Bonding Process for the Joining of Metals to Ceramic Matrix Composites and Ceramics

Case #: UD-474

US Patent Pending; Publication # 20080274362

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Detailed Description

Bonding Process for the Joining of Metals to Ceramic Matrix Composites and Ceramics

Dan Kramer / 04-02-07

The application of newly developed CMC's is being severely handicapped by the general inability of being able to readily join/bond these new materials to metal structural members. For example, jet engine manufacturers in order to increase their engine performance characteristics, have a real need for increasing the operating temperatures of various internal components. Commercially available superalloys, such as Inconel 718, have been "pushed" to their maximum temperatures. CMC's, such as SiC/SiC composites, have higher operating and performance envelopes that are very attractive for certain engine and other high temperature applications. Therefore, there are significant engine performance advantages if CMC's could be joined to superalloys. Since many of the superalloys of interest have high CTE's (CTE of Inconel 718 is ~14.5 x 10^{-6} cm/cm/°C from RT to ~600°C) and many of the CMC's have low CTE's (CTE of SiC/SiC is ~4 x 10^{-6} cm/cm/°C RT to ~600°C), reliably joining these two classes of materials has been very difficult which has greatly limited their commercial application.

The present invention was reduced to practice in several stages utilizing several materials including the superalloy Inconel 718 as the structural substrate (typically using test substrates that are ~0.125" thick x ~0.5" wide x ~1.5" long). Kovar which is an iron-nickel-chromium alloy was selected as the intermediate CTE or "compliant" interlayer between the Inconel 718 and the SiC/SiC composite. Kovar has a CTE of ~7 x 10^{-6} cm/cm/°C from RT to ~600°C which is approximately midway between the CTE's of Inconel 718 and the SiC/SiC composite.

In fabricating the joints, Kovar was first laser welded to a Inconel 718 substrate. Next one of several different braze alloys was used for bonding the SiC/SiC composite to the Kovar. The SiC/SiC composite material was supplied by Goodrich who is one of the collaborators on the OAI project. The various processing steps that resulted in the fabrication of high strength Inconel 718 SiC/SiC bonded components via the application of this invention disclosure is described below.

Figure 1 shows examples of the employed Inconel 718 and Kovar pieceparts. Initial experiments were performed to determine if the strength of the laser weld between the Inconel 718 substrate and the Kovar would be great enough to allow the eventual formation of high strength metal to SiC/SiC composite joints. The laser welding was performed by Precision Joining Technologies, Miamisburg, OH. Figure 2 shows an example of a "fully" welded Inconel 718/Kovar test specimen. The term "fully" designates multiple laser weld beads of ~30. ("4-line" welded Inconel 718/Kovar test specimens were also fabricated). Figures 3 and 4 are close-ups showing the quality of the welds.

Figure 1. (top) Machined Inconel 718 bar and (bottom) 0.007" thick Kovar piece.

