(5.5) BRAZING OF METALLIC-INTERMETALLIC LAMINATE (MIL) Ti-6Al-4V/Al_3Ti COMPOSITES

L. Krüger*, F. Trommer**, K. Vecchio***, B. Wielage**,
S. Mücklich**, L. W. Meyer**, and M. A. Meyers***

ABSTRACT

Due to their excellent specific mechanical properties, metallic-intermetallic laminate (MIL) composites composed of Ti-6Al-4V and Al_3Ti intermetallic layers are very attractive candidates in lightweight, high performance structures. In the present study, these MIL composites were joined by vacuum brazing using a silver-based brazing filler in order to assess their potential integration in engineering structures. Investigations of the microstructure and tensile tests reveal that the best joint is achieved when the MIL composites are brazed to monolithic Ti-6Al-4V, however successful joints were obtained for braze joints between the composites themselves that can be improved by further optimization of the brazing process.

INTRODUCTION

The relatively low density and high stiffness of Ti/Al_3Ti based MIL composites compared to conventional monolithic titanium and titanium alloys, makes these (MIL) composites attractive candidates for aerospace and high performance structures. MIL composites are fabricated by a reactive foil sintering technique in open air using metal foils of Al and Ti or Ti-alloys (Ref. 1, Ref. 2). With this technology, the synthesis of the composite with a layer thickness of the intermetallic Al_3Ti up to 4 mm can be readily achieved, and a wide range of phase volume fractions is possible.

In order to use these MIL composites in structures, appropriate joining techniques must be developed. Welding, diffusion-bonding and brazing are all viable techniques, which can be used to join such materials under industrial conditions. However, the joining of titanium-aluminides does not easily provide desirable properties of the joint. Patterson et al. (Ref. 3) reported that electron beam welding of TiAl is possible, but that welding cracks cannot be avoided. Baeslack et al. (Ref. 4) and Mallory et al. (Ref. 5) carried out studies in welding of different titanium aluminides and revealed that welded joints with good properties can be obtained by properly controlling the cooling rates. Furthermore, diffusion-bonding is possible (e.g. Ref. 6, Ref. 7), but long processing times and high operation costs may prevent this method from widespread use in industrial applications.

In comparison with the abovementioned technologies, joining by brazing offers many advantages, such as a relatively low joining temperature and the possibility to join more complex structures. For these reasons, brazing was chosen to join the MIL composites with themselves or with titanium alloys. The use of brazing as a joining technique may also facilitate easier insertion of MIL composites into existing, complex structures.

* Nordmetall GbR, Eibenberg, Einsiedler Str. 18h, D-09235 Burkhardtsdorf, Germany.
** Chemnitz University of Technology, D-09107 Chemnitz, Germany.
*** University of California, San Diego, La Jolla, CA, 92093-0411, USA.

MATERIALS AND METHODS

Table 1 provides the compositions of the metallic-intermetallic laminate (MIL) composites used as test samples in this study, along with their designations, referred to by the volume fraction of Ti-6Al-4V present in the final composite samples.

Table 1: Designation and volume fraction of MIL composites investigated.

Designation of MIL	Volume Fraction
14 Ti	0.14 Ti-6Al-4V and 0.86 $TiAl_3$
20 Ti	0.20 Ti-6Al-4V and 0.80 $TiAl_3$

In order to braze titanium materials, brazing fillers based on aluminum, silver and titanium are available. Furthermore, brazing with TiNi and TiZr brazing fillers is possible.

The high affinity of titanium and titanium alloys for oxygen, nitrogen and hydrogen, requires brazing to be conducted under a shielding gas atmosphere or in vacuum. The heating of the materials under shielding gas (Ar) occurs by heat conduction and convection and is faster than under vacuum atmosphere. Therefore, this has to be taken into account by increasing brazing times for vacuum brazing.

