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Laser and electron-beam melted amorphous layers

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Metallic-glass layers were produced on metallic bulk material using laser or electron beam melting. The requisite composition $(FeCr_{12})_{80}(C,B)_{20}$ for steel and $Ni_x Nb_{(100-x)}$, ($x = 30$ to 60) for niobium was obtained by coating the substrate prior to melting. X-ray, scanning electron microscopy, transmission electron microscopy and calorimetric methods were used to demonstrate and investigate the amorphous nature of the surface layer.

1. Introduction

Metals can often be retained in an amorphous state if sufficiently rapidly cooled from the melt. The necessary cooling rate depends on the composition of the alloy and ranges from 10^{-6} Ksec^{-1} for $Fe_{83}B_{27}$ to 10^{-2} Ksec^{-1} for $Ni_{60}Nb_{40}$ [1]. The usual methods of producing amorphous metals are splat cooling, melt spinning, sputtering etc. [2]. The limiting factor for the cooling rate is the heat transfer coefficient between the cooling medium (anvil, spinning wheel) and the molten metal. Even higher cooling rates can be achieved for liquid layers on a bulk metal substrate [3, 4]. Such liquid layers can be produced by scanning an electron beam across the surface of a bulk specimen. The thickness of the molten layer, the scan speed and beam focus determine the cooling rate. The composition of the molten layer is determined by the composition and thickness of the surface coating as well as the composition of the bulk material and the penetrating depth of the molten zone [4]. Two examples of the use of surface glazing are [5, 6]: (a) a flat surface produced by beam scanning and specimen translation and (b) a cylindrical surface by rotation, translation and beam scanning. The commercial potential of such a treatment is obvious because of possible improvement in the wear, fatigue and corrosion resistance.

2. Experimental details

2.1. Surface coating

The first stage involves coating the surface with a layer of material of the requisite composition. Several methods are available for coating a surface, e.g. electrolytic, plasma spraying, flame spraying or simply spraying a powder dispersion. The method adopted depends on the material to be deposited. In the examples discussed below the sprayed layer can be the pure component, Ni or B, or the appropriate alloy Fe,B or Ni,Nb. If oxidation of the powders is likely to occur then dispersion spraying is preferred.

2.2. Surface melting of ledeburitic tool steels

A ledeburitic tool steel was chosen as substrate (2.1% C, 12% Cr), which under normal air cooling forms martensite. Steels with such a high carbon (metalloid) concentration, even without additional metalloid such as B, are possible glass forming alloys. The influence of chromium is to retard the diffusion rate of the metalloids and also reduce the melting point, both of which reduce the critical cooling rate for glass formation. The surface of this tool steel (108 cm^2) was coated with Fe,B ~ 40 μm thick in the sprayed condition. This, together with 20 μm of the substrate was melted in a 3 kW laser beam, 0.5 mm diameter and

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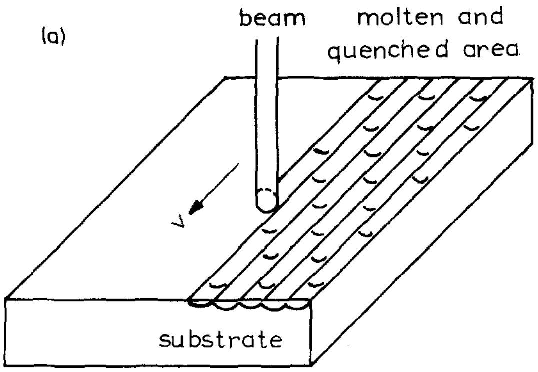

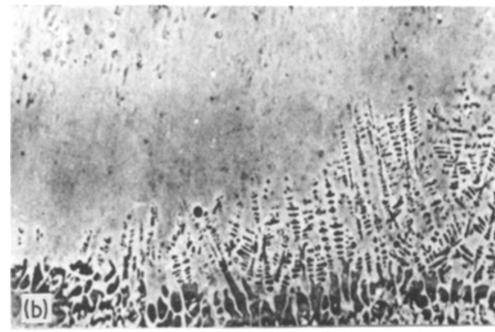

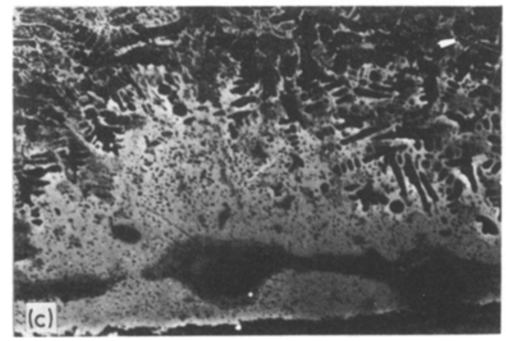

Figure 1 Laser glazing of a ledeburitic tool steel (a) schematic diagram of laser glazing, (b) as-quenched (× 1400) and (c) after annealing (960° C, 15 min) (× 1400).