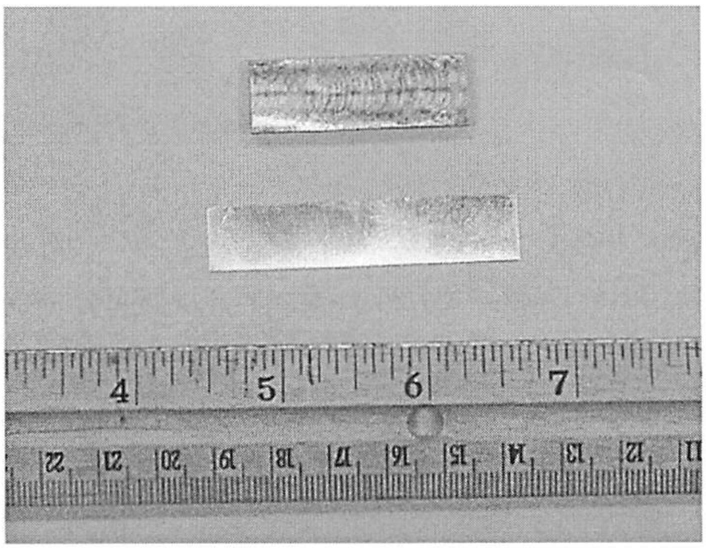


Figure 2. "Full" Laser welded Inconel 718/Kovar lap shear specimen

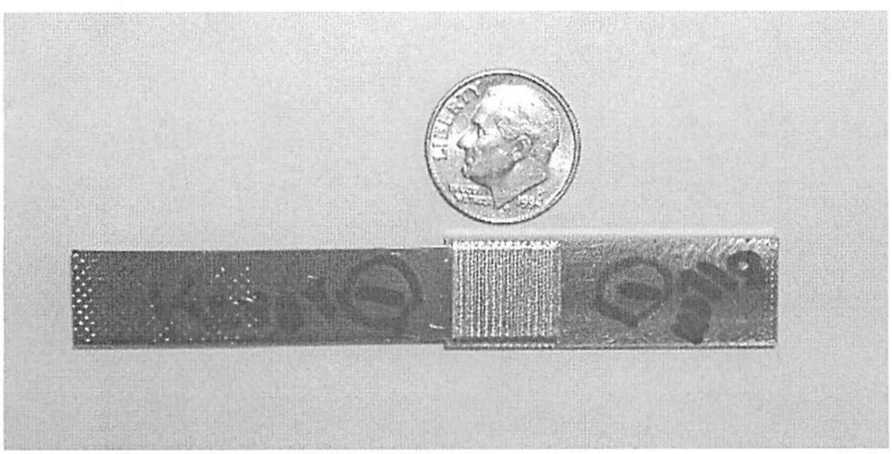


Figure 3. Close-up of Laser Welded "Full" Inconel 718/Kovar Lap Shear Specimen; (left) Kovar and (right) Inconel 718 that is ~0.5" wide.

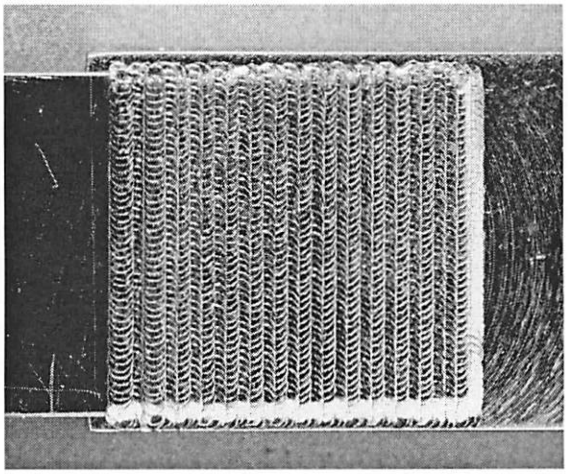
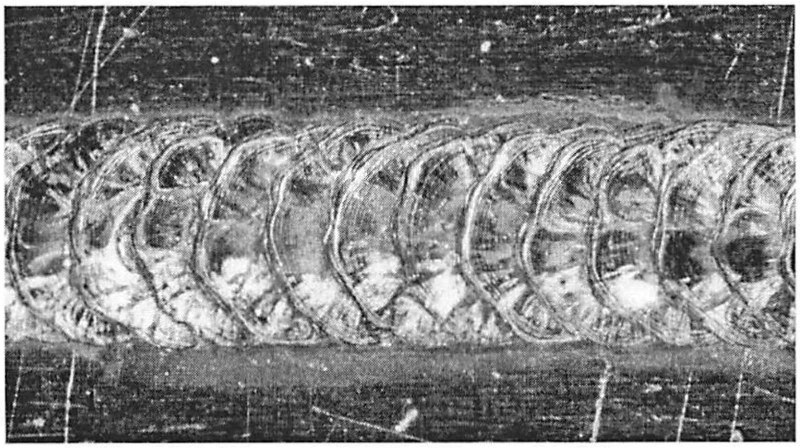


Figure 4. Close-up of Laser Bead on Kovar Surface



Tensile lap shear mechanical tests were performed on laser welded Inconel 718/0.007" thick Kovar specimens. The results obtained on "4-line" laser welded specimens are shown in Figures 5 and 6. The results are very promising as the tensile lap shear specimens failed only via the actual yielding of the Kovar strip material; without any indication of failure in the laser weld itself. Overall the data demonstrates that the Kovar yielded before the failure of the welds, demonstrating that the welds are inherently stronger than the Kovar.

Figure 5. Tensile lap shear results obtained on Inconel 718/Kovar laser welded specimen

