



Layered Structures of Ti-6Al-4V Alloy and Metal Matrix Composites Fabricated Using Solid State Bonding

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Motivation

Metal matrix composites (MMC) of Ti-alloy with TiC and TiB particles in layered structures are looked at to enhance elastic moduli without compromising low-weight. Parts that demand high wear resistance and resistance to ballistic impact benefit from [1]:

- A surface with high hardness
- A core with high toughness

Powder metallurgy is ideal and cost efficient however, this results in each layer behaving differently [2].

To overcome this it is proposed to:

1. Fabricate and process each layer with optimized thermomechanical treatment
2. Join layers using diffusion bonding (DB) and friction welding (FW)

DB and FW are solid-state and near-net joining and can be used to join parts of different alloys or dissimilar alloying systems [3,4].

Materials

Multi-layered structures in this study were based on Ti-64 alloy and its MMC with 10% (vol.) of TiC or TiB. Hydrogenated titanium (TiH₂) powder (3.5 % H, wt.) was used as the base. It was blended with 6%Al-4%V master alloy powder (particles size < 63 µm) to form blend of the alloy's composition. To fabricate the samples of MMC powders (<30 µm) of TiB₂ or TiC were added and mixed before the pressing. Blends for each sample were added to the die and pressed at 640 MPa. Sintering of preforms was conducted in vacuum furnace (1250 °C, 4h) followed by the slow furnace cooling. Such processing provides dehydrogenation of titanium and formation of the bulk cylinder samples 10mm in diameter and length.

