THRESHOLD AND CRACK GROWTH BEHAVIOUR OF SINTERED STEELS FROM PRE-ALLOYED AND DIFFUSION BONDED POWDERS

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ABSTRACT
Powder metallurgy processing of steels typically results in a material characterized by residual porosity, whose dimension and morphology, together with the microstructure, strongly affect the fatigue crack growth behaviour of the material. In this paper, the behaviour of steels from chromium pre-alloyed Astaloy CrM powders and from diffusion bonded Distaloy AE and HP powders were considered.
Astaloy CrM powders were sintered in different conditions, varying the sintering temperature and the cooling rate after sintering: 1120°C, 30 minutes with a cooling rate of 0.3°C/s (Cr-S steel); 1250°C, 30 minutes with a cooling rate of 1°C/s (Cr-SH steel). The latter steel was tempered at 200°C, 1 hour. Distaloy powders were sintered at 1120°C, 30 minutes with a cooling rate of 0.2°C/s. For all the powders the sintering atmosphere was Nitrogen-Hydrogen (90%-10%). Fatigue tests were performed at R-ratio equal to 0.1 in order to find the threshold values and to calculate the Paris laws in the stable crack propagation zone.

1.INTRODUCTION

The mechanical parts produced by powder metallurgy are characterized by some degree of residual porosity after sintering, which is known to affect the final mechanical properties of the component [1]. Moreover, the dimension and morphology of the microstructure strongly affect the fatigue crack behaviour of the steels [2-5]. The nature of porosity and the metallographic phases are influenced by several processing variables, such as the type and amount of alloying additions, the sintering temperature and time, the cooling rate after sintering or the presence of heat treatments after sintering [6-10]. In recent publications, the authors contributed to clarify the role of the processing parameters on the stable and unstable crack growth in chromium pre-alloyed steels [11-13], varying the sintering temperatures and the cooling rates after sintering. In this powders, alloying elements were kept in solid solution in order to induce hardenability but, although beneficial to hardenability, alloying elements in solid solution are harmful to compressibility because of the inevitable solid solution hardening.
In this paper, the fatigue behaviour of chromium pre-alloyed steels was compared with the behaviour of steels from diffusion-bonded powders.
The so called diffusion-bonded powders are characterized by the presence of Nichel and Copper added by diffusion-bonding, i.e. by a partial diffusion of the alloying elements. It is well known that the steels from diffusion-bonded powders show different microstructures depending on the cooling rate and on the local chemical composition after sintering. To improve hardenability, the diffusion-bonded powders can be manufactured with a Mo-alloyed basis and Ni and Cu added by diffusion bonding.
In this paper fatigue tests were performed on steels from pre-alloyed chromium powders (Astaloy CrM) and diffusion-bonded powders (Distaloy AE, Distaloy HP) to investigate the threshold zone and to evaluate the Paris law, varying the sintering and the cooling conditions. The fractographic features

were investigated by optical and SEM observations and finally a microstructural investigation was carried out on all the materials.

2.MATERIALS

Steels obtained from AstaloyCrM powders and from Distaloy AE and Distaloy HP powders were investigated.
The type of powder mixes considered and their composition are collected in Table I.

Table 1. Chemical composition (nominal) of the investigated powders

Commercial designation	Chemical composition				
	% Fe	*% Ni**	*% Cu**	*% Mo#*	*% Cr#*
Astaloy CrM	Bal.	-	-	0.5	3.0
Distaloy AE	Bal.	4.0	1.5	0.5	-
Distaloy HP	Bal.	4.0	2.0	1.5	-

added by diffusion-bonding
pre-alloyed

After adding graphite and lubricant, the powders were compacted and sintered in hydrogen (90%) and nitrogen (10%) atmosphere, with different processing parameters.
The materials codes, the sintering temperatures, the cooling rates after sintering, the added graphite and the density after sintering are reported in Table 2.

Table 2. Materials codes and processing parameters for the different steels.

