The microstructure and wear behaviour of sintered Astaloy 85Mo

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Abstract

Powder metallurgy enables cost effective production of powder metallurgy (PM) parts with complex geometries in automotive applications. PM materials are also extensively used for the production of components subjected to working conditions giving rise to sliding, rolling or abrasive wear, such as gears or cams. In this experimental study, Fe based pre-alloyed Astaloy 85Mo powder was used in the production of camshaft spur gear. The gas carburizing is carried out at 925°C for 3 hours. The camshaft spur gears were waited at 850°C for 1 hour to reach the required carbon concentration. Oil hardening is carried out at 82°C, soaking time is 30 min. The effect of gas carburizing on the microstructure, density, hardness and wear properties of Astaloy 85Mo+0.5% graphite was investigated. Furthermore, the microstructure characterization and worn surfaces of camshaft spur gear were examined using a high magnification optical microscope.
Keywords: powder metallurgy, Astoloy 85Mo, gas carburizing, wear.

1 Introduction

Demands on gear materials are continuously increasing. This is mainly because of developments in the automotive industry towards high performance vehicles with low fuel consumption and low environmental impact. A good example can be to look on car gear transmissions as very demanding ones. In the period from World War II to the present, their gear module decreased from between 4 and 5 mm down to between 2 to 3 mm, while effective torque transmitted increased nearly twice [1]. Powder metallurgy enables cost effective production of gears

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and parts with complex geometries. Besides that there are some advantages of P/M technique such as near net shape, green technique and almost no waste material. Surface quality is very important in production of a gear by P/M technique. In order to improve mechanical properties and surface quality of a gear, some methods are applied such as gear rolling for surface densification, heat treatment for hardness of P/M part and case hardening for improving surface hardness. Gear rolling is a well-known technology for improving the shape, surface densification and surface finish of steel gears [2–5]. Gas carburizing is a surface hardening method in which the surface of the components is saturated with carbon in a gaseous atmosphere containing carbon to accomplish this, the components are first heated in a neutral atmosphere to a predetermined temperature in the range of 870 to 940°C. The furnace is flooded with a suitable gas such as propane, butane or methane. Finally, the components are held at this temperature to allow for the diffusion of carbon into the case. After the carburizing treatment is completed, the components are quenched to obtain the required hardness, wear resistance and fatigue resistance on the surface, supported by a tougher core [6]. The mechanical behavior of sintered steels have been studied mainly by tensile and impact testing procedures [7]. However, the demand for components displaying an adequate resistance under heavy stress conditions, e.g. engine parts and transmission gears, has promoted considerable research efforts on PM components suitable to work under dynamic conditions. PM materials are also extensively used for the production of components subjected to working conditions giving rise to sliding, rolling or abrasive wear, as well as gears or cams. Therefore, a complete understanding of their tribological behavior is important. Several results on the dry sliding behavior of sintered ferrous alloys can be found in the literature [8–13]. In this paper, effect of gas carburization on microstructure and wear properties of hot pressed Astaloy 85Mo was investigated. Wear and micro hardness test were conducted and the mechanical properties were evaluated on the basis of microstructure.

2 Experimental procedure

2.1 Materials and method

The P/M steels were produced in an industrial plant using pre-alloyed Astoloy 85Mo (*Höganäs)* powders. A planetary gear with the gear data given in Table 1 was used in this study. Fig. 1 shows the camshaft spur gear configuration and Astaloy 85Mo with the compositions shown in Table 2 were used as base materials for the gears. PM camshaft spur gear has been manufactured by compaction of cylindrical blanks followed by sintering at 1130°C for 30 min in a mixture of 90% N_2 and 10% H_2 gas atmosphere by Sintek Powder Metallurgy Company. Carbon was added as ultra-fine natural graphite (UF4 graphite). Lubricant (*Intralube*® E) in proportion to 0.8 wt% was added to the powder-graphite mixtures.

Table 1: Gear geometry.

