Fatigue Properties of Sinter-hardened Fe-Ni-Mo-Cu Materials

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Abstract

Fe-4Ni-0.5Mo-1Cu powder was selected as raw material, pressed and sinter-hardened at 1135℃ for 30 min with rapid cooling. The density varies in the range of 7.24-7.29 g/cm^3. Its fatigue properties have been tested in axial loading of alternating tensile/compressive stress at R=-1 with a servo-pulse pump. The fatigue endurance limit was measured to be 260 MPa. The microstructure showed more homogeneous bainite and martensite. Fractography displayed the fatigue cracks initiated from the pore areas near the surface. A non-typical ductile fatigue striation was found. More dimples occurred on fracture surface due to the plastic deformation, which can prohibit cracking propagation and improve its fatigue properties.

Keywords : Fatigue, Fractography, PM-Steel

1. Introduction

Recently PM material has been used more and more for dynamically loaded components, for example, gear, synchronizer hub and conrod in automobile. A reliable bending and contact fatigue performance is absolutely important for gearbox components and a better alternating tensile/compressive fatigue properties is needed for the conrod. For this reason one of the popular themes in the powder metallurgy field is the study of fatigue behavior of PM steels [1]. Its fatigue strength depends mainly on density, alloying elements and their distribution [2, 3]. Heat treatment can also improve the properties. The cooling rate after sintering may be a decisive factor for the behavior [4]. Investigations have revealed that the bending fatigue strength usually exceeded uniaxial fatigue values. The ratio of tensile/bending fatigue was 0.70-0.80[5,6]. This investigation mainly works at tensile/compressive fatigue because a shorter sample can be used for the measurement.

2. Experimental and Results

A type of diffusion banded alloying iron powder was selected as the raw material, which main chemical composition are Fe-3.83%Ni-0.52%Mo-1.02%Cu. The particle size of alloying element Ni was in the range of 5~10 μm. The powders were pressed into bearing cups using 4 MN press at the pressure of 700 MPa, and sintered in the Cremer CBS-600-115/e sinter-hardening furnace at 1135℃ for 30 min in 83/17 N_2/H_2 with rapid cooling and then tempering at 180℃ for 120 min. The unnotched fatigue testing sample has a rectangular cross section of 3×4 mm as shown in Fig.1. The carbon contents after sintering were analysed to be 0.55-0.60%. The value of density for every sample could be carefully measured using the water displacement method and the standard error is 0.023 g/cm^3. The difference of density should not influence the testing result for every sample.

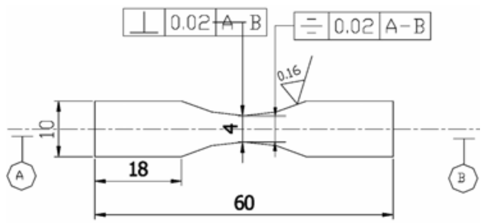

Fig. 1 The shape of the sample

The fatigue testing was performed using a Schenk PC160M machine in axial loading of alternating tensile/compressive stress at R=-1 by an electro hydraulic servo-pulse pump. All specimens should be mounted very carefully for alignment in order to avoid shear stress. A type of sine wave was shown the pulse of stress, which frequency was selected in the range of 20-40 Hz depending on its stress level. The fractography was investigated for ruptured area of samples using JSM-6301F scanning Microscopy by secondary electron imaging (SEI) or back scattered electron imaging (BEI). The microstructure is composed of more homogeneous bainite and martensite. Neither Ni nor Mo rich area nor retained austenite was observed. Previous investigations pointed out that the segregations of alloying elements may damage 20-30% of its fatigue properties [3-4].

The testing results are listed in Table 1 from which a fatigue S-N curve can be obtained as in Fig.2. The No.8 sample did not fail until ten million cycles. The fatigue endurance limit of 260 MPa can be evaluated from the curve for the sintered-hardened materials.