Material code	*Powder*	*% added graphite*	*Sintering temperature [°C]*	*Cooling rate [°C/s]*	*Density*
Cr-S	Astaloy CrM	0.50	1120	0.3	7.00
Cr-SH	Astaloy CrM	0.68	1250	1.0	7.00
AE	Distaloy AE	0.80	1120	0.2	7.07
HP	Distaloy HP	0.80	1120	0.2	7.12

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. The microstrucure and the microhardness (HV0.1) were investigated for all the materials and the obtained results are summarized in Table 3 and Table 4.

Table 3. Microstructure and related average microhardness for Cr-S and Cr-SH steels.

Cr-S		***Cr-SH***	
HV0.1	***Microstructure***	***HV0.1***	***Microstructure***
230	Perlite	477	Transforming Austenite
442	Bainite	673	Martensite
695	Martensite		

Table 4. Microstructure and related average microhardness for AE and HP steels.

AE		***HP***	
HV0.1	***Microstructure***	***HV0.1***	***Microstructure***
261	Perlite	345	Bainite
195	Retained Austenite	164	Retained Austenite
339	Transforming Austenite	312	Transforming Austenite
731	Martensite	649	Martensite

Figures 1-4 show some examples of the microstructures of the investigated steels. In Figure 5 the results from the analysis of porosity were reported.

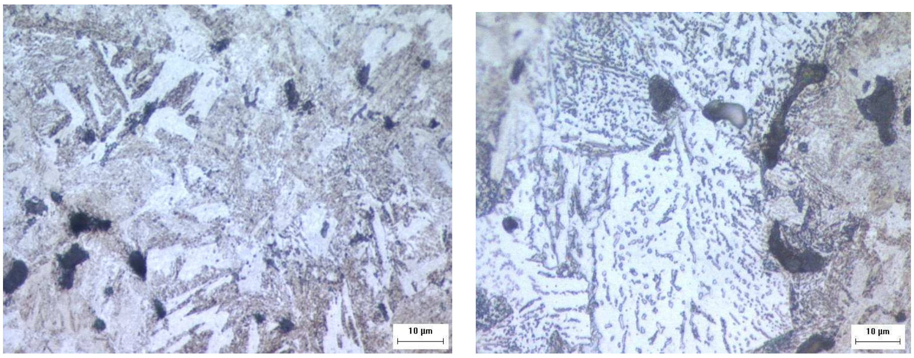


Figure 1. Bainitic, martensitic and perlitic structure in Cr-S steel.

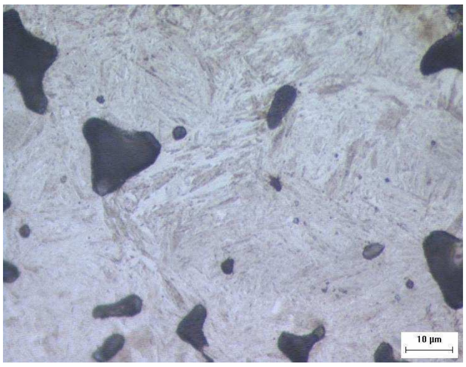


Figure 2. Martensite and transforming austenite in Cr-SH steel.

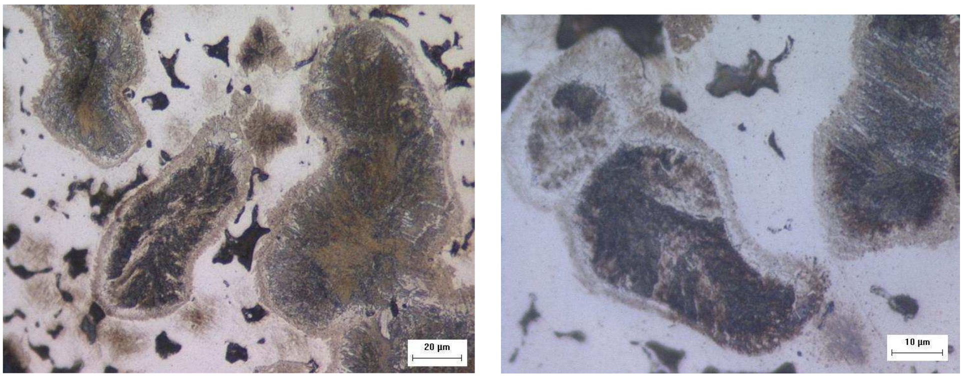


Figure 3. Distaloy AE heterogeneous microstructure. Perlitic isles sorrounded by martensitic layers and retained and trasforming austenite.