20 cm sec^{-1} relative translation speed. The resultant beam was 40 μm deep and 80 μm wide. It is possible by scanning the beam or moving the specimen to melt large surface areas.

2.3. Surface melting of a niobium rod

A niobium single crystal rod 6 mm in diameter was sprayed with $Ni_{60}Nb_{40}$. An electron beam was scanned over 1 cm length (1 kHz) and the specimen simultaneously rotated 800 rev min^{-1} and translated 6 cm min^{-1}. The resultant molten layer completely covered the crystal. The beam was focussed to a ring 60 μm in diameter.

The experimental conditions necessary for producing amorphous layers were predicted by a computer program [4].

3. Results

Figs 1 to 5 show that it is possible using laser or electron beam melting to melt a flat or cylindrical surface and obtain a crack-free amorphous layer. No evidence of heat treatment (i.e. crystallization) of the beads by subsequent passes was detected. In both systems the following structures were observed: matrix, dendritic region, amorphous surface layer. A heat affected zone could be detected in the steel substrate. Two different glasses were observed on the niobium crystals.

Figs 6a and b and 7a and b show the microhardness as a function of the distance from the surface in the as-quenched (amorphous) and crystallized states for both systems. In the case of steel, Fig. 6a, a hardness of 1700 Hv was measured in the amorphous layer, which decreased to 420 Hv in the region of the dendritic layer (solid solution). The substrate itself was heat treated and the hardness increased again. After crystallization (15 min, 960° C and cooling in air) the differences in hardness between the layers disappeared and a resultant surface hardness of 1600 Hv for the microcrystalline state was obtained. In the case of Ni,Nb the surface hardness of the amorphous layers ~ 1050 Hv decreased rapidly as soon as the amorphous phase interface was reached. On crystallization the transition became less sharp and the hardness somewhat reduced (Fig. 6b).

Crystallization produced in both materials a random distribution of fine grains (0.5 to 1 μm). Crystallization occurred by homogeneous nucleation and not by growth of the existing dendrites. It may be possible to find conditions where dendritic growth is favoured. On the other hand if the cooling rate is insufficient to obtain a glass on cooling from the melt, dendritic growth always takes place, e.g. if a glass bead is remelted.

The mechanical adhesion between the glass layer and the substrate was tested by bend and compression tests. In compression, cracks in the glass layer became visible only at strains in excess of 5%. In bending at liquid nitrogen temperatures the fracture surface exhibited three distinct regions: a glass, shell-shaped fracture; a brittle fracture of the dendrites with plastic deformation

