Stable and Unstable Crack Growth in Chromium Pre-alloyed Steel

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Abstract

Sintered steels are materials characterized by residual porosity, whose dimension and morphology strongly affect the fatigue crack growth behaviour of the material. Prismatic specimens were pressed at 7.0 g/cm^3 *from Astaloy CrM powder and sintered varying the sintering temperature and the cooling rate. Optical observations allowed to evaluate the dimensions and the morphology of the porosity and the microstructural characteristics. Fatigue tests were performed to investigate the threshold zone and to calculate the Paris law. Moreover* K_{Ic} *tests were performed to complete the investigation. Both on fatigue and* K_{Ic} *samples a fractographic analysis was carried out to investigate the crack path and the fracture surface features. The results show that the Paris law crack growth exponent is around 6.0 for 1120°C sintered and around 4.7 for 1250°C sintered materials. The same dependence to process parameters is not found for* K_{Ith}.

Keywords : crack growth, fatigue, pre-alloyed steel, fractography, paris law

1. Introduction

The mechanical parts produced by powder metallurgy processing are characterized by some degree of residual porosity after sintering, which is known to affect the final mechanical properties of the component [1]. In this paper fatigue tests were performed on steels from Astaloy CrM powders to investigate the threshold zone and to evaluate the Paris law, varying the sintering temperature and the cooling rate in the furnace after sintering. Moreover, K_{Ic} tests were performed to complete the investigation. The crack path and the fractographic features were investigated by optical and SEM observations and finally a microstructural investigation was carried out on the samples sintered both at 1120°C and 1250°C.

2. Experimental and Results

Three steels, obtained from AstaloyCrM powders (3% Cr, 0.5% Mo), sintered at different temperatures in hydrogen (90%) and nitrogen (10%) atmosphere, were investigated. The nominal density was 7.0 g/cm^3. Table 1 shows the sintering conditions of the samples and the added graphite contents together with the carbon content after sintering.

Table 1. Sintering conditions, added graphite and carbon contents after sintering.

Material code	*Sintering temperature °C]*	*Cooling rate °C/s]*	*% added graphite*	*%C after sintering*
12S	1120	0.8	0.50	0.47
12SH	1120	2.5	0.68	0.57
25SH	1250	2.5	0.68	0.52

The dimensions and characteristics of the pores were analysed, by the calculation of porosity through an image analysis software. The materials were classified considering the area and the roundness of the pores. Details of the obtained results are described in [2]. The total porosity was estimated equal to 10.1%. The microstrucure and the microhardness (HV0.1) were investigated for all the materials.

On each series of materials, fatigue tests were performed at R-ratio equal to 0.1 in order to investigate the crack growth rate, both in the threshold and in the stable and unstable zones. Sample dimensions and precracked geometry were obtained according to the standard BS 6835 [3] for three-point single edge notch bend specimen (SENB3), while the da/dN test procedure was carried out according to the ASTM E647 standard [4]. The dimensions of the specimens are: 90.00 mm length, 6.40 mm thickness, 12.08 mm width, while the span was 48.32 mm and the notch was 2.60 mm. Precracking was performed under load control, according to the compliance method. This method assures low deformation and strain-hardening at the notch tip. The first series of tests aimed to calculate the Paris law and so an increasing ΔK method was performed [5]. For each material, at least three tests were carried out to confirm the validity of the results. In Figure 1 the data obtained from all the tests were represented for each series and the Paris law was calculated. The investigation on the threshold zone was carried out by decreasing ΔK technique. The obtained results are summarized in Figure 1: for all the materials a crack growth rate of 10^{-9} m/cycle was tested, only for 12SH material lower crack growth rate data are available. Microscopic observations allow the investigation of the crack path during precraking and propagation [2]; SEM analysis allowed to characterize the fracture surfaces. In the threshold zone the crack propagates both on sinter-necks and inside powder particles, without any influence of the pores characteristics or dimension, while for higher growth rates the pores seem to influence the propagation heavily, in fact the crack path tends to prefer the sinter-necks. Fracture morphology in the threshold zone appears as serrated, while in the zones where the crack speed is high and in the rupture zone, some cleavage and dimple features can be found (Figure 2) [6-7].

Finally, fracture toughness tests have been performed for all the materials; the obtained results are reported in Table 3 where both K_Q and K_{Max} were reported together with the ratio P_{Max} on P_Q. Each value is evaluated as the average value between three experimental values.

From the analysis of the data, 12S shows both a K_Q and K_{Max} higher than 12SH and 25SH. For 12S and 12SH series, the ratio P_{Max} on P_Q is not able to respect the limit 1.1 of the ASTM E 399 Standard.

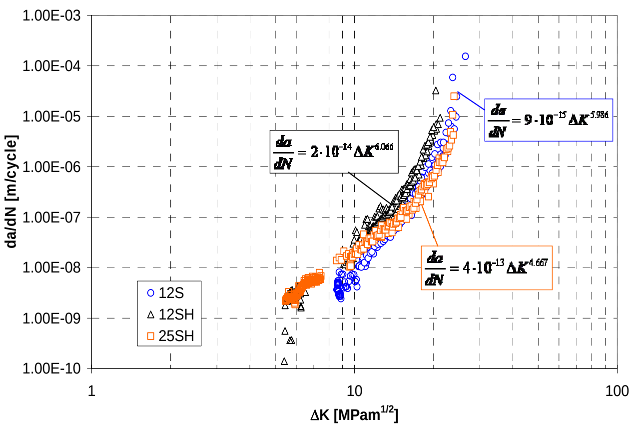

Fig. 1. da/dN curves for the tested materials.

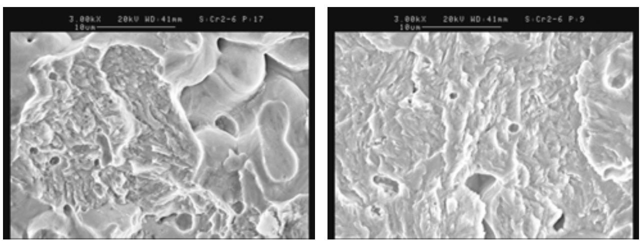

Fig. 2. $da/dN \approx 5\cdot 10^{-8} [m/cycle]$ **(on the left);** $da/dN \approx 2\cdot 10^{-10} [m/cycle]$ **(on the right).**

Table 3. Fracture toughness experimental values.

Material code	*12S*	*12SH*	*25SH*
$K_Q [MPa\sqrt{m}]$	27.0	20.8	26.1
P_{Max}/P_Q	1.14	1.11	1.08
$K_{Max} [MPa\sqrt{m}]$	30.8	23.0	28.2

3. Summary

On the basis of the previous results, the following conclusions can be made

- the Paris law crack growth exponent is around 6.0 for 1120°C sintered and around 4.7 for 1250°C sintered steels
- about the steels sintered at 1120°C, observing the crack growth curve, at a given value of ΔK, the crack growth rate in 12SH steel is higher than 12S. This can be related to the different microstructure due to the different cooling rate from 1120°C sintering temperature; 12S and 12SH steels have similar m-coefficient, but different C-coefficients of the Paris law.
- about the fatigue crack initiation, neither the pores characteristics nor metallographic phases seems to influence the stress intensity threshold value strongly.
- SEM analysis shows different features between fracture morphology in the threshold and in the Paris zones. In the threshold zone the crack propagates both on sinter-necks and inside powder particles, while for higher growth rates the pores seem to influence the propagation heavily.

4. References

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