

# **Effect of Austenite Stability on Phase Transformation and Fatigue Performance of Stainless Steels after Various Mechanical Surface Treatments**

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## **Abstract**

Metastable austenitic stainless steels are known to stress-induced martensitically transform during cold working. Two austenitic stainless steels; AISI 304 and AISI 316Ti, which differ with regard to their austenite stability due to their chemical composition were chosen for the present investigation. Cold rolling to various degrees was done and the transformation to martensite was recorded in both alloys by X-ray diffraction spectra.

Shot peening (SP) and ball-burnishing (BB) were applied and the resulting changes in near-surface properties were characterized by micro-hardness depth profiles and residual stress-depth profiles. The shot peening and ball-burnishing caused changes in high cycle fatigue (HCF) performance of the two alloys with different austenite stability will be compared and contrasted.

**Keywords:** Austenitic stainless steel, shot peening, ball-burnishing, strain-induced martensitic transformation, X-ray diffraction patterns

## **Introduction**

The good combination of mechanical, fabrication and corrosion resistance properties makes austenitic stainless steels one of the most favoured construction materials [1]. Austenitic stainless steels with the approximate composition 18% chromium, 10% nickel and additions of molybdenum, titanium or niobium are today widely used in components designed for elevated temperature applications like boilers, super heaters and chemical reactors. Additions of titanium or niobium prevent precipitation of grain boundary carbides and contribute to precipitation hardening by the formation of carbo-nitrides [2]. The contents of chromium and molybdenum improve the corrosion resistance of the material, but also make the austenite unstable with respect to formation of chromium-rich carbides and intermetallic phases. These intermetallic phases detrimentally affect the mechanical properties when using standard austenitic stainless steels at elevated temperatures and also reduce their corrosion resistance by removing chromium and molybdenum from the austenitic matrix. This work aims to investigate the effects of plastic deformation on the austenite stability of AISI 304 and AISI 316Ti as well as the enhancement of the HCF performance by applying SP and BB.

## **Experimental Methods**

Two commercial austenitic stainless steels AISI 304 and 316Ti were received in plate form with thickness of 30 and 20 mm, respectively. Chemical compositions of the steels are given in Table 1. The tensile properties of the two alloys were given in Table 2. Materials were unidirectionally hot rolled at 800°C to a final thickness of 10 mm which corresponds to deformation degrees of  $\varphi = 0.6$  and 1.0 for AISI 304 and 316Ti, respectively. The rolled-plates were recrystallized at 1050°C for 0.5 hours. Hour-glass specimens with 6mm minimum gage diameter were machined with the load axis perpendicular to the rolling direction. Part of these specimens was shot peened using a direct pressure blast system and spherically conditioned cut wire (SCCW14) having an average diameter of 0.35mm.

Peening was performed to full (100%) coverage at an Almen intensity of 0.20mmA. Other specimens were ball-burnished by means of a conventional lathe using a device by which a hard metal ball of  $\varnothing$  3 mm (HG3) is hydrostatically pressed onto the rotating specimen surface using a pressure of 350 bar. Moreover, some specimens were electrolytically polished (EP) to serve as reference.

Micro-hardness depth-profiles were measured on the SP and BB samples. For estimating the near-surface deformation degrees, hardness measurements were done on material cold rolled to certain deformation degrees. Residual stresses were determined by means of the incremental hole drilling method using a drill with 1.9 mm diameter and strain gage rosettes. The oscillating drill was driven by an air turbine at a rotational speed of  $2 \times 10^5$  rpm. From the measured back strains, the residual stresses were calculated by linear elasticity concepts. Fatigue tests were performed in rotating beam loading ( $R = -1$ ) in air at a frequency of  $50\text{ s}^{-1}$ .

