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Procedia Engineering 183 (2017) 264 – 269

Procedia Engineering

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17th International Conference on Sheet Metal, SHEMET17

On The Microstructural Analysis of LFW Joints Of Ti6Al4V Components Made Via Electron Beam Melting

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Abstract

Additive Manufacturing (AM), applied to metal industry, is a family of processes that allow complex shape components to be realized from raw materials in the form of powders. The compaction of the powders is achieved by local melting of bed. Electron Beam Melting (EBM) is an additive manufacturing process in which a focalized electron beam is the heat source that allows the powders to be compacted. By EBM it is possible to realize complex shape components; this feature is of particular interest in titanium industry where numerous efforts are done to develop near net shape processes.
One of the limits of EBM based AM process is the difficulty to realize large dimension parts. Due to this limit the study of joining processes of different parts is of great interest. In the present work the microstructure evolution of sheets of TI6Al4V made by EBM and joined by Linear Friction Welding (LFW) is analyzed in details.
The bulk microstructure of the specimen is fine lamellar; lamellae are enclosed in alpha colonies. Different types of porosities are observed. In the joint a Thermo Mechanical Affected Zone (TMAZ) and Weld Bead (WB) are evident. In TMAZ a partial recrystallization occurs and the parent microstructure is deformed. Complete recrystallization occurs in WB whose structure is martensitic.

Peer-review under responsibility of the organizing committee of SHEMET17

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Peer-review under responsibility of the organizing committee of SHEMET17
doi:10.1016/j.proeng.2017.04.034

Keywords: Electron Beam Melting; Linear Friction Welding; Ti6Al4V, Microstructure

1. Introduction

Additive Manufacturing is an innovative technology that allows realizing complex shape components using powder as raw material

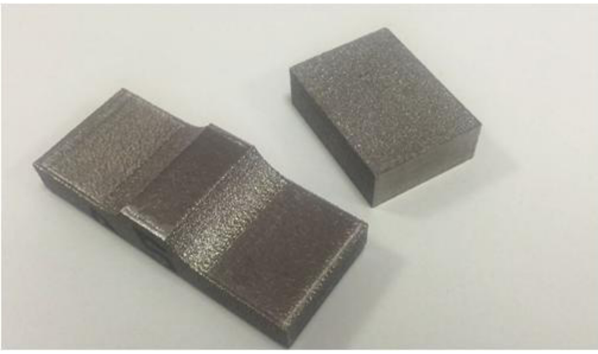
The final shape of components is realized by the addition of different layers of powders. The powders are locally compacted by a focused heat source like a laser or an electron beam. The compaction occurs via melting and generally the process is conducted under vacuum or inert atmosphere [1].

Electron Beam Melting (EBM) uses an electron beam as heat source and operates under vacuum, lens and magnetic fields are used to control the beam. Due to the presence of electron currents EBM is not suitable for magnetic materials, but it is particularly advantageous for titanium alloys that are very difficult to be worked by traditional subtractive techniques.

One of the limits of EBM technology is the difficulty to realize large components, at this aim the necessity to study proper welding processes to join different parts appears very useful. Among the welding procedures Linear Friction Welding (LFW) has been investigate due to its operational flexibility and capability to produce sound joints when applied to titanium alloys and also dissimilar joints.

From operative point of view the source of heat is friction which produces a plasticized zone, once plasticization has reached a desired level a forging pressure is applied and so welding is realized.

During the process severe plastic deformation and heating are experienced by material, which is subject to important microstructural transformations [2,3]. The knowledge of those transformations is of crucial importance because they directly influence the mechanic behavior and other properties.



a

b

Fig. 1. (a) specimen before welding; (b) after welding.

2. Materials and Methods

EBMed specimen suitable for LFW were prepared by CIRA (Centro Italiano Ricerche Aerospaziali) using an ARCAM A2X facility. The geometry of the specimen is reported in Fig. 1. The specimen were joined using a machine designed by Sophia HIGH TECH srl, the parameters used in welding process are: frequency 40 Hz, amplitude 1 mm and forging force 14300 N. The contact surface is 253 mm^2.

The joints were cut using a REMET 3000 metallographic cutter, then the specimen, containing the weld zone, were mounted in epoxy conductive resins. All samples were polished to mirror like finishing using conventional techniques end etched by a 0.5% HF solution [4].