Results

Diffusion Bonding

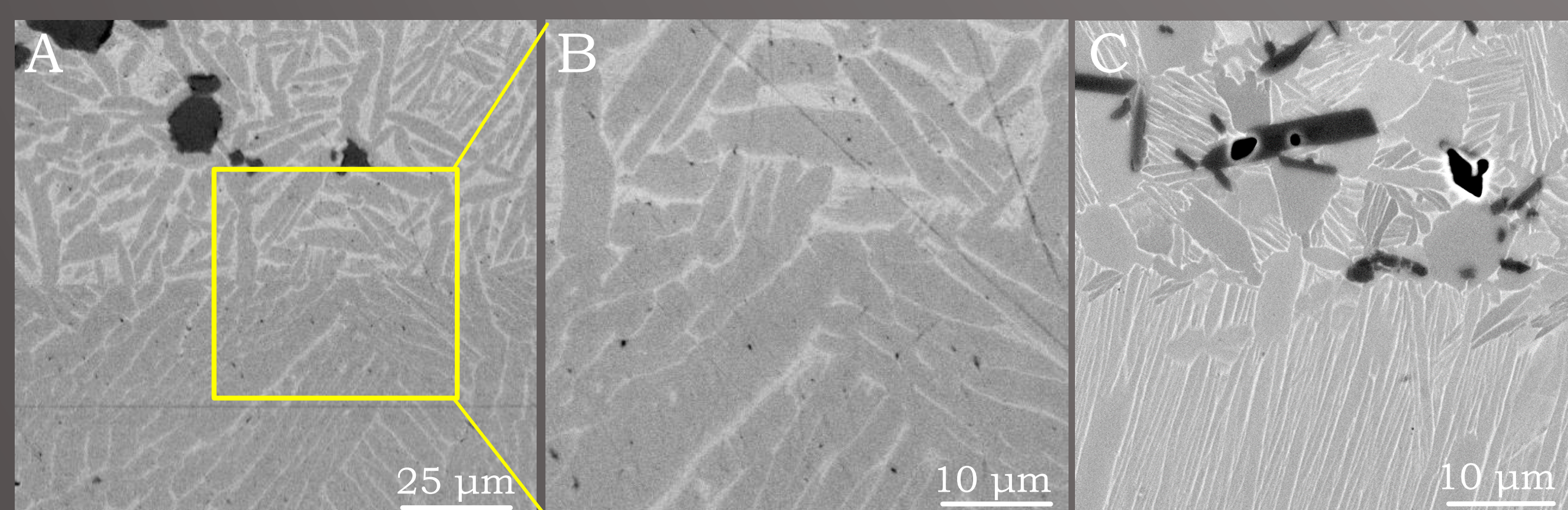


Fig. 1. SEM images of the interface structure between the alloy (bottom) and composite (top) reinforced with TiC (A, B) and TiB (C) after diffusion bonding for 1 h: at 850-900 °C, 1MPa (A and B) and 1000 °C, 0.7 MPa (C). Images show complete integration between the layers. Incept on (B) depicts some α -Ti crystallites infiltrate through the interface. Depending on the processing conditions the thickness of the joint interface varied from sub- to hundreds of microns.

Diffusion Bonding (contd.)

Both cylinders' facing surfaces were brought into contact and held under a holding force of 0.02kN. Bonding was performed in an argon atmosphere. An induction coil was placed around both specimens' bond region. The bond region was heated to 1000 °C at approximately 5 °C/sec and held for 60 minutes at 0.7MPa for regime 1, and 1.5MPa for regime 2. Bonded specimens were air cooled to room temperature.

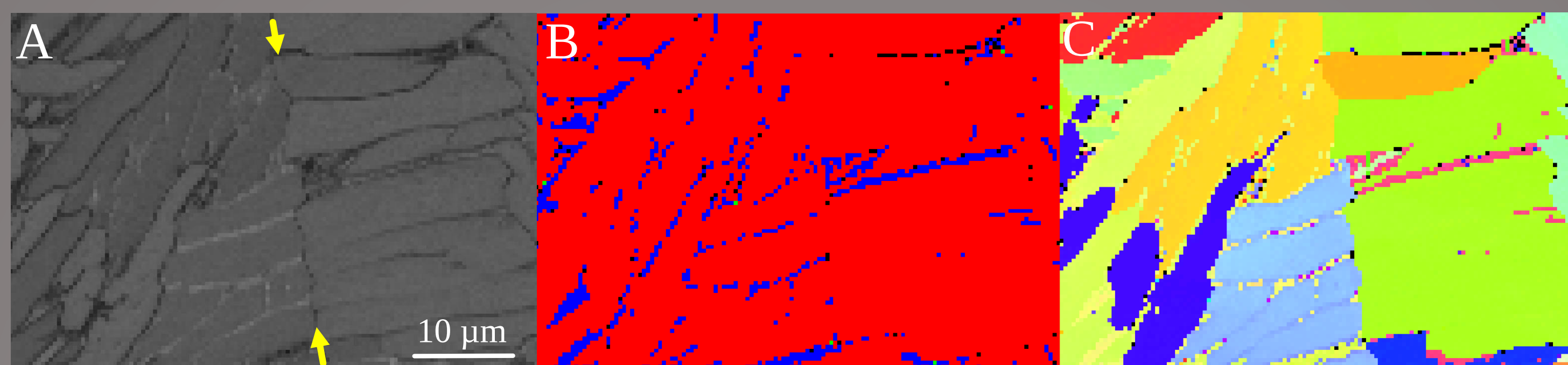


Fig. 2. SEM/EBSD results on DB zone area structure: band contrast image (A), phase color image (B) and orientation map (C). Images are taken at the same magnification; color coding in B: hexagonal α -Ti (red), cubic β -Ti (blue). Interface between two bonded layers is highlighted with yellow arrows in A. The thickness of the bond area is few microns and less. The α -Ti lamellas are characterized with not deformed structure. Some of lamellas has ability to intergrowth into the neighboring layer.

Friction Welding

FW can join the parts with affecting the structure of materials only locally. In this process the friction is generated by rotating of one part against another under a load. Linear friction welding (LFW) can overcome some limitations of rotation welding. LFW is similar to rotation welding, except that the mechanism of movement involves one part moving back and forth. Disadvantage of LFW is high machine & maintenance costs. LFW has a better profile of the heat zone compared to rotation welding and has the ability to do most types of geometry. It generates less of the material loss and can be used to produce near net parts.

