In situ production of Ti–TiC composites by laser melting

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In previously reported work [1–4] high-power CO_2 lasers were used to produce Ti/SiC or TiC composite layers, approximately 1 mm thick, by the injection of the ceramic particles into the laser-melted zone of titanium and titanium alloys. The dimensions of these layers and the volume fractions of the ceramic particles were closely related to the laser processing parameters (e.g. the traverse speed and powder flow rate). For example, the results of the injection of SiC particles into commercial purity Ti plate showed [1] that the width and the thickness of the surface layer increased with decreasing traverse speed and the volume fraction of SiC particles incorporated increased with increasing powder flow rate [2]. It was also shown that enrichment of the matrix with carbon and silicon resulting from the partial solution of SiC was associated with an increase in hardness to about $600H_v$. During solidification TiC dendrites were nucleated at the particle–matrix interfaces and in the matrix, also eutectic consisting of $(\alpha/\alpha') + Ti_5Si_3$ was observed [2]. Ayers and coworkers [3, 4] found that the injection of TiC particles into the laser-melted zone of Ti–6Al–4V alloy led to an increase in the hardness to about $460H_v$ and to a decrease in the coefficient of friction. Partial solution of TiC particles occurred during the laser processing, and TiC dendrites formed during solidification. Walker *et al.* [5] produced high contents on TiN and TiC in the surface of Ti substrates by either surface-melting titanium in a nitrogen-containing atmosphere or precoating the substrate with graphite before laser melting.

In the work described above the composites were produced in the form of surface layers, with the aim of increasing the hardness and hence improving the wear and erosion resistances. This letter reports results of the laser melting of powder mixtures of titanium and graphite to produce a Ti–TiC composite in the form of "pellets", for subsequent consolidation into a bulk sample.

The technique for producing pellets was developed by Weerasinghe [6]. The powder to be processed was placed in a recess in a copper block and subjected to pulsed laser energy to give localized melting, followed by solidification to form pellets of approximately spherical shape. The systems investigated involved mixtures of Al and Si, and of Ti and SiC (particle size approximately 100 μm). For the latter mixture the laser parameters were varied to produce conditions covering the range from partial solution of the SiC to complete solution.

In the present work titanium powder of 75 μm particle size and about 99.5% purity was mixed with various proportions of graphite powder obtained by filing a graphite crucible. The mixture was loosely packed in a slot of approximate dimensions 2 mm width and 3 mm depth in a copper block, and localized melting was achieved using CO_2 pulsed laser operated at 1 kW with a pulse length of 0.5 s. The process was carried out under a shrouding system using argon gas to minimize contamination. The mixtures investigated corresponded to nominal compositions of about 2, 5, 8, 14 and 25 wt% graphite. Several pellets were produced from each mixture. After laser melting, the samples were mounted in Bakelite and standard methods were used for metallographic examination including grinding, polishing and etching. Scanning electron microscopy with energy-dispersive X-ray analysis (EDAX) was used for microstructural and compositional characterization; the C contents of the samples were determined "by difference".

Fig. 1 shows the shape of a pellet produced from a mixture of Ti–4 wt% C (graphite) melted at 1 kW

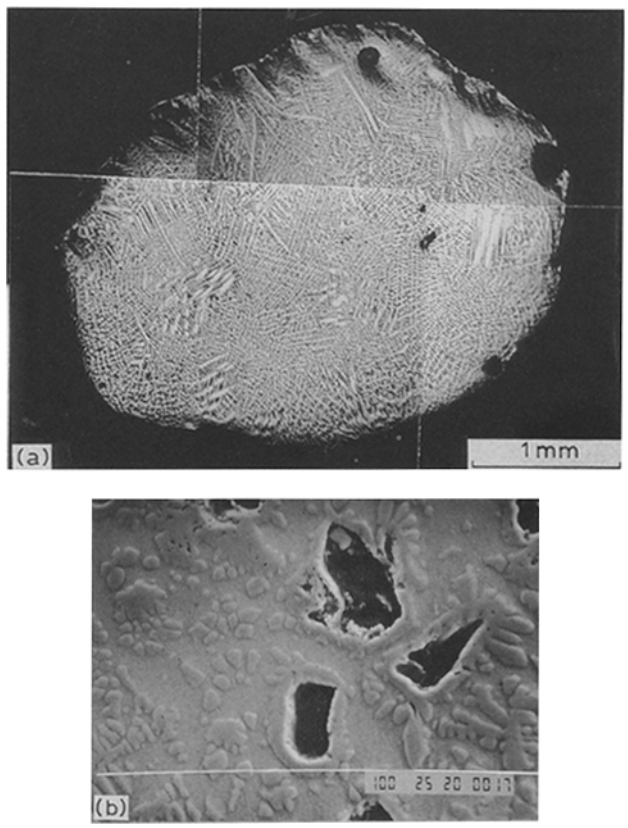

Figure 1 (a) Optical macrograph showing pellet produced from a mixture of Ti–4%C at 800 W laser power, 3 mm beam diameter and 0.5 s pulse time, and (b) SEM micrograph showing some undissolved graphite and nucleation of dendrites at the graphite–matrix interface and within the matrix.

