Wear resistance of laser processed 1·0%C tool steel

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The wear resistance of both laser melted and conventionally quenched 1·0%C tool steel has been investigated. From unlubricated wear tests, the abrasion resistance of laser treated material was found to be superior to that of conventionally treated material, both in the as treated condition and after a range of tempering treatments (room temperature at 300°C), as a result of the presence of retained austenite. MST/1326

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Introduction

Wear processes greatly reduce the effectiveness of mechanical components. To minimise wear, researchers have suggested and attempted numerous surface modifications. In recent years, laser processing techniques have been employed to obtain hardened surfaces for enhanced wear resistance of materials.[1,2] However, studies of the microstructures of laser processed materials are limited owing to the relatively thin layer affected by the laser. In industry, problems with dies made from carbon tool steel include short lifetimes resulting from wear. In the present paper, a 1·0%C tool steel, frequently used in such applications, has been studied to compare the wear resistance of laser processed and conventionally quenched materials and to examine the variations in microstructure resulting from wear and subzero treatment.

Experimental procedure

The material used in this investigation was the high carbon tool steel T10. The as received microstructure was ferrite plus spheroidised cementite. The chemical composition (wt-%) of the steel was 1·0%C, 0·32%Si, 0·36%Mn, 0·031%P, and 0·029%S. Specimens (50 × 50 × 100 mm) were irradiated using a 2 kW CO_2 laser to produce a single track. A laser interaction time of 266 ms was achieved by traversing the specimen at a speed of 30 mm s^{-1}. The maximum laser processed depth and width were 1 and 10 mm, respectively. Laser processed specimens were then tempered in vacuum for 1 h at temperatures of 100, 200, 300, 400, 500, and 600°C. For comparison, conventionally quenched specimens (heated at 820°C for 1 h followed by quenching in water) were subjected to the same tempering treatments.

X-ray diffraction was carried out on a type of D/max rA diffractometer employing Cu $K\alpha$ and a graphite filter. Peaks 211 (martensite) and 200 (austenite) were employed to calculate the volume fraction of austenite for laser processed and conventionally quenched materials before and after subzero treatment (cooled in liquid nitrogen for 48 h).

Scanning electron microscopy (SEM) was used to examine the microstructure of specimens before and after subzero treatment.

A sample-on-wheel reciprocating wear test machine was used. Specimens of size 10 × 10 × 14 mm were clamped to the wear machine. A friction wheel made of a hard alloy (hardness 75 HRC) was employed to produce wear. The areas of specimen in contact with the wheel, the axis of which was parallel to the laser treated trace, were confined to the laser processed regions. The friction wheel was rotated at a speed of 200 rev min^{-1} and the applied load was 10 kg. No lubricant was used. Volume loss V was calculated using the equation

$$V=\frac{bh^3}{12r}$$

where h is width of wear, b is the thickness of the wheel (8 mm), and r is the radius of the wheel (25 mm). The values of volume loss that were used for plotting curves of volume loss versus tempering temperature were obtained using three samples.