Number of teeth	Z	42
Normal module	mn	1.25
Major diameter	De	Ø55.80±0.05
Pitch diameter	Do	Ø53.28
Minor diameter	Di	Ø48.78 + 0 - 0.2
Depth of tooth type	hk	1.26
Tooth thickness	Sc	1.66±0.02
Grip angle	αo	17˚30'
Diameter with pin with two pins		Ø57.72±0.05
Max shimmy		0.03
Pin diameter	P18	Ø2.77

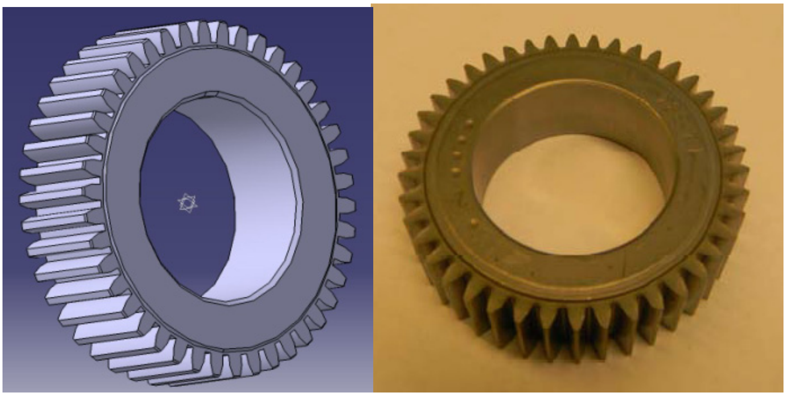

Figure 1: Configuration of the Astaloy 85Mo+0.5%C camshaft spur gear.

Table 2: Chemical composition of base powders (wt. %).

Gear	Material	Cu (%)	Ni (%)	Mo (%)	C (%)	S (%)
Camshaft spur gear	Astoloy 85Mo	0.04	0.04	0.85	0.48	0.005

2.2 Heat treatment

The gas carburizing was performed at 925°C for 3 hours. The camshaft spur gears were waited at 850°C for 1 hour to reach the %C concentration 0.72. Oil hardening is carried out at 82°C, soaking time is 30 min.

2.3 Mechanical tests

Vickers micro hardness values were measured under a load of 1 kg-f for each sample and microstructure of the gear was examined using high magnification optical microscope. For wear test, a pin-on-disc type apparatus was employed to evaluate the wear characteristics of samples. AISI 5190 steel disc having 65 HRc with 12 mm thick, and 160 mm diameter was used to serve as the adhesive medium. The pin specimens made from the samples were machined to approximately 5 mm in length. The pin was then mounted in a steel holder in the wear machine so that it was held firmly perpendicular to that of the flat surface of rotating counter disc. The samples were loaded against the abrasive medium with the help of a cantilever mechanism. Wear test was performed under varied loads such as; 20, 40 and 60 N and at a constant speed of 1 m/s and a constant sliding distance of 60 m with 80 mesh SiC paper for each sample. After the test, the wear pin was cleaned in acetone prior to and after the wear tests, and then dried after being weighed on a micro-balance with 0.1 mg sensitivity. Wear tests were carried out three times for three samples with and without gas carburized samples. Average of amount of weight loss was calculated and presented. Meanwhile confirmation tests were carried out at 60 N and at a constant speed of 1 m/s and a constant sliding distance of 150 m with 80 mesh SiC paper for each spur gear. After the confirmation test worn surface micrographs were taken using high magnification optical microscope.

3 Results and discussion

3.1 Microstructural analyses

Microstructure of the cam shaft spur gear was examined using high magnification optical microscope. After grinding and polishing, the samples were etched with solution of %2 Nital. Fig. 2 shows the microstructural aspects of the Astaloy 85Mo+0.5%C and gas-carburized Astaloy 85Mo+0.5%C samples.

Figure 2(a) shows the microstructure of the Astaloy 85Mo+0.5%C at sintering at 1130 °C for 30 min in a mixture of 90% N_2 and 10% H_2 gas atmosphere. It can be seen that the microstructure of sintered sample is ferritic. Figure 2(b) shows the microstructure in the gas-carburized Astaloy 85Mo+0.5%C spur gears. The microstructure is plate martensite that has high carbon content at the surface and in the core which is lath martensite with low carbon content.

