Diffusion alloyed powders with high fatigue performance in the as-sintered state.

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Abstract

The past decades have shown an increased use of P/M components in passenger cars. However, in order to continue this increase the mechanical and fatigue performance must be further improved. Furthermore, it is important that not only the average level of the critical properties improves, but also their consistency and robustness.
The diffusion bonded iron powders exhibit superior properties in several areas, and the robustness to avoid segregation is very high. The present paper describes detailed aspects of microstructure in relation to the fatigue performance for some diffusion-alloyed powders sintered at 1120^{o}C and cooled at a cooling rate of 0.8^{o}C/sec. Fractographic observations analyse difference in fatigue crack path among the materials.

Introduction

The quest for high fatigue performance in P/M industry requires a deep understanding of materials' microstructure. The present work analyses the relation fatigue endurance-microstructure for a few diffusion-bonded materials, tested in the as-sintered state. The goal is to show how, at given density level, difference in fatigue behavior among materials can be explained by means of metallographic study. The same processing route has been adopted for all the investigated materials; the effect of Carbon addition has been checked by means of three different addition levels. Fractographic observations have also been performed in order to verify differences in fatigue crack paths on a qualitative point of view.

Materials

Three diffusion-bonded materials are here investigated. Distaloy AE is based on ASC100.29 iron powder. 0.5%Mo, 4%Ni and 1.5%Cu are the diffusion-bonded alloying elements. Distaloy DC is based on 1.5%Mo pre-alloyed powder (Astaloy Mo). 2%Ni is diffusion-bonded. Distaloy HP is also based on the same pre-alloyed powder. 4%Ni and 2%Cu are diffusion-bonded.

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Experimental procedures

For all the materials the following processing parameters have been adopted: 0.8% Amid-wax addition, compaction at 7.1-7.15g/cm^3, sintering in belt furnace at 1120°C in 90/10 N_2/H_2 atmosphere for 30', cooling at 0.8°C/sec. The effect of different Carbon levels has been investigated.

Ordinary Light Optical Microscopy (LOM) observations have been made on polished and etched samples in order to reveal materials' microstructures.

Four point bending fatigue tests have been performed for as sintered, un-notched ISO 3928 test bars with modified cross section [1]. The following test parameters have been used: load ratio R =-1 (i.e. mean stress equal to zero); frequency: 25-29 Hz; broken specimens stopped for 1.5% compliance variation; run out at 2 millions cycles; fatigue endurance [$\sigma_{A,50\%}$ and $\sigma_{A,90\%}$] and standard deviation determined with staircase method, according to MPIF Standard No.56, 2001. The staircase step has in all cases been 10MPa.

Light optical fractography has been performed on softly polished and etched surfaces (about 20μm of material have been removed). Scanning electron microscopy (SEM) observations have been performed on fracture cross sections. In all cases observations have been made on specimens tested at stress levels less than 5% higher than the $\sigma_{A,50\%}$ value of the respective material.

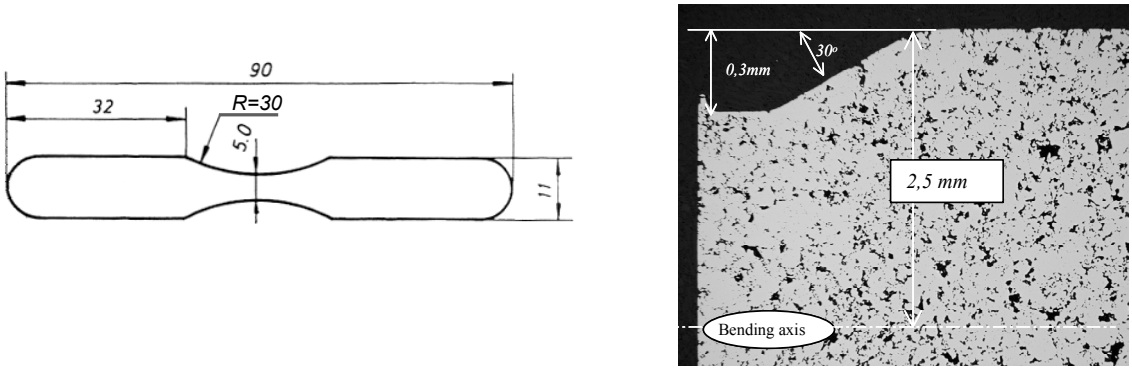


Figure 1. Un-notched ISO 3928 test bar and modified cross section [1].

