The Influence of Shot Peening on the Fatigue Behavior of Gray Cast Iron and Ductile Iron

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Abstract

The fatigue response of cast irons have been investigated in rotating beam loading (R = -1) on smooth (k_t = 1) and notched (k_t = 2.3) specimens with lamellar as well as nodular graphite constituents. The lamellar cast iron denoted as GJL 200 had a ferritic perlitic matrix while the nodular graphite features of GJS 350 were embedded in a ferritic matrix. As expected, the tensile strengths were quite different amounting to 200 and 370 MPa for the lamellar and nodular materials, respectively. Shot peening was applied on both materials on smooth and notched specimens. The lamellar cast iron showed an improvement in fatigue strength due to shot peening compared to the mechanically polished reference. The endurance limit after shot peening amounted to about 75 MPa. For notched specimens, there was a slight improvement in endurance limit from about 50 MPa to about 80 MPa after shot peening. Comparable observations were made with ductile cast iron

Key Words: Grey cast Iron, ductile Iron, smooth specimens, notched specimens, shot peening, fatigue life, endurance limit

Introduction

Mechanical surface treatments such as shot peening or burnishing are often applied to metallic materials to improve their HCF performance [1-4]. In general, this improvement can be derived from two contributing factors: First, surface strengthening by the induced high dislocation densities (work hardening) and secondly by the generation of residual compressive stresses. Surface strengthening gives rise to an enhancement of the resistance to fatigue crack nucleation whereas the micro-crack propagation resistances are detrimentally affected. This is caused by the low residual ductility in the cold worked and strengthened surface layer. On the other hand, it was shown that residual compressive stresses can reduce the growth rate of surface microcracks. In contrast, the crack nucleation resistance is less affected by means of residual compressive stresses [5].The question is whether the facts described are also valid for cast iron. Cast iron differs from most materials by a significant feature. The steel-like matrix is interspersed with graphite-filled cavities. The cavities are to be understood as inner and outer notches. How strongly these notch-like features affect the fatigue behavior depends on their geometry. These features undoubtedly have an influence on the fatigue behavior. This is especially the case for gray cast iron. The graphite constituents are structured as lamellae. High stress concentrations occur mainly at the tips of the lamellae. Because of these numerous inner notches consisting of graphite-filled cavities, an influence of additional outer notches may be absent. Therefore, this material can be considered as notch-insensitive. The situation is different in ductile iron because the stress concentration at the nodular graphite constituent is much less pronounced.

In both cases, the cold working process and the induction of residual stresses caused by shot peening impact the response of the steel-like matrices on cyclic loading. However, this can vary considerably.