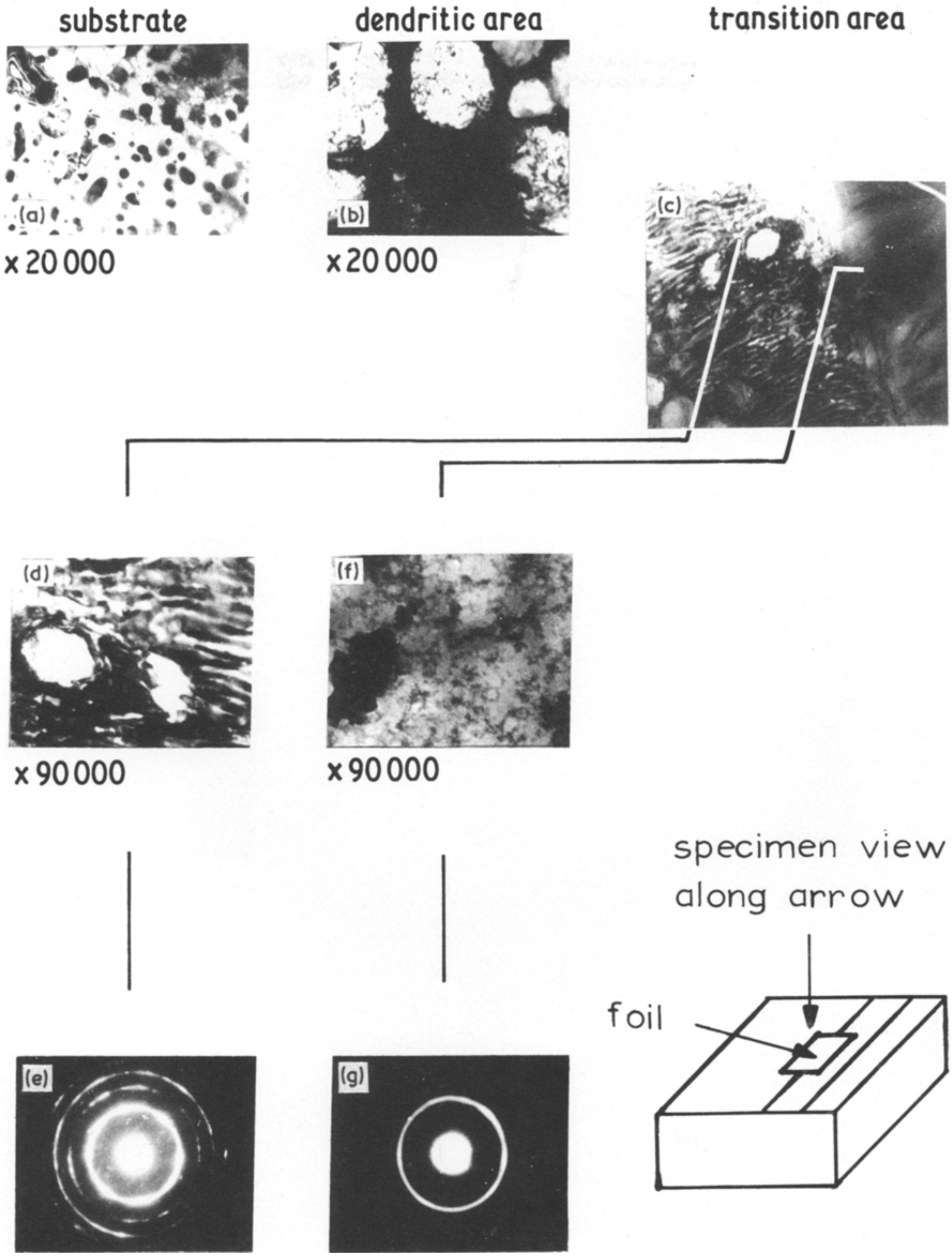

Figure 2 Micrographs of the ledeburitic tool steels in different areas: (a) Microstructure of substrate, (b) microstructure of dendritic region, (c) microstructure of transition region, (d) enlarged section of dendritic region showing eutectic, (e) diffraction pattern from (d), (f) micrograph of glassy region and (g) diffraction pattern from (f).

