Synthesis of high-speed tool steel surfaces on mild steel

A. TAUQIR, H. ZAIGHAM, F.H. HASHMI, A.Q. KHAN
Metallurgy Division, Dr A. Q. Khan Research Laboratories, Kahuta, G.P.O. Box 502, Rawalpindi, Pakistan

Wear-resistant, hard surfaces of high-speed tool steel were synthesized on mild steel specimens. Discs of mild steel were subjected to carburization to a depth of 2.5 mm. Thin strips of tungsten were spot welded and the specimen was subjected to electron beam surface melting. The beam power was varied from 60 kV, 10 mA to 60 kV, 20 mA. Oscillation frequency and the specimen translation velocity were kept at 1000 Hz and 2 cm s^{-1}, respectively. The width of the modified layer was 10 mm while the depth varied from 0.7–2.3 mm. A concentration of up to 30 wt % tungsten could be achieved in the surface layer by varying the thickness of the foil spot welded prior to electron-beam melting. Tungsten concentration was uniform along the depth. The hardness achieved in the as-solidified layer was uniform along the depth and reached 800 H_v. The reprocessing of the alloyed layer with the beam promoted fine carbide precipitation which then resulted in refinement of martensite plates.

1. Introduction

Exposure of metallic surfaces to intense energy beams, electron beams and lasers, can create high temperatures in very localized surface regions [1]. The technique can be used to synthesize high melting point phases on low melting point substrates [2]. The high cooling rates which are characteristic of energy-beam surface melting ensure rapid quenching [3] of the molten surfaces, resulting in refined microstructures [4] and extension in the solid solubility limits [5]. Reprocessing these surfaces with short energy impulses promotes fine dispersion of secondary phases [6]. In the present study, surface layers of carburized mild steel were alloyed with tungsten using electron beams. The surfaces were then reprocessed using the electron beam to give short duration exposures of high temperatures. The energy impulse results in finely dispersed precipitation of tungsten–iron carbide phase from supersaturated solid solution of tungsten and carbon in iron. During subsequent solid-state cooling, these carbides refined the martensitic structure.

2. Experimental procedure

Discs of mild steel of diameter 50 mm and thickness 45 mm were subjected to carburization and a 2.5 mm deep layer of carburized material was introduced. Thin strips of tungsten were then spot welded on to the surfaces of the specimens which were then subjected to electron-beam (EB) surface melting. The beam power was varied from 60 kV, 10 mA to 60 kV, 20 mA. The beam oscillation frequency and the specimen translation velocity were kept at 1000 Hz and 2 cm·s^{-1}, respectively. The width of the modified layer was 10 mm, while the depth varied from 0.7–2.3 mm.

The surfaces were again subjected to electron-beam surface melting, but this time the beam energies were kept low enough to simply reheat the modified layers. The power and the specimen translation velocity were kept at 60 kV, 10 mA and 20 cm s^{-1}, respectively.

The specimens were sectioned and subjected to metallographic preparation in cross-sectional and longitudinal directions to study the uniformity in the chemistry of the alloyed layer in the two directions. These specimens were studied under optical and scanning electron microscopy. Spectro-chemical analysis and microhardness measurements were also obtained. Specimens were polished from the top surface to prepare extraction replicas which were studied in a 200 keV transmission electron microscope, the details are given elsewhere [7].

3. Results and discussion

The carburized surface layer had a 1.3 mm deep region with a uniform hardness of 750 H_v. The hardness values then decreased continuously and reached 300 H_v at a depth of 2.5 mm. The surface was alloyed with tungsten using electron-beam surface melting, see Fig. 1. The beam was used in "line source" and the details are described elsewhere [8]. The alloyed layer had a uniform depth and homogeneous microstructural features, see Fig. 2. Precise control of electron-beam processing parameters ensured uniform depth and a smooth surface. The block of material used as substrate was large enough to ensure rapid quenching of the molten surface layer. It resulted in refined and

0022–2461

uniform microstructural features. The amount of alloying element in the layer was a function of the thickness of the tungsten foil welded prior to surface melting, and the depth of the molten zone. The concentration of tungsten in the alloyed layers varied from 15–30 wt %. A hardness value of 800 H_v was achieved in the layers where 24 wt % tungsten was introduced, see Fig. 3. Within the alloyed surface layer the concentration of tungsten was uniform along the depth. Similarly the hardness of the layer was uniform throughout the depth, see Fig. 3. The microstructure of the rapidly solidified layer was essentially dendritic. The dendritic cells formed were uniform in size and homogeneous in the chemical composition throughout the melt depth, see Fig. 4a. Tungsten–iron carbides decorated the inter-cellular regions while the matrix was essentially martensitic, see Fig. 4b. The uniformity in the solidification structure and the chemistry were attributed to the high degree of turbulence in the molten state. The turbulence was triggered by the steep thermal gradients in the molten pool between the vapour cavity under the beam at the advancing end of the pool, and the solid–liquid interface at the rear end. The temperatures in the metal under the beam were calculated using a heat-flow model described in detail elsewhere [8]. The maximum temperature at a given point decreased as the depth increased, see Fig. 5. In regions very close to the surface, the metal was exposed to temperatures high enough to create a vapour cavity in the metal. The steep thermal gradients in the melt pool resulted in vortex formation [9] which accelerated the mass-transport phenomena. As a result a more uniform composition and homogeneous microstructural features were achieved in the alloyed layer throughout the depth.

