Materials Letters 216 (2018) 203–206

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/mlblue

A bio-inspired concept to improve crack resistance of gray cast iron

Xiao Yang [a,b], Lifeng Shi [a], Shichao Niu [b], Yuchen Shi [a], Guojin Chen [a], Jing Ni [a,*], Can Wu [a]

[a] School of Mechanical Engineering, Hangzhou Dianzi University, Hangzhou 310018, China
[b] Key Laboratory of Bionic Engineering, Jilin University, Changchun 130022, China

ARTICLE INFO

Article history:
Received 6 September 2017
Received in revised form 8 November 2017
Accepted 6 January 2018
Available online 9 January 2018

Keywords:
Natural design
Structural
Fatigue
Laser alloying
Nanoindentation

ABSTRACT

The prospect of introducing natural biological secrets to improve the crack resistance of gray cast iron is presented. We demonstrated that the mechanism of resisting crack owned by plant leaf can be referred to fabricate an alternating structure of hard and soft with low cost, high strength, and an exceptional ability to resist crack growth. Laser alloying was introduced to fabricate the hard phase which associated with the original matrix constituted the alternating structure. A homogeneous microstructure and a uniform distribution of chemical composites were achieved in hard phase. Nanoindentation test showed the resistance to plastic deformation of hard phase was improved. Crack propagation tests verified the crack resistance was enhanced by the alternating structure which could change and prolong crack path, and the effectiveness of resisting crack propagation was proportional to the size of hard phase.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

Gray cast iron (GCI) is a popular cast metal that is widely used in industrial manufacturing and daily life because of the advantages such as good castability, high machinability, and low cost. However, damage occurs constantly in the form of cracks that either originates at the surface or internally, and propagates catastrophically throughout the body. Therefore, it is important to improve the crack resistance of GCI by an efficient and economical method. Until now, methods adopted to improve crack resistance were mainly focused on surface finishing techniques including plasma arc welds [1], laser peening [2–5], and powder coating [6–9]. Great progress had been made, especially in improving the resistance to crack initiation, and revealed the corresponding mechanism by studying extrusions/intrusions of grains, localized cyclic plasticity, and microcracking. However, few studies focused on the ability of resisting crack propagation by drawing on the techniques possessed by living organisms.

Nature is the most wonderful and successful laboratory, which has provided ready answers to the problem of crack resistance and can inspire us with a series of novel designs and high-performance structures [10]. Plant leaf venation played the function of transporting water and nutrients, but also supported the body of leaf and resisted the crack growth, due to its alternating structure that consisted of leaf vein (hard phase) and mesophyll (soft phase). Cracks observed in plant leaf deviated frequently from one direction to another, because the crack growth path was blocked by leaf veins and sequentially propagated along the venation in mesophyll (Fig. 1). Therefore, crack resistance was improved as a consequence of the crack path being lengthened, whereby more destructive energy was required. Based on this mechanism of crack resistance, we fabricated hard phase unit (HPU) on the surface of GCI to obtain an alternating hard and soft structure, and investigated the effect on crack propagation.

2. Experimental

The *compact specimen* was used to evaluate the growth behavior of a crack, of which feature size W was 80 mm (dimension details were available in ASTM E647-15, and the test specimen was exhibited in Fig. 2(a)). Different grooves were milled symmetrically on both the front and back surfaces of specimen to study the effect of the HPU size on crack resistance. The HPU was fabricated by laser alloying using self-fluxing alloy powder of 100 μm particles, the chemical compositions were (in wt%) Cr 17, Ni 3, W 1.5, and balance Fe. Samples were heated up to 500 °C, and the self-fluxing alloy powder was preplaced in the grooves before laser processing. A solid-state Nd-YAG laser with a maximum power of 800 power was employed to fabricate HPU. The optimized processing parameters were: $I_{electric} = 165$ A, $t_{pulse\ \ width} = 5$ ms, $f_{frequency} = 20$ Hz, $D_{beam\ \ diameter} = 2$ mm, $v_{speed} = 5$ mm/s, and $E_{energy} = 23$ J. Crack propagation test was performed on an INSTRON 8501 machine, and the test process followed strictly to ASTM E647-15. The waveform of fatigue loading was sine wave with $f_{frequency} = 3$ Hz, $F_{max} = 3$ 800 N, and $r_{ratio} = 0.1$. The load conditions of nanoindentation were:

* Corresponding author.
E-mail address: nj2000@hdu.edu.cn (J. Ni).

https://doi.org/10.1016/j.matlet.2018.01.029
0167-577X/© 2018 Elsevier B.V. All rights reserved.

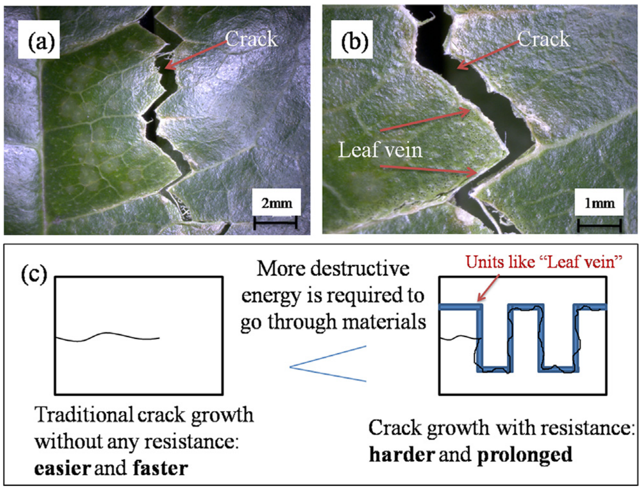

Fig. 1. (a, b) A crack observed in leaf. (c) A bio-inspired concept to improve crack resistance.

displacement at maximum load was 2020 nm, drift correction was 0.40 nm/s, peak holding time was 2.0 s.

3. Results and discussion

A homogenous elemental distribution was acquired in HPU as shown in Fig. 2(b), and the contents of Cr and Ni were increased simultaneously. It was reported that Cr and Ni could stabilize microstructures, whereas they retarded the progress of structural decomposition [11]. Meanwhile the microstructures of HPU became more uniform without any defect like graphite located among pearlite and cementite. Fig. 2(c, e) presented the new phases and microstructures of HPU, which were composed of martensite, residual austenite (γ-Fe), dendritic cementite (Fe_3C), and $(Fe,Cr)_7C_3$. It was verified that a certain amount of austenite combined with a hard phase such as martensite can enhance the toughness and the ability to stop, or at least hampering microcracks [12,13]. Thus the mechanical properties of HPU were hypothesized to be improved due to the homogenous elemental distribution, the contents increase of Cr and Ni, and a more uniform microstructure [14,15].

Fig. 3(a, b) showed the microcracks were easier to be generated around the graphite because of the inhomogeneous microstructures. These microcracks converged to a larger crack as they grew up and bridged together. But the microcracks branched when they grew to the vicinity of the HPU and were stopped by HPU. To explain this result, nanohardness and elastic modulus were calculated from the load-displacements curves (Fig. 2d) [16]. The nanohardness and elastic modulus were 12 GPa, 160 GPa (HPU), and 4 GPa and 170 GPa (GCI), respectively. Thus the crack couldn't go through HPU straightly because the HPU was a hard phase in front of the crack, and a spatial variation in the Young's modulus influenced the direction of crack growth, although the ratio of elastic moduli of different phases was less than 5 [17,18]. Furthermore, the behavior of anti plastic deformation was also characterized by load-displacement curves. Deformation of nanoindentation consisted of elastic and plastic strains in nature as permanent indentation generated as shown in Fig. 2(e, f). The remaining displacements indicated the quantity of plastic deformation, and it was obvious that the plastic deformation observed in HPU was smaller than that in GCI when the same displacement loading was applied. So far, it had been confirmed that a plastic zone was generated ahead of a fatigue crack tip owing to the opening displacement of crack. Therefore, the HPU possessed a better performance in resisting crack propagation because of the high nanohardness and the better resistance to plastic deformation.

