Gigacycle Fatigue Endurance Strength of High Density Mo and Cr-Mo Prealloyed Sintered Steel

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Abstract

For attaining optimum fatigue resistance of PM steels, high density levels are necessary. In this work, sintered steels Fe-1.5%Mo-0.6%C and Fe-1.5%Cr-0.2%Mo-0.6%C were produced with density levels of 7.1 to 7.6 g.cm^{-3}. Ultrasonic fatigue testing with 20 kHz was performed in push- pull mode up to 10E9 cycles. It was shown that the fatigue endurance strength is strongly improved by higher density levels, but also higher sintering temperatures are beneficial. The Cr-Mo steels proved to be superior to the plain Mo alloyed, due to a more favourable as-sintered matrix microstructure.

Keywords : Fatigue; Sintered steels, High velocity compaction, Microstructure

1. Introduction

Many powder metallurgy precision parts are subjected to fatigue loading in service, and their fatigue behaviour is therefore of decisive importance [1, 2]. This holds in particular for components employed in automotive engines and transmissions, and here it must be kept in mind that for engine parts, loading cycle numbers may easily exceed 10E8. In case of fatigue in the gigacycle range the role of crack initiating singular defects is much more pronounced than in the commonly tested range of Nmax <10E7. This holds both for wrought [3, 4] and sintered steels [5, 6], and the singular defects are also held responsible for the non-existence of a true fatigue limit in bcc steels [7, 8].

As many other mechanical properties, the fatigue endurance strength of sintered steels depends strongly on the density [8, 9]. Therefore, increasing the fatigue resistance requires higher density levels. In this work, the gigacycle fatigue behaviour of Cr-Mo and Mo prealloyed sintered steels has been studied, HVC compacted high density parts being compared to standard compacted ones, and also the sintering intensity (temperature and time) being varied.

2. Experimental and Results

The test specimens were manufactured from prealloyed steel powders Fe-1.5%Mo (Astaloy Mo) and Fe-1.5%Cr-0.2%Mo (Astaloy CrL) with addition of 0.6% natural graphite. The powder mixes were compacted by two variants of high velocity compaction (HVC1 and HVC2) to fatigue test specimens (ISO 3928) with green density levels of about 7.35 and 7.6 g.cm^{-3} , respectively. As a reference, also standard die compaction was done. The compacted bars were then sintered following two regimes, i.e. 30 min at 1120°C / 1 h at 1250°C in N_2-H_2 atmosphere. The sintered specimens were then machined to a slightly thinner gauge section by milling the die surfaces of the gauge area with a sharp hard metal tool and turning a thread on one end of the bar; then the gauge section was longitudinally ground and the edges slightly rounded; finally the surfaces of the gauge section were longitudinally polished to mirror finish.

For fatigue loading up to 10E9 cycles, an ultra high frequency fatigue testing system was employed in which specimens are subjected to push-pull loading (R=-1) at a test frequency of 20 kHz. Cooling with a drilling emulsion was afforded. Details of the test method are described in [9]. Since direct stress measurement is not possible in this method, the strain in the gauge area was measured using strain gauges, and the stress was calculated using data for the dynamic Young’s modulus using a resonance method. S-N graphs were taken up to N_{max} = 10E9. The fatigue fracture surfaces were studied by SEM, and the microstructures of the materials were investigated by standard metallographic techniques

The S-N plots revealed that the existence of a true fatigue limit cannot be confirmed even for high density sintered steels. In all cases, fracture of specimens occurred also in the range N=10E7 to 10E9, which indicates that testing up to N_{max} = 10E7 is insufficient for obtaining reliable data if the respective components are loaded up to significantly higher cycle numbers.

The as-sintered property data clearly showed that the higher density obtained by the HVC compaction techniques is very beneficial for the fatigue endurance strength, significantly higher values being recorded especially at the highest density level (Fig. 1). Also the sintering temperature is of considerable importance; 1 h sintering at 1250°C results in generally higher fatigue endurance strength levels. Finally, also the matrix material plays a major role: at least in the as-sintered state, the Cr-Mo steels yield markedly better endurance strength levels that cannot be attributed to the slightly higher sintered density but are related to their finer, more favourable microstructure (see Fig. 2).

