Materials and Design 30 (2009) 674–678

Contents lists available at ScienceDirect

Materials and Design

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

Rapid solidification of M_2 high-speed steel by laser melting

K.Y. Benyounis [a,*], O.M. Fakron [b], J.H. Abboud [b]

[a] Department of Industrial Engineering, Faculty of Engineering, Garyounis University, P.O. Box 1308, Benghazi, Libya
[b] Department of Mechanical Engineering, Faculty of Engineering, Garyounis University, P.O. Box 130, Benghazi, Libya

ARTICLE INFO

Article history:
Received 3 December 2007
Accepted 14 May 2008
Available online 23 May 2008

Keywords:
Laser melting
HSS
Rapid solidification
X-ray
Microstructure

ABSTRACT

The effects of laser surface melting and rapid solidification on the microstructure of M2 high-speed steel (HSS) have been investigated. A solid state pulse Nd-YAG laser of wavelength 1.06 μm, maximum power of 100 W, beam diameter ~1 mm, and pulse duration of 0.8 and 2.5 ms. Optical, scanning electron microscopy, and X-ray diffraction techniques were used to evaluate the microstructure and identify the phases. Results show that laser surface melting has led to a complete dissolution of the carbides and re-solidification of cellular/dendritic structure of a very fine scale surrounded by a continuous interdendritic (or intercellular) network of carbides eutectic. The phases appeared were mainly δ ferrite and M_6C and small amount of austenite γ. Laser surface melting leads to a refinement of the microstructure and altering the morphology and the distribution of the phases. The microhardness of this material was not increased after laser melting.

1. Introduction

High-speed steels are group of materials, which upon heat treatment, exhibit high strength, hardness and wear resistance [1]. The as cast microstructure of this steel contain relatively high proportion of carbides which arise from the initial casting process; these carbides are coarse, heterogeneously distributed and are difficult to break down by conventional heat treatment technique. For this reason conventional high-speed steel undergo hot working to break up the network of carbides produced in the as cast structure. However, even after hot working the distribution does not become uniform and the carbides are arranged in stringer [1].

The application of laser melting and rapid solidification of surface layers permits to obtain structures and properties of practical interest. This technology allows supplying an enormous density of energy precisely to the treated surface during a very short time [2–11]. Since the melting occurs only at the surface, large temperature gradients exist across the boundary between the melted surface region and underlying solid substrate, which results in rapid self – quenching and re-solidification depending on the processing parameters used, laser beam melting results cooling rates of between 10^3 and 10^6 K s^{-1} through the solidification range. This produces a unique microstructure and the possibility of enhanced solid solubility arising from the rapid solidification. This technique is applied on different ferrous and nonferrous materials including alloy steels [4], tool steels [5–8], cast irons [9–10], aluminum alloys [11], titanium alloys [12] and a significant improvement in hardness, corrosion, wear, and oxidation has been reported.

The present work includes the effect of laser melting and rapid solidification on the microstructure of the M_2 high-speed steel using Nd-YAG solid state laser.

2. Experimental technique

Commercial M_2 high-speed steel plate of thickness 3 mm and composition 6.1%W, 4.9%Mo, 3.5%Cr, 1%V and 0.9%C has been used. The plate was cut into several equals' pieces of 20 mm × 20 mm × 3 mm. Before laser treatment, the sample surfaces were mechanically ground, polished, cleaned and etched with nital to decrease the beam reflectivity. The Nd-YAG laser is operated in pulse mode at frequencies 20 and 50 Hz. The maximum power of the laser is 100 Watt but the experiment was carried out at powers 30, 40 and 60 W. The beam diameter was ~0.5 mm. Three specimen speeds were used 0.5, 1 and 2 mm/s. Also two pulse durations were selected 0.8 and 2.5 ms. Argon shielding gas was used during laser melting to avoid oxidation and undesirable contamination.

Microstructure observations were carried out on cross-sectioned using optical and scanning electron microscopy SEM of type LEO. Optical microscopy is used to see the whole melt zone at lower magnification while SEM analyses was used to reveal the microstructural details at high magnification employing secondary electron image. X-ray diffraction (XRD) with a diffractometer using chromium radiation and a vanadium filter has been used for phase's identification. Microhardness tests were carried out using Vickers equipment with applied load of 100 gm on polished sample.

* Corresponding author.
E-mail addresses: kybenyounis@yahoo.com (K.Y. Benyounis), jhabboud@yahoo.com (J.H. Abboud).

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doi:10.1016/j.matdes.2008.05.030

3. Results and discussions

3.1. Shape, morphology, and dimensions of laser melted zones

In the present investigation, smooth, flat, and shinny surface with silver color are observed in the surface of all the laser-processed specimens. The morphology of the top surface of the LMZ is characterized by combination of fine crystal and ripples in the radial direction. These ripples indicate the contours of the solidification fronts. It is reported that surface tension gradients are setup by temperature gradient driven fluid flow [2]. A number of cracks were observed and mostly transverse to the traverse direction.

