Repair brazing and protection of titanium turbine components using polymer bonded tapes

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Superior strength-to-weight ratio, excellent corrosion resistance and mechanical strength of titanium alloys make them ideal for various aircraft as well as industrial applications. At high mechanical load however, as it appears by droplet impact erosion on turbine blades, it is desirable to have technologies available for protection and repair of such parts. In analogy to the repair brazing of nickel or cobalt based superalloys commonly used for repairing turbines, diffusion brazing of titanium was investigated. Titanium based brazing filler metals were chosen in this case in combination with pure titanium as well as titanium alloys of different particle size and shape to produce polymer bonded repair tapes for titanium diffusion brazing. Filler metal as well as additive powders were blended together and mixed with small amount of organic binding agent to form repair tapes of different thickness. The chosen filler metal has a narrow melting temperature range (825-835°C) in order to braze below β-transus temperature and to avoid α-β transformation. The porosity of the coatings has been minimized by varying the brazing parameters as well as the morphology of the additive powders and by varying filler metal – to additive metal proportion. The results were evaluated by microscopic examination and image analysis. Moreover, considering excellent wettability of graphite by titanium, fine graphite powders as well as fibers were used in addition to form hard titanium carbide with the titanium of the matrix and filler metal in situ. The resulting TiC phase is significantly hard with improved wear resistant compared to titanium alloys. The reaction layers of titanium carbide were examined by studying microstructure of the brazed coating and TiC formation in the matrix was optimized in accordance to brazing parameters.

1 Introduction

Titanium alloys offer an outstanding combination of properties, such as low density, hight specific strength, excellent corrosion resistance and superior mechanical properties leading them to the extensive use in various aircraft as well as industrial applications [1]. However, impact erosion specifically on steam turbine blades appears by the impingement of water drops formed by the condensing steam. These drops hit the surface of the turbine blade with high relative velocity creating surface damage. Nickel or Cobalt based turbine blades are commonly repaired by diffusion brazing processes using special Nickel or Cobalt based filler metals in combination with superalloy powders [2]. Similarly Ti-based filler metal in combination with additives are used to develop polymer bonded tapes for repairing titanium turbine components during coating by brazing process.

Pure Titanium undergoes an allotropic transformation from hcp (α) to bcc (β) at temperature above 882°C. In Brazing at temperature higher than the α-β transformation, the mechanical properties, such as ductility and toughness of base metals are impaired because of the phase transformation as well as coarsening of grains during the brazing cycle [3]. Considering β-transus temperature (980°C) to avoid α-β transformation of most commonly used titanium alloy Ti6Al4V, Ti-based filler metal (TiZrCuNi) with a narrow melting temperature range (825-835°C) has been chosen in this regard. Commercial pure titanium CPTi or Ti6Al4V powders of different particle size and shape have been used to produce polymer bonded repair tapes for titanium diffusion brazing. Different volume percentage of filler metal as well as additive powders were blended together and mixed with small amount of organic binding agent to form polymer bonded repair tapes of different thickness. These flexible tapes are applied to the surface using a specially developed adhesive to keep those in position at ambient temperature as well as during the subsequent brazing cycle [4]. Porosity of the coated layers after brazing was minimized by varying brazing parameters, filler metal – to additive metal proportion and morphology of additive powders.

Surface damage, such as cracks or surface ablations of compressors and turbine blades can be repaired by using Ti-based additives with Ti-based filler metals [5]. Additives penetrate into cracks, notches, grooves during titanium diffusion brazing process repairing turbine components. On the other hand, fine graphite powders were used in addition to form hard titanium carbide with the titanium of the matrix and filler metal in situ considering excellent wettability of graphite by titanium [6]. The resulting TiC phase was found significantly hard compared to titanium alloys. Hard materials have higher resistance to wear having advantageously long service life [7]. The reaction layers of titanium carbide were examined by studying microstructure of the brazed coating and TiC formation in the matrix was optimized in accordance to brazing parameters.