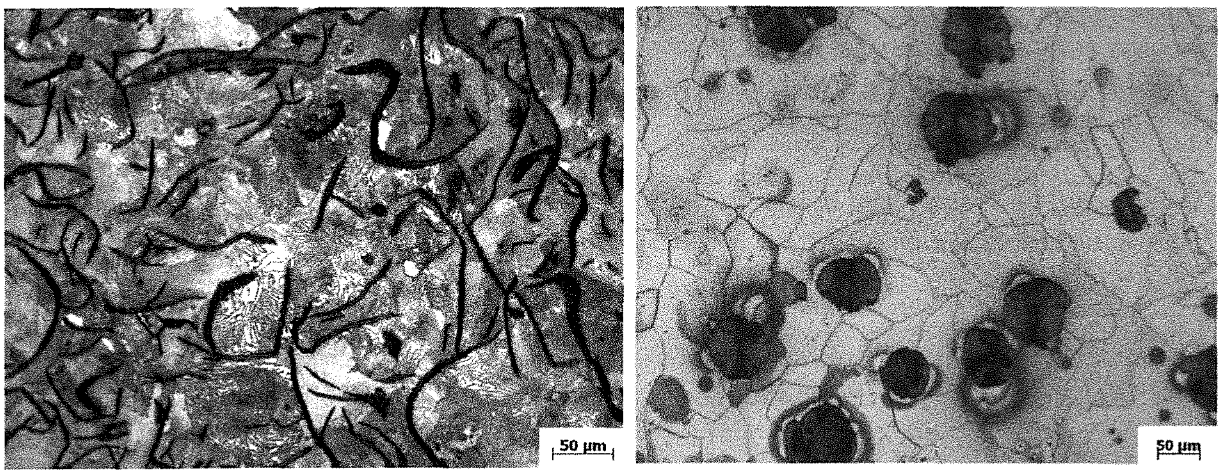
Experimental

The investigation was performed on gray cast iron (flake graphite, GJL-200) and ductile iron (spheroidal graphite cast iron, GJS-350). The tensile properties of both materials are listed in **Table 1**. Specimens for these tests were tested with the load axis in longitudinal direction.

Table 1 Tensile Properties of the investigated grades of cast iron

Material	Young's Modulus (GPa)	YS (MPa)	UTS (MPa)	El (%)
GJL-200	13	178	200	3
GJS-350	132	240	370	28

The microstructures of the two materials are shown in Figure 2. **Figure 2 (a)** shows the typical features of graphite flakes embedded in a perlitic matrix. **Figure 2 (b)** illustrates the spherical nodules of graphite embedded in a ferritic matrix.



a) b)

Figure 2 Microstructures of GJL-200 (a) and GJS-350 (b)

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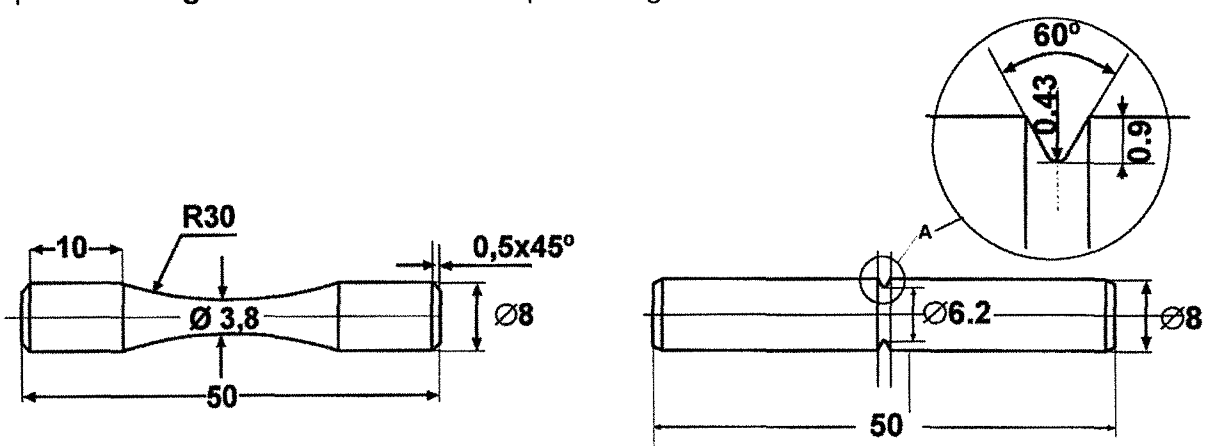
Fatigue testing was carried out on hour glass shaped (smooth) and circumferentially notched specimens. **Figure 3** illustrates the two specimen geometries.



a) hourglass shaped (smooth), $k_t = 1$ b) circumferentially notched, $k_t = 2.3$

Figure 3: Dimensions of fatigue specimens

Shot peening was performed using a direct pressure blast system of OSK at IWW of TU Clausthal. All peening was applied to full coverage on both specimen types using spherically conditioned cut wire (SCCW14). The diameter of the peening media was 0.36 mm. The exposure time was 25 s resulting in an Almen intensity of 0.20mmA. During the peening treatment, the specimens rotated at $1s^{-1}$. In addition to shot peened conditions, mechanically polished specimens were prepared to serve as reference. Fatigue tests were performed in rotating beam loading (R = -1). The various conditions of the tested specimens are listed in **Table 2**.