Table 1: Chemical composition in wt.%

Alloy	C	Si	Mn	P	S	Cr	Mo	Ni	N	Ti
AISI 316Ti	0.024	0.50	1.57	0.038	0.015	17.75	1.949	10.2	0.080	0.23
AISI 304	0.022	0.470	2.146	0.035	0.026	19.10	0.364	8.7	0.098	0.004

Table 2: Tensile properties of the tested alloys

Alloy	Condition	YS (MPa)	UTS (MPa)	$\varepsilon_F = \ln(A_0/A_F)$
AISI 316Ti	As-received	365	620	0.44
	Hot rolled at 800°C	680	785	0.18
	Hot rolled at 800°C + 0.5 h at 1050°C	215	595	0.42
AISI 304	As-received	320	655	0.47
	Hot rolled at 800°C	620	785	1.43
	Hot rolled at 800°C + 0.5 h at 1050°C	270	660	0.97

### Experimental Results and Discussion

The microstructures of AISI 316Ti before and after cold rolling are illustrated in Figure 1. While Figure 1a represents a typical equiaxed grained austenitic microstructure of the undeformed ( $\varphi = 0$ ) condition, after cold rolling ( $\varphi = 2.25$ ) the grains are highly deformed and elongated in rolling direction. Similar results were also obtained for AISI 304.

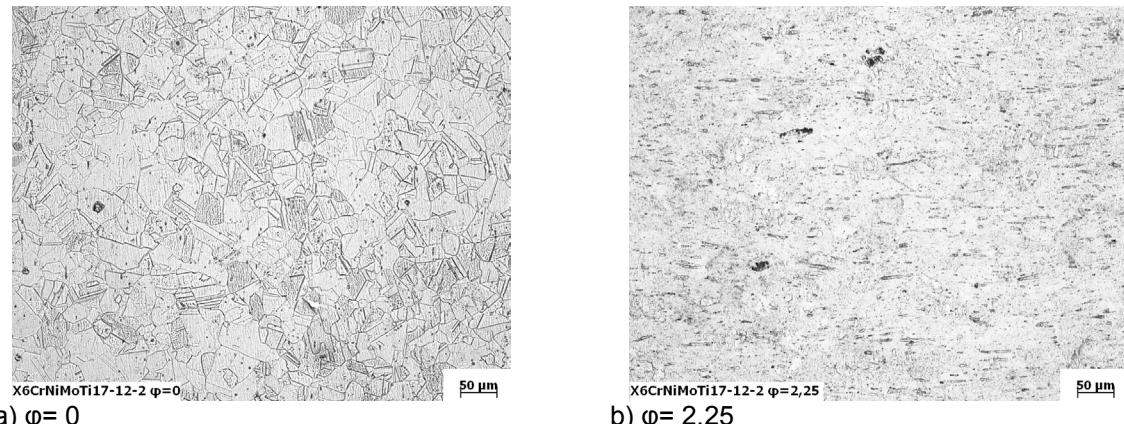


Figure 1: Microstructures of AISI 316Ti

The effect of cold work on the hardness of both AISI 304 and AISI 316Ti is shown in Figure 2. With an increase in the degree of deformation by cold rolling a very marked increase in hardness from about 125 and 140 to 450 and 500 HV10 was measured on AISI 316 Ti and AISI 304, respectively. This strong strain hardening is mainly due to the very low stacking fault energy (SFE) in these materials in which plastic deformation is characterized by the dissociation of perfect dislocations in Shockley partial dislocations and the formation of wide stacking faults [3, 4]. The observed somewhat more marked strengthening in AISI 304 may be caused by higher degrees of strain-induced transformation of the austenite to martensite. However, in contrast to [5] were no martensite transformation was observed in AISI 316, the investigated alloy AISI 316Ti of the present investigation underwent intensive martensite transformation as illustrated in Figure 3.

