INFLUENCE OF MHP-TECHNOLOGY ON THE SURFACE NEAR MATERIAL STRUCTURE OF STAINLESS STEEL 1.4301

Stephan Krall[1], Manuel Reiter[1], Friedrich Bleicher[1]

[1] Technische Universität Wien, IFT – Institute for Production Engineering and Laser Technology, Getreidemarkt 9/311, 1060 Wien, Austria. E-mail: krall@ift.at

1. Introduction

By the application of machine hammer peening (MHP), the treated surfaces may show increased hardness and near-surface compressive residual stresses, next to optimized surface topographies. Due to plastic deformation of the crystalline steel material in the upper layers of the workpiece, phase transformations may be enforced. The aim of this work is the detection of the deformation-induced phase transition to martensitic structures as well as the effects on the hardness in the near-surface areas by multiple machining of the processed material.

2. Machine hammer peening

For the desired application of the machine hammer peening (MHP)-process, an electro-magnetic hammer peening device was used. The processed material, a stainless steel of the type X5CrNi18-10 (1.4301), has high resistance to corrosion and consists of a metastable γ-phase. The experiments were performed on a MoriSeiki NHX 6300 machining center. The applied process parameters have been as follows: Each sample was multiple machined ($n = 4$) with a constant frequency f of 200 Hz. A feed rate v of 1.200 mm/min, a stroke h of 0,8 mm and a distance of indentation a of 0,1 mm, that is equal to the stepover distance s, have been used. Sample No. 1 was peened with a ball- shaped Ø6 mm tool tip and, apart from that, sample No. 2 was treated with a Ø3 mm tool tip.

3. Fundamentals of phase transformation

Due to plastic deformation on a material, a transformation of a metastable austenitic material to an ε-phase with hexagonal closed packed crystal structure and an α'-phase structure with body-centered cubic crystal (bcc) structure can be formed. Previous investigations, like e.g. [1], show that the creation of an α'-phase is boosted and a phase transformation from γ - ε - α' or even directly from γ - α' could take place. In contrast to an ε-martensitic microstructure, α'-martensitic structure shows ferromagnetic properties. In general, the martensitic transformation can happen thermally-, stress- or strain/deformation-induced; cf. [2]. For this work, the deformation-induced martensitic transformation is the major effect. Since the transformation from an austenitic phase to a martensitic one is not done by a temperature drop for this work, an additional energy must be provided to start the transformation at room temperature. This can be achieved by a mechanical treatment process.

4. Microstructural investigations

For the investigation of the metallographic condition of the material, the color etching method according to Lichtenegger and Bloech (LBV) was employed. The outcomes of the color etching are shown in Figure 1. Sample No. 0 represents the initial surface condition before MHP-treatment (homogenous microstructure, single undeformed grains). The resulting microstructure of the etched sample No. 2 clearly shows high deformed areas (measured at a depth of 200 µm) with a high dislocation density. The images were created using an Axioplan microscope of the company Zeiss.

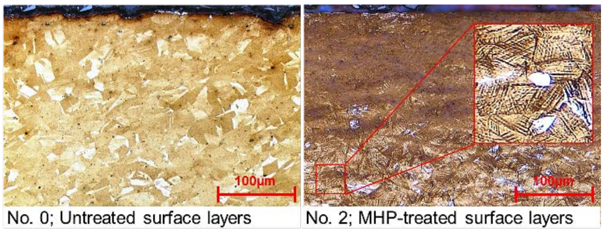

Fig. 1. (a) Untreated and etched surface layers; (b) MHP-treated and etched surface layers.

5. Hardness measurements

In order to determine the depth of impact of the MHP-process, Vickers hardness measurements were carried out to create a depth profile of the subsurface material conditions. The measurements were performed using a HV05 Vickers probe at a standardized exposure time of 15 sec. on an EMCO Test M1C 010. The results of the performed measurements of the investigated samples are shown in Figure 2. The initial hardness of the material (as delivered) is 263 ± 5 HV05 and is represented as a red dotted line. Sample No. 2, which was processed with smaller ball diameter of the tool tip, shows a higher increase in hardness with an achieved value of 490 ± 4 HV05 and higher reachable penetration depth than sample No. 1. This value decreases to the initial hardness of the untreated material until a depth of approximately 800 µm.