Table 2 Conditions of specimens

GJL-200		GJS-350	
smooth	**Notched**	**smooth**	**Notched**
mechanically polished	mechanically polished	mechanically polished	Mechanically polished
Shot peened	shot peened	shot peened	shot peened

Results and Discussion

Gray cast iron

The influence of shot peening on the fatigue behavior of smooth specimens (GJL-200) can be seen in **Figure 4**.

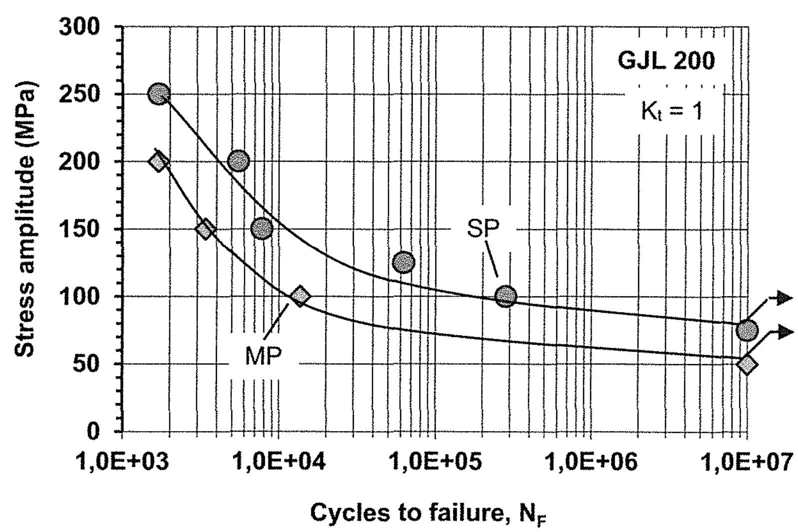


Figure 4 Influence of shot peening on the smooth fatigue performance of GJL 200

Obviously, shot peening of gray cast iron gives rise to a significant improvement of the fatigue performance from 50 MPa (condition MP) to 75 MPa (condition SP).

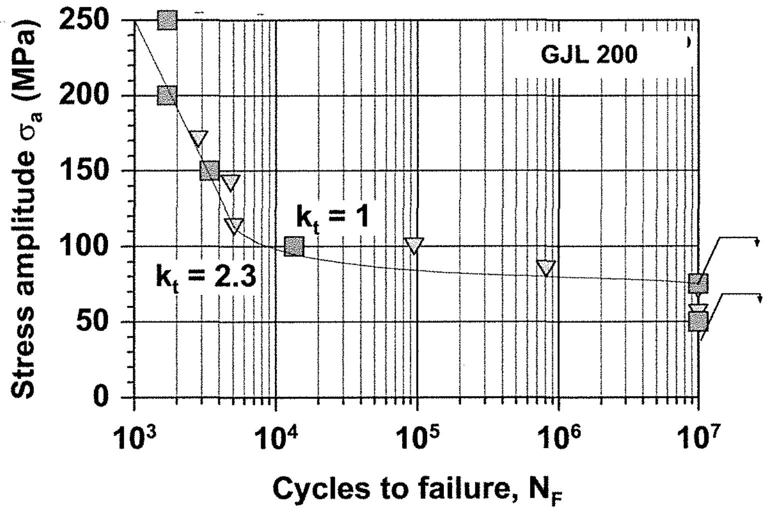


Figure 5 Influence of notches on the fatigue performance of GJL 200

Figure 5 compares the fatigue performances of smooth and notched specimens in the mechanically polished reference conditions. As seen, the smooth ($k_t = 1$) fatigue performance of GJL200 is not affected by the additional notches ($k_t = 2.3$). Obviously, the HCF performance of GJL200 is fully notch insensitive. For investigating the feasibility of an improvement of the notched fatigue performance by means of shot peening, notched specimens were shot peened and tested.