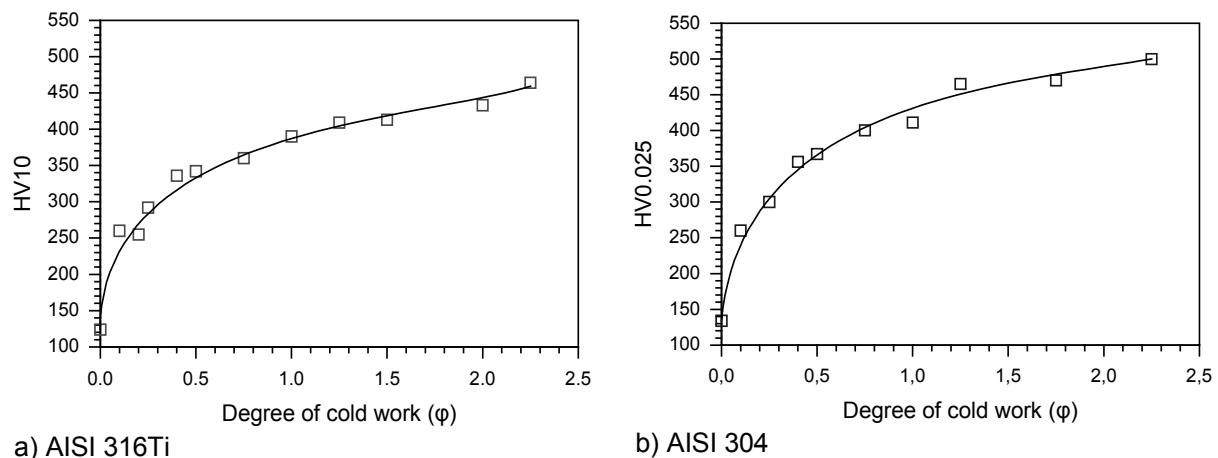


Figure 2: Relation between hardness and deformation degree in cold rolling

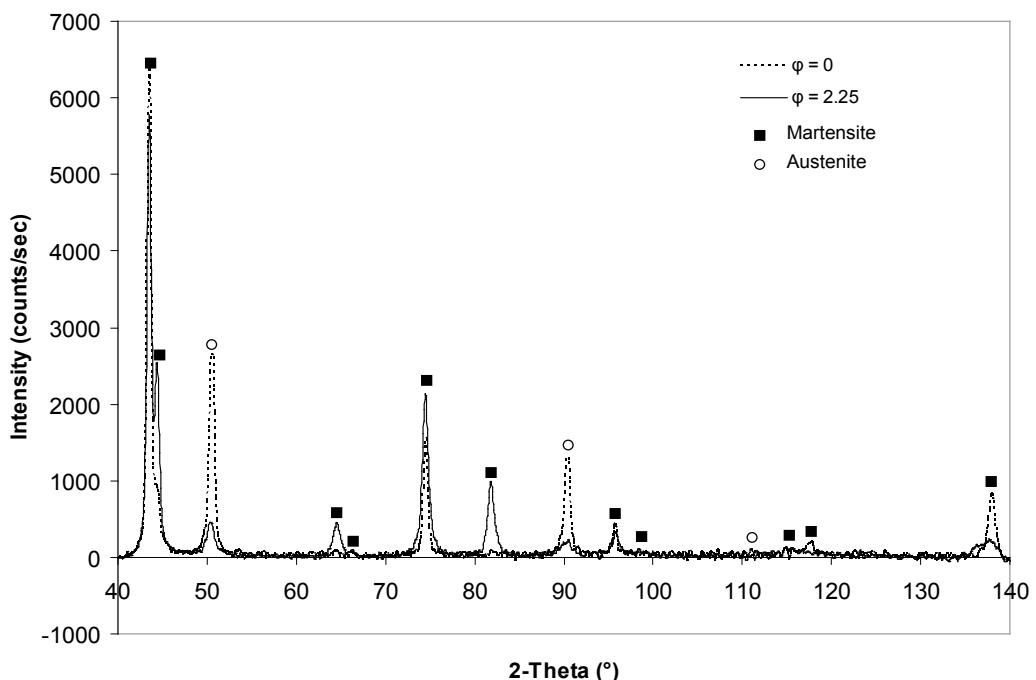


Figure 3: X-ray diffraction spectra of undeformed ( $\phi = 0$ ) and highly deformed ( $\phi = 2.25$ ) AISI 316Ti

The microhardness-depth profiles after BB and SP are shown in Figure 4. Maximum hardness values at the surface are very similar after BB and SP in both AISI 316Ti (Fig. 4a) and AISI 304 (Fig. 4b). As expected, the penetration depths of increased hardness after BB are much greater than after SP (Fig. 4). Comparing the near-surface hardness values in BB (Fig. 4) with hardness measurements after certain amounts of plastic strain as illustrated in Figure 2, it is obvious that local deformation degrees in BB and SP reach values of  $\varphi = 1$ . Similar results were reported in earlier work [6] and are also in agreement with the observation of ultrafine grain sized near-surface microstructures being typical for severe plastic deformation treatments [7, 8].

The residual stress profiles of both alloys (Figure 5) indicate penetration depths of residual compressive stresses after BB much higher than after SP. However, residual compressive stresses in the near-surface areas after SP were higher than after BB.

