Diffusion Bonding and Brazing in 3D Manufacturing of Titanium Alloy Structures

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I. Introduction

- Although traditional machining methods of Titanium alloys can generate rather intricate contours and complex shaped parts, fabrication of three-dimensional (3D) components can often be limited and the application of some additive technologies may be required
- In the situation when no fusion welding is possible, diffusion bonding and brazing would be precious allies
- The main focus of the presented work is joining two-phase (α+β) Ti-6Al-4V (ASTM Grade 5) alloy parts, which is an essential step in designing various plate and shell-type heat-exchangers
- The plate and shell-type heat-exchangers are constructed by bonding (face-to-face) together two or more parts containing a system of channels in such a way that a coolant flow path for is created inside the final assembly

II. Brazing of Ti-6Al-4V (ASTM Grade 5) alloy components

- The β-transus temperature for the Ti-6Al-4V alloy lies at approximately 995°C [1]
- Brazing of the Titanium alloy (Grade 5) parts was carried out in vacuum below the beta-transus using commercially available Ti-Cu-Ni filler metal
- By means of the brazing technique a system of channels inside the joining assembly was created (Fig. 1)
- There are situations when presence of Copper inside the cooling assembly is undesirable. Even when ultra pure water (UPW) is used as a coolant, Copper may be leached from the brazing seam causing serious corrosion issues in some electronic manufacturing.

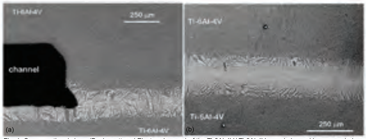

Fig. 1: Cross-sectional views (Back-scattered Electron Images) of the Ti-6Al-4V | Ti-6Al-4V sample brazed in vacuum below the beta-transus with Ti-Cu-Ni filler metal showing: a) channel created inside the joint assembly and b) microstructure of the brazing seam

III. Copper-free filler metals for brazing Ti-6Al-4V alloy

- Unalloyed Aluminum as brazing filler metal for Grade 5 Titanium alloy can provide good shear strength up to 260°C. The brazing temperature should be around 700°C (Fig. 2).
- Pure silver and Ag-Al alloy (Fig. 3) as well as a Ag-Pd filler metal (with liquidus and solidus temperatures below the beta-transus) can also be used to braze Ti-6Al-4V
- Besides brazing, joining of the Ti-6Al-4V alloy components can be accomplished by means of diffusion bonding

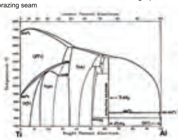

Fig. 2: The binary Ti-Al phase diagram [2]

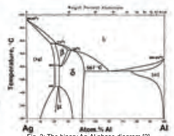

Fig. 3: The binary Ag-Al phase diagram [2]

IV. Direct low-pressure diffusion bonding of Ti-6Al-4V (ASTM Grade 5) alloys

- Solid-state bonding of, for example, two-phase (α+β) Ti-6Al-4V (ASTM Grade 5) alloy components is generally performed at temperatures 900-950°C, at pressures ranging from 1.3-13.8 MPa and for times of about 1 to 6 hours [3]
- Diffusion bonding pressure is important for controlling properties of the joints. However, high precision of the bonded structures cannot be kept if plastic deformation is too large. For this reason, there is a considerable interest in the extension of solid-state joining to lower diffusion bonding pressures.
- Joining of the Ti-6Al-4V alloy components across flat mating surfaces was accomplished by diffusion bonding in vacuum below the β-transus under external pressure below 1 MPa (Fig. 4)
- Obviously, the associated production costs can be reduced by lowering the processing temperature. In principle, this can be achieved if diffusion bonding is conducted through a transient interlayer [3]

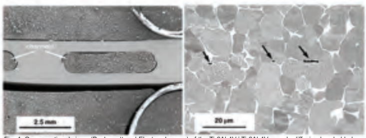

Fig. 4: Cross-sectional views (Back-scattered Electron Images) of the Ti-6Al-4V | Ti-6Al-4V sample diffusion bonded below the beta-transus and external pressure below 1 MPa showing: a) channels created inside the bonded assembly and b) some pores (indicated by arrows in) remained at the initial contact surface of the joint. Note that the two-phase structure of the parent Ti-6Al-4V alloy consisted of β-phase (grey contrast) in an α-phase (white contrast) is preserved [4]

V. Solid-state bonding of Titanium alloy components using a transient interlayer

- Joining of the Ti-6Al-4V alloy components can be accomplished by diffusion bonding in vacuum far below the beta-transus through the electrochemically deposited Cu-interlayer under external pressures well below 1 MPa (Fig. 5)

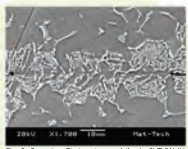

Fig. 5: Secondary Electron Image of the (α+β)-Ti-6Al-4V (ASTM Grade 5) alloy parts after joining through a transient (electrolytically deposited) Cu-interlayer and subsequent annealing at the same circumstances

VI. Concluding remarks

- Joining of the Ti-6Al-4V (ASTM Grade 5) alloy components below temperature of the β-transus can be accomplished in vacuum by brazing or low-pressure diffusion bonding (with or without interlayer)
- Sound Ti-6Al-4V alloy joints can also be fabricated by diffusion bonding in vacuum far below the beta-transus through the electrochemically deposited Cu-interlayer, which reduces production costs and improves dimensional stability of the assembly
- In the situation when the presence of Copper-bearing materials inside the bonded assembly is not desirable, a number of alternative brazing filler alloys are available
- Clearly, the present project can be considered as a first step in solving much broader issue of 3D manufacturing of metallic structures

VII. Outlook

- It is still not clear whether brazing and low-pressure diffusion bonding can be performed on mating surfaces of machined parts without any prior etching
- Issues of surface modification and development of cost-effective technology for metal (Copper or Nickel) electrochemical deposition on Titanium alloys are to be addressed
- The newly developed brazing and diffusion bonding techniques for Titanium Grade 5 alloy are to be optimized
- Integration of newly introduced joining technologies in the processes of 3D- manufacturing of Titanium-based components can now be initiated

References

[1] M.J. Donachie, Titanium - A Technical Guide, ASM International, 2000
[2] Th. B. Massalski, Binary Alloy Phase Diagrams, ASM, Ohio, 1984
[3] N. F. Kazakov, Diffusion Bonding of Materials, Pergamon Press, 1985
[4] M.H. Biglari, L.C.P. Krassenburg, R.P.J. Denteneer, J.H.G. Brom, A.A. Kodentsov, Low pressure diffusion bonding of titanium alloys. Proc. 10th Int. Conf. LÖT 2013, Aaachen, Germany

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