

ANALYSIS OF SHOT-PEENING BEHAVIOR OF SINTERED METAL ON FATIGUE LIFETIME

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Abstract

The shot peening process is recommended for surface cleaning at the end of the component part production process to improve the mechanical properties of cast ferrous and non-ferrous metals. It is one of the mechanical surface treatments. At the surface, the compressive residual stress and the dislocation density (in the work hardening state) for cast metal induced by the shot peening process improves the fatigue lifetime performance. For sintered metals, although the compressive residual stress and work hardening state can be generated by the shot peening process, the porosities in the sintered metal have more of an effect on the fatigue lifetime. Therefore, an increase of the surface roughness and the non-existent surface case depth can reduce the fatigue lifetime of sintered metal. In this work, the effect of shot peening on the near surface properties and microstructure were investigated. It was demonstrated that the high roughness and the non-uniform hardness values in the lower depth from the surface had more effect than the compressive residual stress and work hardening state. Unfortunately, the shot peening process insignificantly increases the fatigue performance of sintered metal.

Keywords: Sintered metal, shot peening, fatigue, surface

Introduction

To enhance the quality of materials, several methods are currently applied, including adding an alloying element, heat treatment, or mechanical processes which improve properties such as hardness, strength, erosion and corrosion resistance, and fatigue lifetime. One preferred method commonly used is surface treatment to harden the surface or near surface of the materials and modify the mechanical properties. Many studies have

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investigated the effect of mechanical surface treatments like deep rolling, shot peening, and laser shock peening processes on bulk metallic materials such as steel, aluminum, and titanium alloys. The results have shown that such mechanical treatments lead to positive effects on those metals. Impacting a surface with shot particles, e.g. round metallic, glass, or ceramic particles, produces a compressive residual stress (Glaeser and Shaffer, 1996; Wagner, 1999; Juijerm and Altenberger, 2007) and plastic deformation. More dislocations are generated and they hinder each other's movement when exposed to loads or forces (the so-called work-hardening process) (Juijerm and Altenberger, 2007). Both processes result in increasing strength at the near surface.

The 2 main causes leading to material fracture due to fatigue are overloading and cyclic loading. Overloading, when the load is higher than expected, rarely occurs because manufacturers always design, calculate, and use material within a given yield stress. However, cyclic loading, when the material is subjected to fluctuating loads, is often a cause of fracture after a working period of time. This can lead to a dislocation movement and more dislocation will be produced and move along the slip planes. The dislocation movement towards grain boundaries causes extrusion or intrusion of that region. Such behavior could happen at different positions around the grain boundaries. Stress concentration around the extrusion and/or intrusion areas increases and leads to crack initiation and propagation, and finally fracture occurs. Therefore, surface

hardness enhancement, roughness reduction, compressive residual stress, and an increasing number of dislocations will help to enhance the fatigue lifetime of the materials (Glaeser and Shaffer, 1996; Torres and Voorwald, 2002; Juijerm and Altenberger, 2007; Miao *et al.*, 2010; Foss *et al.*, 2013; Pant *et al.*, 2016).

Nowadays, the sintered powder metal process has been used for many component parts due to material cost reduction. Additionally, it enables manufacture of a complex shape which may be difficult or costly when produced with other methods. Notwithstanding, sintered metal has a main disadvantage in its low mechanical properties such as the low strength, hardness, and fatigue lifetime (Höganäs AB, 2013; Beiss *et al.*, 2002; Tosangthum *et al.*, 2006; German, 1998; Nusskern *et al.*, 2014).

The objective of this study aims to investigate the effect of shot peening on porosity surface hardness, case depth, and fatigue lifetime of sintered metals.

Materials and Methods

Material and Specimen Preparation

To study the effect of shot peening on fatigue property, specimens were prepared with sponge iron metal powder NC100.24, mixed with zinc-stearate in the ratio of 99:1 by percent weight, as a solid lubrication. The mixture was pressed into shape in bar form with the dimensions of $20 \times 20 \times 186 \text{ mm}^3$, and then sintered at $1,200^\circ\text{C}$ for 75 min. The

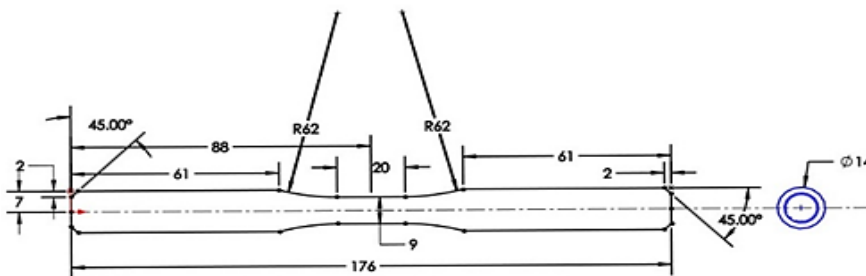


Figure 1. The specimen geometry of sintered metal

specimens were finally machined to the form shown in Figure 1. In this study, the sintered specimens were separated into 2 groups, one which has not been through shot peening (indicated as non-shot peened), and the other which has gone through the shot peening process.

