

Basic Studies on Fatigue Strength of Case-Hardened Gear Steel - Effects of Shot Peening and/or Barrelling Processes

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

The shot peening process is frequently utilized in order to induce compressive residual stresses on/below a surface, which will remarkably improve the bending fatigue strength of a gear tooth. In this study, two kinds of case-hardened steels, namely the carburized and the carbo-nitrided steels were used. First, bending fatigue strength using a notched plate simulating a gear tooth was investigated. As expected, the bending fatigue strengths of two kinds of case-hardened steels are improved by the shot peening process. If the shot peening process is employed in order to improve the bending fatigue strength of a gear tooth, the surface durability of the shot peened surface may be reduced because of degradation of its surface roughness. On the contrary, it is expected that the surface durability may be improved by compressive residual stresses induced by shot peening. To understand these factors, the surface durability of the shot peened or/an barrelled case-hardened steel rollers was investigated using a two roller contact fatigue testing machine.

Key words: Gear, Case-Hardened Steel, Tribology, Fatigue Strength, Bending Fatigue Strength, Surface Durability, Residual Stress, Surface Roughness

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Basic Studies on Fatigue Strength of Case-Hardened Gear Steel

— Effects of Shot Peening and/or Barrelling Processes —

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1. Introduction :

Generally, a low hardness steel is superior to a high hardness steel in the dynamic load and bending stress conditions, because the steel is apt to become brittle with the increase of hardness. On the other hand, the latter is superior to the former for a resistance of wear of the contact surface during a power transmission. Then a case-hardened steel has been developed as a material with both hardness and toughness, which is obtained by heat treatment methods like carburizing, carbo-nitriding, and induction heating, etc. and is often utilized as a gear material. When a gear with a high load carrying capacity needs to be developed in order to down size a speed reducer, a shot peening process may be expected as a method to improve the fatigue strength of case-hardened steel because a gear material has already achieved the limit of endurance.

There are many reports that a shot peening process has improved the bending fatigue strength of a gear tooth [1]-[3]. However, when the shot peening process is applied to the tooth root, the tooth surface for carrying a load may also be shot peened. Then it is interesting whether or not the shot peening process will influence the surface durability of gear. Though to date there are some reports about the effects of the shot peening process upon the surface durability [4][5], it is not clarified whether the shot peening process is effective,

or not. The problem of contact should be solved not only by means of a material strength and an acting stress, but also as a problem of tribology in taking surface roughness and lubricating condition, etc. into consideration. In almost researches the surface roughness, the oil film thickness and the relations between them were not made clear.

In contact fatigue tests conducted using the case-carburized and hardened steel rollers, the authors couldn't obtain the distinct result about whether or not the surface durability of rollers shot peened after grinding to about 3 μmR_y would be improved [6]. Scoring has often occurred at the early stage of running due to severe metallic contacts because the sum of a pair of surface roughnesses is very much larger than the oil film thickness. Therefore, when a barrelling process was employed after shot peening, the surface durability has remarkably increased. It is difficult to improve the surface durability by only compressive residual stress induced by the shot peening process when the surface roughness is very rough. In the present report, the effects of the shot peening and

Table 1 Chemical compositions of test rollers

Material	Chemical compositions (%)							
	C	Si	Mn	P	Ni	Cr	Mo	Cu
SCM822H	0.222	0.320	0.790	0.023	0.070	1.040	0.350	0.100

barrelling processes upon the surface durability will be reconfirmed from the viewpoint of surface roughness, interior stress and observation of the surface failures using two kinds of case-hardened steel rollers.

2. Selection of Conditions of Shot Peening and Bending Fatigue Strength of Tooth :

First of all, it is examined how much the shot peening process will improve the bending fatigue strength of the gear tooth. The material is a chromium-molybdenum steel (SCM822H in JIS steel) and the chemical compositions are shown in Table 1. The depth of effective hardness over 513 HV is about 0.5 mm. The conditions of heat treatment are almost the same as those of rollers shown later, but the time of heat treatment is a little different. In this study, reasonable conditions of the shot peening process — hardness of shot material and pressure of shot, etc. — were selected so that excessive compressive residual stress on/below the surface would not be induced (referred to Table 2).

