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The relationship between case depth and bending fatigue strength of gas carburized SAE 8620 steel

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Abstract

The fatigue performance of gas carburized SAE 8620 steel was evaluated as a function of case depth. To vary the case depths, different carburizing times were applied. The typical times were: 45 min, 3 and 5 h at the temperature of 940 °C. To cause failure in the rotating bending fatigue specimens, the applied load was chosen as the equivalent load at 10^6 cycles for the material when is subjected to bending fatigue. The characterization of the specimens was carried out using X-ray diffraction technique for stress measurement and retained austenite and optical metallographic examination. The fractured surfaces were cleaned in an ultrasonic bath and examined using scanning electron microscope (SEM) equipped with EDX to evaluate the crack initiation and growth characteristics of the materials in the core and carburized case regions of specimens. The results showed that the fatigue limit was associated with the microstructure, the case depth, the distribution of retained austenite, the depth of the internal oxidation and the compressive residual stresses near the surface. The bending fatigue strength of gas carburized specimens was showed to decrease with the increasing case depths caused by the increasing of internal oxidation and nonmartensitic transformation present at the surface.

Keywords: Gas carburizing; Case depth; Internal oxidation; Bending fatigue strength

1. Introduction

Since fatigue is the primary failure mechanisms of machine parts such as gears and shafts, various mechanical and/or thermo-chemical surface treatment processes have been applied to improve their resistance. Among these processes, carburizing is considered one of the most techniques widely used to enhance resistance to wear at the surface of highly stressed machine parts subjected to bending fatigue and rolling-contact fatigue [1–3]. The carburizing process involves the production of a high level of carbon at the surface layer of steel of mechanical parts made from low carbon steel. A major benefit of carburizing is the introduction of compressive residual stresses at the surface and near subsurface. During service, these residual stresses counteract the applied tensile stresses and therefore improve the bending fatigue performance. Different carburizing processes exist such as: liquid salt baths, gas atmosphere, solid carbonaceous material, by vacuum, and by plasma carburizing. Among these processes, gas carburizing is widely applied process in the industry for mechanical parts produced in high volumes.

It is well known that many factors can affect the wear and fatigue resistance of carburized steel. These factors include hardness, case depth, residual stress, surface finish, microstructure, grain size, globular and network carbides, intergranular oxidation, microcracking, and the presence of retained austenite. It is generally accepted that the presence of internal oxidation decreases the fatigue strength [4,5]. Retained austenite plays an important role on fatigue resistance of carburized steels which usually contain an amount of 20 to 30 vol.% in the near-surface of direct-quenched machine parts [2]. Though the effect of retained austenite on mechanical properties is still controversial, low amounts of retained austenite are beneficial to high cycle bending fatigue properties [6,7]. Some investigators state that retained austenite, in moderate amounts, is beneficial to fatigue resistance, while others believe that retained austenite should be minimized for optimum fatigue performance [8].

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One of the important factors which affect the fatigue performance of carburized steels is the effective case depth which is defined as the distance below the surface where the hardness was equal to 550 HV. Many factors, especially those that control surface carbon concentration, such as time and temperature during the various stages of a carburizing process, hardenability, part shape or geometry affect case depth [2]. The case depth for a given part is determined by the service requirements [2,9–11]. For a gear, the specified case depth relates to the dedendum/pitch-line region of the tooth, where case depth is specified to resist deep spalling. The ideal case depth (in terms of bending fatigue) appears to be reached at the value where the failure initiation point is transferred from the core to the surface [2]. It has also been pointed out that the improvement in fatigue strength due to case depth was limited, and heavy case depths might even cause a reduction in fatigue performance, particularly depending on decreased compressive residual stresses at the surface. Therefore, in order to obtain maximum gain in fatigue resistance, the carburized case depth should be kept in a certain range depending on the thickness and size of the specimen.