For our basic investigations brazing under argon atmosphere and in vacuum was used. As equipment for joining under argon atmosphere, a tube furnace with three heating zones was used. During heating, argon was continuously flowed through the quartz tube to minimize oxidation. Furthermore, a vacuum furnace (Torvac 12 Mark IV) was used. For both brazing methods, the processing temperature was measured with a thermocouple fixed on the specimen close to the braze filler. Since in argon atmosphere the heat transfer is faster than under vacuum, shorter brazing times of 4 minutes and the same joining temperature were chosen.

For brazing of MIL to MIL and MIL to Ti-6Al-4V, a silver based Ag-27Cu-13In (wt%) brazing filler metal (commercial product of BrazeTec Degussa Löttechnik, Germany, with commercial name BrazeTec VH720) was used. The foil thickness was 50 µm.

Before processing, the MIL composites and titanium alloy samples were cut, ground and then, together with the foils, degreased in an ultrasonic cleaner, rinsed in acetone and finally rapidly dried. The specimens, with the foil, were then carefully assembled in a device, made of steel plates. A slight load was applied to keep all parts aligned and ensure good contact during brazing.

Figure 1 is compares the real temperature vs. real time profile with the program curve during the whole joining process under vacuum of 10^{-5} mbar. T_S, T_L and T_W are defined as the solidus and liquids of the filler-metal and the joining temperature. The holding time at $T_W = 780$ °C was 10 minutes. A systematic study was performed to investigate the influence of the joining temperature T_W on the quality of the joint. Together with the heating up process and holding time, the time at joining temperature was set as a constant. The joining temperature was systematically reduced from T_W = 780 °C via 750°C to 720 °C.

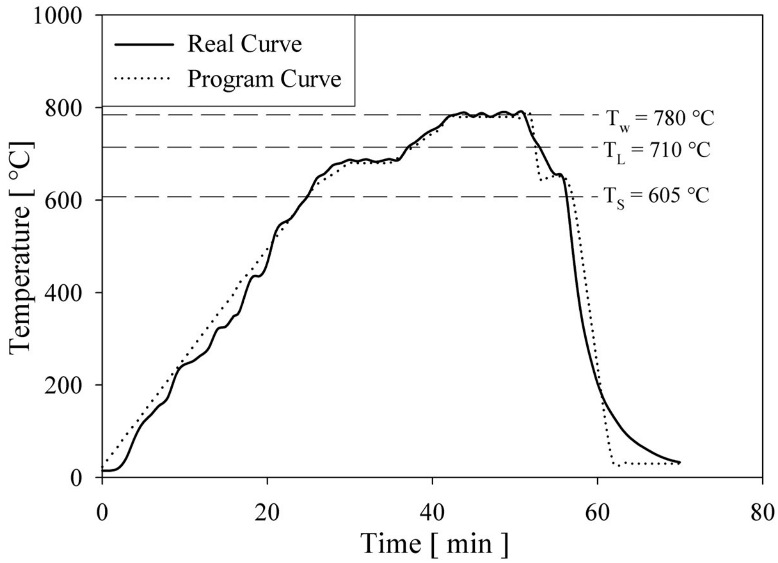

Figure 1: Example for a temperature – time chart during vacuum brazing.

After the brazing process, the samples were cut, mounted, polished for microstructure evaluation. Brazed joint analysis was carried out using optical microscopy, and scanning electron microscopy including energy dispersive X-ray microanalysis (EDX). The hardness was determined using Vickers microhardness testing. For the most promising set of parameters additional tensile samples were brazed as butt joints. Quasi-static tensile tests with a crosshead speed of 0.25 m/min were performed at room temperature to measure the strength of these joints.

RESULTS AND DISCUSSION

Preliminary studies to braze at 780 °C and 4 minutes in argon atmosphere led to a higher tendency to form pores in the braze, especially in joints between the MIL composites in regions of the intermetallic phase Al_3Ti. Figure 2 shows a joint with good bonding and demonstrates how the brazing filler penetrates into the intermetallic phase.

