Effects of the surface treatment on the measured diffraction peak width of Inconel 718

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Abstract

Macroscopic and microscopic residual stresses can be determined by the X-Ray diffraction technique. The macroscopic residual stresses can be deduced from the shift of the diffraction peak position. The diffraction peak widths are a measure of the microscopic residual stresses and are often directly correlated with the cold work of a material. Aspects such as the strain rate or the stress state by which the cold work was induced aren't normally taken into account in the correlation. The induced dislocation structure depends on these parameters. For example there are different dislocation structures after shot peening and deep burnishing. So the strain rate during a deformation process affects the dislocation structure and hence also has an effect on the diffraction peak width.

In order to find out the influence of the strain rate on the diffraction peak width compressive deformations with different strain rates were performed on Inconel 718 specimens. After mechanical loading the specimens were cut in the middle. The new surfaces were electro polished and afterwards the X-ray diffraction peaks of the {311}-planes were measured. The full widths at half maximum (FWHM) of the $K_{\alpha 1}$-interference lines were determined. These FWHM values were correlated with the plastic strains and the different strain rates. The correlations found will be shown and discussed in this paper.

Keywords: Inconel 718, nickel base alloy, cold work, FWHM, micro residual stresses

Introduction

Macroscopic residual stresses can be deduced from the shift of the diffraction peak position by the X-Ray diffraction technique. The diffraction peak widths of the interference lines are also a measure of the microscopic residual stresses. Prevéy [1] proposed an equation to link the cold work and the full width at half maximum (FWHM) of the interference line directly. Prevéy used this equation for different processes such as shot peening, gravity peening, laser shock peening and low plasticity burnishing [2]. Factors such as the strain rate or the stress state, which could also influence the induced dislocation structure, could be assumed to be negligible. In this paper the influence of the strain rate on the development of the FWHM is investigated.

Methods

The investigations were carried out on age hardened IN718 cylinders. The diameter of the cylinders was 4 mm and the length 10 mm.

In order to find out the influence of the strain on the full width at half maximum (FHWM) these cylinders were loaded with different interrupted compression tests. Different specimens were isothermally (RT) loaded for different total strains between 0 % and 25 %. Two different strain rates $\dot{\varepsilon}_t$ were applied (10^{-4} 1/s and 1000 1/s).

The experiments with the low strain rates ($\dot{\varepsilon}_t$ = 10^{-4} 1/s) were performed strain rate controlled in a tensile testing machine.

The tests with the high strain rates ($\dot{\varepsilon}_t$ = 1000 1/s) were performed in a high-speed testing machine (Zwick HTM 5020). This machine allows to load a specimen with maximum piston speed 20 m/s both in tension and compression. For this machine a special device was built to test the specimen up to a specified total strain. Figure 1 shows a schematic diagram.

The device is accelerated from the piston of the machine. The piston of the device impacts on the cylindrical specimen. This specimen is deformed until the piston of the device impacts on the stop ring. Then the force escalates and the shear pin is cut. Afterwards the piston of the device can move free in the cylinder while the piston of the machine is decelerated by the end-of-stroke damper. During this process the force is measured by a piezoelectric load cell.

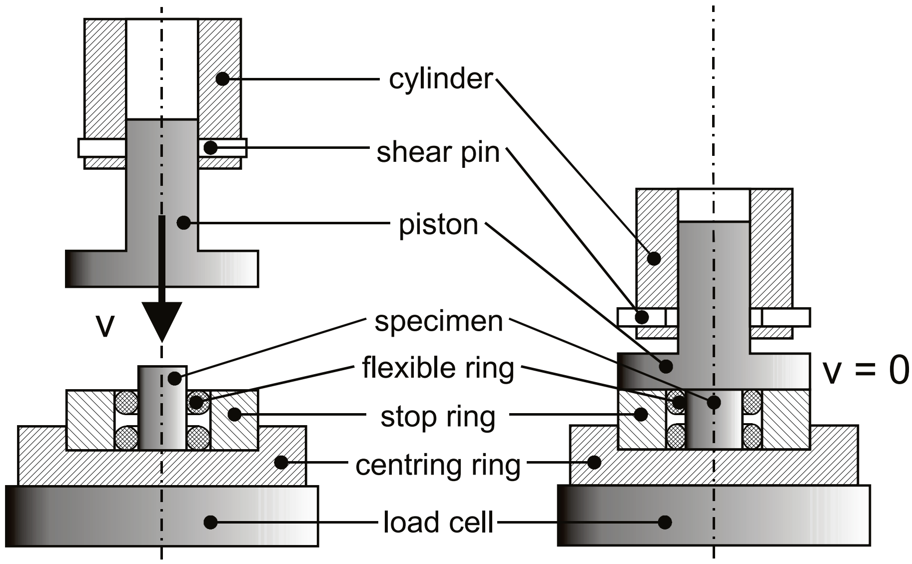

Figure 1: Schematic diagram of the testing device of the high strain rates

The lengths of the specimens before (l_{before}) and after (l_{after}) the experiment were measured and the plastic strain was identified:

$$\varepsilon_p = \frac{l_{before} - l_{after}}{l_{before}} \tag{1}$$

Before the X-ray measurement of the mechanical treated specimens the specimens were cut in the middle and the new surface was electro polished to remove the introduce hardening. Afterwards the full width at half maximum (FWHM) were measured in the middle of the specimens by the X-ray diffraction at the {311}-interference using Cu-Kα-radiation with three different inclinations ψ = -5°, 0° ,5°. The Kα-doublet was separated to determine the width of the stronger Kα_1 peak using the Rachinger correction. Three FWHM made for every specimen were averaged.

To correlate the measured results with the technically relevant FWHM different samples were shot peened with the Almen intensities of 0.1 mmA and 0.25 mmA. Afterwards the FWHM of the shot peened surfaces were measured.

Experimental Results

A typical measured compressive stress strain curve for the two different strain rates ($\dot{\varepsilon}_t$ = 10^{-4} 1/s and 1000 1/s) is shown in Figure 2. The experiments were interrupted at a total strain ε_t = 25 %.

Comparing the two stress strain curves it can be seen that the stress strain curve with the high strain rate shows oscillations. This is due to the impact and the measurement setup. It can also been seen that the stress curve ($\dot{\varepsilon}_t$ = 1000 1/s) shows, generally, a higher stress level than the other stress curve ($\dot{\varepsilon}_t$ = 10^{-4} 1/s).

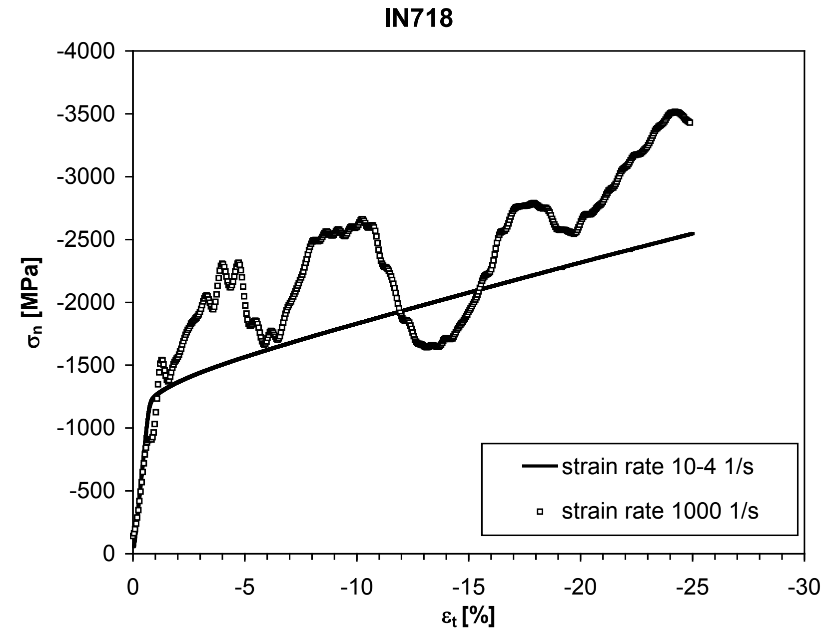

Figure 2: Typical measured compressive stress strain curve for the two different strain rates ($\dot{\varepsilon}_t$ = 10^{-4} 1/s and 1000 1/s) for IN718

The measured FWHM after the different loadings are shown in Figure 3. The FWHM increase with the applied plastic strain ε_p. It can also be seen that the FHWM of the experiments with the higher strain rate ($\dot{\varepsilon}_t$ = 1000 1/s) are on a slightly higher level than the one with the low strain rate ($\dot{\varepsilon}_t$ = 10^{-4} 1/s).