Optical images were taken by means of a Zeiss Axioplan 2 Microscope. Scanning Electron Microscope (SEM) analysis was performed using An Hitachi TM 3000 electron microscope. Energy-Dispersive X-ray Spectroscopy (EDS) was realized by means of an Oxford Instrument Swift ED 3000 silicon drift detector at the operating condition of 15 keV

3. Results and Discussion

In Fig.2 the macrograph of the weld zone is reported. Parent Material, Thermo Mechanical Affected Zone and Weld Bead can be distinguished. The joint is sound without crack or other macroscopic defect.

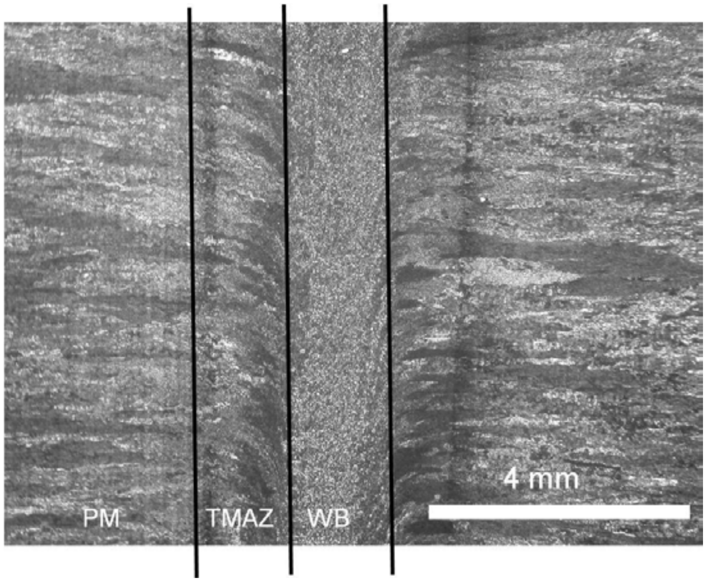
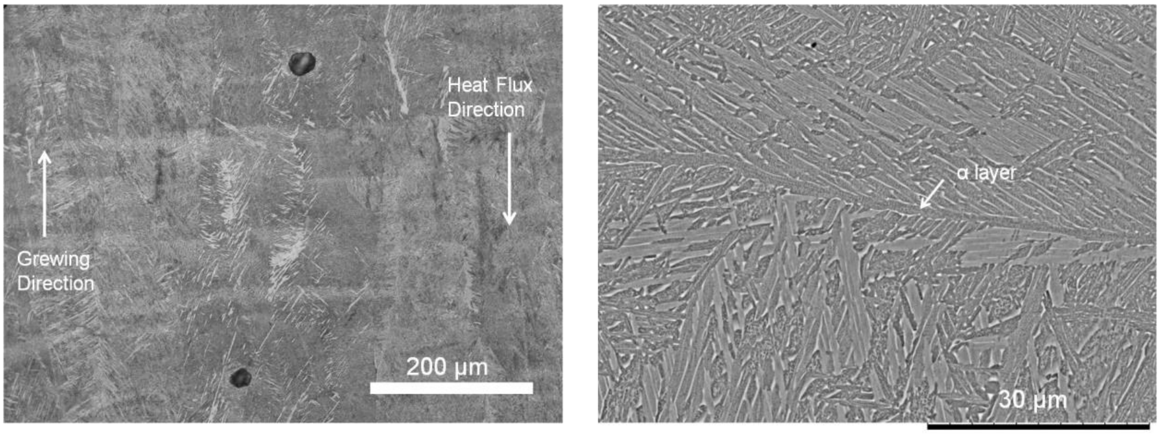


Fig. 2. Welding zone

More in details the PM (Fig. 3a) is characterized by the presence of horizontal stratification and elongated structures in the direction of heat flux. The horizontal stratification corresponds to the different layers added during the EBM process. During the EBM process the cooling of melted Ti6Al4V generates in first β phase, further cooling produces the typical α+β structures. The elongated structures are the former beta grains mentioned above. They grew in epitaxial way due to the presence of substantially unidirectional heat flow [5]. From β grains the α-lamellae originate, the lamellae are separated each other by β phase. Whole α+β structure is Widmanstätten type. From the boundary of the former β grains the alpha layer originates, it is a continuous string made entirely of α phase (Fig 3b) [6].



a b

Fig. 3. (a) Optical image of PM; (b) SEM image of PM with highlighted the α layer

Inside PM two different type of porosity can be distinguished. The first (Fig. 4a) consists of round shaped pores of about 40 µm. The origin of these pores is attributed to the presence of gases that evolve during the melting process. In fact the Ti6Al4V lattice contains dissolved atoms of C, N, O that at melting point are released forming gas molecules. Another source of gases is the sublimation of the different component of the alloy. The second type of porosity (Fig. 4b) consists of irregular shaped pores whose dimension is few microns. The presence of those pores is due to compaction defect inside the powder bed during the EBM process.

