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Thermal Cycling Effect on the Wear Resistance of Bionic Laser Processed Gray Iron

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Abstract

Thermal fatigue and wear both seriously affect the service life of some working parts. Environmental temperature will modify the surface conditions and influences the result of wear. In this research, to come close to working conditions, specimens were tested by a combination of thermal cycles and wear. Different cycles of thermal fatigue was carried out first on the gray iron specimens and subsequently wear test was performed to evaluate the effect of these thermal fatigue cycles. In this case, bionic laser processing was used to enhance the wear performance. The results indicated that bionic laser processing reduces the negative effects from thermal fatigue, such as grain fragmentation and oxidation. Because the initiation and growth of cracks as well as oxidation are suppressed in bionic processed areas. Bionic specimens exhibit high wear resistance compared with the common one. The process described can be considered as an effective method to improve the performance of gray iron in combined thermal fatigue and wear service conditions.

Keywords: gray iron, bionic, laser, thermal fatigue, wear

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1 Introduction

Wear and thermal fatigue are two of the main causes of failure for a lot of working parts. People did a lot research on these. Zhai *et al*. found that grapheme nanoplatelets are helpful to reduce the wear of Ni_3Al matrix self-lubricating composites[1]. Giovanni Bolelli *et al*. studied a kind of HVOF-sprayed WC–$(W,Cr)_2C$–Ni and WC–CoCr hardmetal coatings and found it can be applied at temperatures above 600 ˚C[2]. Pierre D'Ans *et al*. studied the surface multi-treatments and coatings. They proposed a semi-quantitative prediction of the lifetime of surface treated metals in the presence of thermal fatigue[3]. In many cases, the service life of working parts are limited by both wear and thermal fatigue. Brake disc used for vehicles is one of them[4,5]. However, there have been few reports about the wear occurring after fatigue. In fact, thermal fatigue leads to phase change and grain fragmentation. Phase is always connected with performance and, if it changes, the effects of wear may vary. Grain fragmentation is the initial form of crack that can be detected at the microscopic scale. Such fragmentation grows and connects as the number of fatigue cycles increases and it will finally become a macro-crack exposed to the naked eye. Fragmentation adversely affects the integrity of material surfaces and results in the reduction of its performance. The formation of an oxide layer is another result of thermal changes. For instance, brake discs reach temperature of almost 700 ˚C after braking[6]. If discs are used in a vehicle on a wet road, such a high temperature and moist air can make it easy to rust. Each time an oxide layer formed, it may not have much of an effect on failure though, because the next braking process will wear off the thin layer. But within the whole service life of a brake disc, these oxide layers will accumulate and eventually have a large effect on performance. Wear resistance is considered to be seriously affected by these changes from thermal fatigue.

Nature is a continuing source of inspiration in engineering field. For example, the perfect performance on the surface of some animals are derived from the coupling of their different materials, structures and morphologies[7]. Such ideas have led to design and study on

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the bionic coupling surface designed with multiple factors (materials, structure or morphology) which can interact on each other in engineering. Previously, we fabricated the hard areas by laser remelting, cladding or other methods on the relatively soft substrate materials[8,9]. We called the hard area as bionic unit which has a better performance than the substrate. The performance and distribution of bionic units are the main factors affecting the properties of such a bionic functional surface. Many researches have verified that these kinds of structure present various advantages in engineering, like higher wear resistance[10–13], better thermal fatigue resistance[14–16], lower adhesiveness[17] and excellent erosion resistance[18]. However, previous works are mainly focused on testing one single kind of property improvement that is different from the real service conditions of some mechanics and not enough to prove the advantages of bionic coupling surfaces.

In this paper, an attempt was made to improve the wear performance after thermal fatigue. Specimens were put in thermal fatigue first. After observing the changes in structure and microhardness, wear test was carried on. Specimens were processed by bionic laser technique and expected to show multiple enhanced performance: less crack on bionic processed area and higher wear resistance of specimens even after thermal fatigue.

2 Experimental

2.1 Materials and preparation method

The composition of typical material of brake disc, gray cast iron, is listed in Table 1. All specimens were cut to a size of 35 mm (L) × 17.5 (W) mm × 6 mm (D). They were polished and then cleaned by anhydrous ethanol before laser processing. Shell of bivalve mollusk was chosen as the bionic prototype because of the beach environmental features. The most common place to find a shell is sandy beach but the most common item is sand. Because of the temperature difference between day and night, and the impact from wave, stone cracked and broke into small sands. But shells are well preserved. After observation of these shells (Fig. 1a[19]), radial rib was found to be the general structure. According to the strip distribution, bionic processed area (unit) was designed on specimen surface. The distance between each bionic unit was 3 mm. Four units were designed on specimen surface (Fig. 1b). Laser technique was used to process bionic units. It has advantages as follows: it's low cost and easy to control by adjusting parameters; the processed area can be selected and the properties of unprocessed substrate can be remained[15]. Furthermore, laser processed unit shows advantage on wear and thermal fatigue resistance individually in the previous research. Table 2 gives the parameters used in laser processing. The spot diameter is 1.5 mm and energy density is 275 J·cm^{-2}. One specimen without bionic processing was also prepared to compare with the processed ones.

Table 1 Chemical compositions of the HT200 (wt%)

Elements	C	Si	Mn	P	S	Cu	Cr	Fe
Composition (wt%)	3.25	1.57	0.92	0.06	0.059	0.5	0.27	Bal.

Table 2 Laser parameters used in laser processing

Current (A)	Pulse duration (ms)	Frequency (Hz)	Scanning speed (mm·s^{-1})
173	5	7	0.5

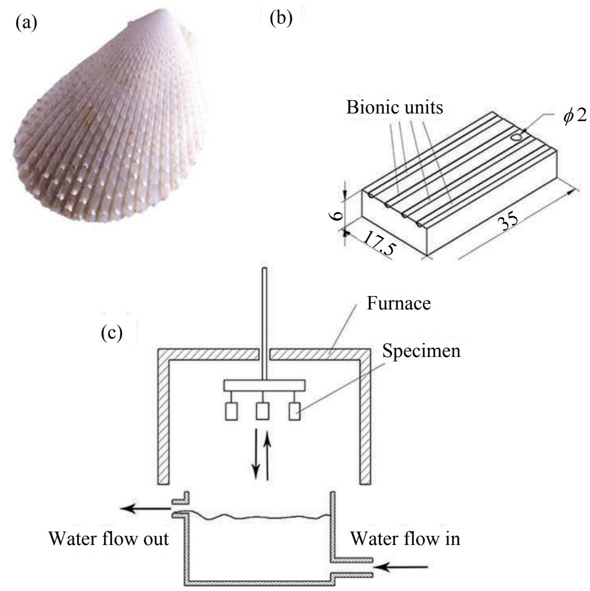

Fig. 1 Bionic prototype (a) and sketches of specimen (b) and fatigue test (c).

2.2 Test methods

A self-made thermal fatigue tester was used to carry out the thermal cycles (Fig. 1c). The parameters could be adjusted and the number of cycles could automatically be recorded. In this research, the specimens were heated to 500 ˚C continuously and held for 70 s then cooled in flowing water at room temperature (20 ˚C) for 4 s. Four