Microstructural analysis

Distaloy AE shows heterogeneous microstructure –see Figure 2. Due to Copper low melting point (1084°C), liquid phase during sintering is formed, establishing a network that surrounds the pure iron base powder particles. At carbon levels below 0.5%, this network is mostly consisting of lath martensite and Ni-rich austenitic islands. Higher Carbon levels cause the transformation to mostly-plates martensite, with austenitic islands. Base powder particles show ferrite and pearlite at low Carbon level, dense pearlite in the region of about 0.8% Carbon addition.

Sintered bars of Astaloy Mo show upper bainite-dominated microstructures –see Figure 3. With high Carbon level a small amount of lower bainite can be observed.

In the range of Carbon levels here considered, Distaloy DC always shows upper bainitic base powder particles with austenitic/martensitic islands, corresponding to the Ni-rich areas –see Figure 4.

Distaloy HP shows upper bainite-dominated base powder particles. Relevant difference is observed in the network originated by the Copper liquid phase during sintering. As for

Distaloy AE, with increasing Carbon level, martensite tends to transform from lath to mostly plates-like. Austenitic islands are observed at all Carbon levels –see Figure 5.

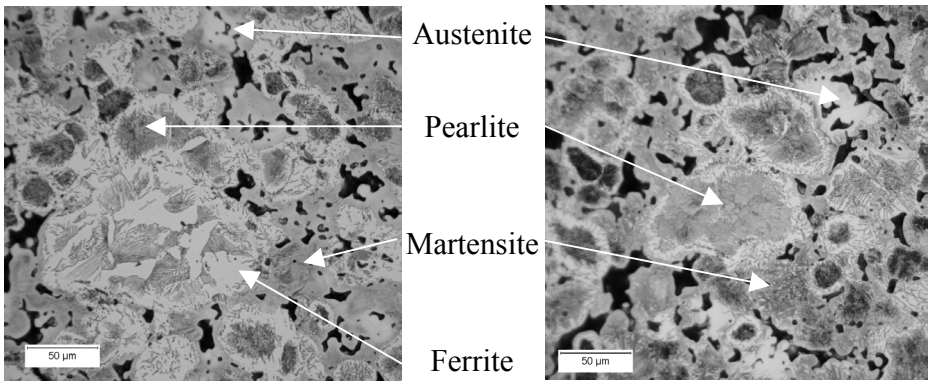


Figure 2. Microstructure of Distaloy AE +0.63%C (to the left) and +0.81%C (to the right).

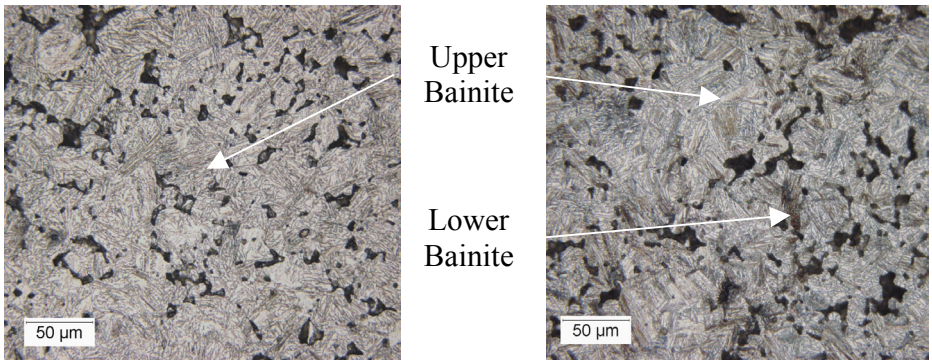


Figure 3. Microstructure of Astaloy Mo +0.65%C (to the left) and +0.82%C (to the right).