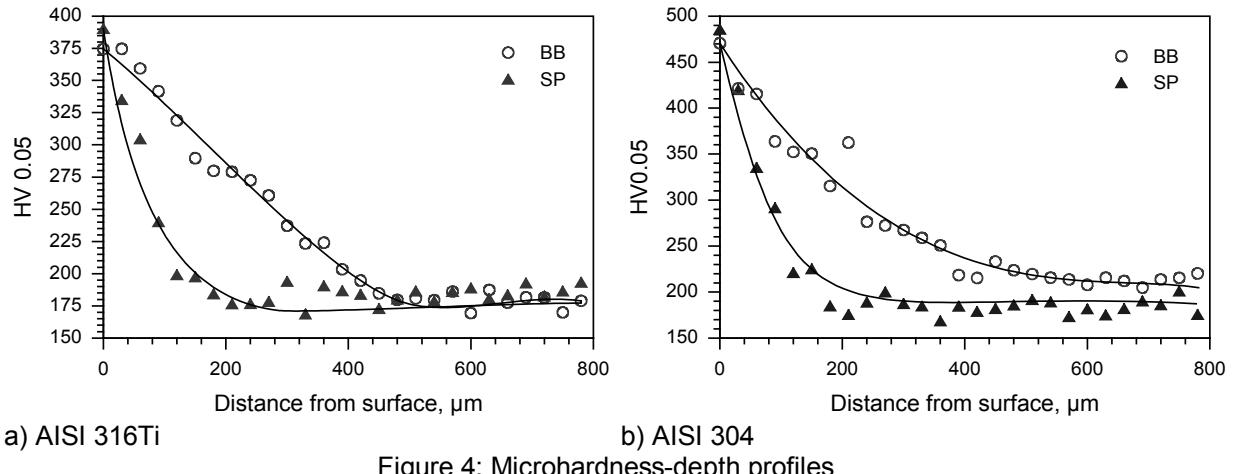


Figure 4: Microhardness-depth profiles

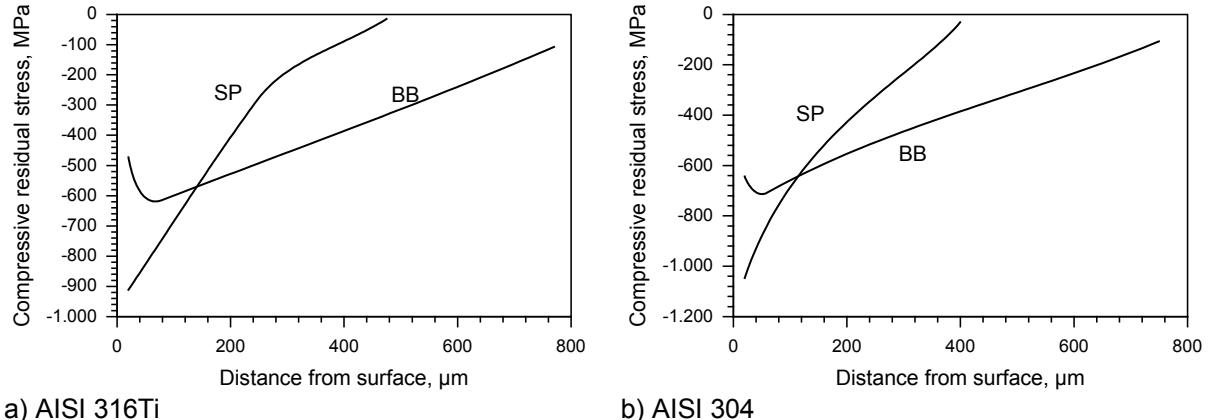


Figure 5: Residual stress-depth profiles

The HCF performance of both AISI 316Ti and AISI 304 is markedly enhanced by BB and SP compared to the reference EP (Figure 6).

The superior HCF performance of BB is explained by the residual compressive stress field reaching to depths much greater than in condition SP which leads a more effective retarding of micro-crack growth into the interior. In addition, the very low surface roughness of condition BB as opposed to SP leads to a retardation of fatigue crack nucleation resulting in most marked overall HCF strength improvement.

Part of the observed improvement in fatigue performance after BB and SP could also be attributed to local strain-induced martensitic transformation in the near-surface regions.

According to the very high local deformation degrees observed, this strain-induced martensitic transformation was also found in SP and BB specimens as illustrated in Figure 7.

