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Thermal fatigue behavior of gray cast iron with striated biomimetic non-smooth surface

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ABSTRACT

In order to enhance thermal fatigue resistance of brake drum materials, gray cast iron samples with biomimetic non-smooth surface were processed by laser to imitate the alternately soft and hard structure of shell nacreous layer. The key feature of this biomimetic non-smooth surface is that some parallel striations with various spacing distribute on the smooth surface of sample. With self-controlled thermal fatigue test method, the thermal fatigue behaviors of smooth and non-smooth samples were investigated and compared. The results indicated that biomimetic non-smooth surface had a beneficial effect on improving thermal fatigue resistance of samples, and the resistance of non-smooth sample which has smaller spacing of striations is the best in the experiment. Function of non-smooth unit such as the resistance to initiation and propagation of thermal crack is the main reason for improved thermal fatigue property of gray cast iron.

1. Introduction

Brake drum is the most important part in braking system for trucks. Because of the huge braking force and frequent braking, the drum would receive giant pressure and static or kinetic friction force from brake disk when vehicles move in the complex areas especially in the mountainous areas. As a result, the brake drum would be a failure earlier than expected. Observation indicates that the failure characteristics of brake drums are a lot of wide and deep cracks which distribute in their working surface, and the length of cracks is similar to the height of drum. According to analysis, the birth of cracks is related to the thermal fatigue factors, and their subsequent propagations lead to the rupture of drum. During braking, the huge friction force transforms to the heat energy absorbed by brake drum, and then the temperature of drum's working surface would increase to 900 °C rapidly. The alternately heating and cooling caused by frequent braking may lead to initiation and propagation of thermal cracks. Moreover, due to stretching force, the long cracks would make the sudden break of brake drum, and this threatens the safety of vehicles (Daimaruya et al., 1997; Thomas et al., 2002; Malak, 2001; Hadavi et al., 2004; Campos et al., 2005; Hecht et al., 1999; Yamabe et al., 2002). Therefore, it is urgent to enhance thermal fatigue resistance of the brake drum material.

Compared with friction materials, the brake drum material has single category and slow development. In longer period, the producer of brake drum prefers to use cheap cast iron material and low cost process. For example, HT150 and HT200 were more used by inboard, while outboards preferred gray cast iron grade 250 and high-carbon gray cast iron; but these

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materials had poor resistance to wear. In order to improve this performance, Ni, Cu, Mo, Cr and other alloy elements were added in the gray cast iron, and the popular low-alloyed brake drum was developed. The intensity, hardness and resistance to wear were all improved; however, the resistance to thermal fatigue was still not ideal, which had become the new researchful point (Cheng et al., 2001).

With perfect and special structures naturally selected through evolution course of zillion years in organisms, biological materials are of unsurpassable advanced performance in comparison to man-made materials. Bionics is a science that imitates the principles of bio-systems to build new technological systems of useful components. Over the past two decades, bionics has had a profound influence on material science and engineering, because the unique structures, compositions and accordingly excellent properties of biology gave researchers many clues to improve the properties of materials or increase the reliability of structural components. In recent years, researchers in material science have taken up studies on structures of natural biological materials, aiming at working out biomimetic designs featured with similar material structure by simulating the precise structural characteristics or obtaining inspiration therefrom (Ren et al., 2001, 2003; Chen, 2001).

For a long time, nacreous layer of shell has been very much focused on its excellent mechanical property. As a sort of natural compound material, nacreous layer is composed of 96% v/v of aragonite and 5% v/v of protein. As indicated in Fig. 1, aragonite flake is fundamentally the basic structural unit of nacreous layer. Aragonite flake's growth transversely in X–Y plane causes nearby crystals conglomerate to form micro-layer; the micro-layer stacks up in Z direction, and whole nacreous-layer structure will be shaped finally; the micro-layers are interlinked by organic matter layers (Curry, 1977, 1978). The hardness of nacreous layer is only two times of that of common aragonite, but the toughness is 1000 times of the later. Kamat et al. (2000) studied the deformation and fracture of nacreous layer by bending resistance tests, and reported that the crack was unable to penetrate the aragonite layer directly and caused deflection at the interface of this layer. H.D. Li and F.Z. Cui from Tsinghua University also indicated that propagating crack in nacreous layer always deflects when reaches aragonite layer, and it is one of the main toughening mechanics (Li et al., 2001). These all researches show

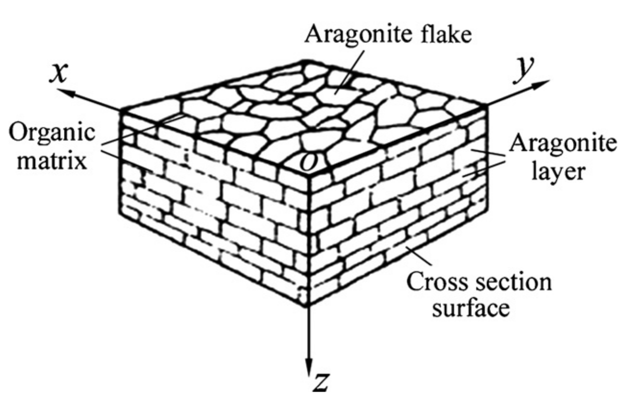

Fig. 1 – Structure of nacreous layer.

that nacreous layer's excellent property is closely related to its special structure.

Enlightened by the fine mechanical property and the fracture-arrest characteristic of nacreous layer, an idea of forming a similar structure on cast iron surface to improve the resistance against thermal cracks was produced. According to the principles of bionics, the shell nacreous layer was abstracted to the toughening structure with characteristic of alternately soft and hard, and then the gray cast iron samples were manufactured by laser melting technique to form a biomimetic non-smooth surface. The key feature of this biomimetic non-smooth surface is that some parallel striations with various spacing distribute on the smooth surface of sample. With self-controlled thermal fatigue test method, the thermal fatigue behaviors of smooth and non-smooth samples were investigated and compared.

2. Experimental

2.1. *Experimental materials*

For this work, a low-alloyed gray cast iron codenamed HT200 was applied. These cast iron materials were cut from a brake drum produced by a domestic manufacturer, and their chemical compositions were listed in Table 1.

2.2. *Samples preparation*

Experimental samples of 40 mm length, 20 mm width and 5 mm thickness were cut by electric spark machine, and a 3 mm diameter round hole was drilled at one side of every sample, so that they could be fixed onto the plate of the thermal fatigue experimental machine. To avoid reducing thermal fatigue life due to premature crack initiated from the surface machining marks, the samples were mechanically polished, using progressively finer grades of silicon carbide impregnated emery paper before thermal fatigue test to remove all the surface irregularities and machining marks. A solid state Nd-YAG laser of 1.06 μm wavelength and maximum power of 300 W was used for processing parallel striations on sample's surface to obtain a regular hardness distribution, because laser processing is a hard-facing method with not only an exceedingly high degree of process controllability, but also a great deal of process flexibility. The processed striations had a width, and were harder than sample base due to the refined grains and the arising of eutectic carbides which were caused by high cooling rate, thus an alternately soft and hard structure which was arranged by sample base and striation zone formed on sample surface. The laser processing parameters were given in Table 2. The un-processed sample is named as Smooth Sample. Due

Table 1 – Chemical compositions of HT200 gray cast iron (wt.%)

	Compositions							
	C	Si	Mn	P	S	Cu	Cr	Fe
Content	3.250	1.570	0.920	0.060	0.059	0.500	0.270	Bal.