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Effects of surface shape on thermal fatigue resistance of biomimetic non-smooth cast iron

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Abstract

According to the principle of bionics, the experimental samples with a biomimetic non-smooth surface were manufactured using a laser. Three kinds of shapes including ‘spot’, ‘striation’ and ‘lattice’, were chosen for forming the non-smooth surface. With the self-controlled thermal fatigue test method, the thermal fatigue behavior of smooth and non-smooth samples was investigated and compared. The results indicated that the biomimetic non-smooth surface had a beneficial effect on improving the thermal fatigue behavior of gray cast iron, and that the non-smooth sample with the lattice shape had the highest resistance to thermal fatigue. Compared to the base material, the non-smooth unit zone was characterized by the alteration of microstructure. The lack of the graphite phase, the enhancing of mechanical properties in the unit zone and the effects of thermal crack deflection are the main reasons for improving the thermal fatigue resistance of gray cast iron with the biomimetic non-smooth surface.

Keywords: Biomimetic; Non-smooth; Cast iron; Thermal fatigue; Surface shape

1. Introduction

A brake drum is one of the most important components in the brake system of trucks. According to the principle of braking, the brake drum receives a huge static friction force or kinetic friction force from the brake disk. The friction on the inner surface is known to generate temperature as high as 900 °C. When trucks travel in regions, such as mountainous areas, due to frequent braking, the inner surface of brake drum suffers high temperatures repeatedly due to frequent braking. As a result, the brake drum can fail earlier than expected. The phenomenon of wide and deep cracks, as long as the height of drum, distributed on the inner surface of the failure drum was discovered. The thermal fatigue occurs in braking process may cause the initiation and subsequent propagation of cracks, which is considered to be the main reason for the failure of brake drums [1–6]. The braking performance and the security of automobile could be affected by the brake drum directly. Therefore, it is important and urgent to investigate and enhance the thermal fatigue resistance of brake drum materials.

Thermal fatigue, caused by internal stresses generated by cyclic temperature gradients, is an important life-limiting factor for many operating parts [7] especially for those serving in fast heating and quickly cooling conditions, such as brake drums. Gray cast iron has long been used in trucks as the material for brake drums because of low squeal, low vibration, good wear resistance and other good properties [2]. In recent years, gray cast iron with nickel, chromium and molybdenum additions has been the focus of a great deal of research on improving thermal fatigue resistance of brake drum materials. Until now, Mitsubishi Motors has used gray cast iron with 1.2% of nickel, plus chromium and molybdenum added in trucks as the material for brake drums [2]. However, the disadvantage of this material is the high cost. Cheng et al. found that the microstructure and mechanical properties of cast iron were improved by means of micro-alloying with 0.51% Cu and 0.32% Cr. He suggested that this method may improve the service life of a brake drum, but it has not been confirmed [8]. Nowadays, many investigators have studied the effects of graphite on the thermal diffusivity and thermal cracking of gray cast irons used for brake drums. For example, J. Yamabe (2002) showed that the crack propagation rate was lower when a larger amount of graphite had been distributed in refined grains [2].