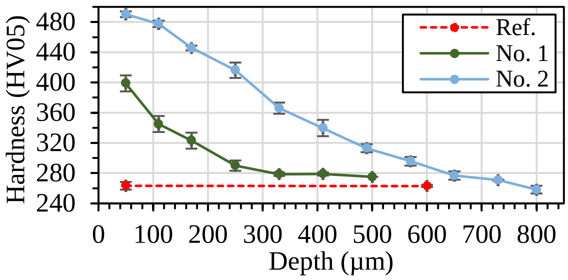

Fig. 2. Vickers HV05/15 hardness depth profile for X5CrNi18-10 (1.4301) after MHP-machining.

6. Microstructural-crystallographic investigations

To characterize the microstructural-crystallographic structure of a material and to understand the crystal orientation and its phases, a scanning electron microscope equipped with a field emission gun of the type FEI Quanta 200 FEG was used to analyze the material behavior. An electron backscatter diffraction (EBSD) analysis was faced to get a deeper knowledge of the MHP-treated areas. An accelerating voltage of 15 kV was used to influence the electron wavelengths and therefore improve the diffraction patterns. To investigate a possible phase transformation from an austenitic to a martensitic structure, the specimen was tilted to approximately 70° inside the measuring instrument. The EBSD analysis was carried out for both samples as follows: Sample No. 2 was evaluated according to a depth of 160 µm and a measurement area of 3 μm^2, whereas the measurement properties of sample No. 1 are a depth of 200 µm and an area of 15 μm^2. The preparation of the surfaces was performed by an electrochemical polishing process. However, Figure 3 shows the resulting IPF (inverse pole figure) of both samples No. 1 and 2, and the CCPM (color coded phase map) for sample No. 2. In the IPF of sample No. 1, the individual grains in the slightly deformed state of the material can be seen. This area shows solely austenitic parts regarding its phase mapping. However, sample No. 2 shows significant deformed structures and deformation patterns. Because of its high dislocation density, a smaller measurement area compared to sample No. 1 was chosen. The phase mapping for the detection of the martensitic proportion was carried out by the bcc crystal structure of a ferrite. Both, α'-martensite and α-ferrite have a bcc crystal structure [3].

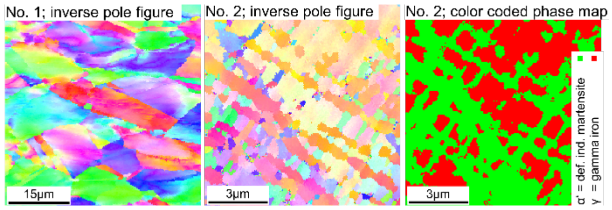

Fig. 3. IPF of samples No. 1 and No. 2, and CCPM of sample No. 2.

7. Conclusion

In order to summarize the results of experimental investigation the following main topics can be emphasized:

- cold forming by MHP achieves martensitic crystallographic structures while machining X5CrNi18-9, but with same chemical composition as base material.
- EBSD analysis is appropriate for α'-martensite detection (phase mapping by using the bcc crystal structure of a ferrite).
- multiple machining leads to a higher deformation and thus more martensite is created; smaller tool tips lead to a higher induced energy level.

Acknowledgements

The authors want to thank the Machine Tool Technologies Research Foundation (MTTRF) for supporting the research work.

References

[1] Hans-J. Christ et al., "Metastable Austenitic Stainless Steels and the Effect of Deformation-Induced Phase Transformation on the Fatigue Properties," Universität Siegen, 2015.

[2] Jan Scheil, “Entwicklung von Austenitisch-Ferritischem Gusseisen (ADI) aus EN-JS2070,“ TU Darmstadt, 2016.

[3] George Krauss, “Steels: Processing, Structure, and Performance,” ASM International, Ohio, 2015.