3.2 Hardness and wear resistance

Micro-hardness was measured under 40x objective and an applied load of 1 kg-f using Vickers micro hardness tester. Five readings were taken and the hardness value has been reported in Figure 3. The blank density was 6.91–6.95 g/cm^3 range for the camshaft spur gear before the gas carburizing process and the

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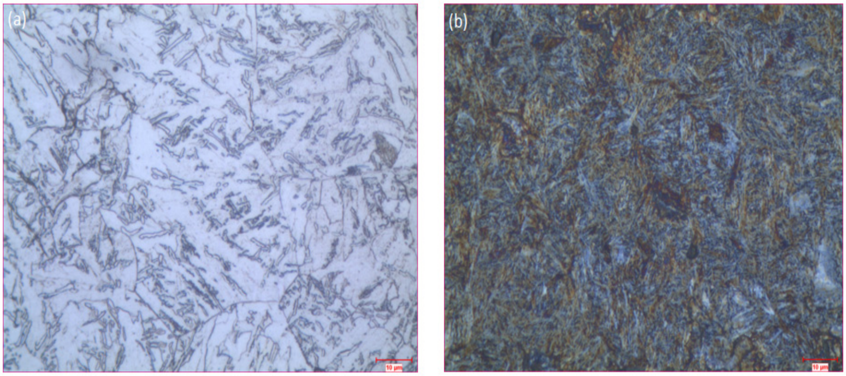

Figure 2: Microstructure photographs of (a) Astaloy 85Mo+0.5%C and (b) gas-carburized Astaloy 85Mo+0.5%C materials.

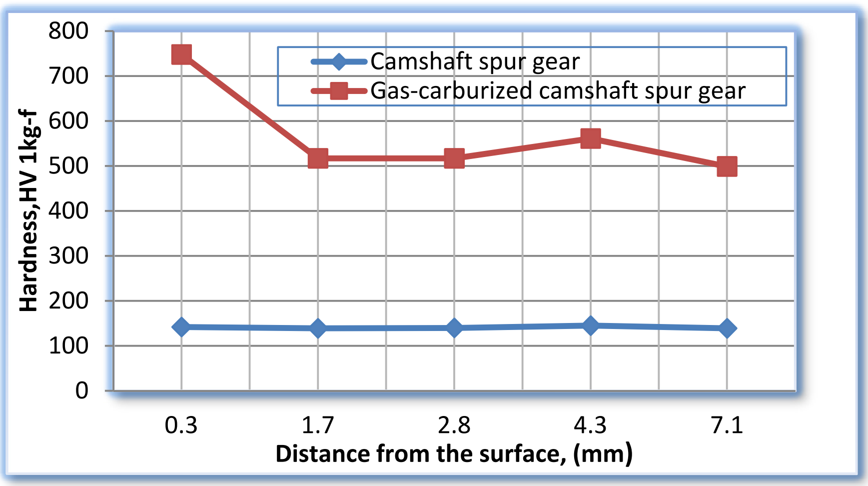

Figure 3: Micro-Hardness's for the Astaloy 85Mo+0.5%C and gas carburized Astaloy 85Mo+0.5%C spur gear.

surface micro hardness values is 142–139 HV in the range of 0.3–7.1 mm. After the gas carburizing process the blank density is 7.036–7.05 g/cm^3 range for the camshaft spur gear and the surface hardness is 748–499 HV in the range of 0.3–7.1 mm.

Fig. 4 shows the results of wear resistance for the the Astaloy 85Mo+0.5%C and gas carburized Astaloy 85Mo+0.5%C spur gear. The wear rate increased more or less linearly with increasing load for all tested samples. The wear rate was slightly higher for the Astaloy 85Mo+0.5%C spur gear due to decreased hardness and its microstructure.