The Shot Peening Process

In the shot peening process, sintered specimens were fixed and rotated with a lathe machine which has a closed cover. The speed of the rotated lathe machine used in this study was 85 rpm during the shot peening process. Sphere-shaped steel balls with a diameter of 0.5 mm were applied as the shot peening media. The forces of the shot peening process that were used were 5 bars and 10 bars. Figure 2 shows a specimen after the shot peening process.



Figure 2. The shot peening specimen

Surface Analysis

To analyze the structure at the near surface of the specimens, a series of measurements were done, starting with a microstructure study of the surface roughness, hardness case-depth, residual stress, and full width at half maximum (FWHM) values.

To study the microstructure, an optical microscope was used for the analysis. The surface roughnesses of the non-shot peening and shot peening conditions were measured, according to standard ISO 4287. The hardness case-depth and thickness of the hardened layer were analyzed with the micro Vickers hardness method.

Residual stresses and the work hardening states at the surface and near-surface regions of all specimens were measured using the X-ray diffraction technique. The machine used for the test is shown in Figure. 3, where the classical $\sin^2\psi$ method with $\text{CrK}\alpha$ radiation at

the $\{211\}$ planes and $\frac{1}{2}S_2 = 6.16 \times 10^{-6}$ mm, $2/N$ as an elastic constant was applied. The work hardening states (micro-residual stress states) were characterized by the FWHM values of the X-ray diffraction peaks. All residual stresses and FWHM values were measured in the longitudinal direction of the specimens.

Fatigue Test

The fatigue test was conducted in a rotary bending fatigue tester. Specimens from both conditions, the non-shot peening and shot peening processes with the force of 5 bars and 10 bars, were tested with the stress amplitude at 200, 300, 400, and 500 MPa. Then the S-N curves was determined and compared.

Results and Discussion

Microstructure

Figure 4 displays the structure of a non-shot peened sintered specimen. Porosity inside the ferrite particles can clearly be seen. Such a ferrite structure arises from the chemical mixture of the sintered metal powder NC100.24.

A comparison of the microstructures at the near surface of the non-shot peened and shot peened specimens is shown in Figure 5. Obviously, the specimens with shot peening (Figures 5(b) and 5(c)) have rougher surfaces. Though metal particles were shot with external forces at the surface, there was no compacted



Figure 3. The X-ray diffraction instrument

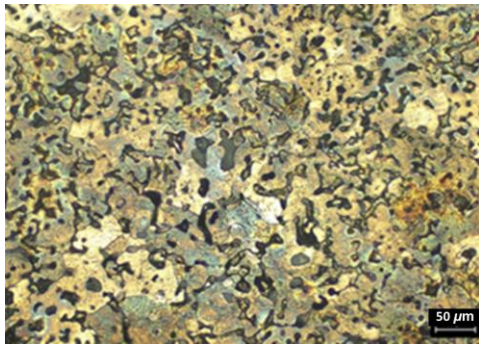


Figure 4. Pore distribution of the as-sintered specimen

layer found at the near surface. This could be due to the porosity which helps to absorb the forces and therefore hindered compaction. Those forces caused the plastic deformation in many small areas distributed on the near surface and increased the surface roughness more. Figure 6 shows results of the surface roughness measurement, compared between the non-shot peened (Figure 6(a)) and shot peened specimens with 5 bars (Figure 6(b)) and 10 bars (Figure 6(c)).

Figure 7 demonstrates a comparison of the surface roughness with the different shot peening forces. The surface roughness of the shot peened specimens significantly increased due to the applied forces in the shot peening process, especially for the roughness (R_t) value, and depth measured from the highest point to the deepest point of the surface. At the area with a high R_t , high stress intensity gathers which results in fracture of the specimen during operation.

The compressive residual stress on the near surface of the shot peened specimens increases slightly with the higher shot peening forces (Figure 8), leading to a slight increase in the near surface hardness. The slight increase in the FWHM value (Figure 9) can be referred to the higher density of the dislocations. With a higher density of dislocations, the movement of the dislocations could be hindered by themselves. This is called the work hardening process in materials.