2 Materials and experimental procedures

Ti6Al4V alloy was used as base metal and TiZrCuNi (Tibraze®375) was used as a filler metal [8]. Table 1 gives their chemical compositions.

Materials	Ti	Al	V	Zr	Cu	Ni
Ti6Al4V	rest	6.0	4.0			
TiZrCuNi	rest			37.5	15.0	10.0

Table 1 : Chemical compositions (wt-%)

Additives	Grain size	Grain shape
CPTi	<45µm	irregular
CPTi	<45µm	spherical
Ti6Al4V	<100µm	spherical
Ti6Al4V	<45µm	spherical
Graphite powder	<45µm	spherical

Table 2 : Grain size and shape of additives

Different volume percentage (30 - 70 vol%) of filler metal as well as additive powders were blended together and mixed with small amount of organic binding agent (1.5 wt.% approx.) depending on the grain size of the powders to form polymer bonded repair tapes of different thickness (0.6 – 2 mm). Table 2 gives grain information of additive powders used for tape production.

Tapes are mostly attached to the base metal surface by means of a specially developed adhesive. However, some times some sustainable weight was put on the top of tapes with/without adhesive addition in order to overcome differential thermal expansion behaviour of materials. Brazing of filler metal was done first in a hight vacuum metal furnace mostly at 850°C and 950°C for 90 minutes and that with additives was done at 910°C for 10 and 90 minutes.

The coating by brazing was evaluated by scanning electron microscopic (SEM) examination and porosity was evaluated by image analysis.

3 Results and discussion

3.1 Repair Brazing

Organic bindering agent has been transformed to gaseous decomposition products at 450°C leaving pores in the tapes. The brazing alloy infiltrates into these cavities and forms cohesive bond to the substrate because of its high capillary action [9].

Fig. 1 (a) and (b) show scanning electron micrographs of 850°C and 950°C respectively. Significant amount of porosities as well as cracks were seen in the microstructures. Porosity formation may take place during outgassing of the binders, which can be minimized by varying brazing parameters as well as adding additives with filler metals. Commercial pure titanium CPTi or Ti6Al4V powders of different particle size and shape have been used as an additive along with filler metal TiZrCuNi to produce denser coating after brazing. In order to overcome differential thermal expansion behaviour of filler metal as well as additive metal and to ensure good interfacial bonding between