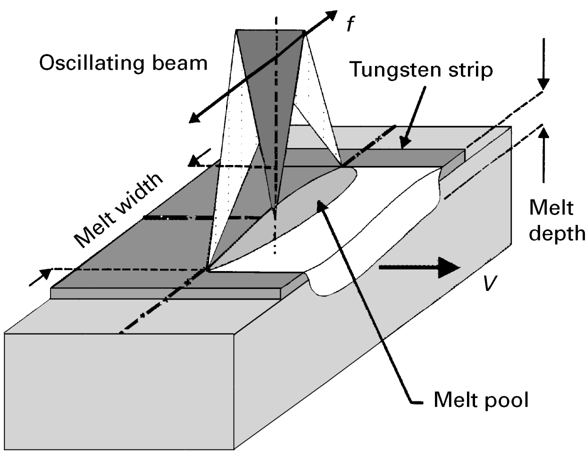

Figure 1 Schematic drawing of electron-beam surface alloying.

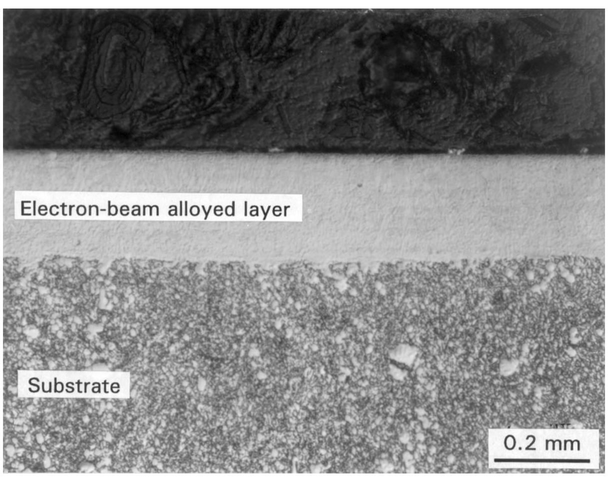

Figure 2 Electron-beam-modified surface layer.

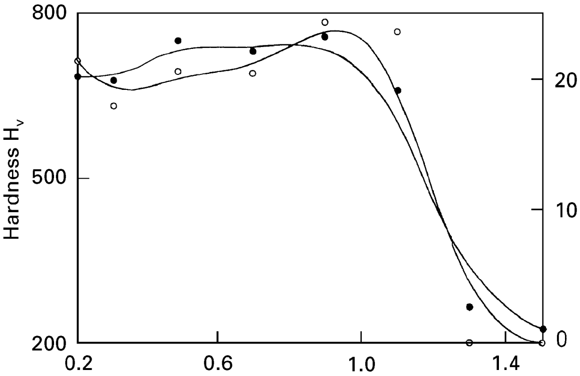

Figure 3 The variation in (●) hardness and (○) concentration of tungsten with depth.