Table 1. Experimental data of fatigue testing

Sample	Density [g/cm^3]	Open Porosity [%]	Stress [MPa]	Frequ-ency [Hz]	Cycle to failure
No.1	7.273	1.96	500	20	4.80E+03
No.9	7.248	1.95	450	20	8.84E+03
No.2	7.234	1.50	400	30	4.47E+04
No.5	7.279	1.24	400	30	5.26E+04
No.6	7.254	2.48	350	30	2.70E+05
No.4*	7.286	1.24	300	30	5.07E+05
No.7	7.233	1.82	300	30	1.40E+06
No.8	7.292	1.31	260	40	$>1\times10^7$

*: Rupture occurred in clamping area

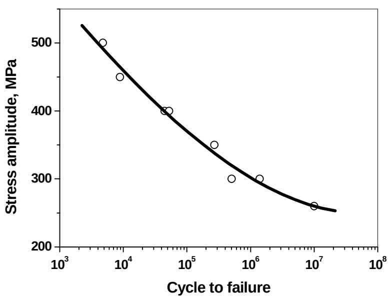

Fig. 2 S-N curve for Fe-4Ni-0.5Mo-1Cu materials

At a lower stress the fatigue cracks initiated from the areas near the surface, showed on the right of Fig.3(a). Enlarged photo can be seen in Fig.3(b) revealing many pores in it. A non-typical fatigue striation can be seen as Fig.3(d), which occurred under an alternative stress resulting from stress concentration in pore edge. C.Laird stated a typical fatigue striation has a parallel strip. The typical fatigue striation shows uniform hill and valley surface morphology [7]. More dimples due to the plastic deformation can been found in the center of Fig.3(a), enlarged in Fig. 3(c).

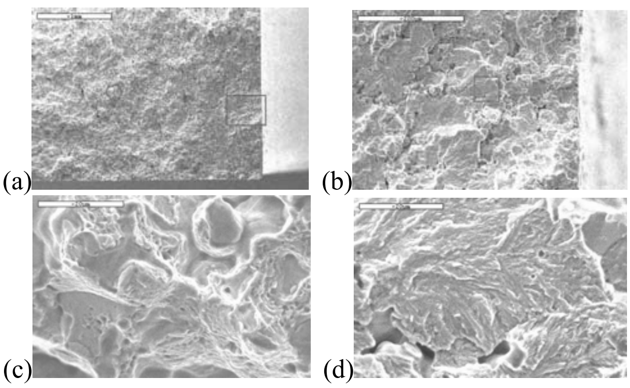

Fig. 3. SEM fractograph at lower stress of 300 MPa

At a higher stress the fatigue cracks also initiated near the surface showed on the right of Fig.4(a). But it contained more mini-crackings as shown in Fig.4(b). The fatigue striation can be observed in Fig.4(d) although it was not typical as at lower stress. In the rupture section selected from circular area in Fig.4(a), in larged in Fig.4(c) more dimples also occurred.

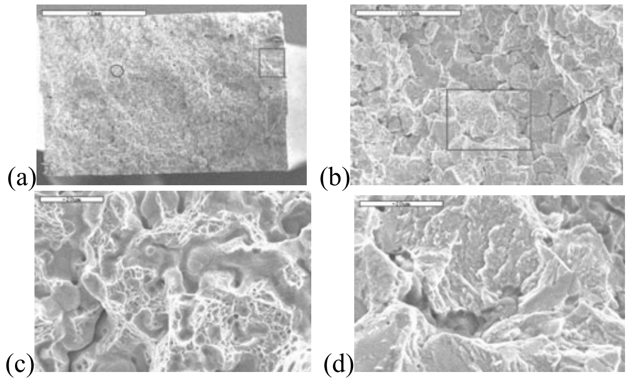

Fig.4 SEM fractograph at higher stress of 500 MPa

3. Summary

Sinter-hardened Fe-4Ni-0.5Mo-1Cu steels have a fatigue limit of 260MPa. The initial cracks appear in residual pores and propagate along with the particle. A non-typical fatigue striation and dimples can be observed respectively.

4. References

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