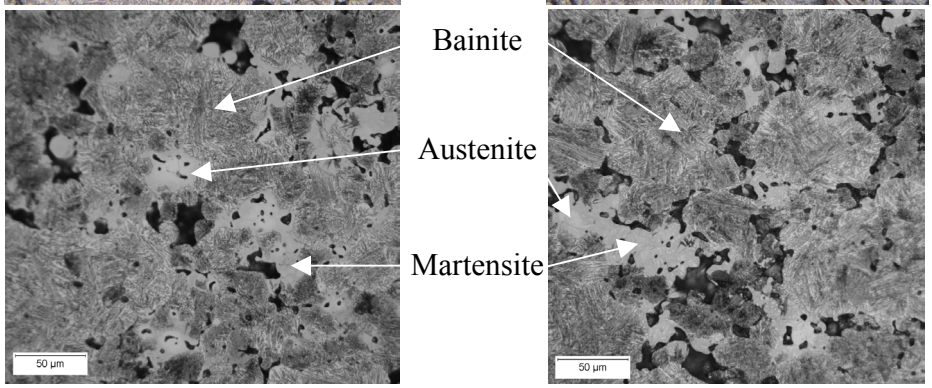


Figure 4. Microstructure of Distaloy DC +0.64%C (to the left) and +0.83%C (to the right).

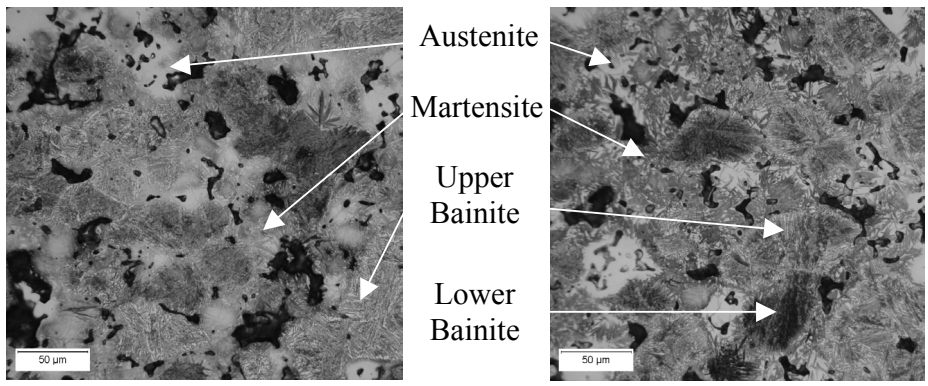


Figure 5. Microstructure of Distaloy HP +0.65%C (to the left) and +0.85%C (to the right).

Mechanical performance

Table 1 shows the $\sigma_{50\%}$, $\sigma_{90\%}$, and standard deviations values for the investigated materials. When the criterion for the calculation of standard deviation is not respected a conservative estimation of half the stress step used in the staircase method is adopted. The mark "<5" is here conventionally used to indicate this fact.

Table 1. Fatigue endurance evaluation at 2 million cycles, according to MPIF Standard No.56 (2001) for as-sintered materials. Sintering performed in belt furnace at 1120°C in 90/10 N_2/H_2 atmosphere for 30', 0.8°C/sec cooling rate.