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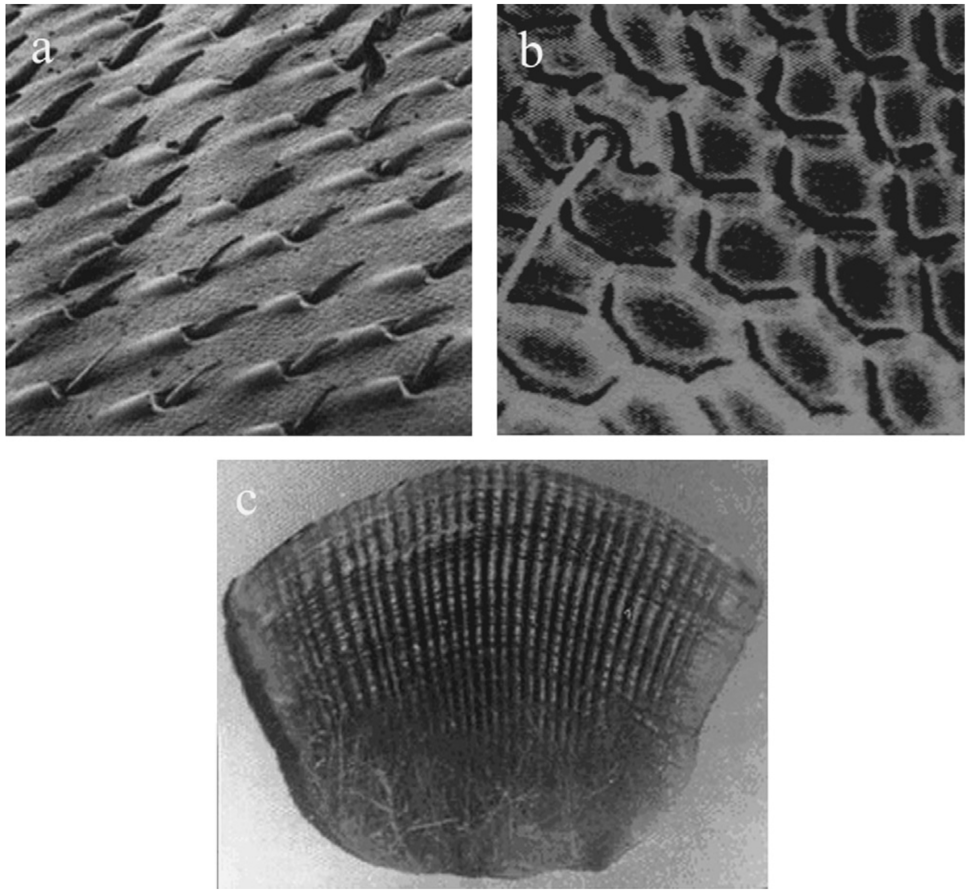

Fig. 1. The surface shapes of soil-burrowing animals (a–c).

Although much work has been done on improving thermal fatigue resistance of brake drum materials, there has not been an effective and low cost method. According to some studies [9–13], bionics is one of the most effective methods to design and manufacture materials in the future. For the investigation of bionics, scanning electron microscopy (SEM) and other methods were used to observe the body surface of animals, and the results showed that their surface was non-smooth. The non-smooth body surface of some animals and plants always shows very reasonable shapes and structures which give them many excellent properties, such as good carrying capacity, good toughness, good wear resistance and good adhesion resistance. This is the result of their evolution and optimization to adapt themselves to the environment for millions of years [14–16]. Non-smooth shapes are not only found on different kinds of animals, but also on different positions on a single animal. The non-smooth surfaces of soil-burrowing animals, such as the ant, dung beetle and pangolin are shown in Fig. 1. By imitating the shapes found on the bodies of these animals, a laser was used for processing non-smooth units on a medium-carbon steel and alloy steel surface. The experimental results indicated that it could not only enhance thermal fatigue resistance but could also enhance wear and adhesion resistance of these materials [17–20].

This article deals with the low-alloy cast iron materials which are widely used for brake drums. A laser was used to process biomimetic non-smooth surface samples with different unit shapes including ‘spot’, ‘striation’ and ‘lattice’. The thermal fatigue resistance of all the samples was compared, and it supplied a theoretical basis for processing brake drums with a biomimetic non-smooth surface which have the highest resistance to thermal fatigue.

2. Experimental

2.1. Experimental materials

For this work, a low-alloy gray cast iron, codenamed HT250 was used. Its chemical composition, similar to which is widely used for brake drums, is given in Table 1.

Table 1
The compositions of HT250 gray cast iron (wt%)

Composition	C	Si	Mn	P	S	Cu	Cr	Fe
Content	3.250	1.570	0.920	0.060	0.059	0.500	0.270	Balance