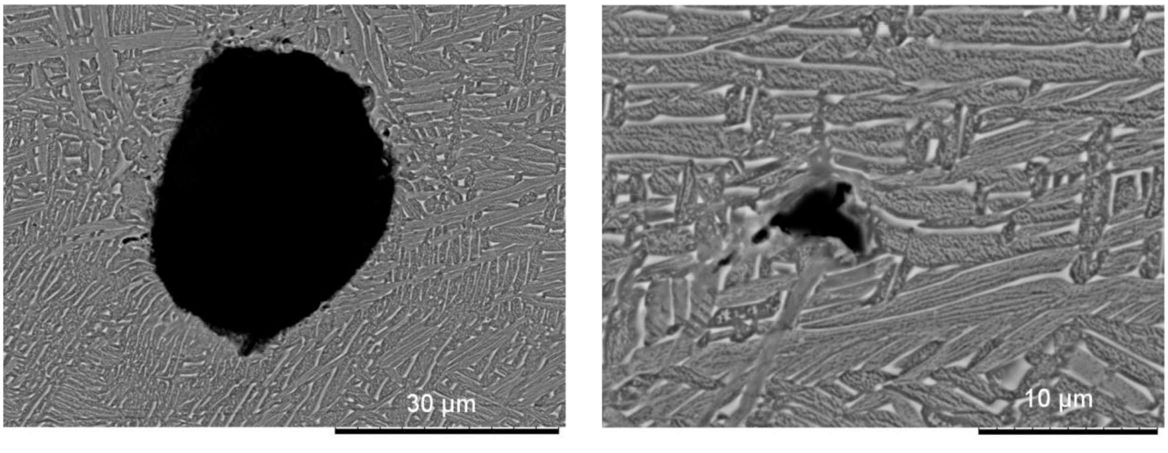


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Fig. 4. (a) Round shaped pore observed in parent material; (b) Irregular shaped pore

The microstructure of TMAZ is reported in Fig. 5, the former beta grains are still distinguishable, but they are deformed. In some areas of TMAZ a change in microstructure occurs. As showed in Fig. 5b a basket-wave microstructure is present. The presence of this type of structure is attributed to phenomena of recrystallization that occurs when the material experiences heating above the β-transus followed by a cooling faster to respect PM.

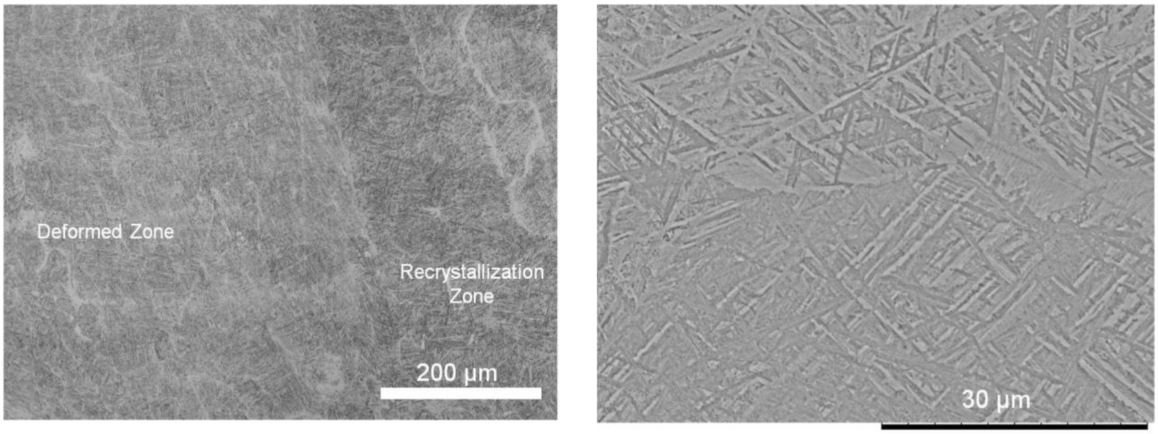

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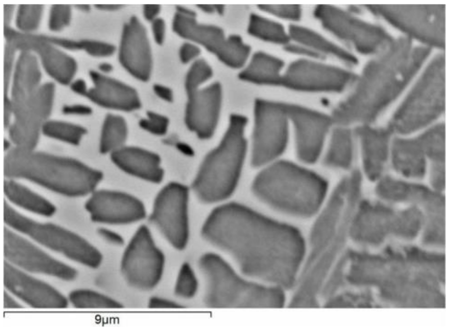
Fig. 5. (a) Optical image of TMAZ; (b) Basket wave microstructure of the Recrystallization Zone