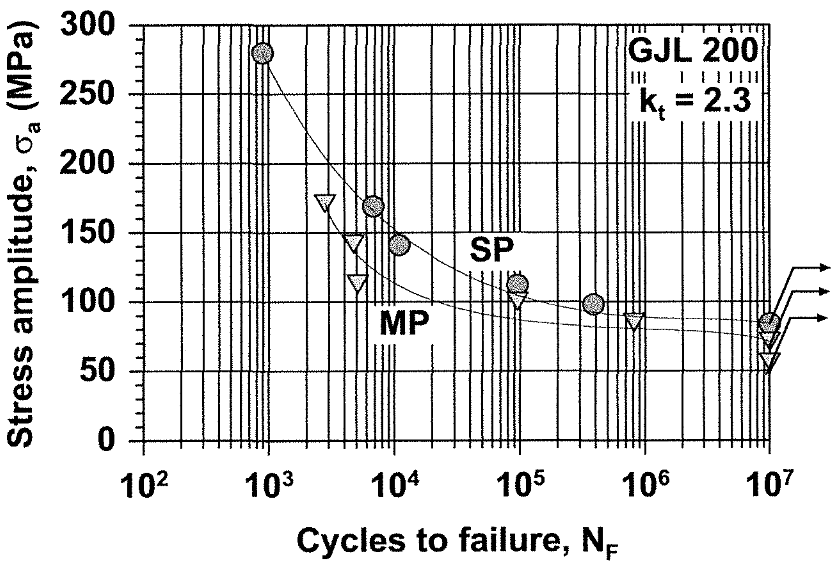


Figure 6 Influence of shot peening on the notched fatigue performance of GJL 200

Figure 6 illustrates the comparison of the notched fatigue performance of mechanically polished and shot peened specimens. As seen, shot peening slightly improves the fatigue life of notched specimens. By comparing **Figures 4** und **6**, it can be seen that notched specimens respond somewhat more beneficially to shot peening than smooth specimens.

The fatigue behavior of shot peened smooth and notched specimens is compared in **Figure 7**. As already observed on the mechanically polished references (Fig. 5), the fatigue performance of shot peened specimens is fully notch insensitive.

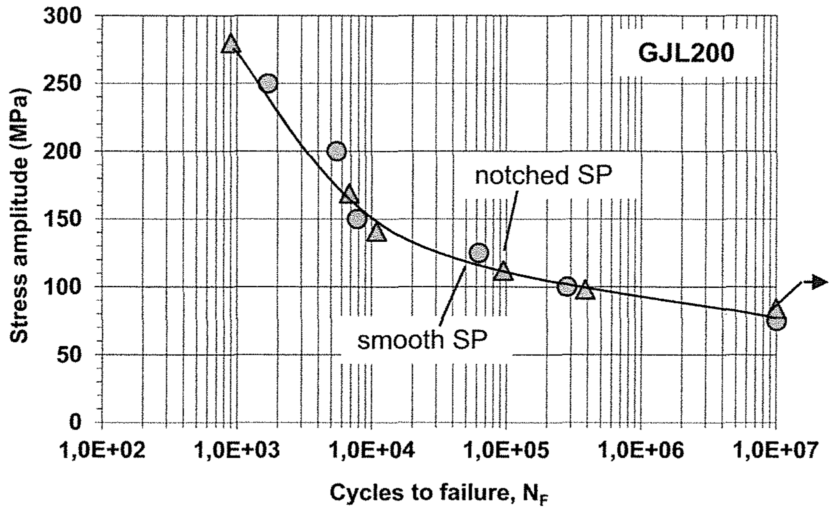


Figure 7 Comparison of shot peened smooth and notched specimens of GJL 200

Ductile Iron

The influence of shot peening on the fatigue performance of smooth ductile iron is presented in **Figure 8**. Shot peening increases the fatigue limit from 200 MPa (condition MP) to about 225 MPa (condition SP).

