Laser Melting of T1-High Speed Tool Steel

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Metallographic (optical, TEM, SEM), spectroscopic, and microhardness investigations of T1 high speed tool steel heated by neodymium-pulsed laser (NPL) are described. Martensite, retained austenite, delta (\(\delta\))-ferrite, M\(_6\)C carbides, and cellular segregations of W, V, and Cr were observed in the laser-melted zone. The high chemical homogeneity and fine structure of the melted zone were attributed to high cooling rates due to the short interaction time with the neodymium-pulsed radiation and relatively small volume of the melted material. Fine precipitates, cellular M\(_6\)C carbides, and plate-like MC carbides were formed in the melted zone during tempering. An increase in micro-hardness of the laser-melted zone with tempering temperature was observed and attributed to these precipitates and the transformation of the retained austenite.

I. INTRODUCTION

LASER processing of materials has progressed markedly in the past twenty years. Recent applications of lasers to materials processing include surface melting, alloying, cladding, heat treating, and shock hardening.\(^1\) The present status of the various aspects of laser-heating processes can be found in a number of conference proceedings,\(^5\) review papers,\(^1\) and books.\(^7,8,9\)

A review of the literature shows that, while significant advances have been made recently in the theory of laser heating of solids,\(^10,11\) rapid solidification,\(^12,13\) cutting and welding of alloys,\(^7,9,14\) properties of steels, and cast irons after laser-surface heating or melting,\(^7,12\) a detailed understanding of the basic phenomena of laser hardening remains to be obtained. Although Ashby and Easterling\(^16\) have given a good mathematical and metallographic description of laser hardening, they have not discussed the details of the structure developed during laser hardening that cause a higher hardness of steels than that after conventional hardening. Hence, more TEM, SEM, and other analytical examinations should be done for a better comprehension of the laser-hardening process.

Based on past research, the following benefits can be anticipated from laser hardening:

1. The structural refinement and increased homogeneity resulting from rapid solidification can be expected to improve the mechanical properties.
2. The residual compressive stresses developed at the laser-treated layer due to martensitic transformation improve fatigue, hardness, abrasive and erosive wear, and corrosive resistances.
3. Higher hardness and strength of steels, compared to those observed after conventional heat treatment, can be achieved without necessarily losing toughness.

The reasons for these benefits are not only the extreme rates of heating and cooling of the material (which cause unusually high restraints), but also frequently the high pressure, which involves deformation of the materials (i.e., laser shocking\(^3\)). Rapid cooling after heating has a notable influence on the solidification processes, if melting has occurred, on phase transformations, and precipitation processes. The structure formed after laser melting has high chemical homogeneity and is extremely refined. Structural refinement caused by rapid solidification hardens many alloys, an effect that could well improve their resistance to wear.\(^2\) From a practical standpoint laser melting will undoubtedly produce interesting microstructures in many materials, particularly in high-speed tool steels.\(^6\) In these alloys one anticipates that a significant improvement in machining properties and tool lifetime will result from extremely fine grains and a homogeneous dispersion of fine carbide particles.

In recent years surface melting of high-speed tool steels was examined by several researchers, including Rayment and Cantor,\(^3\) Strutt and Nowotny,\(^4\) Kear et al.,\(^13\) Sare and Honeycombe,\(^17\) Åhman,\(^18\) and Niewiarowski and Matyja.\(^19\) Among the features obtainable by melting and rapid cooling of materials are high homogeneity and fine microcrystalline structure.\(^17\) Some differences in the results obtained by these authors (i.e., presence or absence of \(\delta\)-ferrite) were explained by Åhman\(^18\) as caused by differences in cooling rate.

II. MATERIAL AND EXPERIMENTS

This article presents the results of an investigation of the changes in phase and chemical composition, microstructure, and hardness of a laser-melted, high-speed tool steel, namely T1 (0.85 pct C, 18.5 pct W, 4.2 pct Cr, 1.2 pct V). Before laser treatment the samples were conventionally hardened. Neodymium-pulsed laser (7 J energy, 0.4 mm beam diameter) was used. In the present work laser treatment involving near-surface melting was examined for the following reason: controlled surface melting and high-speed solidification are currently utilized to obtain structures and properties of practical interest. Different parameters (\(-1\) mm, 0, \(+1\) mm focal point position relative to the sample surface) were used to obtain penetration depth of structural changes (melted + heat-affected zones) of max. 500 \(\mu\)m. After laser treatment the specimens were tempered in furnaces at 500 °C, 600 °C, and 700 °C for 2 hours.

Microstructural and compositional analysis consisted of optical, SEM, TEM, wavelength- and energy-dispersive
X-ray and X-ray diffraction analyses. For optical and SEM examinations, the samples were polished and etched electrolytically in 6 pct aqueous solution of CrO₃ at 8 V. Thin foils for TEM were prepared according to standard procedure and examined in JEM-100B and Philips 400 electron microscopes. Spectroscopy was done using a CAMECA microprobe. X-ray diffraction analyses were carried out using a Kristalloflex 4W X-ray generator and CoKα radiation. Microhardness was determined using a Hanemann microhardness tester.

III. RESULTS

Typical examples of structures after laser melting are shown in Figures 1 and 2. The microstructure of NPL-melted samples consisted generally of fine internally twinned martensite, with some amount of retained austenite (as identified by X-ray examinations, Figure 3) and residues of large undissolved carbides (see Figure 4(b)). TEM study showed in some areas martensite crossed by thin layers of segregated in cellular network carbide forming elements W, V, and Cr (Figures 2(a) and (b)). In triple junction points some carbides were observed. A small portion of δ-ferrite was also identified as either a network of large needles or an agglomeration of fine grains (see Figures 2(b) and 4).

With increased tempering temperature notable changes in the structure of the melted area were observed. Figures 4(a) through (d) show the typical, optical, SEM, and TEM microstructures of the samples melted by NPL and then tempered at 700 °C. As is shown in Figure 4(c), a fine dendritic and a white etched interdendritic phase were characteristic for this structure. EDS (Figure 5(b)) and CBD (Figure 6(c)) analyses show the interdendritic phase as M₆C carbides. A coarse, acicular, black-etched phase was also observed. Microanalysis (using EDS) shows this phase containing lower amounts of W, V, and Cr than tempered martensite (see Figures 5(a) and 6(c)). CBD analysis shows that these were probably δ-ferrite areas. TEM shows these areas substantially free of MC carbides precipitated in the adjoining martensite during tempering (Figures 6(a) through (c)). The structure of the tempered substrate (after conventional hardening) shows spheroidal M₆C carbides in a ferritic matrix (Figure 6(d)).

The microprobe studies of the chemical composition of the NPL-melted zones have shown their high chemical homogeneity, and the concentration of the alloying elements (Cr, V, W) corresponds to their average in the steel (Figure 7). However, the results presented above and those obtained from EDS X-ray using a nanoprobe in Philips 400 show that zone as nonhomogeneous, consisting of the dendritic segregations of these elements. These dendritic segregations were smaller than the probe size, about 1 µm and not indicated.

The microhardness of the NPL-melted zones, which in the as-solidified condition was lower than that of the conventionally hardened samples, increases significantly with tempering temperature and has a highest value at 600 °C (Figure 8). After tempering at 700 °C, the microhardness of NPL-melted zones is much higher (about 1050 µHV) than that of the substrate (about 550 µHV).

Fig. 1 — Metallographic structure (a) optical, (b) SEM, and (c) TEM of the melted zone in a plane parallel to the surface.