Materials and Design 49 (2013) 168–172

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Short Communication

Gradient distribution of mechanical properties in the high carbon steel induced by the detour effect of the pulse current

Bingdong Ma [a], Yuguang Zhao [a,*], Hui Bai [b], Jun Ma [a], Jiatao Zhang [a], Xiaofeng Xu [a]

[a] Key Laboratory of Automobile Materials, Ministry of Education, and Department of Materials Science and Engineering, Jilin University, No. 5988 Renmin Street, Changchun 130025, PR China
[b] Technical Department of Cheng Du Non-Ferrous Foundry Branch, FAW Foundry, Chengdu 130062, PR China

ARTICLE INFO

Article history:
Received 30 December 2012
Accepted 5 February 2013
Available online 18 February 2013

ABSTRACT

The gradient mechanical properties were obtained in the electropulsing-tempered saw blade made by the high carbon steel. The tooth has a high hardness, whereas at the back the hardness is low. Owing to the high temperature induced by the electropulsing, a plastic area formed at the tooth root. In addition, the thermal compressive stress and the strong electroplasticity effect at the tooth root helped heal the cracks there effectively. Therefore, the strength and toughness of the saw blade were improved obviously, making it meet the high requirements for the cutting performance. The results are attributed to the detour effect of the pulse current during the electropulsing–tempering treatment.

1. Introduction

Saws are frequently used in our daily life, for cutting pipe, solid body, wood, plastic, and metals. The high carbon steel with the microstructure of martensite after quenching is generally used to make the saws. However, tempering is critical to improve the fracture strength of the steel [1]. Due to its characteristic of overall treatment, mechanical properties at any locations tend to be consistent. As we all know that the tooth and back of the saws have different requirements for the cutting performance. The back requires a high toughness to prevent the brittle fracture, whereas the tooth wants to be very hard. Particularly, for the cutting of soft metals in the industry the strength and hardness of the tooth need to be high enough to ensure the sharpness of the edge. Moreover, since the tooth root is a gap, it is easy to produce a concentration of stress. Cracks often generate there first and extend, resulting in the fracture failure of the saws. Therefore, it needs to find a new tempering method to make them meet the high requirements.

Electropulsing on modifying the properties of materials has been widely studied in the past decades, such as electroplasticity [2,3], electromigration [4,5] and recrystallization [6]. Zhu et al. [7] exhibited that the brittle TiNi shape memory alloy strips could be processed by electroplastic rolling (EPR) without intermediate annealing. The maximum thickness reduction of the alloy strip in the individual EPR pass can be 21.6%, and the total deformation in terms of thickness reduction can reach 74% in the seven passes of EPR processing. Li et al. [8] studied the effects of electropulsing on the deformation behavior, dislocation structure, microstructural evolution and cavity morphology of the coarse-grained AZ31 magnesium alloy during gas bulging process. The results showed that the dislocation motion was mainly glide, and the dislocation lines were approximate parallel with few dislocation tangles. Besides, electropulsing can accelerate the phase dissolution into matrix in a very short time of several seconds due to the reduction of the nucleation thermodynamic barrier and enhancement of atomic diffusion, respectively [9].

Zhang et al. [10] found that nanostructures were formed in several conventional materials under single electropulsing, that is nanophases of α-Cu(Zn) and β'-(CuZn) in a cold-worked α-Cu(Zn) alloy, nanosized γ-Fe in a low-carbon steel, nanosized α-Al in a superduralumin, and orientated nanosized TiC in a TiC/NiCr cermet. They pointed out that the mechanisms responsible for the above nanostructured transitions can be attributed to the competition of many factors induced by electropulsing, including high-rate heating, thermal stress, reduced thermodynamic energy barrier and high-rate electron impacting. Moreover, the phenomenon of detour effect of the pulse current has attracted more and more attention these years. It was diffusely studied in the investigations such as crack arrest [11,12], crack healing [13,14] and the improvement of fatigue resistance [15,16]. However, work on taking advantage of this effect to treat the realistic parts with complex shapes, making them have different mechanical properties at the different areas, is rarely reported so far.

In this study, the electropulsing was applied to temper a hand-saw blade after quenching. Microstructure and hardness distribution at different locations were attentively investigated. Moreover, the reasons for the results were discussed as well.

---

* Corresponding author. Tel./fax: +86 431 8509 4481.
E-mail address: zhaoyg@jlu.edu.cn (Y. Zhao).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.02.015

Table 1
The chemical composition of the hand-saw blade.