Material	Carbon [%]	S.D. [MPa]	$\sigma_{50\%}$ [MPa]	Std Dev [MPa]	$\sigma_{90\%}$ [MPa]
Distaloy AE	0.46	7.11	224	7	214
Distaloy AE	0.63	7.12	250	<5	242
Distaloy AE	0.81	7.10	274	8.6	260
Astaloy Mo	0.42	7.10	201	<5	>194
Astaloy Mo	0.65	7.10	211	<5	>203
Astaloy Mo	0.82	7.15	210	<5	>201
Distaloy DC	0.47	7.15	230	<5	>222
Distaloy DC	0.64	7.12	235	<5	>227
Distaloy DC	0.83	7.11	239	<5	>232
Distaloy HP	0.48	7.13	251	13	231
Distaloy HP	0.65	7.13	294	22	259
Distaloy HP	0.85	7.13	326	<5	>318

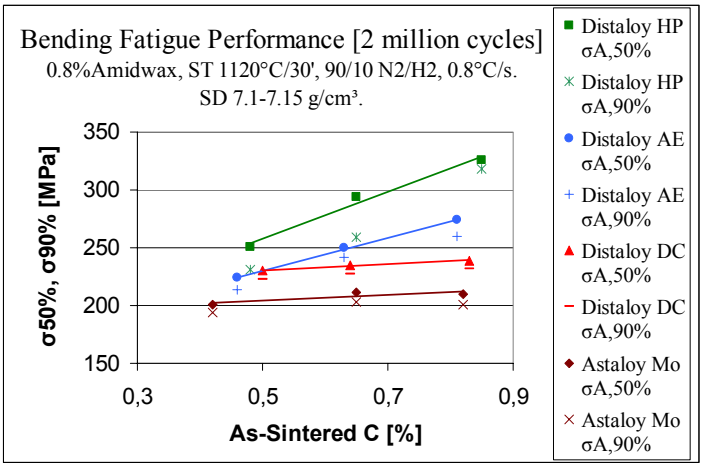


Figure 6. Dependence of bending fatigue performance on Carbon level**.**

Fractography

SEM fractography reveals different behavior of diffusion bonded materials, compared to Astaloy Mo. The latter shows crack early propagation mainly developed by inter/particles modality, i.e. through the sinternecks –see Figure 7. In crack initial propagation area Distaloy materials show mainly trans-particles fracture, i.e. through the base powder particles –see Figure 8 and Figure 9.

Figure 7. Crack initiation and early propagation area for Astaloy Mo +0.84%C. Mainly inter-particles fracture, i.e. through the sinter-necks.

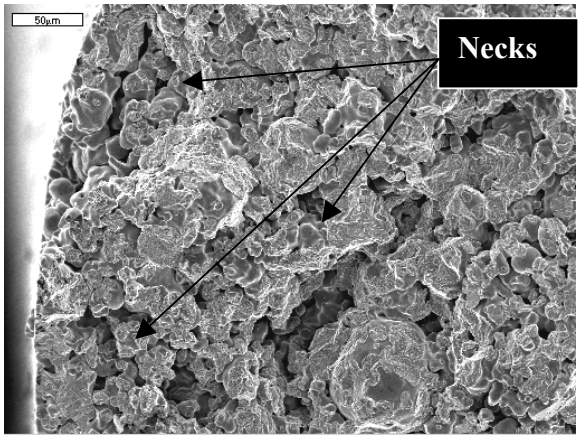


Figure 8. Crack initiation and early propagation area for Distaloy DC +0.64%C. Mainly trans-particles fracture (T-P); also inter/particles propagation is shown (I-P).