Crack propagation tests showed that the time consumed by a crack in passing a certain horizontal distance was improved significantly when the specimen possessed HPU. The fatigue life of specimen with HPU was prolonged almost 3–5 times than that of the specimen without HPU, the depth of HPU was larger the time consumed was longer. The crack growth rates versus the stress intensity factor ranges were showed in Fig. 3(d), the stress intensity factor ranges varied between 12.97 MPa $m^{1/2}$ and 31.05 MPa $m^{1/2}$, and the growth rates were between 1.54^{-6} mm/cycle and 6^{-3} mm/cycle. The mechanism of HPU in resisting crack propagation could be concluded from Fig. 4. It was obvious that the crack grew around the symmetrical axis of the specimen. The length of the

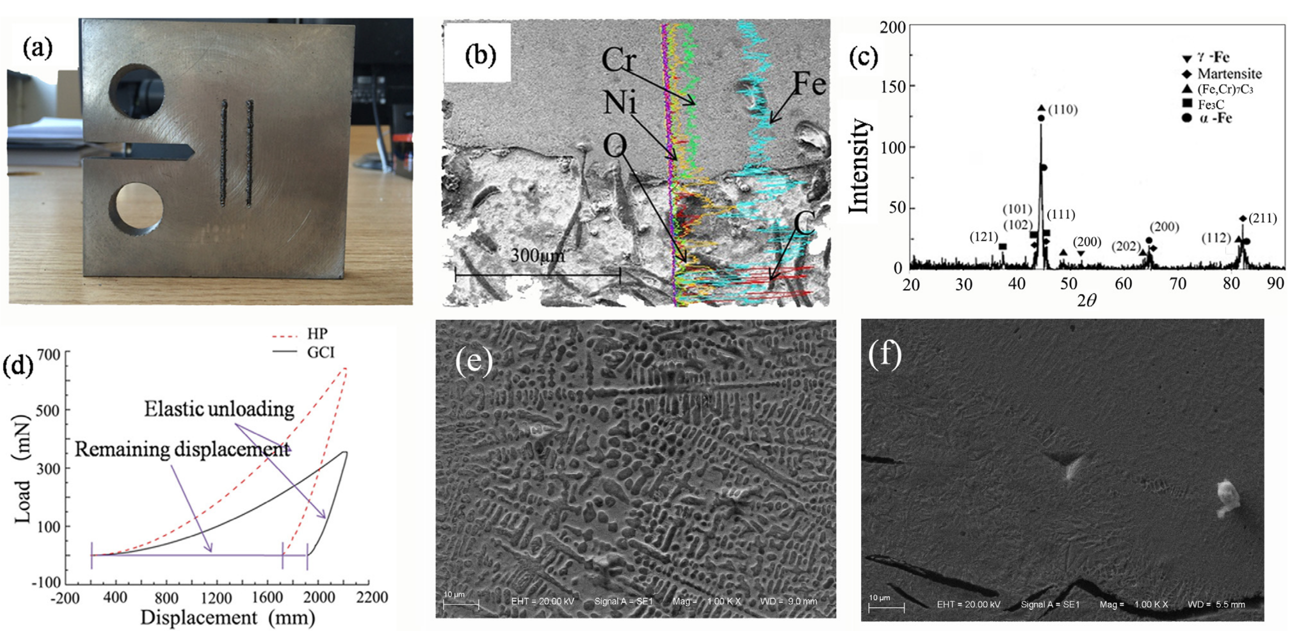

Fig. 2. (a) Test specimen. (b) Area of testing. (c) Results of XRD. (d) Load-displacement curves. (e) Nanoindentation in HPU. (f) Nanoindentation in GCI.

Download English Version:

https://daneshyari.com/en/article/8014636

Download Persian Version:

https://daneshyari.com/article/8014636

Daneshyari.com