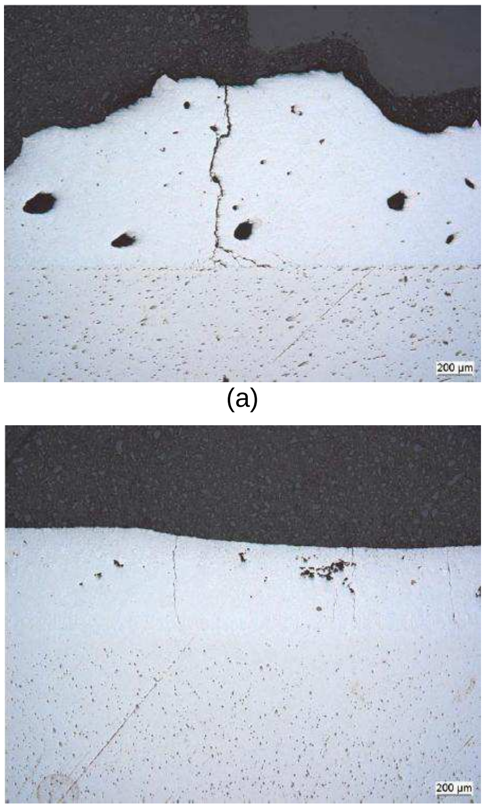


Fig. 1. SEM images of TiZrCuNi coated surface brazed at (a) 850°C and (b) 950°C

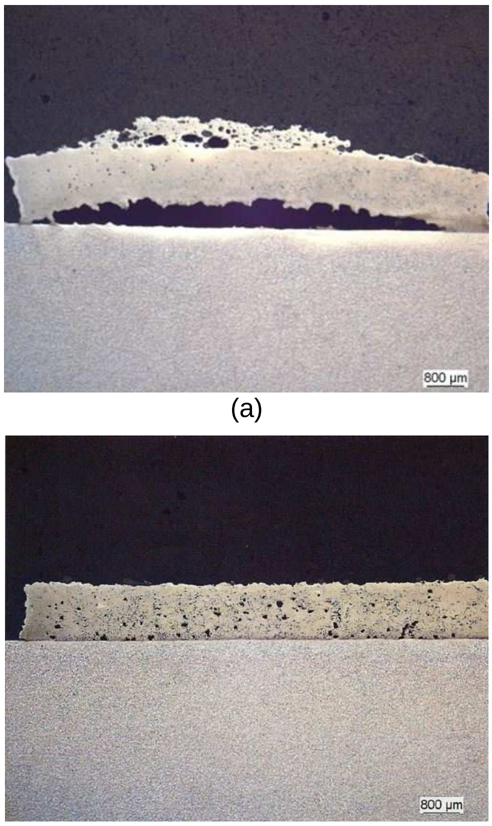
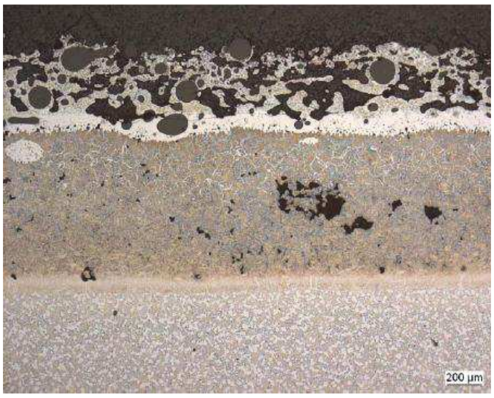


Fig. 2. SEM images of TiZrCuNi/Ti (-45µm, irregular) 50/50 vol% coated surface brazed at 910°C for 10 minutes (a) with weight but without adhesive and (b) with weight and adhesive



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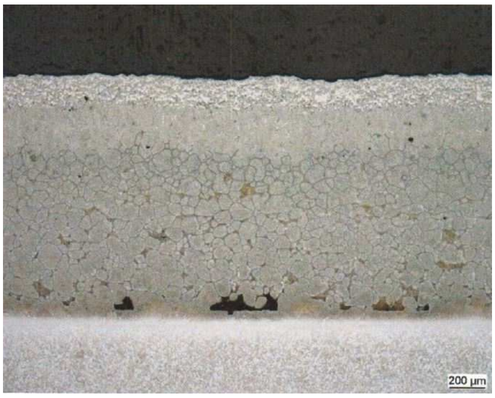

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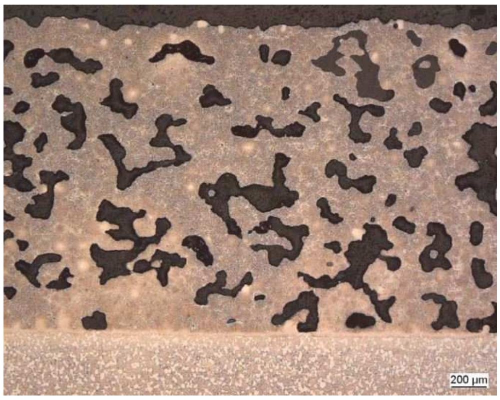
Fig. 3. SEM images of (a) TiZrCuNi/Ti (-45µm, irregular) 50/50 vol%, (b) TiZrCuNi/Ti (-45µm, irregular) 60/40 vol% (c) TiZrCuNi/Ti (-45µm, spherical) 60/40 vol% (d) TiZrCuNi/Ti6Al4V (-45µm, spherical) 60/40 vol% coated surface brazed at 910°C for 90 minutes with weight and adhesive.