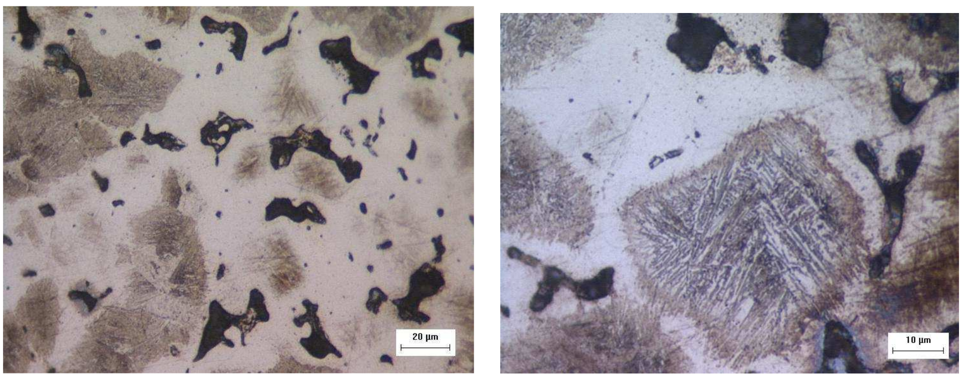


Figure 4. Distaloy HP heterogeneous microstructure. Bainitic isles sorrounded by martensitic layers and retained and trasforming austenite.

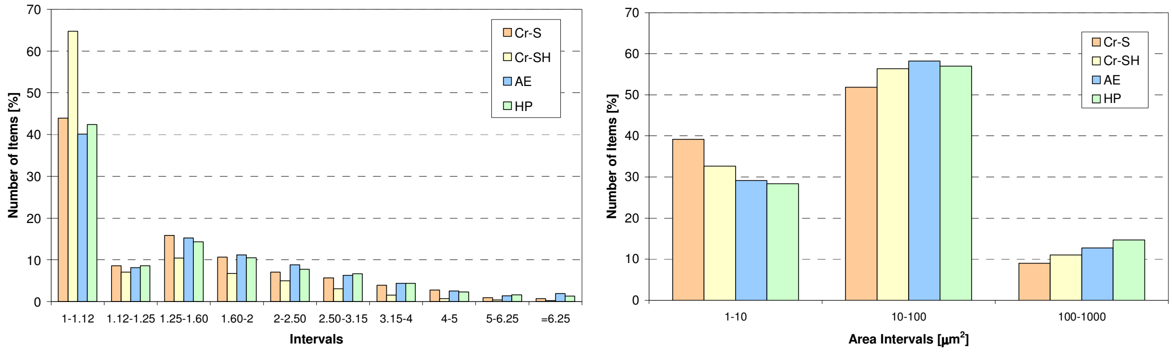


Figure 5. Pores area and roundness distribution for all the tested materials.

3. EXPERIMENTAL TESTS

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 [14] for three-point single edge notch bend specimen (SENB3), while the da/dN test procedure was carried out according to the ASTM E647 standard [15].The dimensions of Cr-S and Cr-SH specimens were: 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.
For AE and HP specimens the dimensions were: 130.00 mm length, 10.00 mm thickness, 20.00 mm width; the span was 80.00 mm and the notch was 4.00 mm. Precracking was performed under load control, according to the compliance method: starting from an initial K value (K_{max}), the load decreases in order to give a final K (K_{min}), kept constant for a minimum crack propagation equal to 2.5% of the crack length itself. 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. In Figure 6 the data obtained from all the tests were represented for each series and the Paris law for each series was calculated between 10^{-8} and 10^{-6} m/cycle (table 4). In the second part of this paper the investigation on the threshold zone was carried out by decreasing ΔK technique. The obtained results are summarized in Figure 7: for all the materials a crack growth rate of 10^{-9} m/cycle was tested; for AE and HP materials lower crack growth rate data are available.