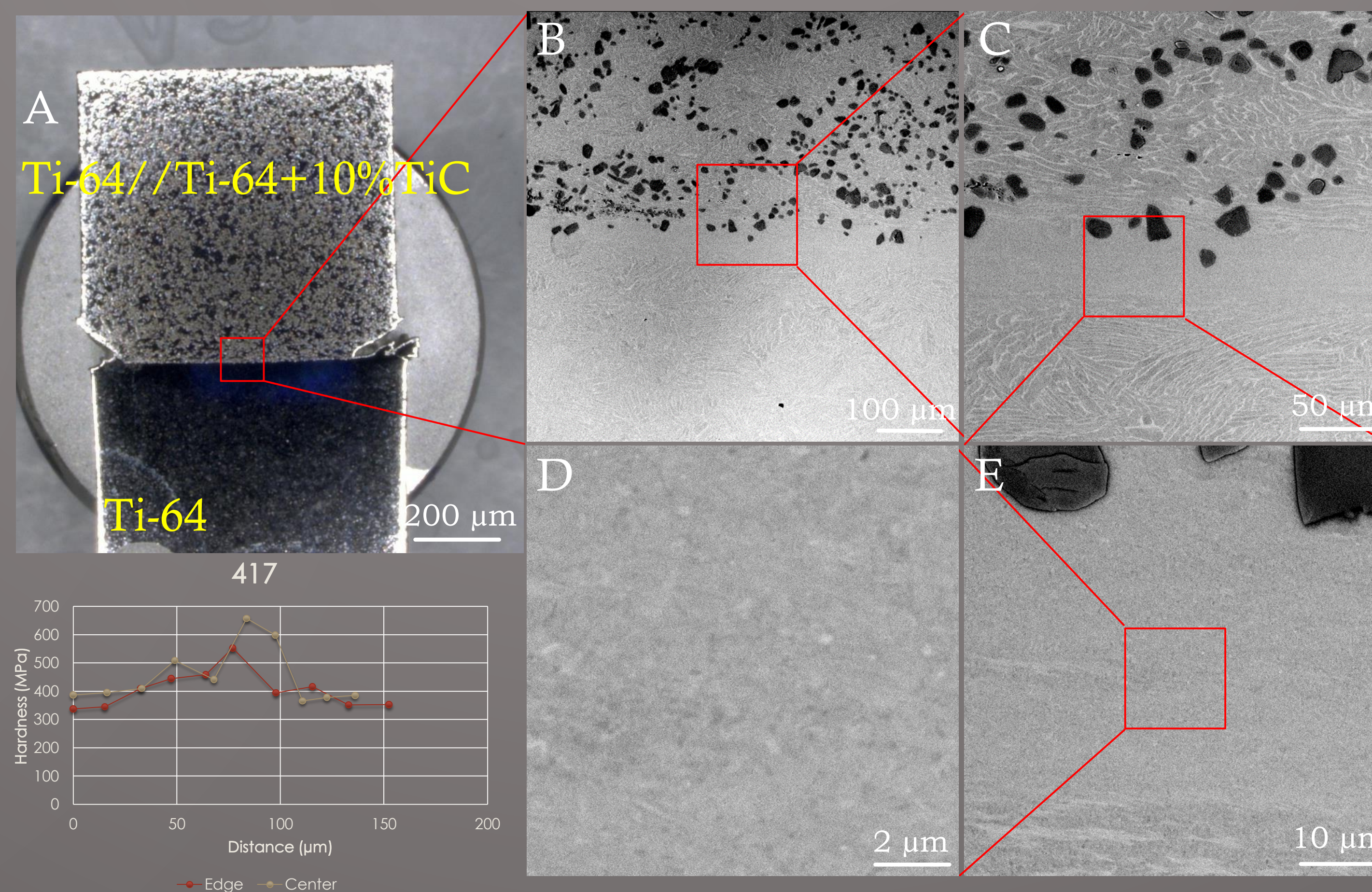


Fig. 3. LOM (A) and SEM (B-E) images of Ti-64 alloy and TiC MMC after LFW: stages 1/2; frequency 50/0 Hz; interface pressure 84/127 MPa; time 0.4/10.2 sec. The chart shows microhardness measurements across the bond interface in the center and at the edge of the cylinder sample.