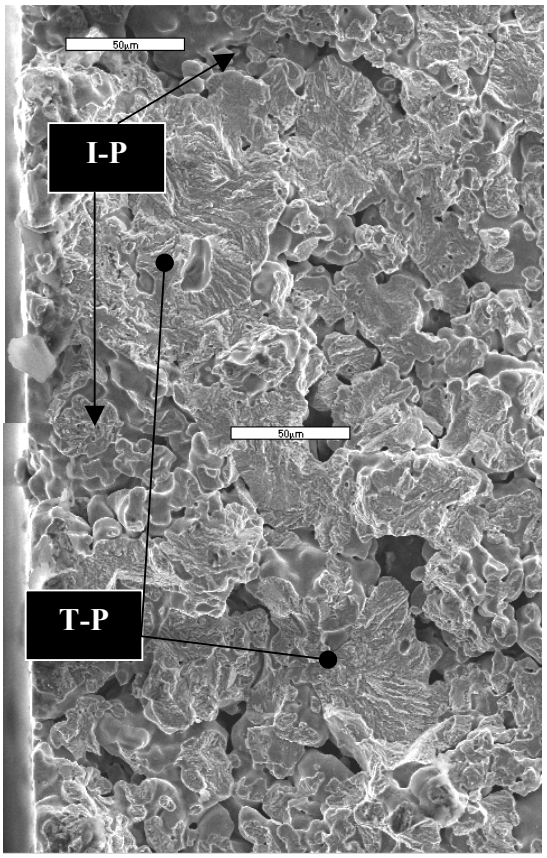
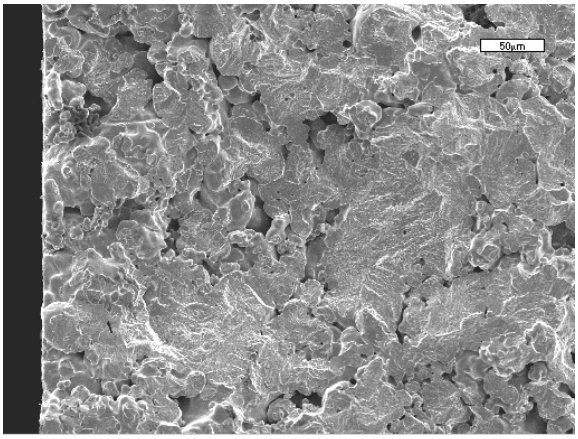


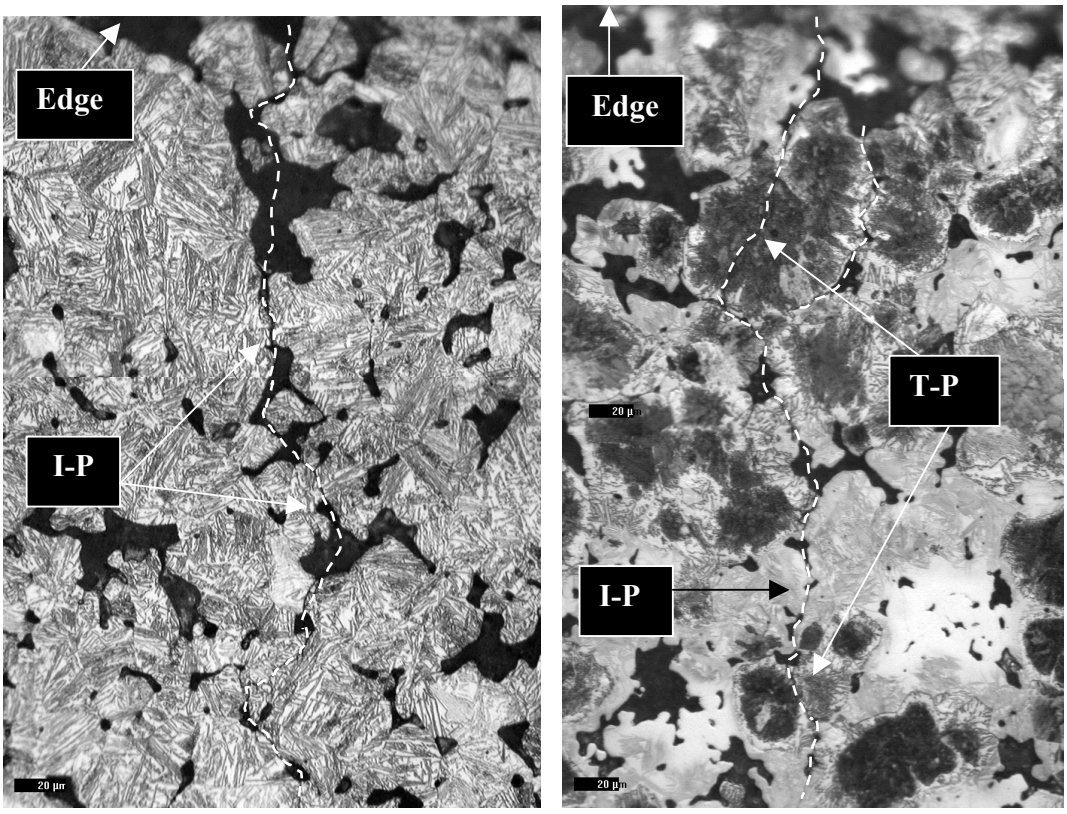
Figure 9. Crack initiation and early propagation area for Distaloy HP +0.65%C. Mainly trans-particles fracture, i.e. through the base powder particles.



