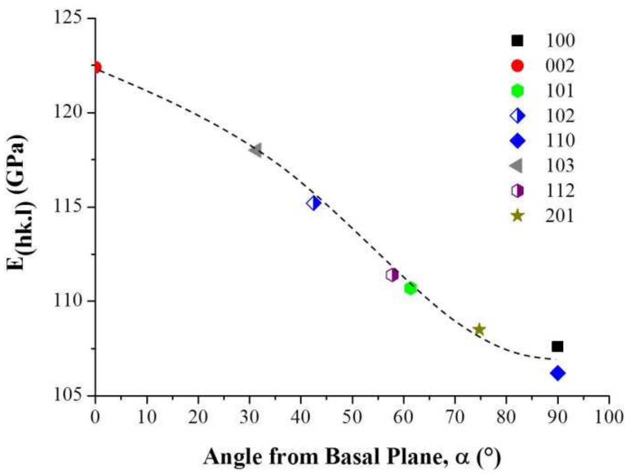


Figure 3: Relation between $E_{(hkl)}$ and lattice plane angles with respect to the basal plane.

Table 1: Experimental $E_{(hkl)}$, $\gamma_{(hkl)}$ and DEC's compared with calculated ones by Kröner Model.

Reflection	$E_{(hkl)}$ (GPa)		$\gamma_{(hkl)}$	DEC's (Experimental) (10^{-6} MPa^{-1})				DEC's (Kröner Model) (10^{-6} MPa^{-1})	
	Value	Error		S_1	Error	½ S_2	Error	S_1	½ S_2
(10.0)& (11.0)	107.6	1.0	0.41	-3.81	0.07	13.10	0.24	-2.98	12.03
(00.2)	122.4	1.5	0.35	-2.89	0.07	11.06	0.27	-2.32	10.11
(10.1)	110.7	1.1	0.40	-3.59	0.07	12.63	0.25	-2.90	11.80
(10.2)	115.2	1.2	0.38	-3.29	0.07	11.98	0.25	-2.72	11.28
(10.3)	118.0	1.3	0.37	-3.13	0.07	11.61	0.26	-2.58	10.87
(11.2)	111.4	1.1	0.35	-3.13	0.07	12.11	0.24	-2.87	11.73
(20.1)	108.5	1.0	0.40	-3.74	0.07	12.96	0.24	-2.96	11.97

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