Element	C	Mn	Si	P	S	Fe
Amount (wt.%)	0.97	0.35	0.24	0.010	0.015	Balance

2. Experiments

The commercial hand-saw blade was employed as the research object, which has a typical chemical composition showed in Table 1. The samples were cut as 40-mm long directly from the saw blade, of which the width and thickness are 10-mm and 0.6-mm, respectively. They were divided into two groups: AR (as-received) and QE (quenched at 800 °C in water and then electropulsing-tempered). AR was not subjected to any treatment in the experiment and was employed as the reference sample. In fact, AR was quenched and tempered in the production process before selling. QE was electropulsing-tempered after the quenching on a self-made electropulsing system (Fig. 1) with the optimized parameters, as shown in Table 2, under ambient condition. The system can generate AC pulse current with 50 Hz frequency, and the discharging duration and density of the pulse current were determined by a controllable program on a computer. Current parameters were monitored by an oscilloscope with Hall-effect component. The surface temperature at the back of the saw blade was measured by using an infrared thermoscope. Vickers hardness measurement was conducted on the microhardness testing equipment (Everone, MH-3) under a load of 200 gf with an indentation time of 5 s. The hardness measurement position (P) was shown in Fig. 2, where a and b are the 3D and 2D view, respectively. Location 1 (L1) denotes the measurement positions from the tooth root to the back of the saw blade, while the location 2 (L2) expresses that from the tooth tip (Fig. 2a), in which the distance between the two positions is about 0.3 mm. The bending strength of the samples was obtained in the three-point bending test on a servo-hydraulic materials testing system (Sans, CMT5105), and the distance between the two bearing points was 30 mm. The metallographic images were obtained by a field emission scanning electron microscope (FESEM, JSM-6700F, Japan).

Table 2
Pulse current parameters for the electropulsing–tempering treatment.

Pulse current parameters	Values
Frequency (Hz)	50
Discharging duration (ms)	60
Maximum current density j_m (MA/m^2)	612.4
Equivalent current density I_e (MA/m^2)	425.7

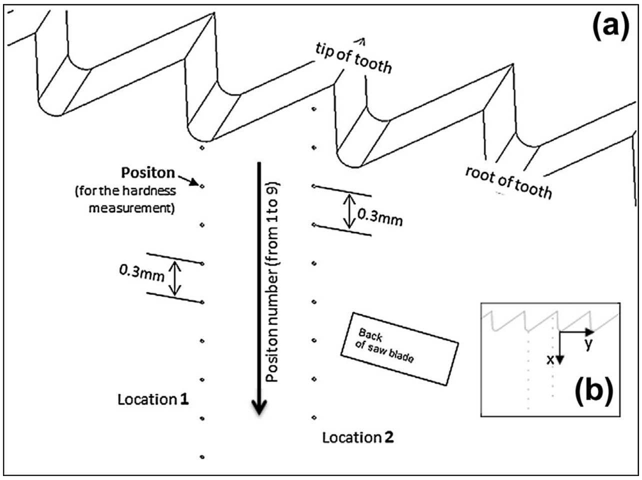

Fig. 2. Positions for the hardness measurement displayed in (a) 3D and (b) 2D view, where in (b) the Cartesian coordinate system is expressed.

3. Results and discussion

Microstructure of QE at the back of the saw blade was shown in Fig. 3a, which is low-temperature tempered plate-martensite, uniformly distributed small granular carbide and the residual austenite owing to the low tempering temperature (~280 °C). However, the microstructure at the tooth root, as shown in Fig. 3b, is slightly different from that at the back. The direction of the plates is indis-

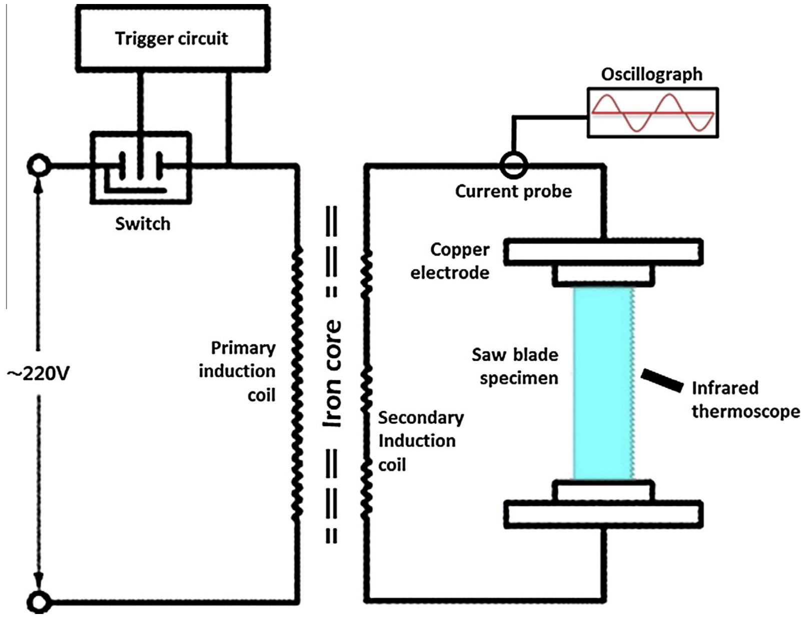

Fig. 1. Schematic illustration of the electropulsing system.