Table 1 illustrates the results of measuring the depth, the width, surface roughness (*R* max), the depth to which the heat affected zone is extending, and average microhardness of all laser melted zones. All these measurements were performed done on transverse section perpendicular to the laser track accept roughness values were measured on the surface plane parallel to the laser scanning direction with out any polishing.

Experimental results showed that for a given pulse duration and power, the melted depth decrease when scanning speed increased provided that the plasma which formed above the substrate should be removed specially at the slowest speed. Also for a given scanning speed and pulse duration, the melted depth increases with increasing power. Deep melted zone with a keyhole shape is obtained at relatively high power and long pulse duration. Increasing pulse duration leads to a significant increase in the melted depth while the width remains unchanged. Roughness measurements of all the processed samples showed a peak to valley height (*R* max) values ranged between 2.52 and 5.76 μm compared to 10 μm of the as received material. The microhardness of the laser melted zone was measured in different locations and the average value is illustrated in Table 1 above. Generally the microhardness of the melted zone is slightly lower than the substrate while the heat affected zone is higher.

Table 1
Dimensions, roughness, average hardness of LMZ of M_2 H.S.S at different conditions

Specimen no.	Laser power (W)	Pulse duration (ms)	Scanning speed (mm/s)	Melted depth (mm)	Melted width (mm)	Heat affected zone (mm)	Roughness *R* max (μm)	Average hardness (HV)
2-V_1	30	0.8	0.5	0.17	0.61	0.05	5.76	430
2-V_2	30	0.8	2	0.14	0.61	0.05	3.19	440
6-V_1	40	0.8	0.5	0.16	0.62	0.04	5.17	425
6-V_2	40	0.8	1	0.13	0.62	0.05	3.10	435
6-V_3	40	0.8	2	0.11	0.58	0.04	2.71	440
8-V_1	50	0.8	0.5	0.177	0.61	0.045	4.85	423
8-V_2	50	0.8	1	0.15	0.60	0.04	2.95	440
8-V_3	50	0.8	2	0.13	0.61	0.04	2.52	430
9-V_3	50	2.5	0.5	0.44	0.55	0.02	4.75	400

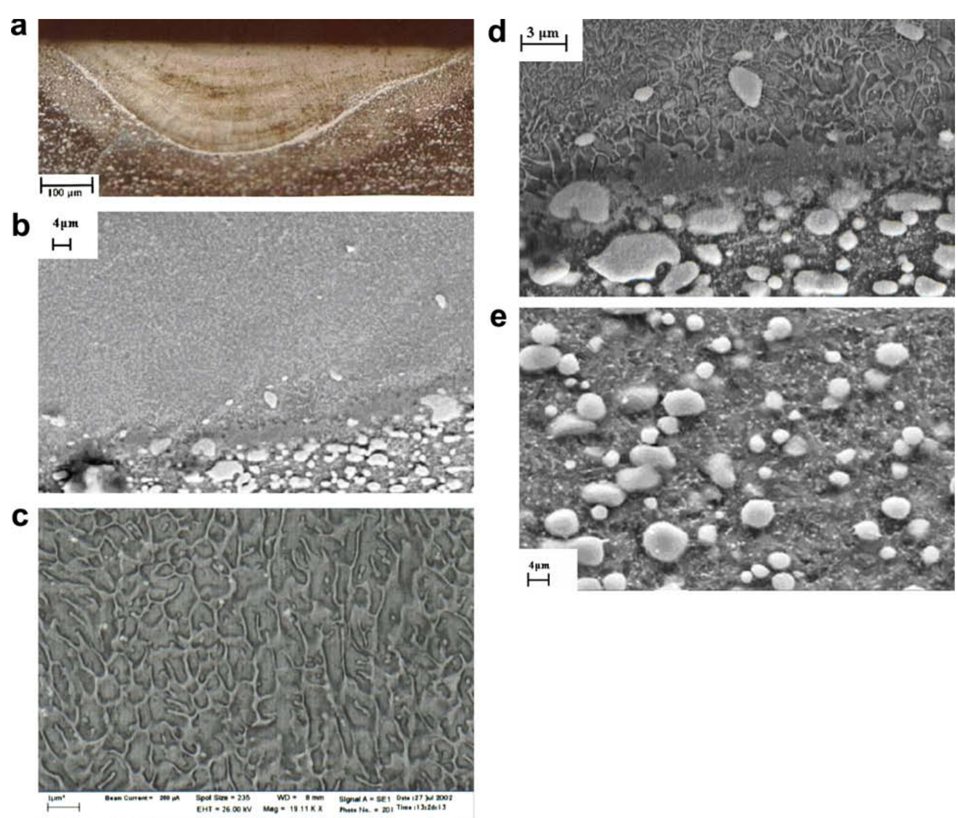

Fig. 1. (a) Optical micrograph shows the laser melted zone (30 W, 0.8 ms, and 1 mm/s), (b) SEM micrograph shows the structure of the interface, (c) SEM micrograph shows the structure of the melted zone at high magnification, (d) SEM micrograph shows the structure at interface at high magnification and (e) SEM micrograph shows the unaffected zone.