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laser power and 0.5 s pulse length. The structure consisted mainly of dendrites identified by the EDAX as TiC, in a martensitic α' matrix. The secondary dendrite arm spacings of the TiC were in the approximate range 5–10 μm, suggesting cooling rates of about 10^3 K s^{-1} [7]. EDAX at several positions in the 2 wt % C pellets showed that the composition was nearly homogeneous with a scatter within about 1 wt % C; some undissolved particles of graphite were observed and dendrites of TiC were present at the graphite–matrix interface (Fig. 1b).

Fig. 2a–d shows the microstructures of pellets produced from mixtures of Ti–2, 5, 8, 14 and 25 wt % C, respectively. In all of the samples, small amounts of undissolved graphite were observed (Fig. 2a). The 2, 5, 8 and 14 wt % C mixtures produced pellets with a progressive increase in the proportion of TiC with increasing C content of the mixture. Measurements on the 2, 5 and 8 wt % C pellets showed that the carbon content of the TiC dendrites was about 11 wt %, and the pellets were reasonably homogeneous in overall composition.

The structure of the 14 wt % C mixture pellet consisted of equiaxed grains of TiC (size approximately 10–50 μm), essentially single phase but with intergranular regions containing Mn and Fe as impurities: the pellets were inhomogeneous in composition and the carbon content was in the approximate range 11–18.5 wt % in various regions.

The pellets produced from the Ti–25 wt % C mixture showed a microstructure consisting of TiC dendrites containing about 18 wt % C and interdendritic areas of (TiC + graphite) containing about 28.5–30 wt % C.

The microstructures can be interpreted consistently in relation to the Ti–C phase diagram [8], which shows TiC existing over a wide range of stoichiometry with a maximum melting temperature of about 3070 °C at about 16.5 wt % C. Ti–C forms eutectics with TiC and graphite, respectively:

1648 °C Liq (~10 wt % C) → β-Ti(~0.5 wt % C) + TiC(~10 wt % C)

2776 °C Liq (~30 wt % C) → TiC(~18 wt % C) + graphite

The pellets produced from the mixtures with 2, 5 and 8 wt % C were hypereutectic with respect to the β-Ti + TiC eutectic. Following the formation of the primary TiC dendrites, the eutectic does not form as a duplex structure, but shows only divorced morphologies; upon cooling in the solid state, β transforms to α' or α. The value of about 11 wt % for the carbon content of the TiC dendrites is in reasonable agreement with the phase diagram, bearing in mind the error in the EDAX procedure of determining the carbon by difference.

The single-phase TiC structure of the 14 wt % C sample is anticipated from the phase diagram. Also, in the 25 wt % C sample the C contents of the TiC dendrites (about 18.5 wt % C) and of the (TiC + graphite) eutectic (about 30 wt % C) agree well with the phase diagram.

