IMPROVED FATIGUE RESISTANCE OF SINTERED STEELS VIA LOCAL HARDENING

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1. Introduction

The current status of powder metallurgy marked demands for either a reduction of costs or a sensible increase in properties. This concept applies, especially in the automotive sector, where the average weight of PM parts per car is now nearly 10 kg and a growth of 37 % is assumed to be reached in 10 years⁵. The increase of properties could affect the design as well as the customer’s demands but can be obtained only through new tendency and technological innovation and/or through the application of either new or adapted solutions.

Modification of density and microstructure, via classical route as pressing and sintering, can be successfully achieved for the fatigue limits of powder metallurgy steels at about 300 MPa average⁵, this means that secondary operations are generally necessary to reach the higher fatigue properties. If compared to wrought steels⁴⁵, fatigue behavior of sintered steels is more complicated and depends on some factors related to sintered microstructures, such as pore agglomerates⁵. Fatigue properties of sintered steels depend on plasticity and strength of microstructures, as well as porosity. The pores act as crack initiators, the distribution of stress is inhomogeneous across the cross section of the investigated material and reduces the effective load bearing area. Both the morphology and distribution of pores have a significant effect on the mechanical behavior of powder metallurgy steels. Two types of porosity are typically observed in sintered materials⁴⁵; interconnected and isolated porosity. Interconnected porosity has more pronounced effect on properties than isolated porosity. Relationship to strength is expressed by ratio between fatigue strength and tensile strength. Ratio between fatigue strength and tensile strength, σf/Rm, is close to 0.38 (ref.⁷).

A suitable modification of functional surfaces may determine a sensible upgrade in the required properties of low alloyed steel. Shot peening is an industrial process often used to improve the component properties⁸–¹³, especially fatigue life and fatigue strength. In powder metallurgy, shot peening is a relatively new technological solution for higher strength sintered materials, especially in fatigue performance. Nakazawa et al.¹⁴ tested the subgear (in order to replace forging by powder metallurgy) through the addition of the shot peening operations; the bending fatigue strength (parts were tested using test rig and motored engine test) was improved by 30 %. Additional researchers evaluated results Ancorsteel 1000 B with 2 % copper and 0.9 % graphite and showed that by optimising the controlled shot peening parameters, the endurance limit of sintered steel powder metal alloys can be raised by 16 % and 22 % (ref.¹⁵). Automotive components such as gears, sprockets and connecting rods are excellent candidates for powder metallurgy and controlled shot peening.

The aim of this work is to determine the effect of local hardening cause by surface modification on the fatigue failure resistance. Fatigue strength was evaluated by Wöhler curves for the plane bending fatigue tests on unnotched specimens of as-sintered and shot peened alloys.

2. Material and experimental procedure

Commercially pre-alloyed water-atomised Höganäs Fe-Cr, Mo powder (Astaloy CrL, which contains 1.5 % Cr and 0.2 % Mo) was used as base material. The other commercial raw materials were CR 12 graphite powder and HW wax powder as lubricant. Graphite was added in mixture as 0.5 % and 0.7 %. Final powder mixtures were homogenized in a Turbula mixer. Two different specimen types, compacted at 600 MPa to a green density of ~7.0 g cm⁻³, were prepared: “dog-bone” tensile (ISO 2740) and fatigue (ISO 3928) specimens. Formulation and processing parameters of the tested alloys are presented in Table I. Sintering was carried out in laboratory tube furnace in an atmosphere of pure gases 75 % N₂ + 25 % H₂. The sintering temperature was 1180 °C for 60 minutes. Heating and cooling rates were 10 °C min⁻¹. The surface modifications were carried out on laboratory testing apparatus. Parameters of testing apparatus were steel granulate S11 with diameter dₗ = 0.6 mm, angle between shot stream and peened surface 90°, shot velocity v₇₀₀₀ = 71 m s⁻¹. Specimens were tested in static tensile test on a ZWICK 1387 machine, extension rate = 0.1 mm min⁻¹. Fatigue tests were carried out in symmetric plane bending at R = −1, using SCHENCK P1050 testing apparatus. The maximum cycle number was 10⁷. Batches of 15 specimens were tested.

Table I

<table>
<thead>
<tr>
<th>Material</th>
<th>State</th>
<th>Sintering (°C min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astaloy CrL + 0.5C</td>
<td>as-sintered</td>
<td>1180 / 60</td>
</tr>
<tr>
<td>Astaloy CrL + 0.5C</td>
<td>shot-peened</td>
<td>1180 / 60</td>
</tr>
<tr>
<td>Astaloy CrL + 0.7C</td>
<td>as-sintered</td>
<td>1180 / 60</td>
</tr>
<tr>
<td>Astaloy CrL + 0.7C</td>
<td>shot-peened</td>
<td>1180 / 60</td>
</tr>
</tbody>
</table>
The profile surface roughness, Ra, was measured by Hommel Tester T1000 profilometer.