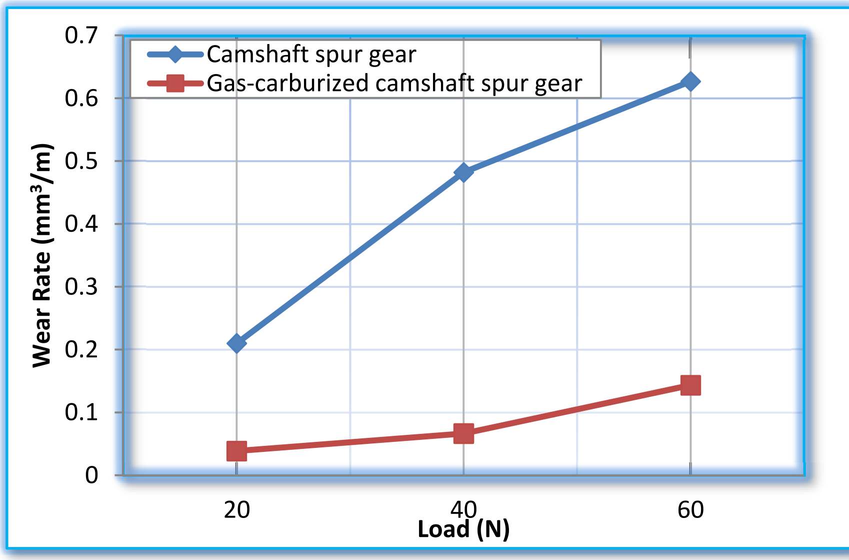

Figure 4: Results of wear resistance for the spur gears.

The worn surfaces, after tests carried out at 60 N, with SiC paper (abrasive size=201 μm) were characterized by the presence of fine and coarse grooves parallel to the sliding direction. Worn surfaces of the Astaloy 85Mo+0.5%C camshaft spur gear showing cracking of flakes along the wear track (marked arrow), diversion of wear grooves (Fig. 5(a)). Gas carburized Astaloy 85Mo+0.5%C camshaft spur gear showing abrasive traces, wear debris (marked arrow), material removal without delamination (Fig. 5(b)). Figure 5 shows the worn surfaces of the Astaloy 85Mo+0.5%C and gas carburized Astaloy 85Mo+0.5%C samples.

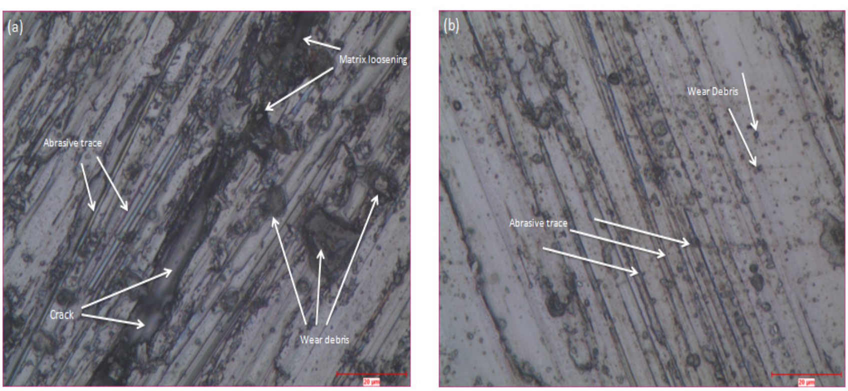

Figure 5: (a) Worn surfaces of the Astaloy 85Mo+0.5%C camshaft spur gear; (b) gas carburized Astaloy 85Mo+0.5%C camshaft spur gear.

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4 Conclusions

The effect of gas carburizing on the microstructure, density, hardness and wear properties of Astaloy 85Mo+0.5% graphite were investigated. The following conclusions have been reached:

1-) It can be seen that the microstructure of sintered Astaloy 85Mo+0.5%C is ferritic and in gas carburized Astaloy 85Mo+0.5%C microstructure is plate martensite that has high carbon content at the surface and in the core which is lath martensite with low carbon content.

2-) For gas carburized Astaloy 85Mo+0.5%C, wear rate was very small, and wear rate was observed mainly as abrasive traces and wear debris. Gas carburized spur gear exhibit lower wear rate than the un-heat treated spur gear due to increased hardness and its microstructure. The weight loss of gears under 60 N applied load was measured as 0.1433 mm^3/m g for gas carburized Astaloy 85Mo+0.5%C and that is 4.374 times greater than that of gears without gas carburized gears.

3-) Gas carburized Astaloy 85Mo+0.5%C is suitable for gear production in automotive applications.

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