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Brazing joining of Ti_3AlC_2 ceramic and 40Cr steel based on Ag-Cu-Ti filler metal

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A R T I C L E I N F O

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A B S T R A C T

The following paper investigated the vacuum brazing joining of Ti_3AlC_2 ceramic and 40Cr steel with Ag-Cu-Ti filler metal at 850 °C. A characterization of the brazing joint revealed that it consisted of the Ti_3AlC_2 ceramic, the brazing seam, and the 40Cr steel. There were four phase types found in the brazing seam that included AlCu2Ti, Al4Cu9, Cu[s, s], and Ag[s, s]. These occurred as a result of the interface reactions, which precipitated from the liquid alloy during solidification. When the brazing time was increased from 10 min to 30–60 min, there was a formation of a continuous reaction layer and a strong combination at the filler metal/40Cr steel interface. This led to the transformation of the joint facture position from the filler metal/40Cr steel interface to the Ti_3AlC_2/filler metal interface, thus resulting a significant enhancement of the joint shear strength from 27.7 MPa (10 min) to 196.4 MPa (30 min), and again to 191.3 MPa (60 min). The results showed that the optimal brazing time was 30 min.

1. Introduction

The ternary-layered carbides MAX phase ceramics have outstanding properties which combined with both metals and ceramics ($M_{n+1}AX_n$, where n = 1, 2, 3, M is an early-transition metal, where A is generally group IIIA or the IVA element, and X is a carbon and/or nitrogen). Gupta et al. (2008a,b) found that there was a good wear-resistance property when the tribological behavior of the select MAX phases were tested against the Ni-based superalloys and Al_2O_3. Naveed et al. (2015) examined the erosion resistance property of the Ti6242 alloy with the Ti_2AlC MAX phase coatings. The results showed that the Ti6242 alloy that had the Ti_2AlC MAX phase coating had higher erosion resistance properties than when compared to the uncoated Ti6242 alloy. Li et al. (2013) found that the Cr_2AlC MAX phase ceramic demonstrated a good oxidation resistance, as well an excellent healing behaviors. The Ti_3AlC_2 ceramic can be incorporated into tools or equipment when a specific part of them experienced abrasion and high temperature, since they are part of the MAX phases. Although sintering is the traditional fabrication method, it is not applicable in this situation due to the complicated structure of the MAX phases (Xu et al. (2015) and Lapauw et al. (2015)). There have been many attempts to join the MAX phase ceramics with other materials, including the most approaches: brazing and diffusion-bonding. Wang et al. (2015) examined the microstructure and mechanical properties of a Ti_2AlC-Ti_2AlC brazing joint that was brazed with pure Ag. The molten Ag infiltrated into the Ti_2AlC along the grain boundaries during the brazing process, where the Al and the Ti transferred out of the Ti_2AlC and dissolved into the Ag, which formed the Ag[Al, Ti] solid solution. The joining between the MAX phase ceramics and metals would be more meaningful given that the MAX phase ceramics could effectively protect metals from oxidation, erosion and abrasion, particularly at high temperatures. Zhang et al. (2013) investigated the microstructure and the shear strength of a Ti_2AlC-Cu joint, where the $AlCu_2Ti$, $TiAl_2$, TiC, and Ag[Cu] solid solution were all found within the brazing joint. The highest shear strength (203.3 MPa) was obtained when brazed at 850 °C for 40 min. Special attention has been paid to the joining between the MAX phase ceramics and the Ti-based or Ni-based high-temperature resistant metals. Liu et al. (2014) studied the interfacial microstructure and joining properties of a Ti_3AlC_2-TiAl diffusion bonded joint with an interlayer of Ni and Zr. The results revealed that the bonding temperature had a strong influence on the diffusion and the reaction between Ni and other elements. The highest shear strength (103.6 MPa) was obtained at 850 °C for 60 min. Cao et al. (2014) also investigated the diffusion bonding process between the TiAl intermetallic and the Ti_3AlC_2 ceramic. The results showed that a high bonding strength of 151.6 MPa is obtained when the binding occurs at 920 °C for 60 min with a Ti/Ni interlayer. The phase

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Table 1
The chemical composition of Ti3AlC2, Ag-Cu-Ti, and 40Cr steel.

Materials	Composition, wt.%
Ti_3AlC_2	Ti: 73.8, Al: 13.8, C: 12.4:
Ag-Cu-Ti	Ag: 72, Cu: 25, Ti: 3
40Cr steel	C: 0.40, Cr: 1.00, Mn: 0.60, Si: 0.27, Fe: balance

and the morphology evolution of the Ti_3SiC_2-NiTi diffusion-bonded joints were also characterized by Basu et al. (2011). From the above results, it can be seen that a reliable joining could be obtained between MAX phase ceramic and metals.

40Cr steel is commonly used in the mechanical manufacturing field. There has been research that attempts to expand the application of 40Cr steel by studying the joining processes between 40Cr and other materials. Guo et al. (2016) conducted a rapid diffusion bonding process that transformed the WC-Co to the 40Cr steel with a pure Ni interlayer. The maximum joint shear strength (293.07 MPa) is obtained when they are bonded at 750 °C for 13 min under 40 MPa pressure. Dong et al. (2015) conducted vacuum brazing of the TiAl alloy with the 40Cr steel sheets using newly developed CuTiNiZrV amorphous foils. The results demonstrated that the high joint shear strength (107 MPa) could be obtained.