Friction Welding (contd.)

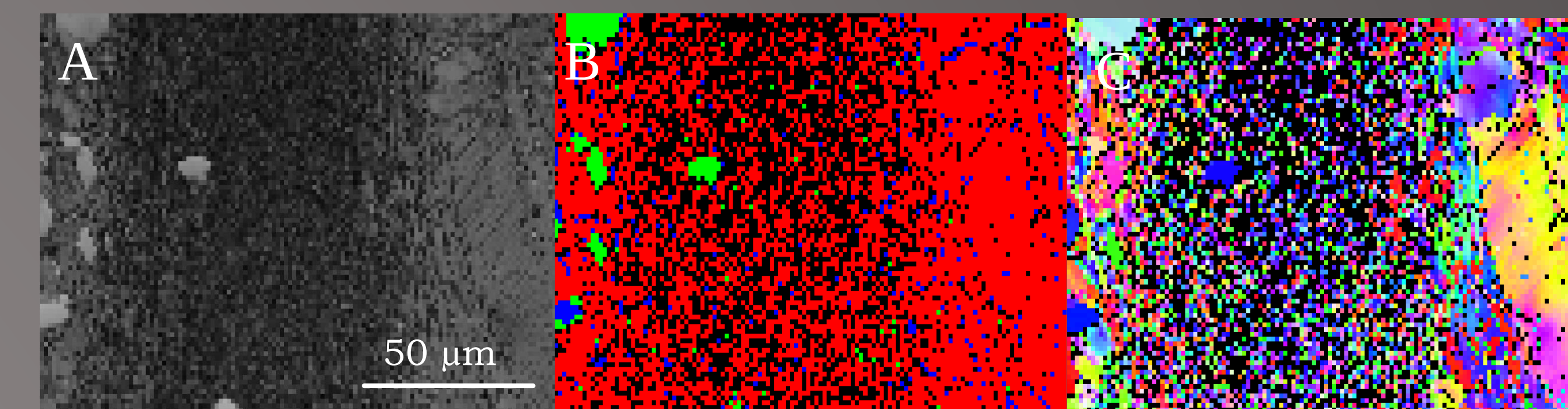


Fig. 4. SEM/EBSD results on welding zone area structure after LFW: band contrast image (A), phase color image (B) and orientation map (C). Phase color image shows three phases identified: hexagonal α -Ti (red), cubic β -Ti (blue) and cubic TiC (green). Orientation map image shows that α -grains of Ti close to the weld area underwent severe plastic deformation without losing the grain identity. The large yellow grain on the right (C) changes orientation of about 20 degrees within a distance of 10-20 µm. The weld area is composed of highly fragmented α -grains of Ti that have lost their lamellar structure; TiC crystals stay intact and are not affected by the welding.