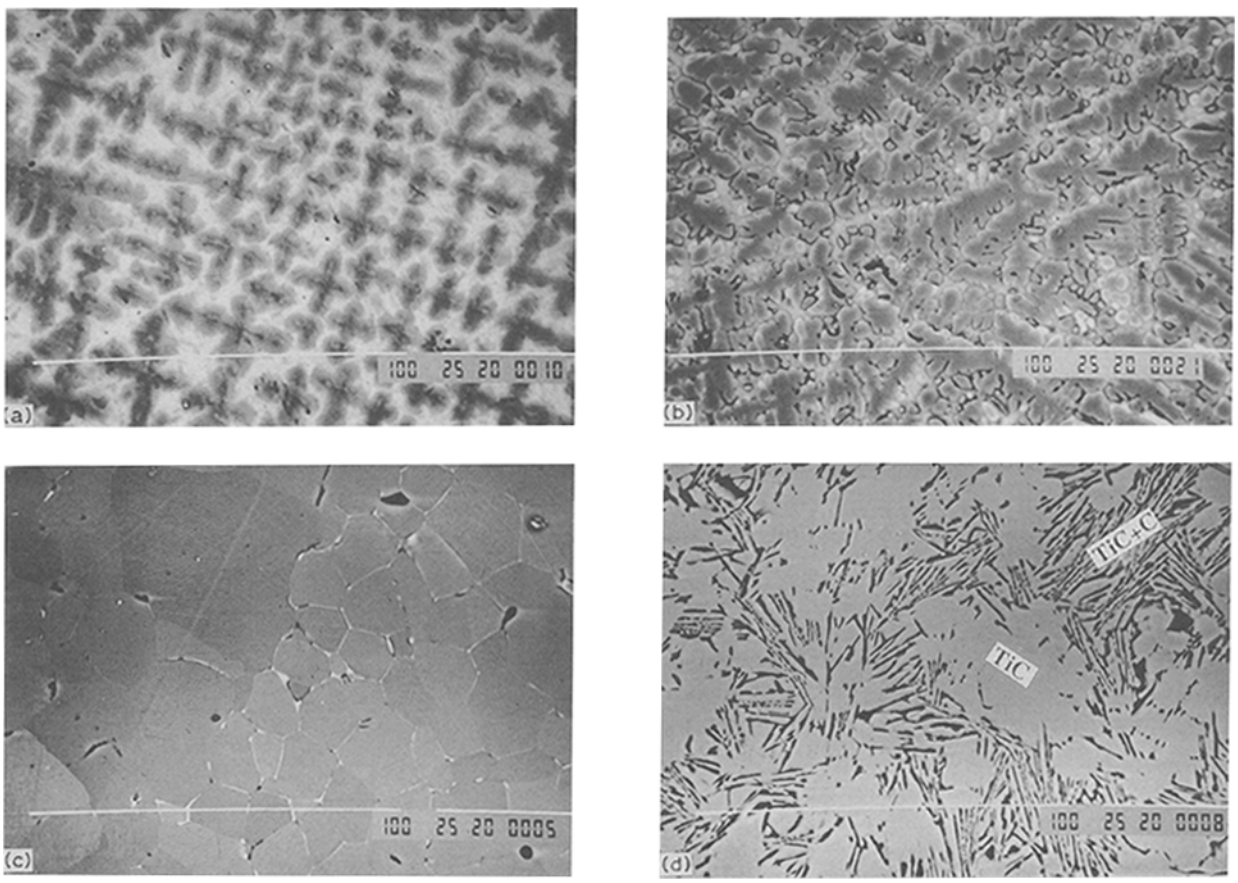

Figure 2 SEM-backscattered imaging micrographs showing the microstructures of pellets for different C contents: (a) 5 wt %, (b) 9 wt %, (c) 14 wt % and (d) 25 wt %.

The hardness data (Fig. 3) show an increase with C content up to a value of about $2000 H_v$ for the single-phase structure with a decrease as graphite appears in the 25 wt% C alloy. These results for structures consisting of hard carbide phase plus a soft second phase indicate, as expected, that the volume fraction of TiC is the dominant feature in determining overall hardness.

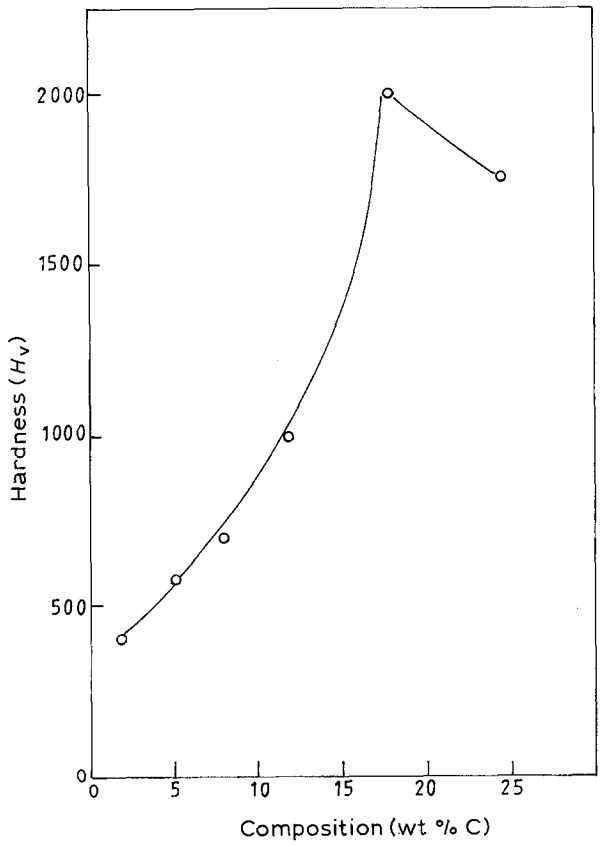

Figure 3 Variation of hardness with C content, at 800 W laser power, 3 mm beam diameter and 0.5 s pulse time.

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