Controlled Microstructure for Optimum Fatigue Performance

Yoshinobu Takeda[1,a], Anders Bergmark[2,b], Luigi Alzati[3,c] and Sven Bengtsson[2,d]

[1]HJJK Hoganas Japan
[2]Höganäs AB, SE 26383 Höganäs SWEDEN
[3] Hoganas Italy, ITALY
[a] Yoshinobu.Takeda@hoganas.com, [b]Anders.Bergmark@hoganas.com,
[c] Luigi.Alzati@hoganas.com, [d]Sven.Bengtsson@hoganas.com

Abstract

Optimized choice of material for two principally different types of PM components is presented. The first is characterized by high stresses in areas with high stress concentrations (for example synchronizer hubs with very sharp notches, typically <0.25mm in the pre-synchronizer slot and the inner splines). The second type has slightly larger notch radii (small spur gears and sprockets with typically notch radii between 1- 3mm). Diffusion alloyed materials are well suited for sharp notch components. Pre-alloyed materials are also well suited for applications with sharp notches if compressive residual stresses in the notch roots are created by appropriate process control. A free choice of material is available for components with the larger notch radii.

Keywords : optimization, material, component, notches, fatigue

1. Introduction

Choice of material for high loaded PM parts is a balance between material performance, complexity (cost) of the process and cost of the material. Traditionally, the diffusion alloyed PM materials with Ni/Cu/Mo have shown to be very successful with the combination of high performance and simple process routes. The increased cost for the alloying elements calls for alternatives. The Cr/Mo pre-alloyed PM steels have been developed starting with AstaloyCrM in the 90-ties as alternatives to the diffusion alloyed materials. Can diffusion-alloyed materials be directly replaced by pre-alloyed Cr/Mo grades? Is there an optimum choice for specific types of components? The optimization is made for components where the bending stresses at stress concentrations are critical.

Many PM parts have sharp notches and the high stress concentration in the notch root is often the limiting factor of the overall performance. Ideally, a design modification is the most effective way to increase the performance. However, this is often not possible of functional reasons. One typical example is the synchronizer hub where high stresses are present in the pre-synchronizer slot and in the root of the inner splines. The high stress gradients in the notch root also means that the stress declines very fast in the material below the notch. The obvious characteristics for a material for synchronizer hubs are high resistance to crack initiation. The high loaded volume is small and any secondary process to improve the material performance can be concentrated on the notch root areas. Materials for synchronizer hubs must, of course also have sufficient resistance to wear.

Examples of PM parts with blunt notches are gear roots and sprockets. Typically notch radius between 1 and 3 mm are found in PM spur gears. The stress concentrations are here of the order $K_t < 1.5$ and a fracture mechanics approach shall not be applied.

2. Materials

Four materials from Höganäs AB, suitable for both types of components are shown in TABLE 1. Combined carbon after sintering is also shown in the table.

Table 1. Materials and alloying elements

Material	Cu	Ni	Mo	Cr	C	Remark
A	1,5	4	0,5	-	0,81	Diff*
B	2	4	1,5	-	0,80	Diff*
C	-	-	0,2	1,5	0,78	Pre$^+$
D	-	-	0,5	3	0,45	Pre$^+$

*: Diffusion-alloyed $^+$: Pre-alloyed

The commercial names of the materials are DistaloyAE, DistaloyHP, AstaloyCrL and AstaloyCrM respectively. Materials A and B are cold compacted to density 7.1 g/cm^3 and sintered in 90/10 N_2/H_2 at 1120^{o}C. Material C is warm-compacted and high temperature sintered at 1250^{o}C to density 7,28 g/cm^3. Material D is tested in two versions. D1 is cold compacted to green density 6.9 g/cm^3 and sintered at 1160^{o}C in 90/10 N_2/H_2 followed by rapid cooling $\approx 2^{o}$C/s.

D2 is cold compacted to density 7.1 g/cm^3 and sintered in 90/10 N_2/H_2 at 1120^{o}C with addition of 0,3% methane to the sintering atmosphere followed by rapid cooling with cooling rate ≈ 2^{o}C/s. Materials A, B and C are tested in as sintered state without and with shot-peening.

Plane bending fatigue tests are performed in displacement control with test frequency 25 - 30 Hz. Tests are terminated when the compliance has increased 2.5% or run out limit 2 million cycles is reached. Fatigue limits are evaluated from the staircase method with 11 - 15 samples. The fatigue limits are accepted provided the S-N curve shows a clear plateuax that is developed below 500.000 cycles.

The nominal 50% probability fatigue limits of un-notched (UN) and notched test bars with notch radii 0.9 and 0.25mm respectively are shown in TABLE 2 below.

Table 2. Fatigue limits of un-notched and notched test bars [MPa]. Standard deviations are given within brackets

Material	UN	N0.9	N0.25
A	275 (10)	212 (4)	168 (<3)
A+SP	322 (10)	306 (12)	284 (9)
B	322 (10)	243 (12)	188 (6)
B+SP	397 (17)	355 (33)	339 (<5)
C	296 (21)	190 (<5)	117 (<4)
C+SP	226 (<8)	298 (<5)	285 (11)
D1	NA*	NA*	145 (8)
D2	437 (14)	308 (20)	234 (7)

* Not Available

3. Components with sharp notches

An inspection of sharp notched (N0.25mm) materials A, B, C and D1 in TABLE 2 (light gray) show highest performance for material B followed by A, D1 and C. The diffusion alloyed materials B and A are the optimum choice of material among these materials. Material B show about 12% higher performance compared to A. The sharply notched Cr/Mo pre-alloyed materials (C and D1) both have lower performance than the diffusion alloyed. The performance of the pre-alloyed material D increases considerably by sintering with methane followed by sinter-hardening, see material D2 in TABLE 2. This is an effective way to create a martensite gradient in the material. The compressive residual stresses measured in material D2 by the hole-drilling method is about 150MPa. This is a relatively low value compared to what can be received with case hardening. However, the increased performance due to crack closure from the residual stress is enough to raise the performance considerably.

The results for three shot-peened materials show the very strong effect from closure of surface pores and introduction of compressive residual stresses. The larger sensitivity of sharp notches on the pre-alloyed materials is almost completely eliminated by shot peening. It must, however, be remembered that shot peening of low hardness surfaces causes distortion.

4. Components with notch radius 1 - 3 mm

An inspection of performance data for un-notched and 0.9mm notch radius samples in TABLE 2 reveals considerably smaller differences between pre-alloyed and diffusion alloyed materials. There is obvious a free choice of material from the bending fatigue point of view.

TABLE 2 also shows the strong beneficial effect from shot peening for all alternatives and also from the methane addition to the sintering atmosphere for material D.

5. Summary

Two principally different classes of PM components are identified. Parts with sharp notches, typically below 0.25mm notch radius and parts with larger notch radius 1 – 3 mm. Different strategies for choice of materials and secondary operations after sintering are recommended for the two classes. Diffusion alloyed materials can be used directly in the as sintered condition for parts with sharp notches. Pre-alloyed materials can be used but it is recommended to apply secondary operations to create a martensite gradient with compressive residual surface stresses. This can be done directly during the sintering process for sinter-hardening materials by addition of carbon activity in the sintering atmosphere, by separate case hardening or shot peening as secondary operation. Shot peening has also been shown to be a very effective way to increase the performance of the diffusion alloyed materials.

6. References

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