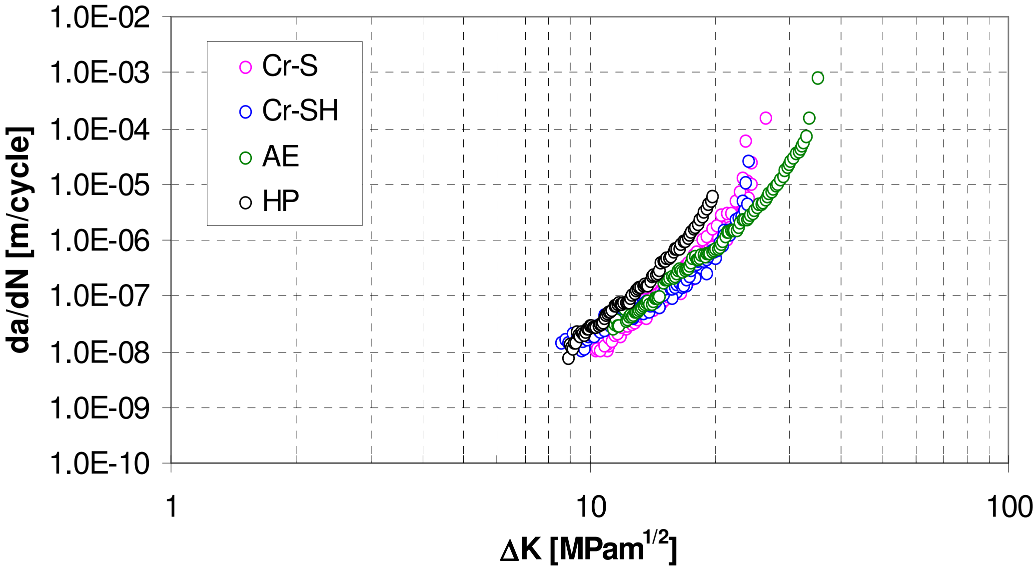


Figure 6. da/dN curves for the Cr-S,Cr-SH, AE and HP series, ΔK increasing.

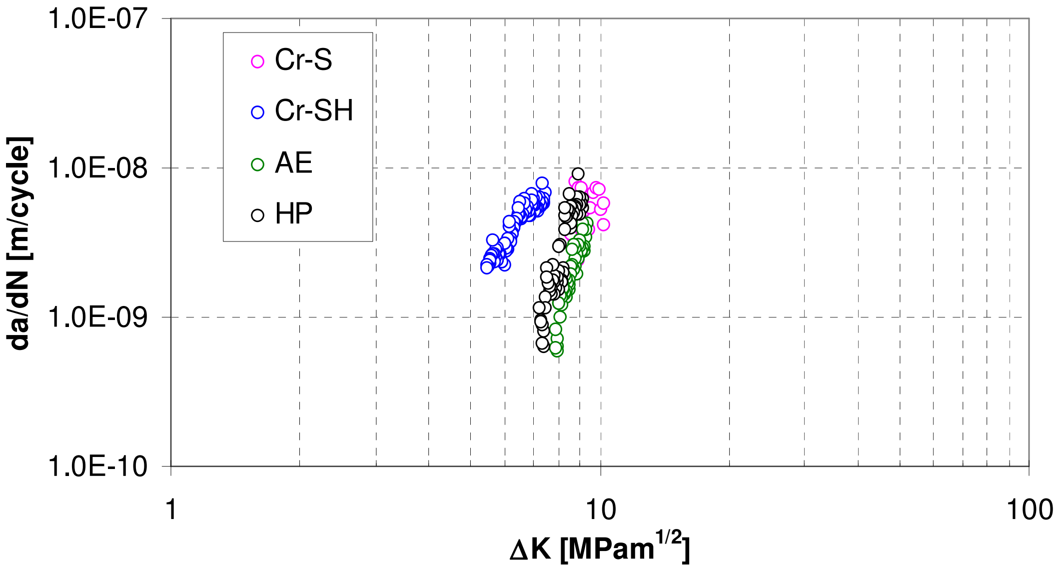


Figure 7. Threshold behaviour for the tested materials.