When the carrying load acts on the tooth, a tensile stress σ_b will be induced at the fillet of tooth root in the meshing side. The resultant stress ($\sigma_b + \sigma_R$) will act in the tangential direction at the fillet of the tooth root, where σ_R is the compressive residual stress induced by shot peening. Since tension is positive and compression is negative, the resultant stress $|\sigma_b + \sigma_R|$ will become small. On the other hand, the fillet of tooth root in non-meshing side will have a compressive stress σ_b . The resultant stress ($\sigma_b + \sigma_R$) may become very much large, because both σ_b and σ_R are negative. Then yielding may occur. When σ_Y is the yield stress, the yielding condition is $|\sigma_b + \sigma_R| \geq (1 \sim 1.15) \sigma_Y$, which is given by Tresca's maximum shear stress theory or von Mises' maximum strain theory. As it is estimated that the yield stress of the carburized or the carbo-nitrided and hardened steels must be over 1600 MPa because of their inherent

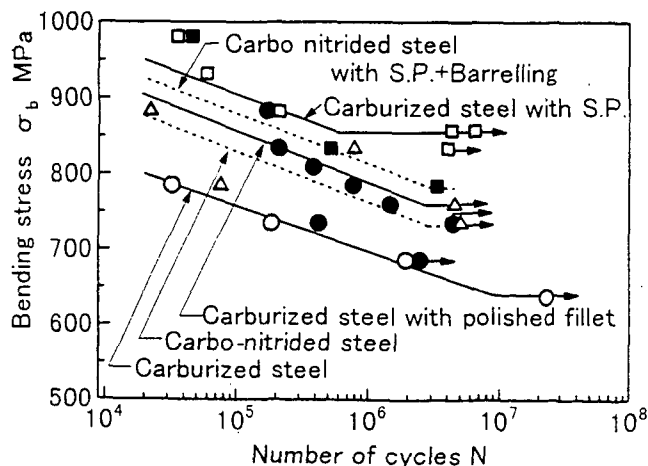


Fig. 1 S-N curves (bending fatigue strength)

hardness, and the compressive residual stress will be $\sigma_R = -1000$ MPa, the allowable compressive stress due to loading is $|\sigma_b| \leq 600 \sim 800$ MPa.

The examination of the bending fatigue strength was conducted using a notched plate simulating a gear tooth whose module is 3. The results are shown in Fig. 1. The bending fatigue limit of test pieces that were only case-carburized and hardened after machining was $\sigma_w \approx 640$ MPa. As a machining mark was found out at the arc of fillet, by polishing there using the emery paper, σ_w increased to about 760 MPa. Furthermore, the bending fatigue strength increased to $\sigma_w \approx 850$ MPa by the shot peening process. It is confirmed that this condition of shot peening is proper to improve the bending fatigue strength. The bending fatigue strength of the carbo-nitrided and hardened steel was $\sigma_w \approx 720$ MPa, which was higher than that of the case-carburized steel. And, the bending fatigue strength of the carbo-nitrided steel was barely increased to $\sigma_w \approx 780$ MPa by the shot peening and barrelling processes.

3. Experimental Conditions :

3.1 Test Rollers

Figure 2 shows a pair of test rollers. The outside diameter is $d=68$ mm and the effective face width is $B=10$ mm. The material is a chromium-molybdenum steel (refer to Table 1). Figure 3 shows the conditions of the heat treatment of the carburized and the carbo-nitrided steels. The depths of effective hardness of the carburized and the carbo-nitrided and hardened steels are about 2 mm and about 1.2 mm, respectively.

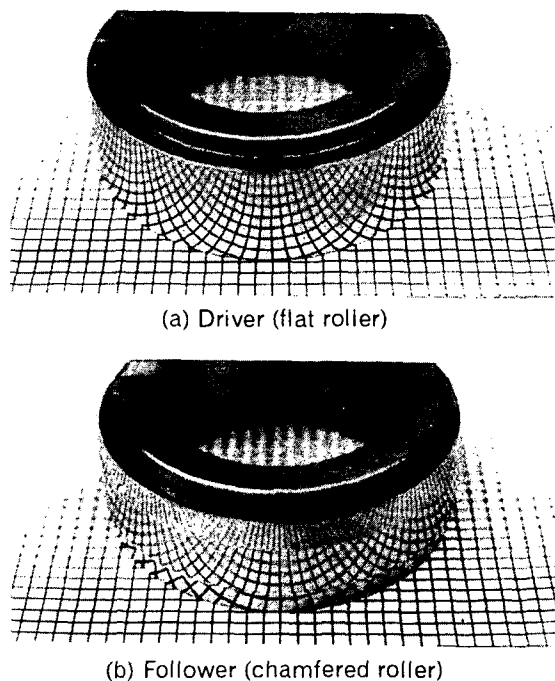


Fig. 2 A pair of test rollers finished by barrelling process