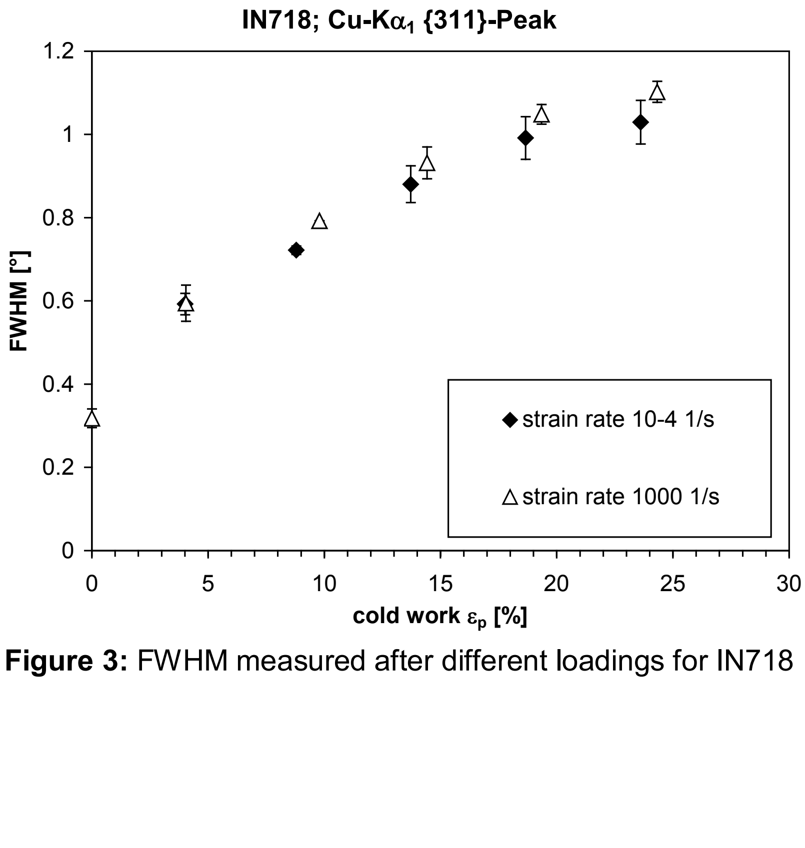

Figure 3: FWHM measured after different loadings for IN718

Discussion

Prevéy suggested an equation to correlate the cold work (plastic strain ε_p) with the FWHM [1]:

$$FWHM = A\left(1 - exp(-B \cdot \varepsilon_p)\right) + C \cdot \varepsilon_p + D \tag{2}$$

Where A, B, C and D are fitting parameters. With this equation the results which are shown in Figure 3 are fitted with a least-square algorithm. For the different strain rates different fitting parameters are used. This result is shown in Figure 4.

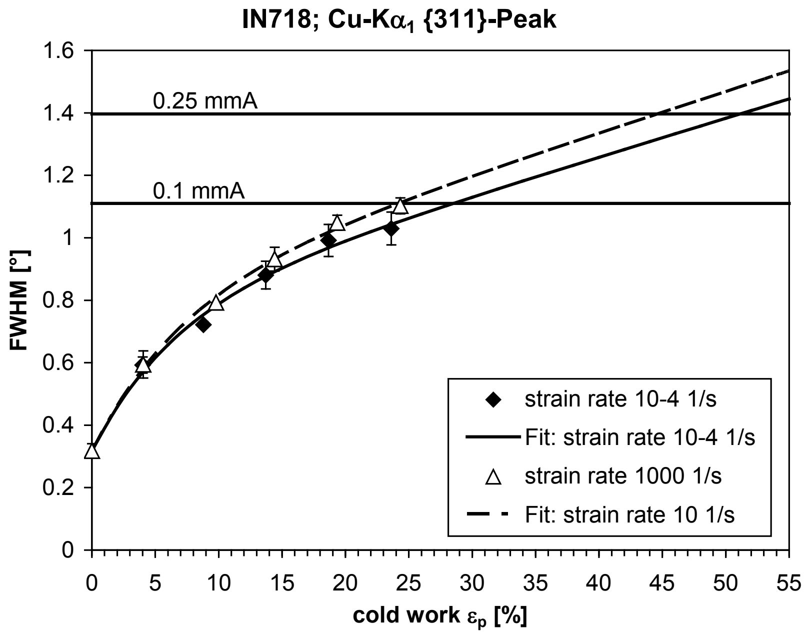

Figure 4: FWHM measured after shot peening and different loadings and for the different strain rates fitted with equation (2) for IN718