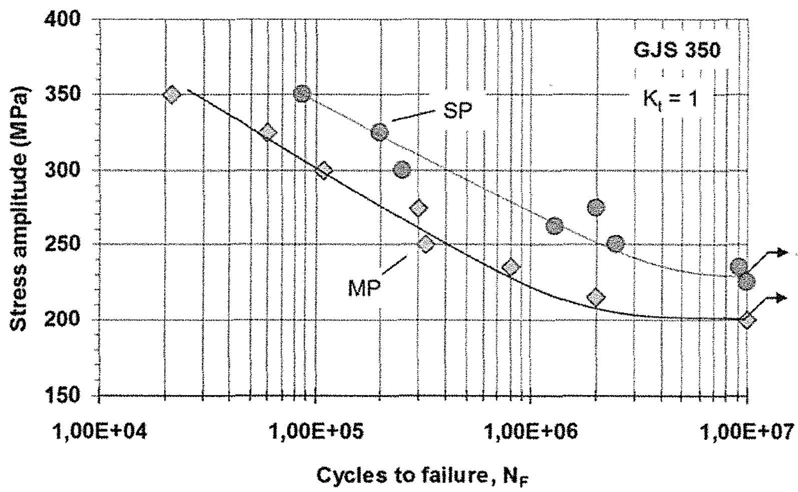


Figure 8: Influence of shot peening on the smooth fatigue performance of GJS 350

The fatigue performance of smooth specimens of ductile iron is compared with the fatigue performance of notched specimens in **Figure 9**. As seen, a notch factor of k_t = 2.3 clearly decreases the fatigue life and the fatigue strength of the mechanically polished references relative to the smooth condition. This pronounced loss in fatigue performance due to notches indicates a slight notch sensitivity of the fatigue performance in GJS 350. A similar slight notch sensitivity was found in previous work on stainless steel AISI 304 [6]. For comparison, the wrought magnesium alloy AZ80 is fully affected by the geometrical notch factor indicating that AZ80 is 100 % fatigue notch sensitive [7].

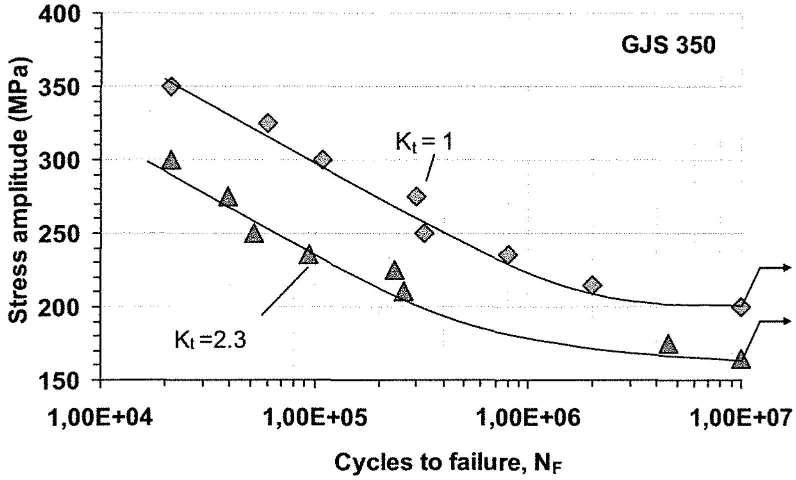


Figure 9 Influence of notches on the fatigue performance of GJS 350

The influence of shot peening on the fatigue performance of notched specimens of ductile iron is presented in **Figure 10**. As observed before on gray cast iron, an improvement of the notched fatigue performance can be asserted.

