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# Thermal relaxation of residual stresses in shot peened surface layer of (TiB + TiC)/Ti–6Al–4V composite at elevated temperatures

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ABSTRACT

As an effective and important surface treatment method, shot peening can introduce high residual compressive stress and microstructure variation at near surface deformation layers. In this work, residual stresses relaxation behaviors of the shot peened layer of (TiB + TiC)/Ti–6Al–4V composite were investigated during thermal exposure, and the microstrain was calculated according to the integral breadth after isothermal annealing. The microstrain decreased fast and reached the minimum at 500 °C, which resulted from the thermal recovery and dynamic recrystallization. At elevated temperatures, the residual compressive stresses were relaxed in the whole deformation layers, which were caused by the thermally activated gliding of dislocations. The processes of relaxation can be described using a Zener–Wert–Avrami function and the activation energy of the residual stresses relaxation was higher than that of titanium self diffusion, which was ascribed to the hindrance effects of reinforcements as sink sources of dislocations during annealing.



## 1. Introduction

As one kind of metal matrix composites, titanium matrix composites have been widely concerned because of their excellent physical and mechanical properties [1,2]. However, in the process of manufacturing and subsequent heat treatments, the tensile stresses always generated and deteriorate the fatigue properties [3]. In order to improve their fatigue strength and fatigue life, crack initiation and growth at surface layers must be suppressed using surface mechanical treatments [4]. As an effective and important surface treatment method, shot peening (SP) can introduce high residual compressive stress (RCS) and microstructure variation at near surface layers, which can enhance their fatigue properties compared to un-peened materials. The process of SP involves the bombardment of spherical balls of a hard material against the surface of components, which induces the strong elastic–plastic deformation at the surface and sub-surface regions. In the deformation layers, high RCS and microstructure refinements are introduced after SP.

However, RCS could relax significantly under thermo-mechanical loadings, thermal exposure, static loading and cyclic loading [5,6]. The stability of the RCS on near-surface regions against thermal and mechanical loading is crucial to the fatigue properties improvement [7]. The relaxation behaviors in traditional alloys and metals have been extensively investigated [8–12]. But few investigations have been made on the relaxation behaviors in shot peened titanium matrix composites at elevated temperatures. Therefore it is significant to understand the residual stresses relaxation behaviors of titanium matrix composites reinforced with TiB and TiC.

The residual stresses relaxation involves mechanical and thermal relaxation mechanisms [8]. In this work, the thermal residual stresses relaxations of the shot peened (TiB + TiC)/Ti–6Al–4V have been studied and thermal relaxation mechanisms have been discussed in detail. Besides, the residual stress distribution and microstrain variations have also been investigated after isothermal annealing.

## 2. Experimental

### 2.1. Preparation of materials

The samples of (TiB + TiC)/Ti–6Al–4V (TiB:TiC = 1:1 (vol%)) were fabricated via in situ technology [13–15], and the volume fraction of reinforcements (TiB + TiC) was 8%. Stoichiometric raw materials of sponge titanium, $B_4C$ and graphite powder were melted homogeneously in a consumable vacuum arc remelting (VAR) furnace to produce titanium matrix composites via self-propagation high-temperature synthesis. In order to obtain the even composition, the process of melt was three times. The samples were cut directly from

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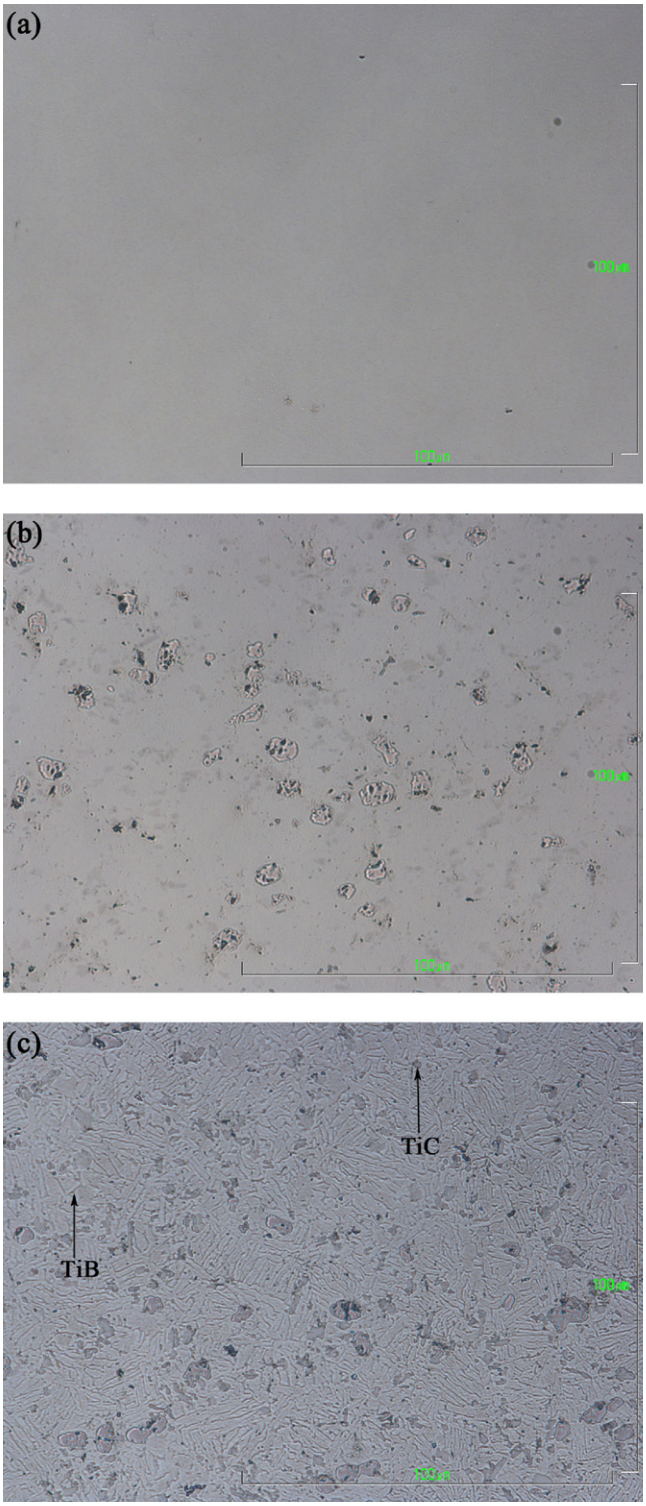