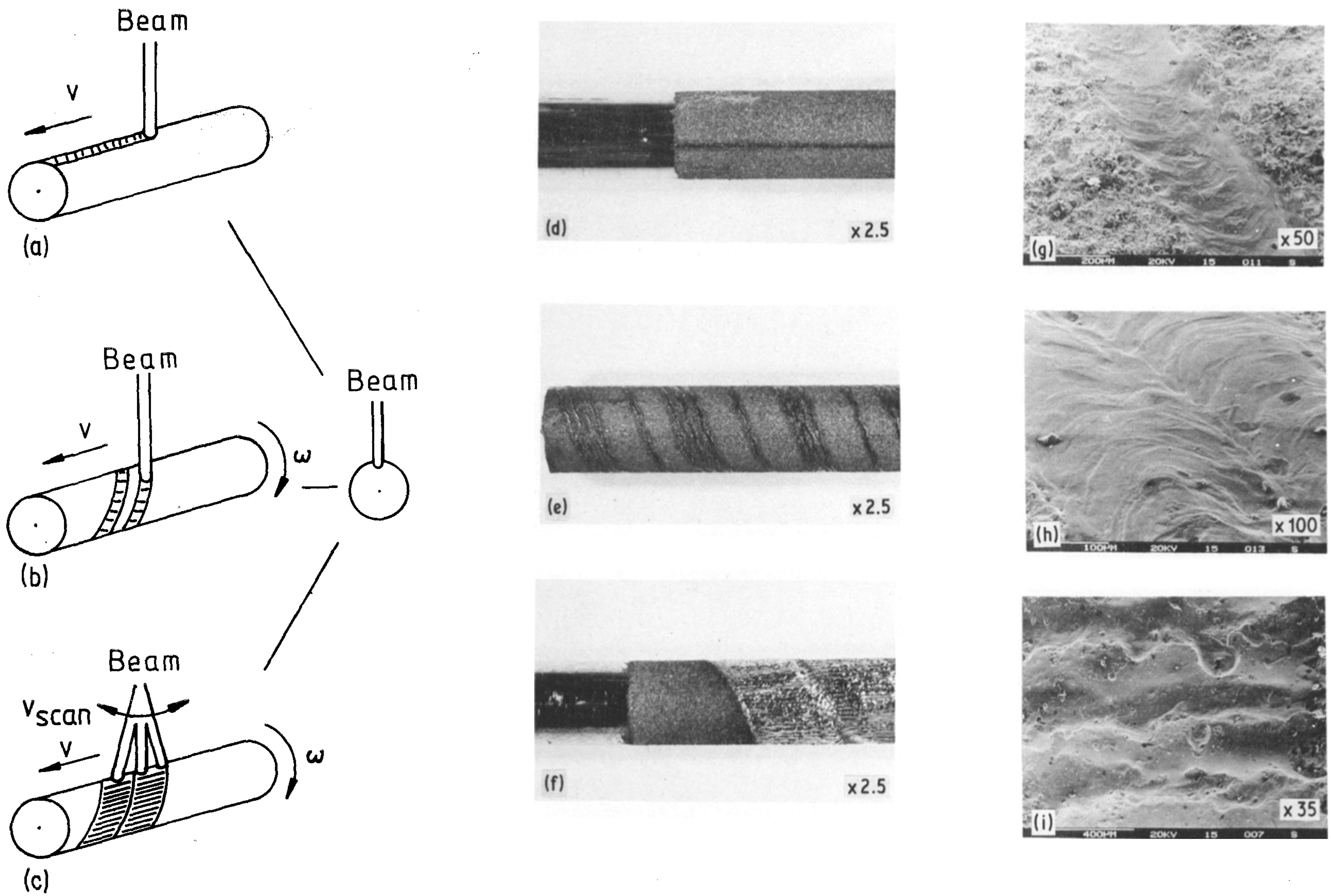

Figure 3 Various beam specimen movements in laser glazing: (a) Simple translation, (b) rotation and translation, (c) oscillation and rotation and translation, (d) single bead, (e) spiral beads , (f) oscillatory beads, (g) surface structure of single bead, (h) surface structure of neighbouring beads produced by rotation and transition and (i) surface structure of oscillatory bead.