Light and scanning microscopy were employed for microstructural evaluations. For optical microscopy, samples were individually mounted, mechanically polished and finally etched at room temperature using a Nital reagent. Scanning microscopy was carried out using SEM JEOL 7000F.

3. Results and discussions

3.1. Surface roughness

The implementation of plastic deformation via shot peening caused profile unevenness. The profile unevenness was expressed by the arithmetical mean deviation of the profile surface roughness; R_a. The profile surface roughness is the average arithmetical deflection of all unevenness from the central line in the measured length 16-18. The average results from 5 measurements of the profile surface roughness are presented in Table II.

Table II
Average values of surface roughness

<table>
<thead>
<tr>
<th>Material</th>
<th>State</th>
<th>R_a [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astaloy CrL + 0.5C</td>
<td>as-sintered</td>
<td>1.31 ± 0.17</td>
</tr>
<tr>
<td>Astaloy CrL + 0.5C</td>
<td>shot-peened</td>
<td>7.56 ± 0.23</td>
</tr>
<tr>
<td>Astaloy CrL + 0.7C</td>
<td>as-sintered</td>
<td>1.32 ± 0.19</td>
</tr>
<tr>
<td>Astaloy CrL + 0.7C</td>
<td>shot-peened</td>
<td>7.21 ± 0.21</td>
</tr>
</tbody>
</table>

3.2. Properties and microstructures

Mechanical properties of prealloyed sintered Astaloy CrL steels are presented in Fig. 1.

S-N curves of investigated materials are presented in Fig. 2 and 3.

Prealloyed Astaloy CrL with 0.7 % C is a material with good combination of mechanical properties and fatigue strength. The observed rankings in fatigue strength of the as-sintered and shot peened states are readily explained by the different microstructures due to different processing conditions. Microstructure of Astaloy CrL with 0.5 % C consist of mainly fine pearlite with areas of ferrite and bainite, Fig. 4.
The microstructure of Astaloy CrL with 0.7 % C consists of predominate upper bainite with small areas of pearlite, Fig. 5.

3.3. Local hardening

The detailed research of local area showed that the effects of local hardening caused by surface modification via shot peening exhibit higher hardness. Microhardness profiles, Fig. 6, confirmed the important role of microstructure constituents. The presence of bainite in specimens with higher graphite contents exhibited higher values of microhardness (the blank circle); on the other hand, the dominant presence of fine pearlite determined lower microhardness in the range HV 0.025 = 200–250. The highest microhardness values located at average value of 25 μm from outer surface. This corresponds to the details focused on local hardened area.

The modification of functional surfaces of investigated steels increased the mechanical and fatigue properties by means of stronger segments on the surfaces of specimens due to something close to a fully densified surface layer, as well as by the elimination of the detrimental effect of pores near the surface; the result was the decrease of crack propagation, Fig. 7.

On the other hand, the creation of a rough surface (represented by values of Rₐ) and notch production increasing strain localization caused the formation of local distribution secondary cracks, thus decreasing the tensile strength. The role of weak interfaces seems to be considered as a significant factor. Mechanical properties are controlled by the mechanisms of fracture in sintering necks. Characteristic for a duc-
tile fracture are the nucleation, coalescence and growth of voids within the sintering necks. Such voids are often nucleated at small brittle inclusions in the neck region. Shot peening has positive effect for fatigue endurance but it has also been demonstrated than negative results may arise\textsuperscript{19,20}. It is therefore important, in the future, to evaluate the parameters of shot peening.

4. Conclusion

The detailed research of local area has showed that the effect of local hardening causes by shot peening exhibits non-uniform distribution. The modification of functional surfaces of investigated steels increased mechanical and fatigue properties by means of stronger segments on the surfaces of specimens due to something close to a fully densified surface layer, as well as by the elimination of the detrimental effect of pores near the surface. The number and distribution of such inclusions might control the final mechanical properties. Further research in this area may lead eventually to the publication of a design specification for sintered shot peened components. Controlled shot peening seems to be most effective on higher hardness and higher density powder metallurgy components.

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REFERENCES


R. Bidulský\textsuperscript{a}, M. Actis Grande\textsuperscript{b}, and M. Kabátová\textsuperscript{b} (\textsuperscript{a} Politecnico Torino, Alessandria Campus, Alessandria, Italy, \textsuperscript{b} IMR SAS, Kosice, Slovakia): Improved Fatigue Resistance of Sintered Steels Via Local Hardening

The aim at the present paper was to find out how the local hardening via surface modification and also microstructures affect the fatigue characteristics of the considered sintered materials. Two different systems were prepared: as-sintered and shot peened prealloyed sintered (Astaloy CrL based) steels with addition of 0.5 and 0.7 % C. Fatigue tests were carried out in symmetric plane bending at $R=–1$. The detailed research of local area showed local hardening caused by surface modification via shot peening. Local hardening exhibit positive effect on the fatigue failure resistance, due to a surface something close to a fully densified surface layer obtained by shot peening, as well as by the elimination of the detrimental effect of pores near the surface.