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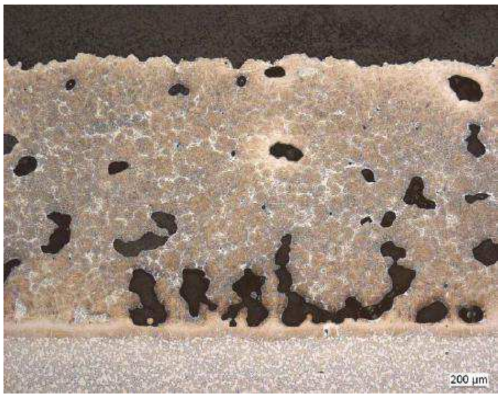

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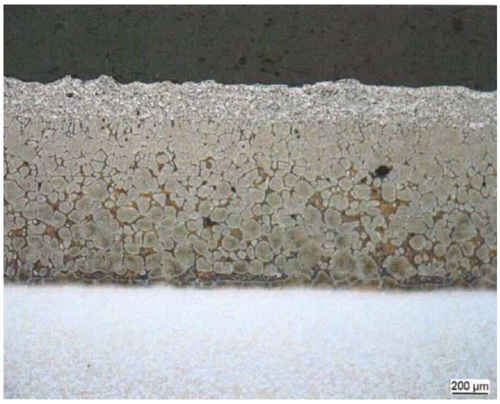


(d)

Fig. 4. SEM images of TiZrCuNi/Ti6Al4V (-100µm, spherical) coated surface (a) 40/60 vol% brazed at 910°C for 10 minutes, (b) 40/60 vol%, (c) 50/50 vol% and (d) 60/40 vol% brazed at 910°C for 90 minutes.

base metal and filler metal, some sustainable weight was put on the tapes before brazing. However, a specially developed adhesive was also used to attach tapes to the base metal.

Fig. 2a shows even after putting some weight on the tapes before brazing, brazed product was bended due to differential thermal expansion of filler metal and additive metal and no interfacial bonding took place between the base metal and filler metal. However, Fig. 2b shows that of a very good interface when adhesive was used to fix the tape to the base metal before brazing.

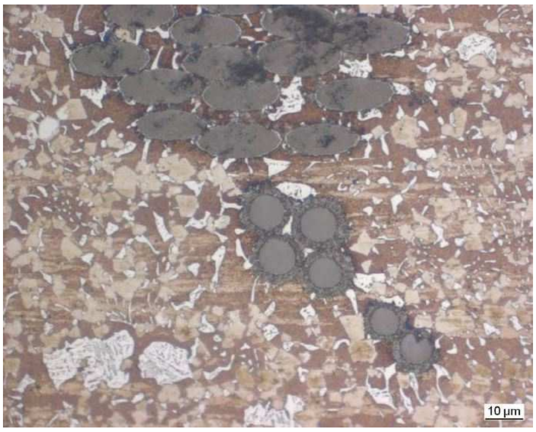
Fig. 3a shows micrograph of TiZrCuNi/Ti (-45µm, irregular) 50/50 vol% coated surface brazed at 910°C for 90 minutes with weight and adhesive, where a very good interface was seen with the base metal and filler metal. However, significant amount of porosity (2.9%) was seen in the microstructures. Changing volume percentage of TiZrCuNi/Ti (-45µm, irregular) to 60/40 vol%, amount of porosity was rather increased to 9.2% (Fig. 3b).

However, as porosity of the coating was not minimized due to the irregular shape of Ti particle, spherical Ti powder was chosen in the later case. The microstructure of TiZrCuNi/Ti (-45µm, spherical) 60/40 vol% coated surface brazed at 910°C for 90 minutes showed that significant amount of porosity can be reduced by using spherical Ti particle instead of irregular Ti (Fig. 3c). The amount of porosity was estimated in this case as 1.03% from the image analysis process. However, in order to increase compatibility of additive metals to the base metals, Ti6Al4V (-45µm, spherical) particle was used in place of Ti particles. Fig. 3d shows microstructure of TiZrCuNi/Ti6Al4V (-45µm, spherical) 60/40 vol% coated surface brazed at 910°C for 90 minutes. Porosity content was minimized to 0.13% and good interfacial bonding was achieved in this case.