**Fig. 1.** Optical micrograph of the microstructure of samples: (a) The matrix of Ti–6Al–4V (Unetched surface); (b) (TiB+TiC)/Ti–6Al–4V (Vol. 8%, unetched surface); (c) (TiB+TiC)/Ti–6Al–4V (Vol. 8%, etched surface).

ingots and then polished. The shape of samples liked disk, diameter is 15 mm and thickness is 3 mm. Young's modulus of the samples is 133 GPa, and the yield strength is 1150 MPa. The microstructure of Ti–6Al–4V and (TiB + TiC)/Ti–6Al–4V (Vol. 8%) have been shown in Fig. 1. Fig. 1(a) and (b) represent unetched surfaces of Ti–6Al–4V and (TiB + TiC)/Ti–6Al–4V respectively, and it can be found that the existence of reinforcements are obvious in Fig. 1(b)

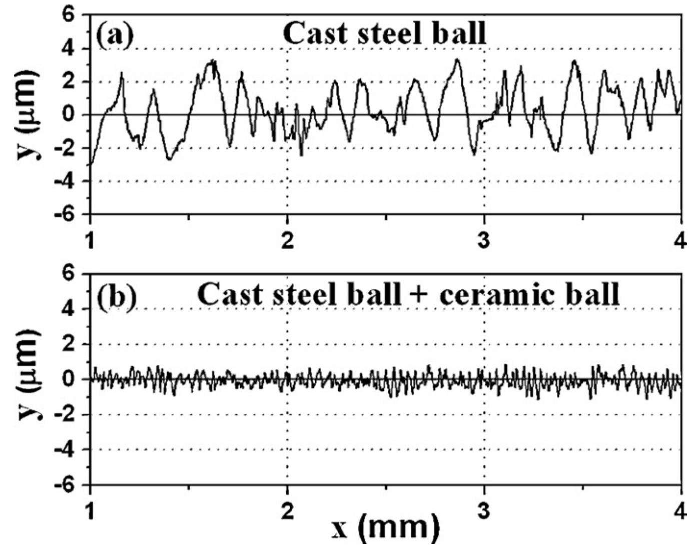


**Fig. 2.** The surface roughness of titanium matrix composites after the first and second SP.

compared to Fig. 1(a). In order to observe the microstructure of reinforcements clearly, the microstructure of etched surface of (TiB + TiC)/Ti–6Al–4V has been obtained and displayed in Fig. 1(c), and the results reveal that the reinforcements of TiB and TiC are distributed uniformly in the titanium matrix composites. The morphologies of reinforcements mainly exhibit needle-shaped, short fibre-shaped and particle-shaped. The needle-shaped and short fibre-shaped reinforcements are TiB, while the particle-shaped reinforcements are TiC. The differences in morphologies ascribe to their solidification paths and crystal structure.

### *2.2. SP and isothermal annealing treatments*

The SP treatments were performed using an air blast machine (Carthing Machinery Company, Shanghai). The first and second SP treatments were carried out and shot media were cast steel balls and $Al_2O_3$ ceramic balls respectively. Cast steel ball with hardness 610 HV and $Al_2O_3$ ceramic ball with hardness 700 HV were used on all samples. The diameter of peening nozzle was 15 mm and the distance between nozzle and samples was 100 mm. The coverage of SP was 100% in all peening steps. According to previous investigations [16], the detailed SP parameters were given as follows: 0.3 + 0.2 MPa

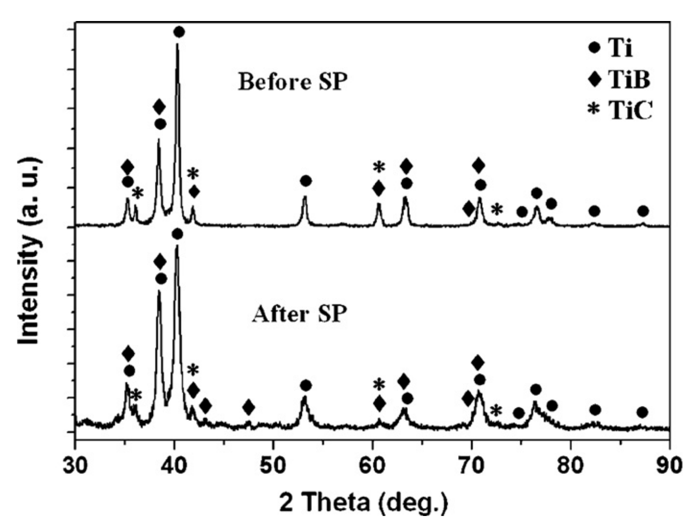


**Fig. 3.** XRD patterns of 8% (TiB+TiC)/Ti–6Al–4V composite before and after SP.