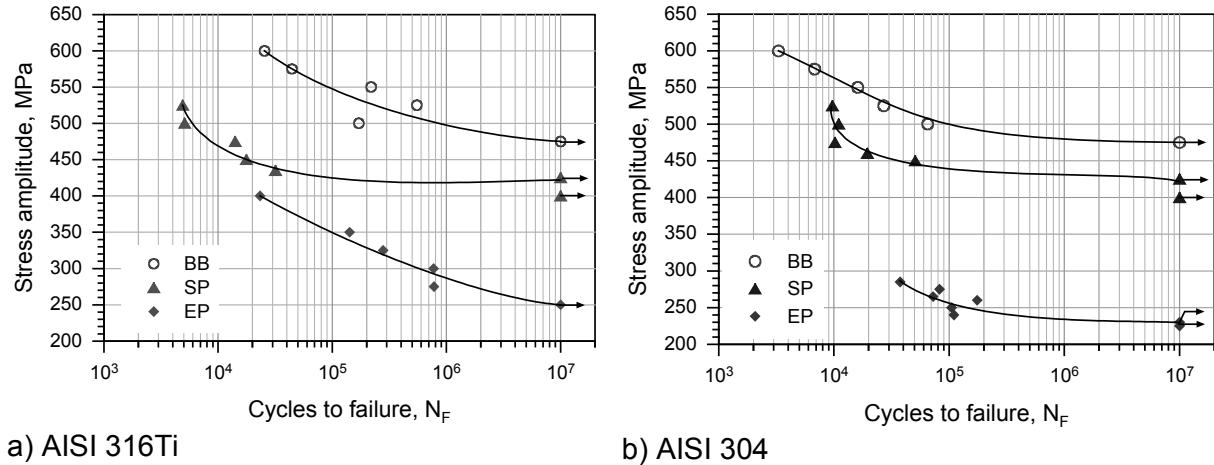


Figure 6: S-N curves

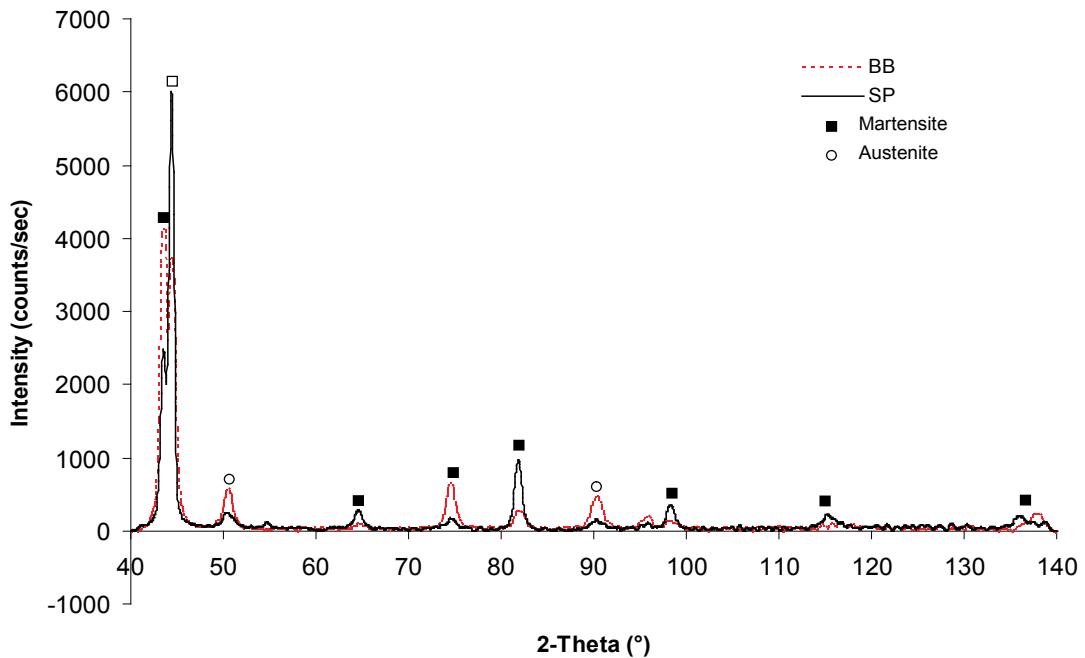


Figure 7: X-ray diffraction spectra on the BB and SP surface of AISI 316Ti

More work is needed to establish to what extent the strain-induced martensitic transformation during BB and SP contributes to the observed HCF improvement relative to the reference EP.

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## References

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