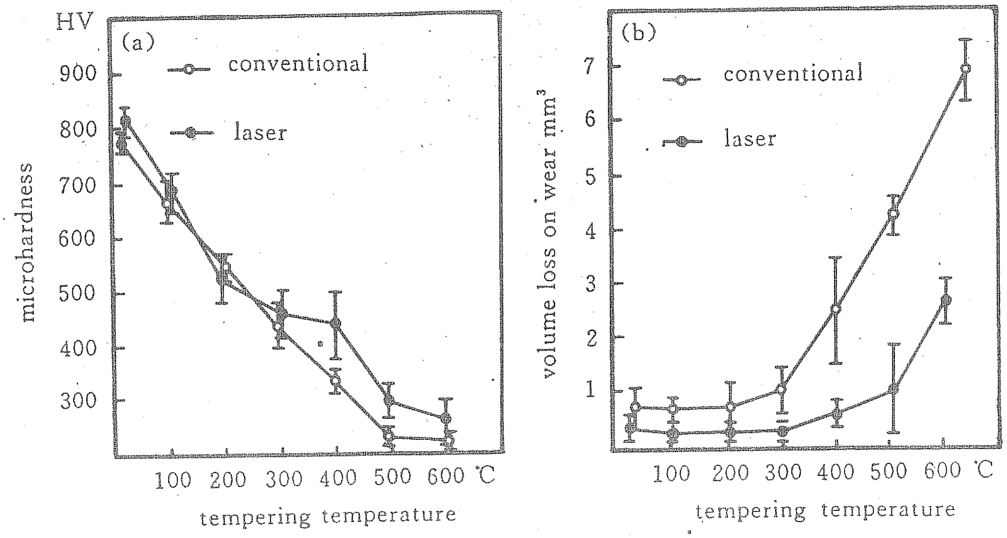
Results and discussion

The region affected by the laser can be subdivided into three zones: the melted surface, a zone in which solid state transformation has taken place, and the area adjacent to the unaffected substrate where cementite is slightly dissolved. The melted zone possessed a cellular growth morphology consisting of austenite and martensite. Using the method reported in Ref. 3, the carbon content of retained austenite was measured to be about 1 wt-%. It was calculated from X-ray diffraction results that the volume fraction of retained austenite before and after subzero treatment (cooled in liquid nitrogen for 48 h) was 10 and 4%, respectively.

The variation of microhardness with tempering temperature is shown in Fig. 1*a*. In the range 300–600°C, the microhardness values of the laser processed specimens are higher than those of the conventionally quenched specimens. This is interpreted as being a result of the refined microstructure in the laser processed zone.

In Fig. 1*b*, the volume loss during wear is shown plotted against tempering temperature for specimens in the laser processed and conventionally quenched conditions. The volume loss increases with tempering temperature. However, laser processed specimens undergo reduced volume loss compared with conventionally quenched specimens over the entire range of tempering temperatures: the difference being more marked above 300°C.

Cast iron as well as tool steel has frequently been used for laser processing and it has been shown that high carbon phases such as graphite and cementite can easily be dissolved in the laser melted zone. However, their dissolution in the solid phase transformation zone is often incomplete when irradiated. In this case, the carbon content of the austenite formed will be non-homogeneous.[4,5] The retained austenite in the laser processed zone has been the subject of previous study[6] and literature values of carbon



1 *a* Microhardness (HV 50 g) and *b* wear resistance of laser processed and conventionally quenched materials: average values of three samples were used to plot curves

content of retained austenite are given in Table 1.[7–10] It can be seen that there is a large scatter among the values listed, but all are very large and higher than 0·8%. Carbon supersaturation in austenite depresses the M_s temperature, leading to increased amounts of retained austenite at room temperature. This could be beneficial in relation to strength and toughness, in a manner similar to that found[11] for metastable austenitic steels, i.e. via transformation induced plasticity. Retained austenite is unstable at room temperature and, in the present study, the microhardness of the laser processed zone increases (from 900 to 950 HV) after cooling to −196°C, indicating that some transformation from austenite to martensite had occurred. Observations made using SEM revealed differences in microstructure for specimens before and after subzero treatment. Many strain induced slip lines were present in the areas of retained austenite of specimens after subzero treatment, owing to the transformation from austenite to martensite. X-ray diffraction also showed evidence of the reduction in retained austenite resulting from subzero treatment.