Joints between Ti-6Al-4V and the MIL composites appeared to be less susceptible to porosity. In general, it was observed that MIL composites with higher volume fraction intermetallic or larger thickness of intermetallic (Al_3Ti) (up to 4 mm) are more susceptible to porosity formation and growth of cracks in the joints.

Microhardness measurement in the brazed joint revealed low values of 200 HV in the silver rich (~82 wt% Ag) center at point 3 in Figure 3. Sporadic areas of brittle phases containing a higher content of Cu are formed in the brazing joint (e.g. point 4 with 550 to 620 HV0.05). It is expected that this formation can be influenced by the brazing time.

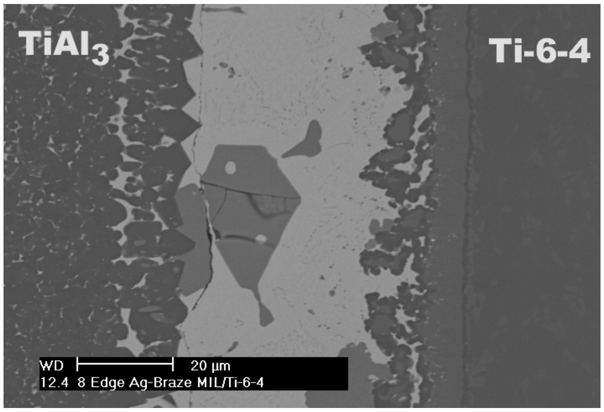

Figure 2: Joint between $TiAl_3$-phase in the MIL composite (left) and Ti-6Al-4V alloy (right).

Brazing parameters:
780 °C, 4 min, argon atmosphere

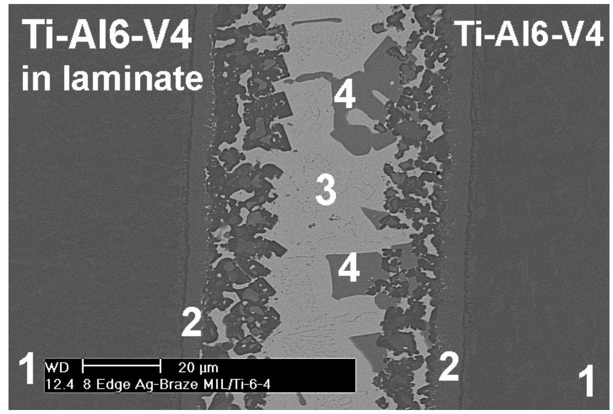

Figure 3: Hardness values across a joint brazed in Ar.

1	330 HV0.05
2	330 HV0.05
3	200 HV0.05
4	550 to 620 HV0.05

Brazing in vacuum at the same temperature of 780 °C improved the quality of the joints significantly. Less pores and holes was observed in the joints between the MIL composites. A decrease in joining temperature to 750 °C and 720 °C revealed no further improvement.

As an example, Figure 4 and Figure 5 show an overview of brazed MIL to Ti-6Al-4V and MIL to MIL at 720 °C. Compared with brazing in argon atmosphere, a better quality can be achieved in both types of the joint. However, some small amount of pores still appeared in joints between two MIL composite samples, as shown in Figure 5.

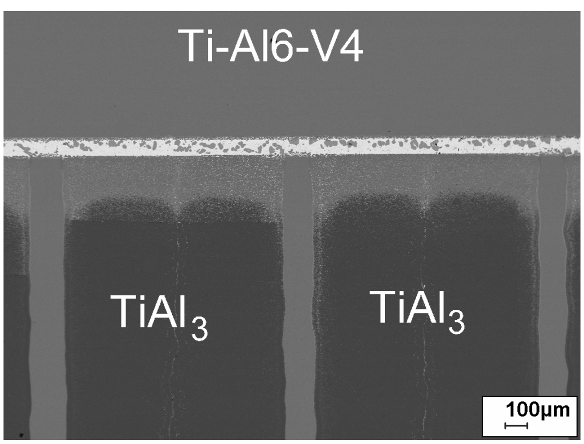

Figure 4: Joint between Ti-6Al-4V and MIL. Brazing parameters: 720 °C, 10 min, 10^{-5} mbar.