Different grain size (-100µm, spherical) of Ti6Al4V additive powder, different proportion of filler metal to additive metal powder and different brazing parameters were also investigated to confirm whether similar results can be obtained. Fig. 4a shows micrograph of TiZrCuNi/Ti6Al4V (-100µm, spherical) 40/60 vol% coated surface brazed at 910°C for 10 minutes. Huge amount of porosity (24.6%) was seen in the microstructures. Changing brazing time to 90 minutes in the same coating showed even increased amount of porosity content (33,9%) (Fig. 4b). However, varying proportion of filler metal to additive metal powder from 40/60 vol% to 50/50 vol%, amount of porosity was clearly reduced to 11.4% (Fig. 4c). Microstucture with very less amount of porosity (0.37%) was found with TiZrCuNi/Ti6Al4V (-100µm, spherical) 60/40 vol% coated surface brazed at 910°C for 90 minutes (Fig. 4d).

3.2 Wear Protection

Wear protection is a major application of coating process by brazing. Surfaces with very well-defined properties and precise contours close to the final dimensions can be obtained using polymer bonded tapes to coat those by brazing process [10]. Considering excellent wettability of graphite by titanium, graphite powder was used in addition to form hard titanium carbide with the titanium of the matrix and filler metal in situ. 30 vol% of fine graphite powder (<45µm) and 70 vol% of filler metal (TiZrCuNi) were mixed with organic binder to form brazing tapes which were attached to the base metal surface by means of a specially developed adhesive. Brazing of the tape was done in a hight vacuum metal furnace at 910°C for 10 minutes. Fig. 5 (a) and (b) show a reaction zone of TiC formed between carbon particles and titanium of the matrix as well as filler metal after brazing at 910°C only for 10 minutes. The resulting TiC phase was found significantly hard (up to 752 HV) compared to titanium alloys (average hardness of Ti6Al4V measured was 347 HV) indicating wear resistance improvement of the coated layers.



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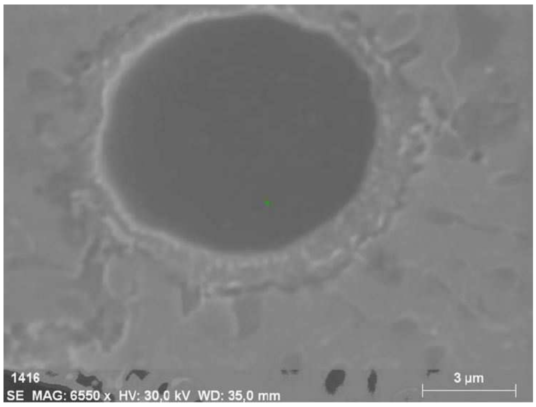
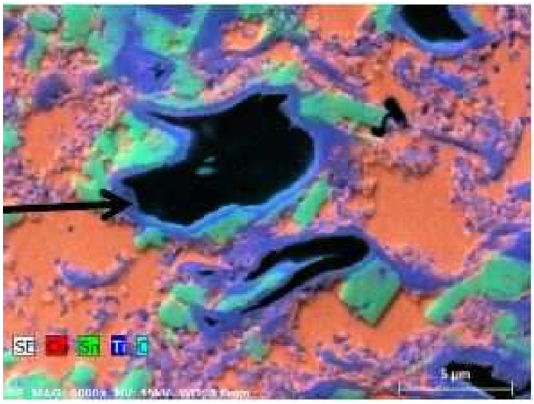


(b)

Fig. 5. SEM images of TiZrCuNi/Graphite 70/30 vol% coated surface brazed at 910°C for 10 minutes

An intensive study on TiC formation in situ in the brazed coated surface depending on brazing time was examined by microstructural analysis [11]. Fig. 6 (a-d) show micrographs of CuSn13.9Ti30.4/Graphite 80/20