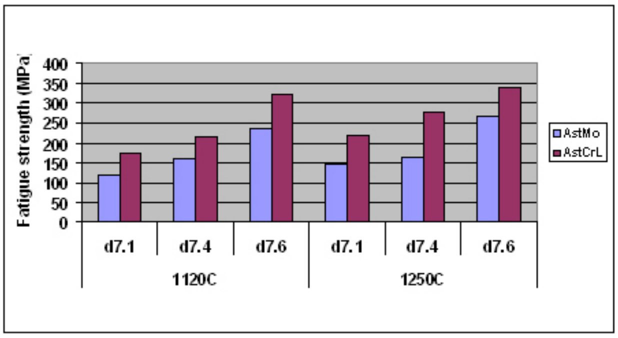
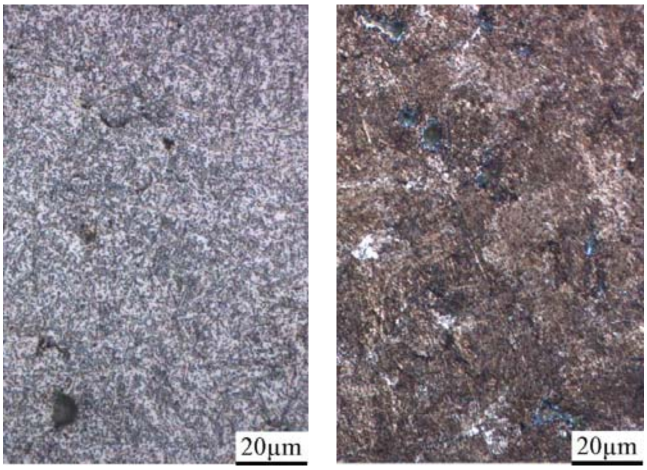


Fig. 1. Fatigue endurance strength data for Mo and Cr-Mo prealloyed sintered steels, differently compacted and sintered. Ultrasonic fatigue testing, 20 kHz, R = -1



Astaloy Mo-0.6%C **Astaloy CrL-0.6%C**

Fig. 2. Metallographic sections of sintered steels, sintered 30 min at 1120°C

From Fig.2, the different microstructures are evident: the Mo alloyed steel exhibits the typical coarse upper bainite, while for the Cr-Mo alloyed variant a mix of fine bainite and pearlite is typical, which also results in higher hardness of the latter material.

3. Conclusions

For studying the ultra high cycle (gigacycle) fatigue behaviour of sintered steels, the ultrasonic resonance technique is well suited. Rectangular test bars ISO 3928, with rounded edges, can be successfully employed although specimens with round cross section are preferable. The S-N graphs confirm that higher density, as attained by high velocity compaction techniques, is very beneficial for the fatigue endurance strength, increases by up to100% compared to standard compaction being attained. Also the sintering route is of relevance, higher temperatures combined with longer isothermal soaking times resulted in significantly better Sw values. Finally, also the material chosen plays an important role, in the as-sintered state the fine upper/lower bainitic microstructure of Cr-Mo prealloyed steels resulted in higher fatigue strength levels than the uniform coarse upper bainite in the Mo prealloyed materials. In all cases, the S-N curves have indicated that the existence of a true fatigue limit for the sintered steels investigated is highly improbable.

Acknowledgement

This work has been carried out within the international project “Höganäs Chair”, organized and financially supported by Höganäs AB, Sweden

4. References

1. F.J. Esper, C.M. Sonsino, “Fatigue Design for P/M Components: Manual for Design and Production Engineers”, EPMA, London, 1994
2. A. Hadrboletz, B. Weiss: *Int. Mat. Reviews*, Vol.42, No.1, 1997, p.1-44
3. Y. Furuya, S. Matsuoka, T. Abe, *Met. and Mat. Trans.* Vol.34A , Vol. 11(2003) p. 2517
4. Y. Furuya, S. Matsuoka, T. Abe, *Met. and Mat. Trans.*Vol.35A, No.12(2004) p. 3737
5. D. Spoljaric et al.: Proc. PM’94 Powder Metall. World Congress Paris (1994) Vol.2, p. 827
6. H. Danninger, D. Spoljaric, B. Weiss: *Int. J. Powder Metall.* Vol.33 No.4 (1997) p.43
7. C.M. Sonsino: *Konstruktion* 2005 No.4, p.87
8. H. Danninger, B. Weiss: *Powder Metall. Progress* Vol.1 No.1 (2001) p.19
9. P. Beiss: Pulvermetallurgie in Wiss. & Praxis Vol.19, H.Kolaska ed. (2003) p.3