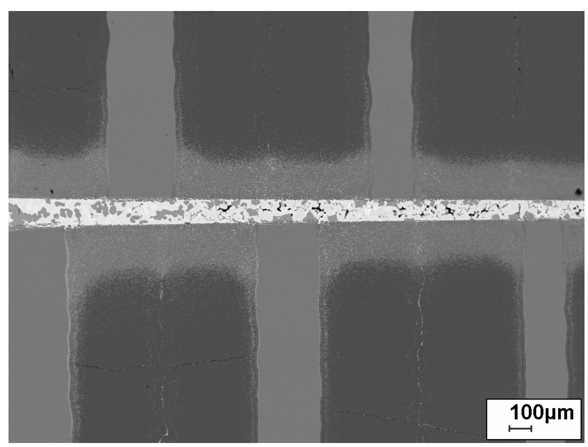

Figure 5: Joint between MIL and MIL. Brazing parameters: 720 °C, 10 min, 10^{-5} mbar.

Joints brazed under vacuum and at brazing temperatures of 780 °C and 720 °C were tested under tensile loading. For each type of joint two to three test samples were used. Additionally, the tensile strength of the MIL composites with 14 and 20 vol.-% Ti-6Al-4V as bulk material and of brazed Ti-6Al-4V was estimated. As can be seen in Figure 6, MIL composites with higher volume fraction of intermetallics have the lowest tensile strength.

Figure 6 and Figure 7 show the maximum values of measured tensile strengths. Joints between Ti-6Al-4V and Ti-6Al-4V have about 50 % of the tensile strength of the bulk material.

When MIL composites were brazed to MIL composites, the lowest strength was measured. This is explained by a relatively low tensile strength of Al_3Ti, a certain amount of microcracks and porosity inside the intermetallic phase and the observed porosity in the brazing clearance.

Higher tensile strengths were measured for joints of titanium alloy to the MIL composites. It is interesting that the joining temperature alone has no pronounced effect on the tensile strength. Up to now, no experiments to investigate the influence of the brazing time were performed. However, a higher duration on the joining temperature of 720 °C might lead to extended metallurgical reactions and higher strength.

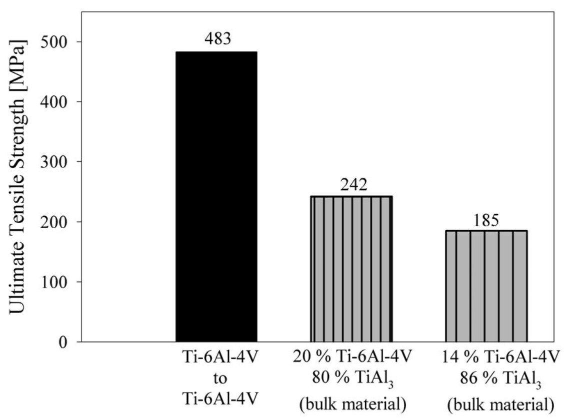

Figure 6: Tensile strength of vacuum brazed joints of Ti-6Al-4V to Ti-6Al-4V and the MIL composites as bulk material. Brazing parameters: 720 °C, 10 min., 10^{-5} mbar

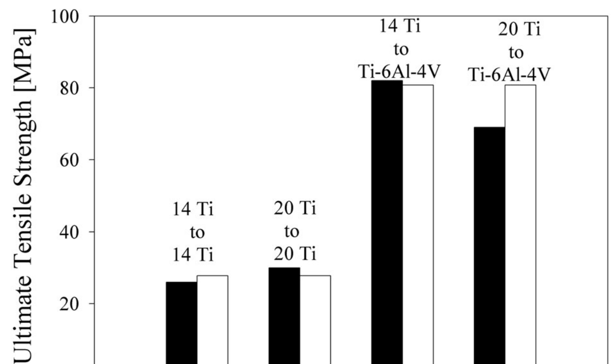

Figure 7: Comparison of tensile strength of joints brazed at 720 °C (white) and 780 °C (black) for 10 min and 10^{-5} mbar.