The fits show the same tendency as already implied: FHWM of the experiments with the high strain rate are higher than those of the experiments with the low strain rate. This can be explained by the strain rate effects. At the low strain rates the dislocations have a lot of time to annihilate and to order in new arrangements like subgrain boundaries. At high strain rates the dislocation movements are handicapped because of obstruction of the cross slip of screw dislocations which leads to more planer dislocation structures. On the one hand this causes hardening of the material (cf. Figure 2) on the other hand the developed dislocation structures are different. The dislocations have less time to arrange and to annihilate because of the shorter time of the cold work and therefore more dislocations are left in the material [3]. This phenomenon has been observed by a transmission electron micrograph of untreated, shot peened and ball burnished AISI4140 specimens (cf. Figure 5). It can be seen that the microstructure of a shot peened and a ball burnished specimen is completely different. It should be noted, however, that AISI14140 has a b.c.c. structure so that it is not directly comparable with IN718 which has a f.c.c. structure.The specimen after shot peening (high strain rates during the impact of the shots) shows in comparison with the untreated specimen a lot of unsystematic dislocations. This dislocation structure is typical for deformation with high strain rates. The ball burnished specimen is also work hardened but with lower strain rates. In contrast to the shot peened specimen there are few dislocations and this dislocation are ordered in subgrain boundaries.

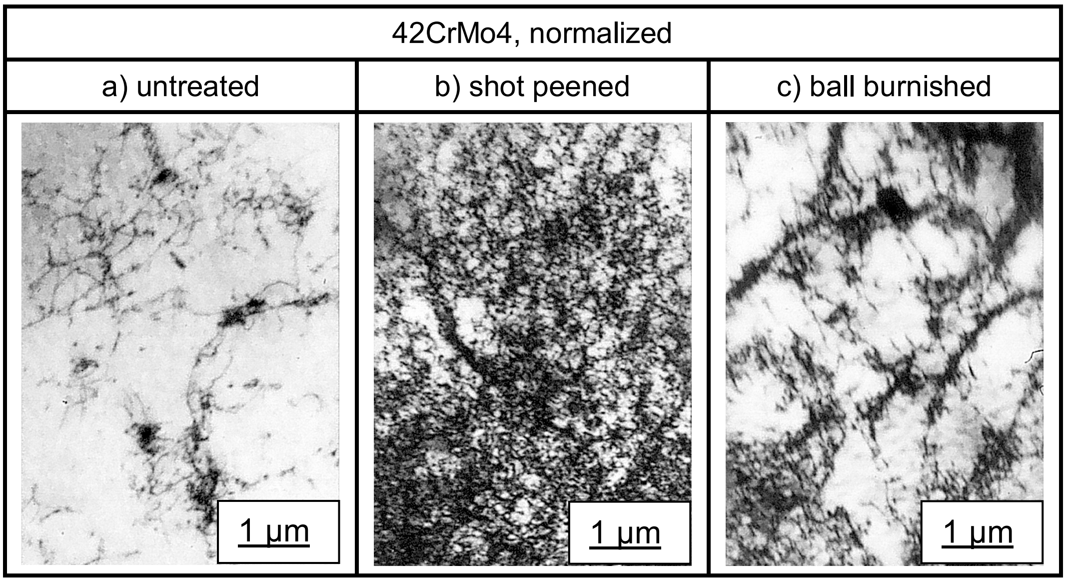

Figure 5: Transmission electron micrograph at surface distance of 0.08 mm in a untreated (a), a shotpeened (b) and a ball burnished (c) normalized AISI4140 specimen [4]

Because the dislocations have little time to arrange and annihilate there are more dislocations after deformation at high than at low strain rates. So the measured FWHM at same cold work and higher strain rate are higher.

In Figure 4 the two FHWM-values of the shot peened specimens (Almen intensity of 0.1 mmA and 0.25 mmA) are also shown. For the two specimens there is a slight difference between the correlated cold work according equation (2) for the high and the low strain rates. For the specimen with the Almen intensity of 0.1 mmA the equation for the low strain rate predicts a cold work ε_p = 28.5 %, for the high strain rates 24.5 %. This corresponds to a difference of 16 %. For the specimen with the higher Almen intensity (0.25 mmA) the fits of the equation (2) for different strain rates must be extrapolated strongly. There the equation for the low strain rates predict a cold work ε_p = 51 %, for the high strain rates 44.5 %. This corresponds to a discrepancy of 14 %.

Conclusion

It has been shown that the strain influences the full width at half maximum (FWHM) of the interference line. So the FWHM can not directly be correlated simply with the amount of cold work. At the example of two shot peened specimen the emerging failure was estimated. The discrepancy to the predicate equation of Prevéy [1] for the two estimated strain rates ($\dot{\varepsilon}_t$ = 10^{-4} 1/s and 10^{3} 1/s) was about 15 %. So the equation according Prevéy can be used to predict a range of cold work as function of FWHM. Nevertheless the exact value of cold work as function of FHWM is dependent on the process which produces the cold work and respectively the strain rate.

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