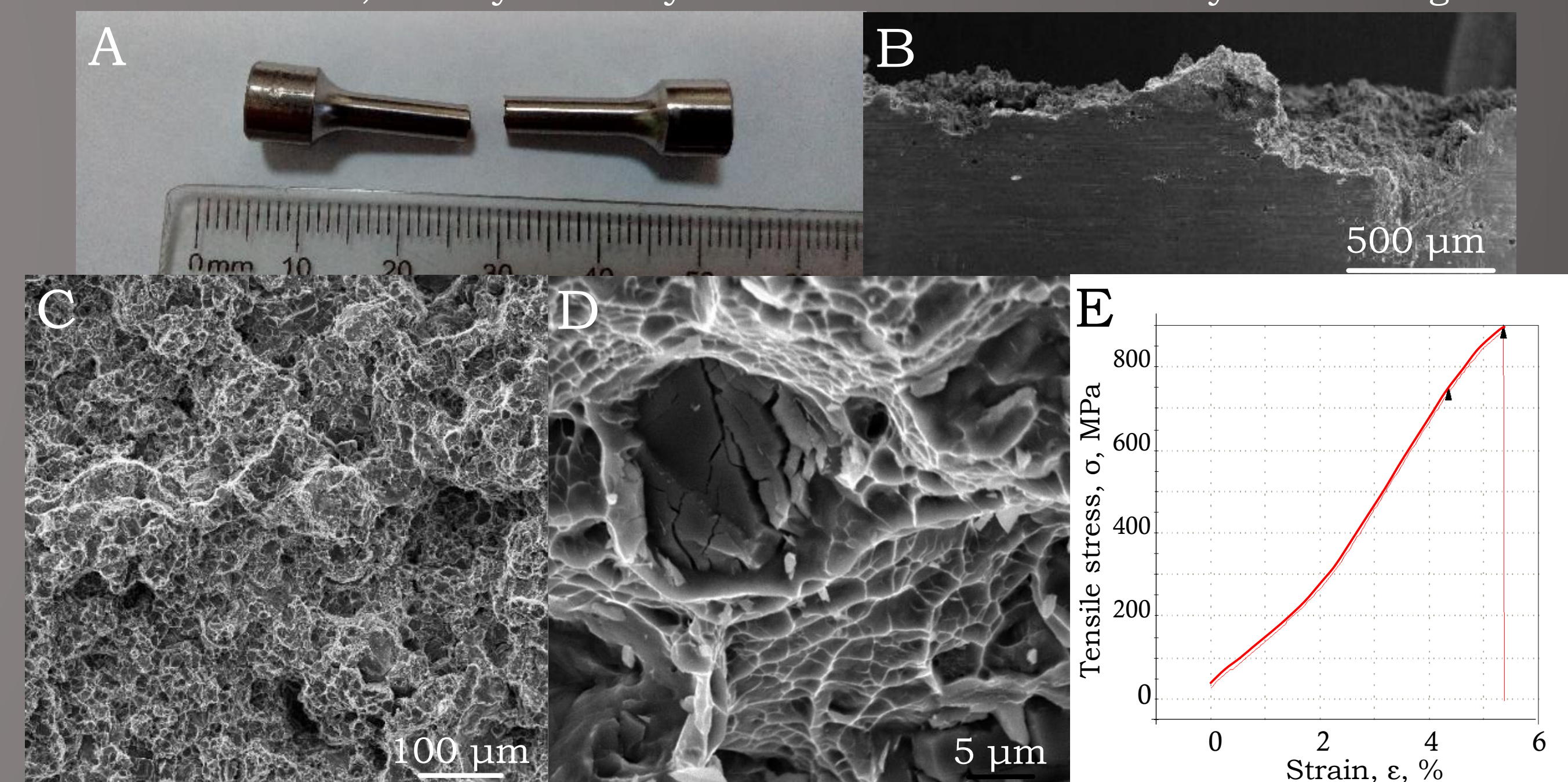


Fig. 5. Tensile test experiment (ASTM E8-M) of the sample after LFW. The bond pair: Ti-64 alloy and Ti-64+10%TiC composite. Welding parameters: area 50 mm²; friction amplitude, 3.63 mm; interface pressure, 110 MPa. Sample after the test (A), side view of the fractured area (B), fracture (C, D) and tensile test chart (E). Fracture occurs outside of the weld area within the composite layer. TiC inclusions are clearly seen on the fracture surface (D). The UTS is close to 900 MPa, elongation 5.36%. Measured UTS is close to this value of the sintered Ti-64 alloy (960-1030MPa) and significantly higher than Ti-64+10%TiC composite (620 MPa).

Summary

The study on DB and FW validates the prospects of joining of Ti-64 alloy and MMC of this alloy with TiC and TiB to form layered structures. That opens possibilities of layered structures fabrication after each layer processed separately to its optimal performance. This approach facilitates the hardness increase of MMC layers since it removes the restraints on the concentration of the reinforcement phase. It takes away the concern on shrinkage mismatch between the alloy and composite during the cost-efficient powder metallurgy fabrication process.

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