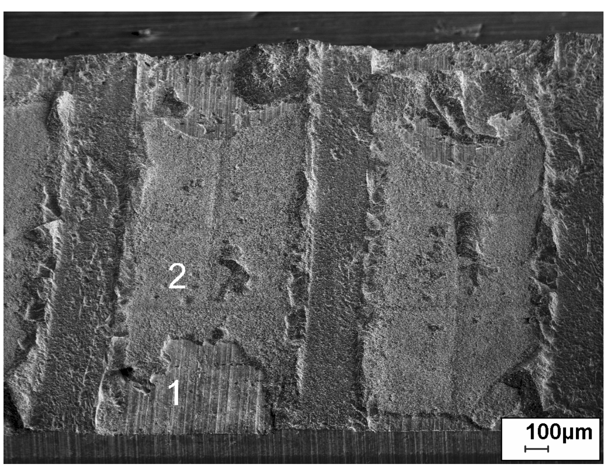

Figure 8: Fractured tensile specimen of MIL composite.

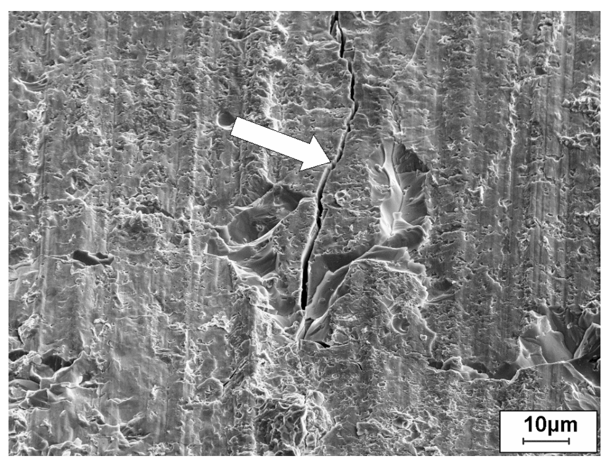

Figure 9: Detail of area on Al_3Ti. Point 1 in Fig. 8.

The surfaces of fractured joints were investigated after mechanical testing using scanning electron microscopy. As an example, investigations on a brazed joint between MIL composites and Ti-6Al-4V are shown in Figure 8 to Figure 11.

Figure 8 presents an overview of the fractured surface of the MIL composites. Braze filler metal was found on the parts of Ti-6Al-4V and on the Al_3Ti. In the intermetallic phase, regions with different bonding strengths between the brazing filler and Al_3Ti were observed.
Figure 9 is a close-up of point 1 in Figure 8. The texture from the former grinding as well as cracks are visible in the regions with no brazing filler. In the middle of the sample in the intermetallic phase regions (point 2 in Figure 8) high amount of brazing filler were found. The failure mode of the joint is more ductile. As can be seen from Figure 10, parts of brittle Al_3Ti occur together with more ductile brazing filler. This is in accordance with the observation in Figure 2 where the filler penetrates into the intermetallic phase.

Detailed investigations of the fractured surface of the brazed joint to Ti-6Al-4V revealed a more ductile mechanism with cracks, Figure 11.

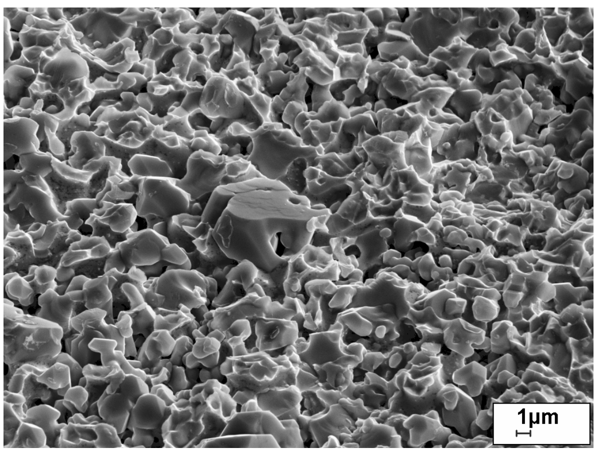

Figure 10: Fractured surface with failure on side of Al_3Ti. Point 1 in Fig. 8.