The shot peening process causes plastic deformation on the surface. The microstructure

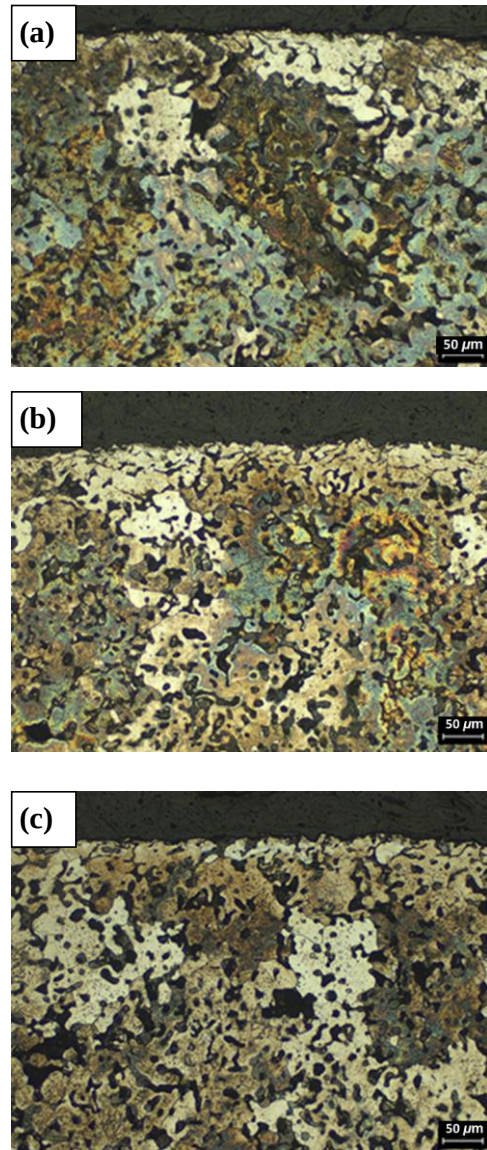


Figure 5. Microstructures of (a) non-shot peened, (b) 5 bars shot peened, and (c) 10 bars shot peened specimens

of sintered material is composed of small porosities and a ferrite matrix. The shot peening force could be absorbed by these porosities and the areas near the surface can freely expand due to these porosities on and under the surface, which easily become plastic. The hardness value for the non-shot peened

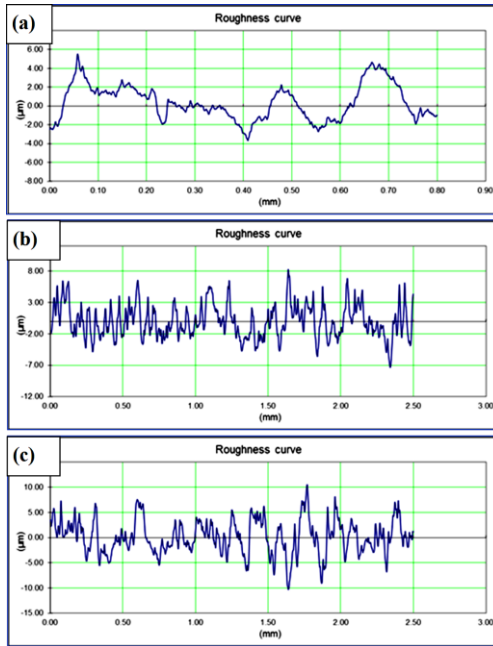


Figure 6. Surface roughness of (a) non-shot peened specimen, (b) 5 bars shot peened, and (c) 10 bars shot peened materials

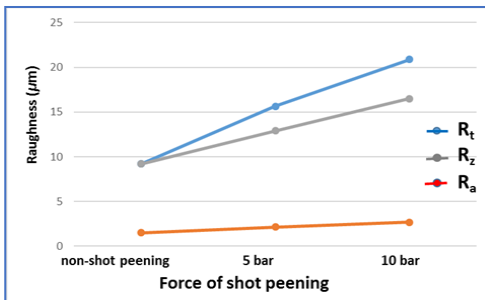


Figure 7. Surface roughness of different shot peening forces

specimen is 53.25 HV, and minimally increases to 55.00 HV for the 5 bars shot peened specimen and 61.70 HV for the 10 bars shot peened specimen. Also, a similar trend was observed in the hardness case depth of the shot peened sintered specimens. Figure 10 shows the effect of the shot peening process on the hardness case depth. The hardness values for