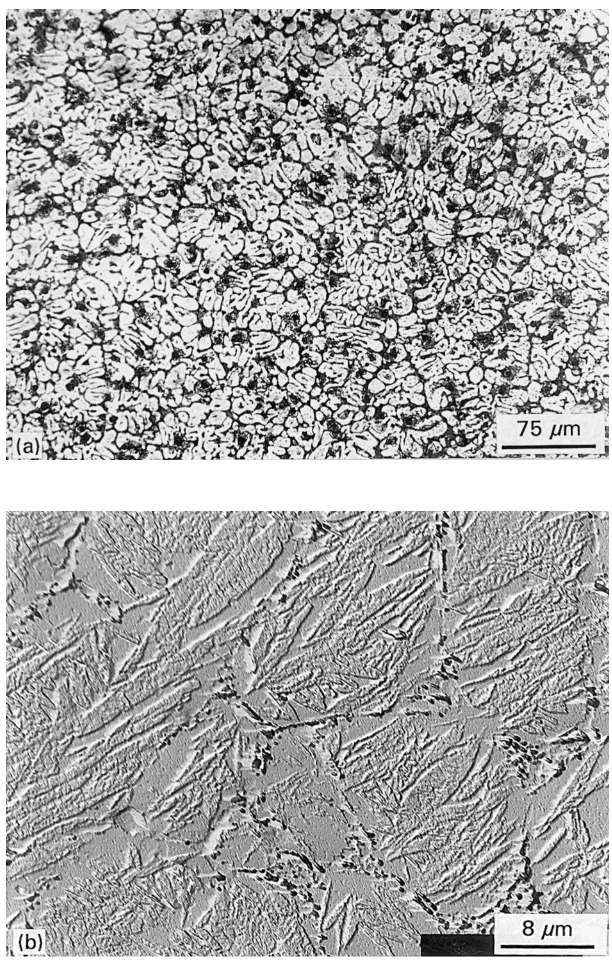

Figure 4 (a) Scanning electron micrograph of the alloyed layer showing uniformity in microstructural features. (b) Transmission electron micrograph of the double-stage replica showing martensitic structure within the solidification cells.

As mentioned above, it can be seen from the extraction replica in Fig. 6 that the cell boundaries are decorated with carbides. The carbides at the boundaries acted as barriers for advancing martensite plates. The plates of martensite within the cells are trapped between carbides at the cell boundaries. This phenomenon was utilized to refine the martensite structure within the cells. The rapidly solidified material is composed of iron saturated with tungsten and carbon. It has been shown in a previous study that a short duration electron-beam heating of supersaturated solid solutions can trigger solid-state transformations [6]. A short thermal exposure at high temperatures precipitated fine carbides in the matrix. The electron beam was operated at a low power density. A very thin surface layer was melted while the rest of the pre-electron-beam-alloyed layer underwent solid-state heating. The resultant microstructure was refined, as shown in Fig. 7. The kinetics of refinement can be understood by considering the schematic drawing in Fig. 7a and the thermal profiles of solid-state heating in Fig. 5. The material was heated to temperatures below the melting point and carbides precipitate out. The rapidity of precipitation is probably not only due to the super saturation of alloying elements, but also

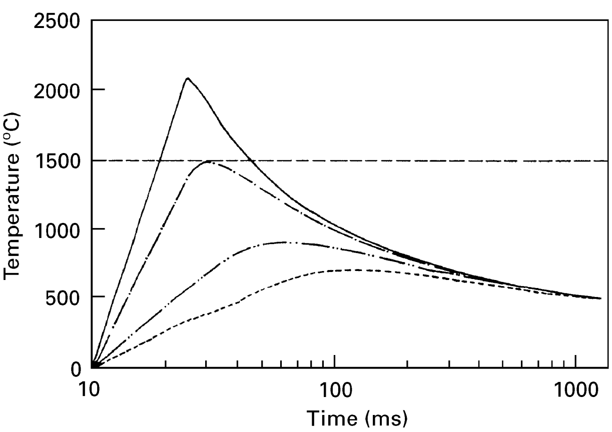

Figure 5 Time–temperature curves at different depths from the surface: (—) 0.34 mm, (—·—) 0.69 mm (—··—) 1.45 mm, (– – –) 2.20 mm.

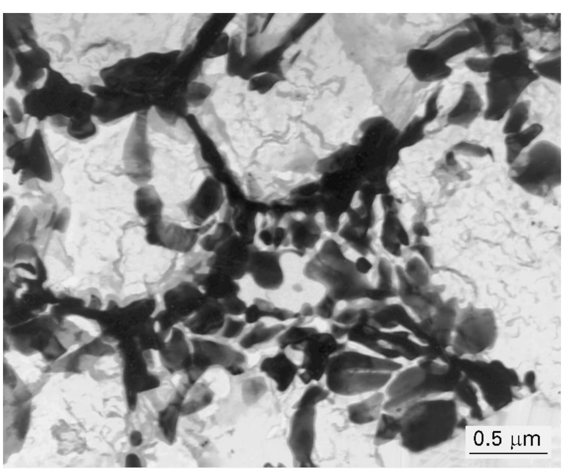

Figure 6 Extraction replica showing dispersion of solidification carbides along grain boundaries.