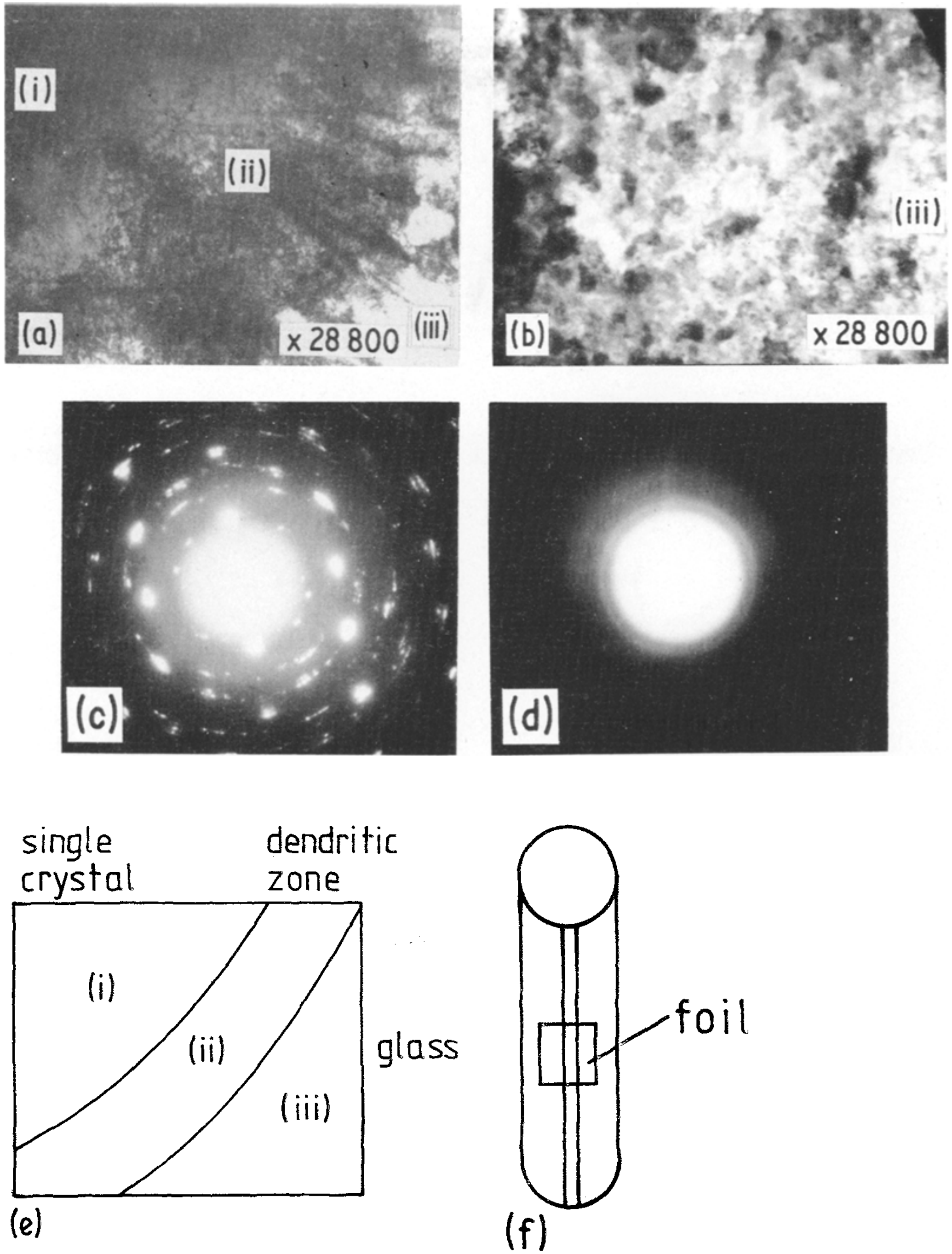

Figure 4 Micrographs of the surface-glazed Nb single crystals: (a) Transition area through glazed Nb-single crystal, (b) glassy region, (c) electron diffraction of single crystal substrate, (d) electron diffraction of glassy region, (e) section through foil as depicted in Fig. 4a and (f) position of foil removed for electron microscopy.

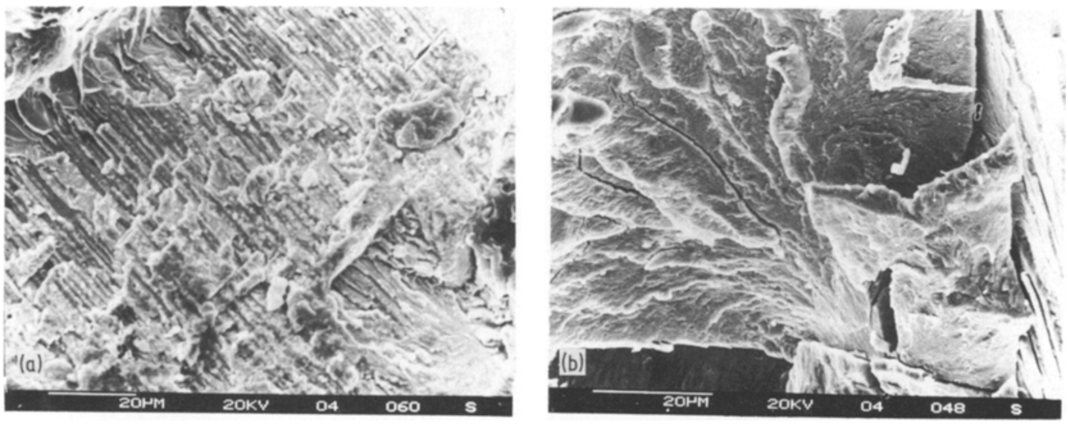

Figure 5 Fractographs of the (a) dendritic area and (b) amorphous area.