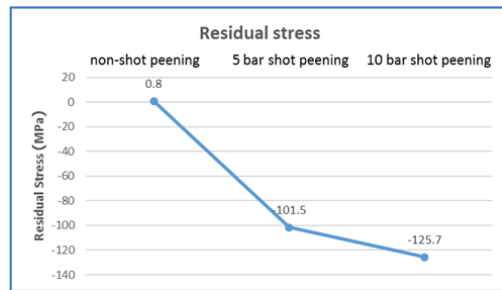


Figure 8. Effect of different shot peening forces on the residual stresses at the near surface for sintered metal

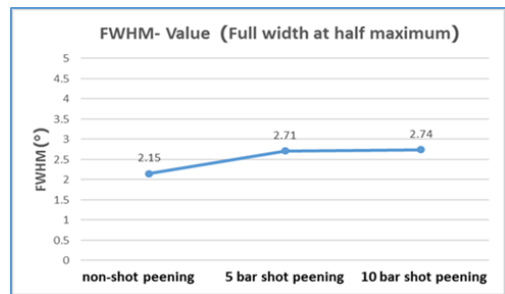


Figure 9. Effect of different shot peening forces on the FWHM values at the near surface for sintered metal

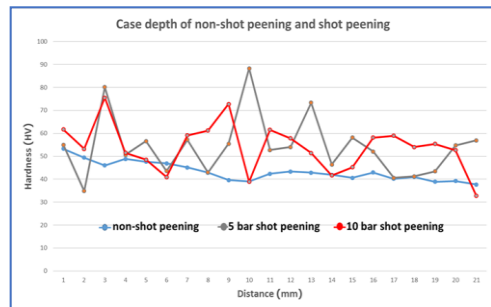


Figure 10. Hardness case depth of different shot peening forces

the shot peened sintered specimens are not constant, especially in the lower depths from the surface. Despite inducing the compressive residual stress and FWHM values of the shot peened specimens, their hardness marginally increased.

The influence of the shot peening process on the fatigue lifetime is shown in Figure. 11. In the regime of low cycles, the number of cycles of the shot peened specimens decreased with increasing the shot peening force. The fatigue lifetime for the non-shot peened specimen was 8,463 cycles with the test of stress amplitude at 400 MPa, and was reduced to 3,063 cycles for the 5 bars force and 1,039 cycles for the 10 bars force shot peening. That means that the shot peening process reduces the fatigue lifetime for the sintered metal.

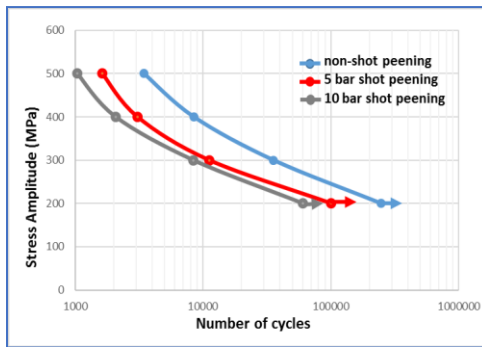


Figure 11. S-N curve compared between non-shot peened and various forces of shot peened specimens

In the shot peening process, the peening media were shot at the surface of the sintered metal. The compressive stress was induced near the surface. Especially, the stress concentration was intensive in the tipped area of high roughness. The porosities in the ferrite matrix of the sintered metal partly absorbed the shot peening force and the materials on the near surface were deformed plastically. When subjected to fatigue loading, the vacancy defect atoms and especially the dislocations moved and accumulated themselves along the grain boundary. The dislocations' movement caused intrusion and extrusion of persistent slip bands which developed and continued to the crack initiation and propagation of the material.

Even though the compressive residual stress and FWHM values were increased and could prevent the crack initiation and

propagation of the material, the high surface roughness of the shot peened sintered metal was overwhelming.

In addition, the hardness of the case depth did not occur in the shot peened sintered metal. That means that the shot peened material did not generate a hard layer on the surface. Further, the measured hardness value revealed that it was inconsistent and scattered. As a result, this eventually affects the fatigue lifetime of the sintered metal.

Conclusions

The effect of the shot peening process on the fatigue lifetime of low carbon sintered metal was investigated. As a consequence of the existence of porosities in or near the surface, these pores were absorbed by the shot peening force and the sintered metal was effortlessly deformed to plastic. The shot peening process on the sintered metal could not produce the hardness case depth layer. Moreover, with this surface treatment, high surface roughness was observed. Although the compressive residual stress and FWHM values of the shot peened sintered metal were increased, these effects have less effect compared to the high surface roughness. Therefore, it can be concluded that the shot peening process could not improve the fatigue lifetime of the sintered material.

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