Although there has been considerable research devoted to this area, there is still lack of a through understanding of the effect of case depth on fatigue performance of gas carburized steels. Genel and Demirkol [12] have characterized the effect of case depth on fatigue performance of AISI 8620 steel specimens which were carburized in salt bath. Evanson et al. [13] have presented bending fatigue behavior of vacuum carburized AISI 8620 steel. However, it is well known that gas carburizing methods are widely used. When the steel is carburized in the endothermic atmosphere, the internal oxidation will unavoidably take place in the surface layer. There are a number of literature contributions dealing with the internal oxidation to microstructure in gas carburized steels. However, the extent to which varying degrees of internal oxidation affect properties has not been studied extensively and the date available are largely historical. It has been widely reported that fatigue crack initiation and development is confined to surface grains, but the effect of the depth of internal oxidation upon fatigue strength is not fully understood. It has also been reported that the fatigue strength is dependent upon the depth of internal oxidation, while some studies suggest otherwise [2].

The objective of this research is to investigate the relationship between case depth and bending fatigue strength for gas carburized SAE 8620 steel which is widely used as carburizing steel.

2. Experimental procedure

2.1. Specimen preparation

A standard low carbon SAE 8620 steel has been used in the study. Its chemical composition of the steel is given in Table 1.

Table 1
The chemical composition of SAE 8620 steel used in this study

C	Si	Mn	P	S	Cu	Ni	Cr	Mo
0.197	0.207	0.714	0.015	0.0081	0.205	0.449	0.413	0.154

Compositions given in wt.%.

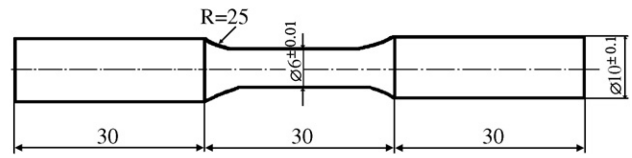

Fig. 1. Schematic drawing of the rotating bending fatigue test specimen. Dimensions in mm.

After normalizing at 920 °C, 1 h, the specimens were machined and surface polished using emery paper to the shape of the rotating bending fatigue specimen described in Fig. 1. Therefore, the specimen does not have the structure anomalies near the surface before carburizing treatment.

2.2. Carburizing

Carburizing of the specimens was performed in a gas atmosphere according to the heat treatment cycle and processes which are given in Fig. 2. In order to obtain the different case depths, the specimens were divided into three groups A, B and C, and carburized in a gas atmosphere at 940 °C with 45 min, 3 and 5 h, respectively. Gas carburizing atmospheres consists of an endothermic carrier gas (33% H_2, 28% CO, 0.8% CH_4) that is enriched by propane (C_3H_8). During the carburizing process the carbon potential of furnaces was adjusted to 1.2% C at 940 °C for rapid carburizing rate and then reduced to 0.7% C for the remaining time. With this carburizing cycle it was expected that the final surface carbon content would be ~0.7%. Specimens were directly quenched in oil from 850 °C then tempered at 170 °C for 2 h. The hardening temperature of 850 °C was chosen to ensure that the materials were fully austenitic prior to quenching and to minimize any distortion that may occur.

2.3. Hardness

The micro-hardness profile measurements of the carburized case were performed using 9.81 N loads in Vickers hardness scale, and the effective case depth was defined as the distance below the surface where the hardness was equal to 550 HV.

2.4. Retained austenite and residual stress measurement

The retained austenite and residual stresses were performed using X-ray diffraction technique. The residual stress measurement conditions are: Target: Cr, wavelength: $\lambda_{k\alpha}$=2.291 Angstroms, crystallographic plane: (211) and the Bragg angle: 156.4°. The retained austenite and residual stress measurements were determined in the subsurface layer by removing material using electropolishing technique. Further details of the diffraction set-up are given in Refs. [14–16].

2.5. Fatigue testing

Fatigue tests were carried out on a rotating bending fatigue test machine with a speed of 2790 rpm at room temperature. No