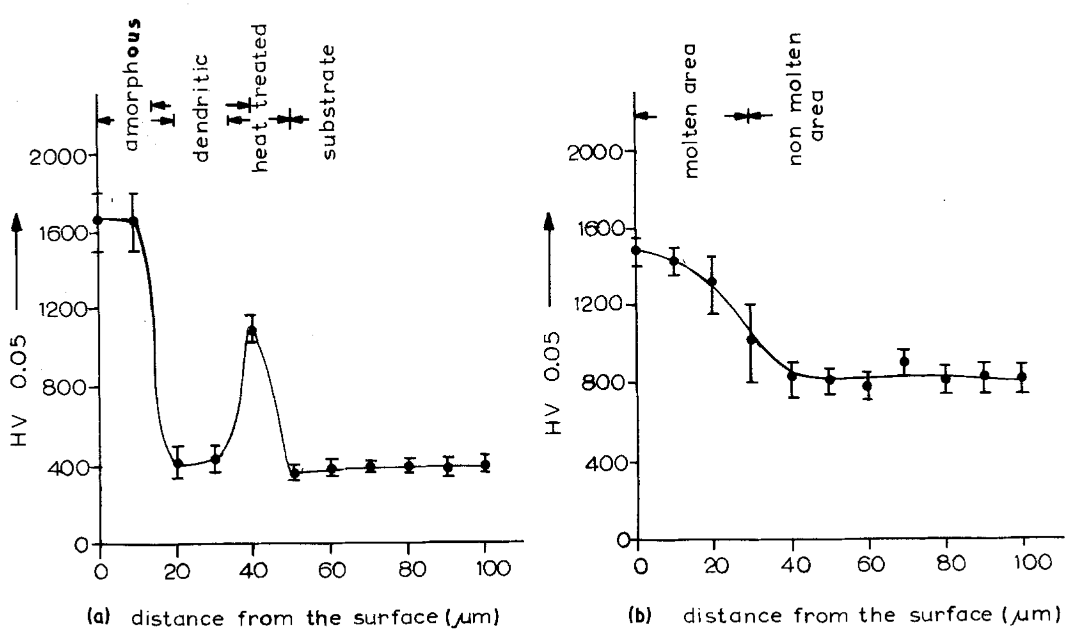

Figure 6 Microhardness of the ledeburitic tool steel (a) as-quenched and (b) after heat treatment (960° C, 15 min).

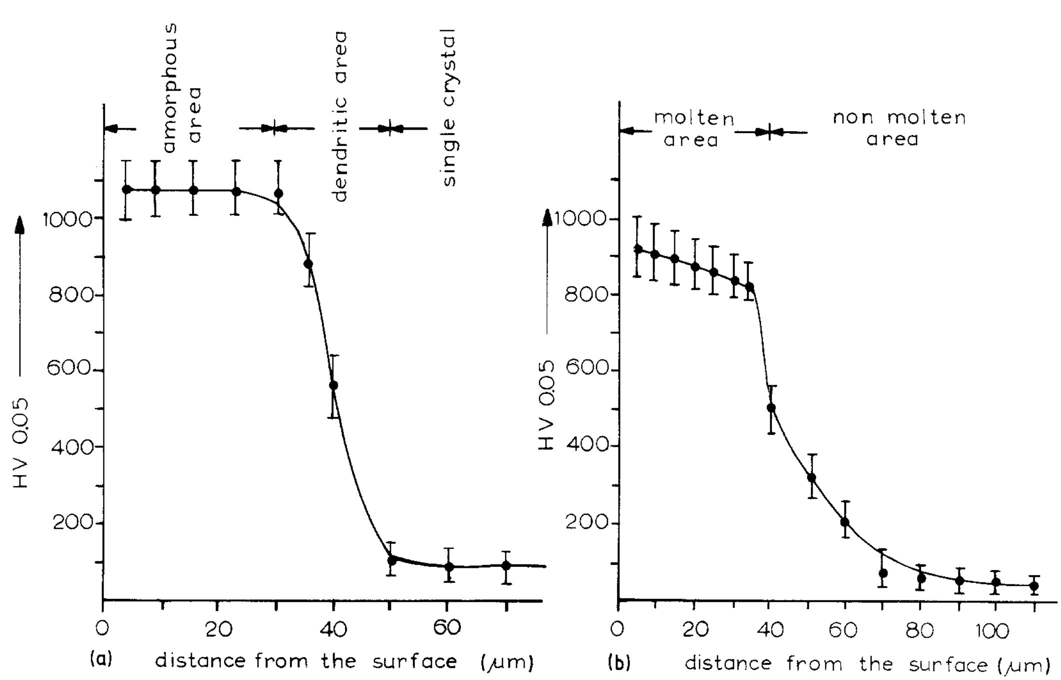

Figure 7 Microhardness of $Ni_{60}Nb_{40}$ (a) as-quenched and (b) after heat treatment (960° C, 15 min).

of the grain boundaries in the dendritic region; and a substantially brittle fracture of the substrate.

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