Previous research has suggested that it would be meaningful to join the MAX phase ceramics and the 40Cr steel where the MAX phase ceramics could provide effective protection for the 40Cr steel. The following studying used a novel brazing process in order to join the Ti_3AlC_2 and the 40Cr steel by using the Ag-Cu-Ti filler metal. The intermetallic compounds (IMCs) in the brazing seam were identified, and the interfacial reaction of the Ti_3AlC_2/filler metal and the filler metal/40Cr steel were investigated. The phase transformation of the brazing seam during the brazing and the solidification was analyzed, and the shear strength and the fracture mode of the joint were investigated.

2. Materials and experimental methods

The chemical compositions of the Ti_3AlC_2 ceramic, the Ag-Cu-Ti alloy, and the 40Cr steel are listed in Table 1. The microstructures of the Ti_3AlC_2 ceramic, the Ag-Cu alloy, and the 40Cr steel are shown in Fig. 1. The X-ray diffraction (XRD) patterns Fig. 2 demonstrated that the Ti_3AlC_2 ceramic was pure, with no additional phases present. The microstructure of the polished surface of the Ti_3AlC_2 is shown in Fig. 1(a). The phases of Ag-Cu-Ti were primarily composed of Ag and Cu. The primary and eutectic phases of Ag-Cu-Ti alloy were observed (Fig. 1(b)). It was seen in Fig. 1(c) that the microstructure of 40Cr steel, consisted of darker pearlite and lighter ferrite. The Ti content in the Ag-Cu-Ti was relatively smaller, so the effect of the Ti on the phase transformation of the Ag-Cu-Ti was ingored. As the temperature declined, the Ag[s, s] solid solution precipitated from the liquid Ag-Cu-Ti alloy. When the temperature decreased to a certain degree, the residual liquid alloy was converted into the eutectic phase. When the temperature reached to room temperature, some of the Cu precipitated from the Ag[s, s] solid solution.

The heat flow as a function of temperature is plotted in Fig. 2(b). The melting start and end points were ~795 °C and 802 °C. The melting start point was slightly higher than the Ag-Cu eutectic temperature (780 °C). The temperature-time curve of the brazing process is shown in Fig. 3 (a). The peak temperature was 850 °C, with holding times of 10 min, 30 min and 60 min. The structure of the brazing sample is illustrated in Fig. 3(b). During the brazing, a pressure of 1 MPa was applied on the joint. The shear test was conducted using an Instron 2335 mechanical test machine, the fixture is shown in Fig. 3(c). The reaction between the Ti_3AlC_2 and the Ag-Cu-Ti alloy was investigating by conducting the spreading test at 850 °C for 30 min. A schematic diagram of the spreading test is shown in Fig. 3(d). The top-view microstructure and the phases were characterized by optical microscope during the spreading sample (OM, VHX-900) and XRD. The microstructure of brazing seam was observed by the OM and the scanning

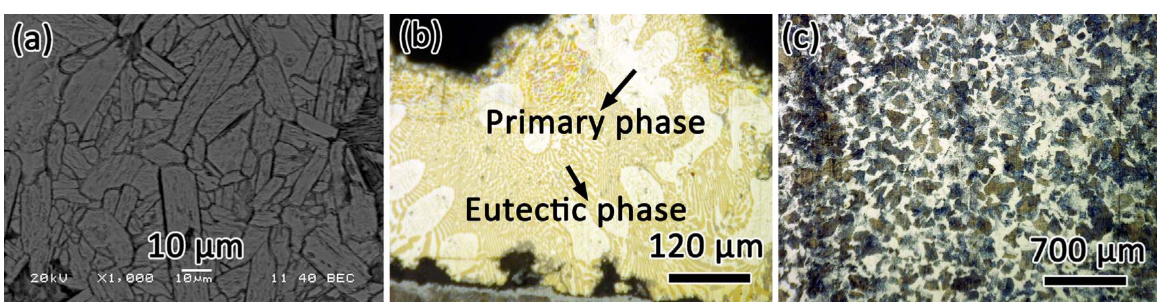

Fig. 1. The microstructure of Ti_3AlC_2, Ag-Cu-Ti, and 40Cr steel (a) Ti_3AlC_2; (b) Ag-Cu-Ti; (c) 40Cr steel.

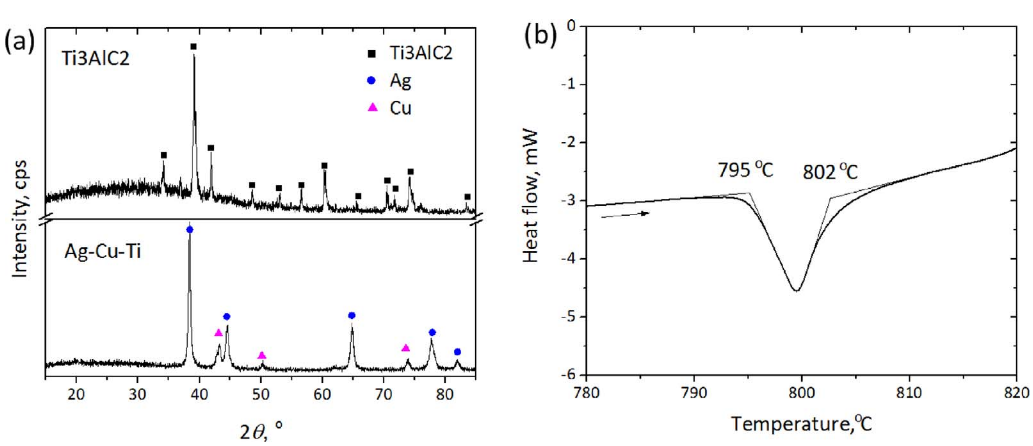

Fig. 2. (a) The x-ray diffraction patterns of Ti3AlC2 and Ag-Cu-Ti; (b) heat flow-temperature curve of Ag-Cu-Ti.