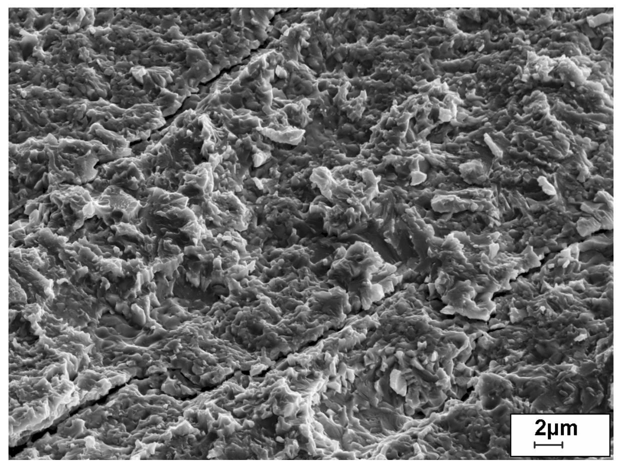

Figure 11: Ductile failure with secondary cracks on Ti-6Al-4V side of the joint.

SUMMARY AND CONCLUSION

A study was performed to investigate if metallic-intermetallic laminate (MIL) composites made of titanium alloy Ti-6Al-4V as metal and Al_3Ti as intermetallic phase can be joined by brazing. Brazing in argon or vacuum using silver based brazing filler metal revealed a good possibility to manufacture joints. Vacuum brazing of MIL to Ti-6Al-4V showed the highest tensile strength and lowest strength variations. It is expected that the strength properties of joints of MIL composite to MIL composites can be improved if the brazing time is further optimized.

ACKNOWLEDGMENT

The authors would like to express their appreciation to Dr.-Ing. Luis Leoncio Martinez Ruis, Dr.-Ing. Holger Klose and Dipl.-Phys. Uta Faust, Chemnitz University of Technology, Germany, for assistance and discussions. The practical support by Dr. Aashish Rohatgi and Ken Harvey is highly appreciated. This work has been supported by the Defence Advanced Research Project Agency (DARPA) under contract DAAD19-00-1-0511 (Program Manager, Dr. Leo Christodoulou) with the University of California, San Diego.

REFERENCES

1. Harach, D. J. 2000. Processing, Properties, and Ballistic Performance of Ti-Al3Ti Metal -Intermetallic Laminate (MIL) Composites. Ph. D. dissertation. San Diego, Ca.: University of California, San Diego.
2. Harach, D. J. and Vecchio, K. S. 2001. Microstructure Evolution in Metal-Intermetallic Laminate (MIL) Composites Synthesized by Reactive Foil Sintering in Air. Metallurgical and Materials Transactions A 32A (6), 1493-1505.
3. Patterson, R. A., Martin, P. L., Damkroger, B. K., and Christodoulou, L. 1990. Titanium Aluminide: Electron Beam Weldability. Welding Journal 69 (1), 39-s to 44-s.
4. Baeslack III, W. A., Mascorella, T. J., and Kelly, T. J. 1989. Weldability of a Titanium Aluminide. Welding Journal 68 (12), 483-s to 498-s.
5. Mallory, L. C., Baeslack III, W. A., Phillips, D., J. Mater. Sci. Lett., 1994, 13, 1061.
6. Yan, P., Wallach, E. R., Intermetallics, 1993, 1, 83.
7. Cam, G., Bohm, K.-H., Mullauer, J., Kocak, M., JOM, 1996, 48, 68.