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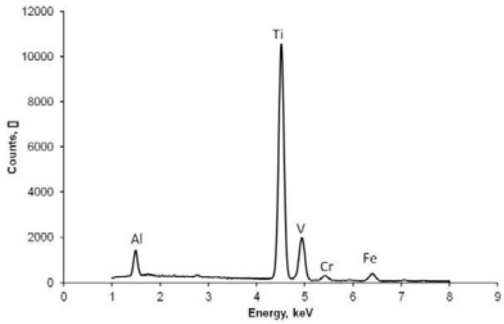

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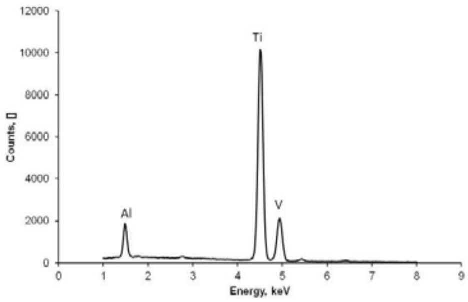

c

Fig. 6. (a) Areas of TMAZ with different morphology of β phase and relative EDS spectrum (b); (c) EDS spectrum of β phase in PM

Again in TMAZ some small areas characterized, in comparison to PM, by both a change in composition and morphology of β phases can be noticed. In Fig. 6 the results of EDS analysis performed on aforementioned areas and on β phase of PM are reported. Those differences are attributed to local diffusion phenomena caused by the combined effect of deformation and heat.

In Fig. 7 the microstructure of WB is reported. It is martensitic type that means that the material experienced a rapid cooling from temperature above the β-transus. Finally in both TMAZ and WB a considerable decrease of porosity is observed.

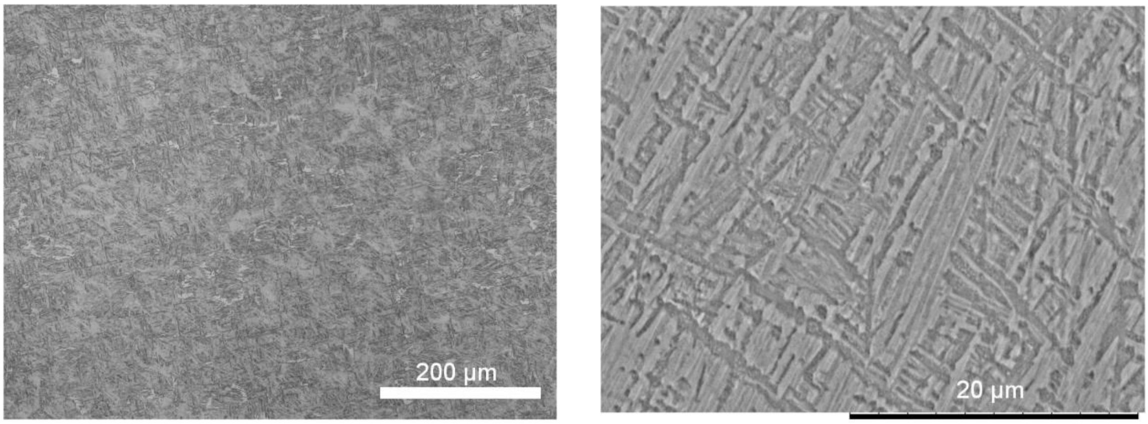

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Fig. 7. (a) Optical image of WB (b); SEM image of WB

4. Conclusion

On the basis of the results discussed above the following conclusion can be deduced:

- The LFW process applied to EBMed Ti6Al4V specimen produces sound joint
- Both in WB and TMAZ a decrease in porosity is observed to respect parent material
- IN TMAZ recrystallization and redistribution of alloy components occurs
- The WB has a martensitic microstructure that indicates fast cooling from temperature above the β-transus

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