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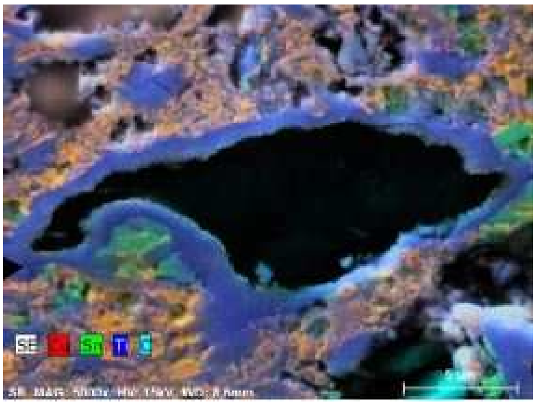

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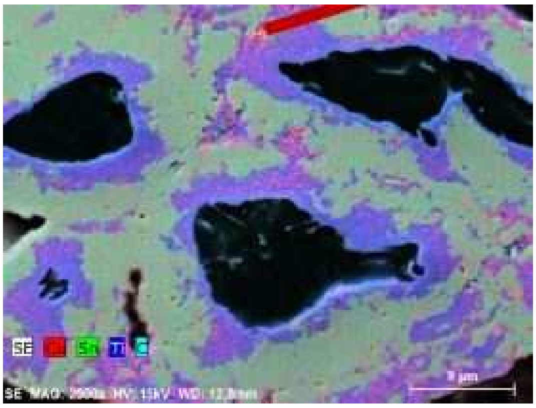

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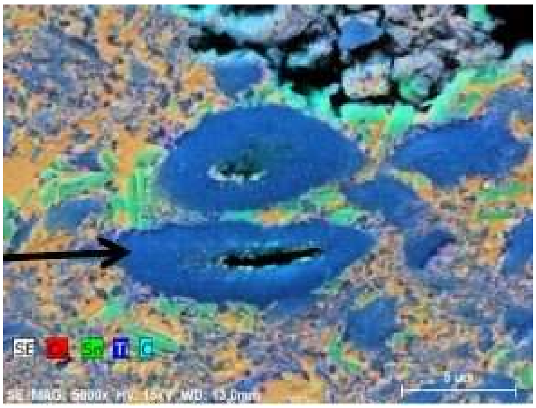

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Fig. 6. SEM images of CuSn13,9Ti30,4/Graphite 80/20 vol% coated surface brazed at 950°C for (a) 20 minutes, (b) 60 minutes, (c) 240 minutes, (b) 480 minutes

vol% coated surface brazed at 950°C for 20 minutes, 60 minutes, 240 minutes and 480 minutes respectively. The reaction zone of TiC formation was increased by increasing brazing time. Due to improved hardness of TiC produced in situ, it is expected that the resistant to imapact erosion of turbine components should be improved.

4 Conclusions

In order to enable the repair technology of Ti6Al4V, brazing investigation of Ti-based filler metal (TiZrCuNi) as a coating on Ti6Al4V substrate was done. CPTi or Ti6Al4V powders of different particle size and shape have been used as an additive to produce polymer bonded repair tapes for titanium diffusion brazing. Different volume percentage of filler metal as well as additive powders were blended together and mixed with small amount of organic binding agent to form polymer bonded repair tapes of different thickness. Porosity of the coated layers was minimized by varying brazing parameters, filler metal – to additive metal proportion and morphology of additive powders. Coating produced by brazing with 40 vol% of Ti6Al4V (-45µm, spherical) additive powder and 60 vol% of TiZrCuNi brazing powder at 910°C for 90 minutes provided denser coating after brazing. Porosity content was minimized to 0.13% in this case. Some sustainable weight was put on the tapes as well as a specially developed adhesive was used to attach tapes to the base metal before brazing in order to overcome different thermal expansion behaviour of filler metal as well as additive metal and to ensure good interfacial bonding between base metal and filler metal.

On the other hand, fine graphite powders were used in addition to form hard titanium carbide with the titanium of the matrix and filler metal in situ considering excellent wettability of graphite by titanium. A reaction zone of TiC formed between graphite powder and titanium of base metal as well as filler metal of the matrix after brazing. The resulting TiC phase has significantly higher hardness (more than double) compared to titanium alloy Ti6Al4V of base metal indicating wear resistance improvement of the coated layers. TiC formation is a time dependent process and can significantly be increased by increasing brazing time.

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