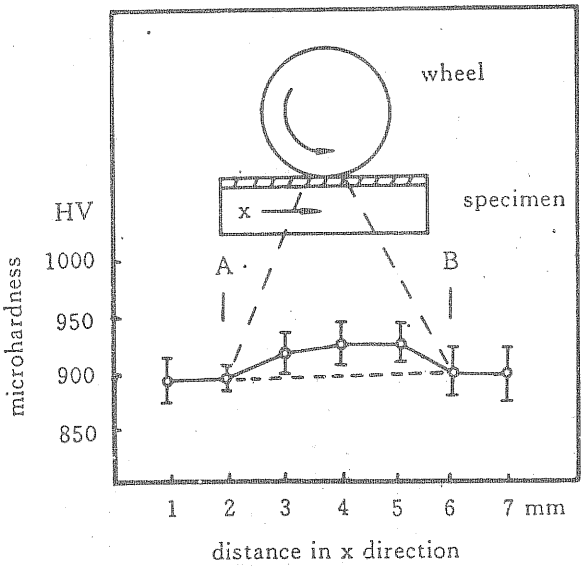
As shown in Fig. 1*a*, laser processed and conventionally quenched samples had almost the same hardness at or below 300°C tempering temperature, but the volume loss of the laser processed samples during wear testing was less than for the conventionally quenched specimens, which may be related to the presence of the retained austenite. To investigate this, the microhardness of the worn surfaces was carefully determined. The surface of the laser processed region was polished before wear testing was performed and the microhardness test was carried out after a worn depth of 40 µm was reached under a load of 10 kg. This depth was confined to the solid phase transformation zone. A schematic diagram of the wear test and the variation of microhardness compared with the original laser processed traces are shown in Fig. 2. Compared with the original hardness produced by laser hardening, there is an increase in microhardness in the worn area. It is suggested that this increase is a result of transformation from retained austenite to martensite, which is strain induced by the sliding wear.

Table 1 Carbon content of retained austenite (RA) in laser processed materials

Material	Carbon content of RA, wt-%	Ref.
Nodular cast iron	1·6–2·0	7
Fe–4·2C	1·2	8
Ferritic malleable iron	2	9
Grey cast iron	1·8	10
1·0%C tool steel	1·0	Present work

As observed by SEM, the worn surfaces of the laser hardened materials were characterised by ridges, chips, and microcracks. Thus, it is concluded that the predominant wear mechanisms were ploughing fatigue, fracture, and delamination. In this case, the rate of wear is controlled by crack nucleation and propagation beneath the surface, which is related to the strength and toughness of the material. Retained austenite may prevent crack propagation either by changing the growth direction of an advancing crack in front of the retained austenite or by greater energy absorption as the crack cuts through the retained austenite.

In addition, some retained austenite can be transformed into martensite via a strain induced mechanism, resulting in an increase of microhardness. The rate of wear was retarded because the formation of strain induced martensite



2 Variation of microhardness (HV 50 g) during wear test: broken line indicates microhardness (HV 50 g) of laser processed material before wear testing and A–B is contact area between wheel and laser processed zone

under the stresses set up by the sliding wear increased the strain hardening rate and delayed the initiation and propagation of the cracks which cause the chip to break away from the wear surface. This explains why wear resistance was enhanced at or below a tempering temperature of 300°C. In laser hardening, significant austenite can be retained at room temperature and have an important influence on wear resistance. However, information concerning the presence of retained austenite in the laser hardened zone is limited. Results showing that the wear resistance of a laser processed cast iron was enhanced by the presence of retained austenite at room temperature have been reported by Ju *et al.*[12] This is consistent with the present study. Differences in wear volume loss become more marked above 300°C, as shown in Fig. 1*b*. Fine grain size, together with high hardness, is thought to be responsible for the generally enhanced wear resistance for laser hardened materials. The fine grain size is probably responsible for the observation that martensite plus austenite in laser processed material can result in hardness values similar to those of the fully martensitic structure of conventionally processed materials (Fig. 1*a*).

Conclusion

The volume loss during wear for laser processed and conventionally quenched materials increases with tempering temperature. The wear resistance of the laser processed material is superior to that of the conventionally processed material. Retained austenite is thought to be responsible for the enhanced wear resistance of the laser processed material between room temperature and 300°C tempering temperature, although high hardness and refined microstructure may also play an important role in improving wear resistance.

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