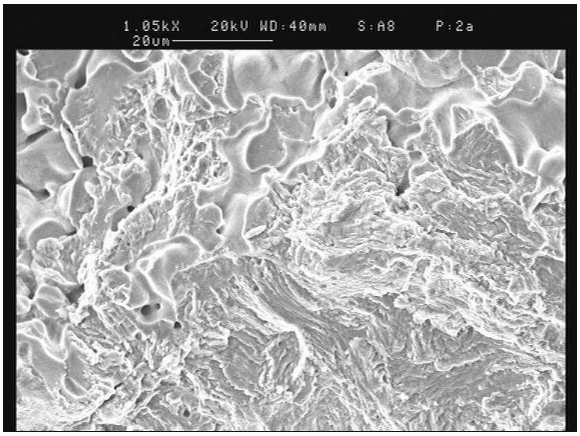
Table 5. Paris law coefficients for the investigated materials.

Material Code	***C***	***m***
Cr -S	$9 \cdot 10^{-15}$	5.986
Cr - SH	$4 \cdot 10^{-13}$	4.667
AE	$1 \cdot 10^{-14}$	6.022
HP	$5 \cdot 10^{-15}$	6.652

Table 6. Threshold values for the investigated materials.

Material Code	***ΔK_{th} [MPa $\sqrt{m}$]***
Cr -S	9.00
Cr - SH	5.50
AE	7.93
HP	7.33

SEM analysis allowed to characterize the fracture surfaces in the threshold and in the Paris zones [17-18]. In Figures 8-9 some examples are shown.



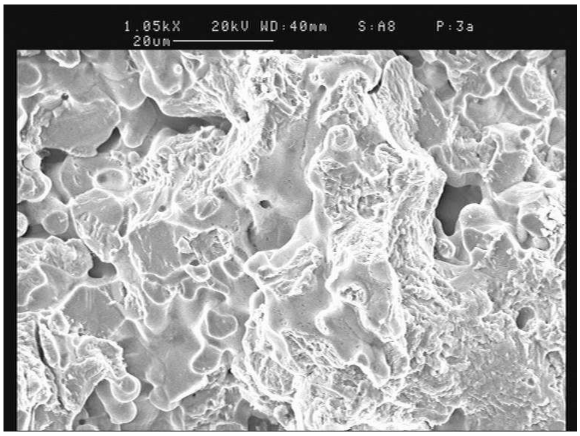


Figure 8. $da/dN \approx 6\cdot10^{-10}[m/cycle]$; AE sample. Figure 9. $da/dN \approx 8\cdot10^{-8}[m/cycle]$;AE sample

4. CONCLUDING REMARKS

In this paper, results about the fatigue crack initiation and propagation in steels from Chromium pre-alloyed and diffusion-bonded powders were reported. On the basis of these results, the following conclusions can be made

- It is confirmed that the Paris law crack growth exponent is around 6.0 for 1120°C sintered and around 4.7 for 1250°C sintered steels.
- The C coefficients are important parameters to understand the fatigue behaviour of a given material, because, according to their values, the da/dN curve can move upward and downward so changing the crack growth rate significantly.
- The stable crack propagation is influenced by the morphology of the pores and hence from the sintering temperature. The presence of nichel gives trifling effects on the propagation of the crack.
- About the fatigue crack initiation, the presence of martensite and transforming austenite, due to higher cooling rate after sintering, lowers the threshold of Astaloy Cr-M steels (Cr-S), while the presence of nichel in Distaloy AE and HP is not so effective in increasing the fatigue performance of the steels
- The results obtained for the steel from Distaloy HP powders could have been influenced by the fact that the observed crack front was not straight.
- In the evaluation of the whole fatigue behaviour, the threshold values have a very important role, because they represent a limit for the crack propagation and finally for the life or failure of the component.
- 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. 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.

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