LOM based fractography shows the same features: surface analysis reveals inter-particles walk for the crack developing in Astaloy Mo –see Figure 10. Distaloy AE shows fracture in a base powder particle close to the edge of the specimen. Further crack walk is inter-particles –see Figure 11.

Figure 10. Crack initiation and early propagation area for Astaloy Mo +0.82%C. The crack, starting from the edge of the specimens, develops mainly through the sinternecks, by inter-particles modality (I-P).

Figure 11. Crack initiation and early propagation area for Distaloy AE +0.81%C. Crack initiation occurred in a base powder particle (T-P), about 60μm distant from the edge. Further propagation is both along the network (I-P) and through base powder particles.



Discussion

Carbon level relevantly influences the fatigue endurance of Distaloy AE. Explanation of this fact can be given by the microstructural reinforcement obtained by increasing Carbon addition. At low Carbon levels the base powder particles present extended portions consisting of ferrite. Pearlitic areas of different finesse can also be detected. Higher Carbon levels allow obtaining finely graded pearlitic base powder particles. The Cu/Ni-rich network with higher Carbon levels presents increasing portions of plate martensite. Astaloy Mo shows slight increase (5%) in fatigue performance in the range from 0.42% to 0.84%C. This fact corresponds to the limited variation in microstructure observed: upper bainite dominates the structure of Astaloy Mo.

Distaloy DC shows fatigue endurance about 10% higher than for Astaloy Mo and equally not sensitive to Carbon addition. As the upper bainitic base powder particles are consisting of Astaloy Mo, it has to be concluded that 2% Ni diffusion bonded is responsible for the higher fatigue endurance of Distaloy DC. Ni-rich areas consist of martensitic/austenitic islands, about 50μm the maximum diameter. Interconnection of

two or more of these areas can occur, but no continuous network around the base powder particles is formed.
Distaloy HP shows a martensitic/austenitic network comparable to the one of Distaloy AE. Fatigue endurance is 20% to 50% higher than for Astaloy Mo in the Carbon addition range here considered and increases with increasing Carbon addition. In comparison with Distaloy DC, it can be concluded that higher fatigue performance is obtained either by diffusion alloying Nickel and Nickel-Copper and that the possibility to achieve further increase in fatigue endurance is allowed by the presence of the continuous network linking the base powder particles, formed by Copper melting during sintering. Higher Carbon levels produce mostly plates-martensite, responsible for the high performance of Distaloy HP +0.83%C.
Fractographic analysis shows a different fracture mechanism in Distaloy materials compared to Astaloy Mo. The latter shows crack initiation related to porosity and sinternecks failure. Diffusion bonded materials present crack initiation mostly related to base powder particles failure, due to the fact that sinternecks result effectively reinforced by the alloying mechanism.

Conclusions

This work shows how the study of materials microstructure allows the interpretation of fatigue results.
Diffusion bonded Distaloy DC, Distaloy AE and Distaloy HP present higher bending fatigue performance, compared to prealloyed Astaloy Mo. All materials compacted density close to 7.1 g/cm^3, have been sintered at 1120°C/30' in 90/10 N_2/H_2 atmosphere and tested in the as sintered state.
Sensitivity to Carbon addition is characteristic of Cu-alloyed Distaloy AE and Distaloy HP, due to microstructural transformation in the continuous Cu-rich network around the base powder particles.
Effective reinforcement of sinternecks is operated by diffusion bonded alloying elements.

References

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