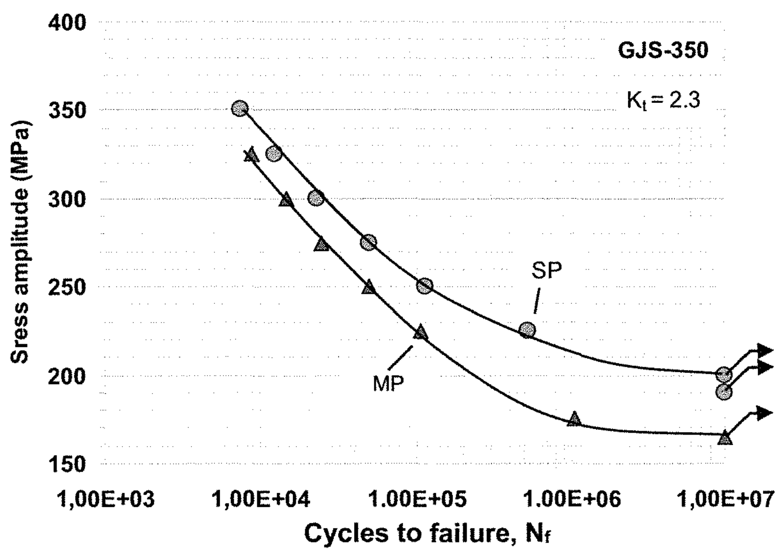


Figure 10 Influence of shot peening on the notched fatigue performance of GJS 350

Discussion

The fatigue performance of gray cast iron exhibits a significant improvement after shot peening. Similarly, the fatigue performance of ductile iron was improved as well. With respect to the notch effect, however, significant differences were determined. Smooth and notched specimens of gray cast iron showed no differences concerning the fatigue behavior. The lamellar graphite patterns act as inner and outer notches. With other words: This material may be regarded as steel full of stress raisers. These features have the form of holes or cavities which are filled with graphite flakes. An external notch, which is usually not as severe as the internal notches, cannot develop further severe reduction of strength. The material is notch insensitive [8]. Shot peening results in an improvement of the fatigue behavior. The notched samples show the same degree of improvement such as the smooth peened samples. Samples from ductile iron showed in contrast to gray cast iron a clear deterioration of the fatigue properties in the notched condition. The additional notch leads to severe stress concentrations. This gives rise to premature failure resulting in increased notch sensitivity. Cause of the better fatigue behavior of ductile iron compared to gray cast iron is the more favorable stress distribution. The occurrence of stress concentration as it is well known from lamellar structures is less pronounced. The notch sensitivity of ductile iron is larger than in gray cast iron but lower than that of various other materials, e. g. Ti-6Al-4V, Beta C or LCB [6]. As with gray cast iron, the fatigue behavior can be improved by shot peening treatment of the notched areas.

References

[1] V. Schulze, Modern Mechanical Surface Treatment, Wiley-VCH (2006)

[2]H. Wohlfahrt, in: Shot Peening (H.O. Fuchs, ed.) American Shot Peening Society, Paramus (1982) 316.

[3] H. Wohlfahrt, in: Shot peening (H. Wohlfahrt, R. Kopp and O. Vöhringer, eds.) DGM (1987) 125.

[4] I. Altenberger, in: Shot Peening (L. Wagner, ed.) Wiley-VCH (2002) 421.

[5] E. Maawad, S. Yi, H.-G. Brokmeier, M. Wollmann, L. Wagner, Residual Stress-Induced Subsurface Fatigue Crack Nucleation in Shot Peened Titanium Alloys, ICSP 10 (K. Tosha, ed.) ACMU (2008) 499.

[6] L. Wagner, T. Ludian, M. Wollmann, Ball-Burnishing and Roller-Burnishing to Improve Fatigue Performance of Structural Alloys, Engineering Against Fracture, 2009, 1, 1-11

[7] B. Küster, M. Hilpert, A. Kiefer, L. Wagner, Influence of Mechanical Surface Treatments on Notched Fatigue Strength of Magnesium Alloys, Shot Peening, (L. Wagner, ed.) Wiley-VCH-Verlag, Weinheim (2003) 367.

[8] C. S. Yen, T. J. Dolan, A Critical Review of the Criteria for Notch-Sensitivity in Fatigue of Metals, Published by the University of Illinois, Urbana (2007)