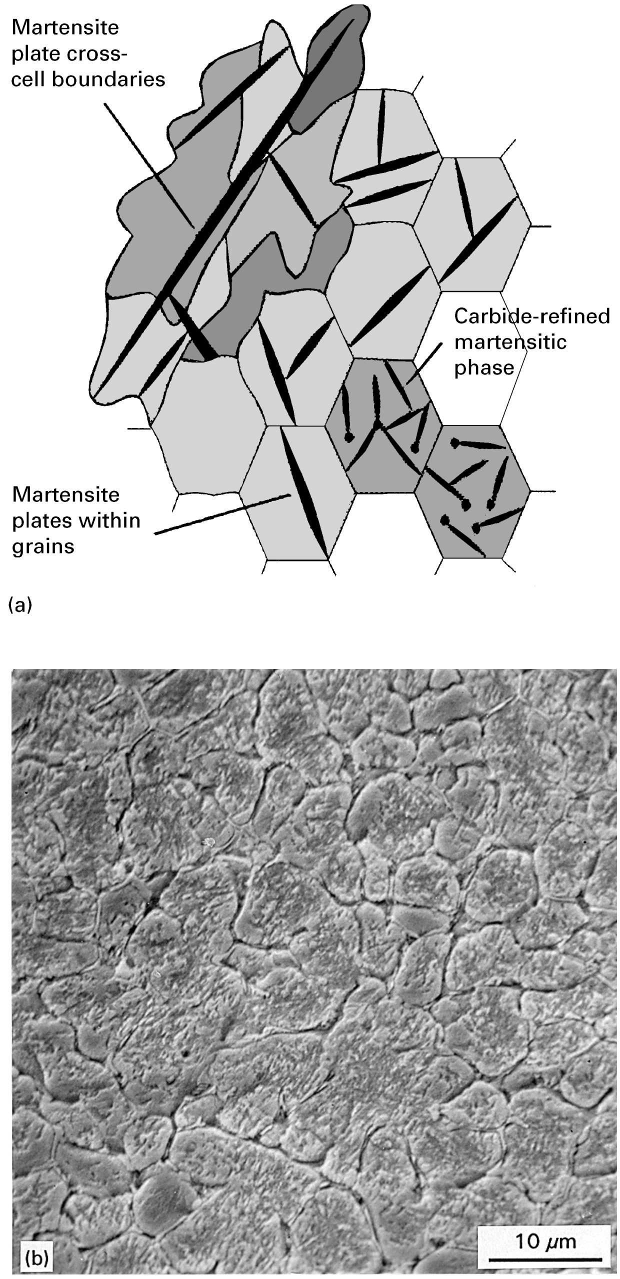

Figure 7 Refinement of martensitic structure by carbide precipitation. (a) Schematic drawing, (b) scanning electron micrograph.

due to the high concentration of defects typically present in a rapidly solidified material [10]. As the material cools, the martensite plates nucleate and the carbides in the matrix act not only as nucleation sites but also prohibit their propagation. The scanning electron micrograph in Fig. 7b shows the martensite plates refined by the carbide dispersion in the matrix.

4. Conclusions

1. Electron-beam surface melting has synthesized high melting point tungsten–iron carbides on mild steel.

2. The microstructural features are refined and homogeneous.

3. Reprocessing the alloyed layer with an electron beam promotes solid-state transformation. The carbides precipitate and refine the martensitic structure.

Acknowledgement
The authors thank Dr Anwar ul Haq, Mr. Z. Ahsan and Dr Z. Iqbal, and acknowledge assistance from Mr I. Nasim, Mr A. Hussain, Mr T. Mehmood and Mr M. Afzal.

References

1. P. G. KLEMENS, *J. Appl. Phys.* **47** (1976) 2165.
2. A. TAUQIR, F. H. HASHMI and A. Q. KHAN, in "Proceedings of the First International Symposium of Iran", Shaheed Chamran University, Vol. **2**, No. 16, edited by M. T. Bank, Ahwaz, Iran, March 1991, (Iran Science Technical University Publishing, Tehran, 1991) pp. 1–11.
3. H. W. BERGMANN and B. L. MORDIKE, in "Rapidly Solidified Amorphous and Crystaline Alloys", edited by B. H. Kear, B. C. Giessen and M. Cohen (Elsevier, New York, 1982) pp. 497–504.
4. R. H. KEAR, R. W. MAYER, J. M. POATE and P. R. STRUTT, *Metall. Treat. AIME* (1981) 321.
5. H. JONES, *J. Mater. Sci.* **19** (1984) 1043.
6. A. TAUQIR, F. H. HASHMI and A. Q. KHAN, *Mater. Sci. Engng* **A165** (1993) 75.
7. A. TAUQIR, P. R. STRUTT and H. NOWOTNY, *Metall. Mater. Trans.* **2A** (1990) 3021.
8. A. TAUQIR, P. R. STRUTT and P. G. KLEMENS, *J. Appl. Phys.* **62** (1987) 3953.
9. *Idem, Mater. Sci. Eng.* **94** (1987) 251.
10. R. F. VYHNAL and S. V. RADCHIFFE, *Acta Metall.* **20** (1970) 435.

Received 8 January
and accepted 18 March 1996