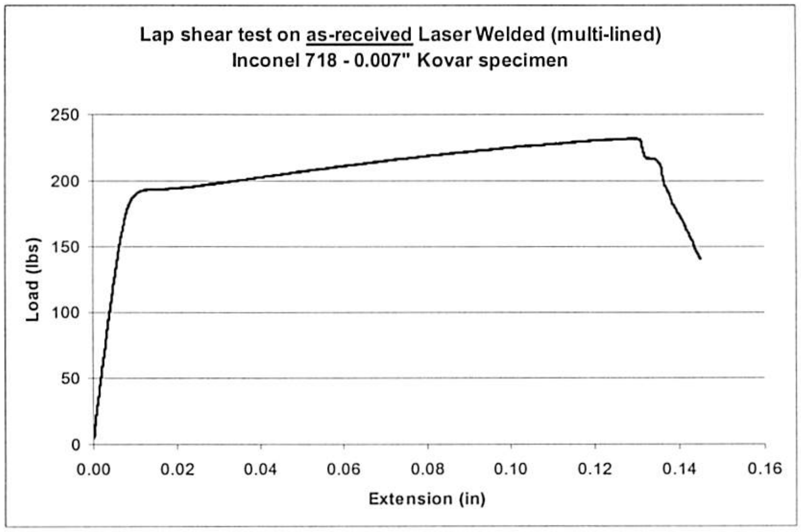
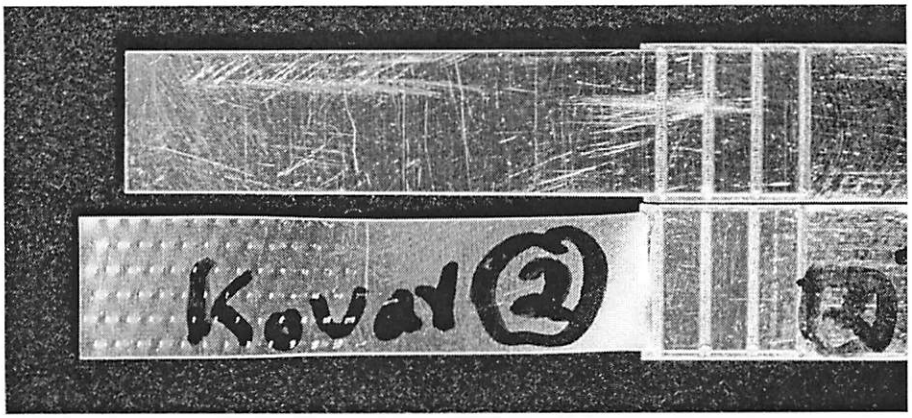


Figure 6. (top) Close-up of an untested "4-line" laser welded specimen (left – Kovar sheet and right – Inconel 718 substrate); and (bottom) after a tensile lap shear test showing Kovar elongation and necking.



Once it was demonstrated that laser welding resulted in a strong Inconel 718 / Kovar subassembly, experiments were initiated on joining the SiC/SiC composite to the laser welded Kovar using various braze materials. Several braze foils including Incuro, Nioro, Nioro ABA, or Ticuni (manufactured by Morgan Advanced Ceramics/Wesgo located in Hayward, CA) were obtained for these experiments. Figure 7 shows the "sequence" of pieceparts prior to assembly for the brazing operation. Figure 8 is a photograph taken through a window on the hot press showing the assembled pieceparts during a brazing operation. Figure 9 shows a set of Inconel 718-Laser welded Kovar/Incuro braze/SiC-SiC composite bonded tensile lap shear test components. Several of these components were tensile lap shear tested. The tensile lap shear test results shown in Figure 10 were obtained on test specimen IN-4 that was a Inconel 718-Laser welded Kovar/Incuro braze/SiC-SiC composite. The results show that the bond as fabricated was very strong as it eventually failed only after the application of ~750 pounds of load which corresponds to a bond strength of ~4250psi.

These results demonstrate that the developed processing techniques as described in this disclosure can yield high strength joints between a high CTE superalloy such as Inconel 718 and low CTE ceramic based SiC/SiC composites. This will allow the product or engine designer much greater latitude in the design of high strength metal to CMC components.

Figure 7. Pieceparts prior to brazing (Left to Right); SiC/SiC composite, Braze foil, Inconel 718 substrate with laser welded Kovar square.

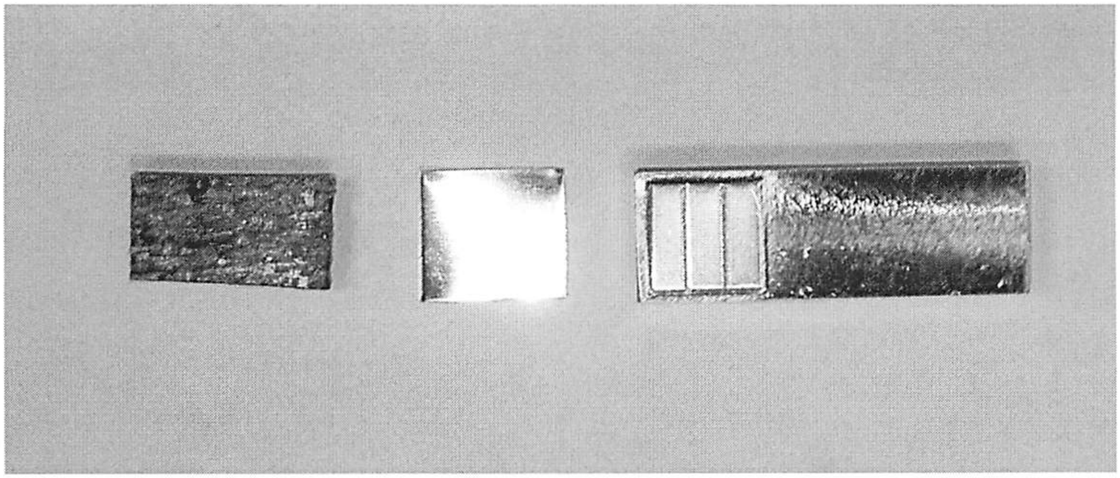


Figure 8. Picture taken through window on the hot press during a brazing operation.

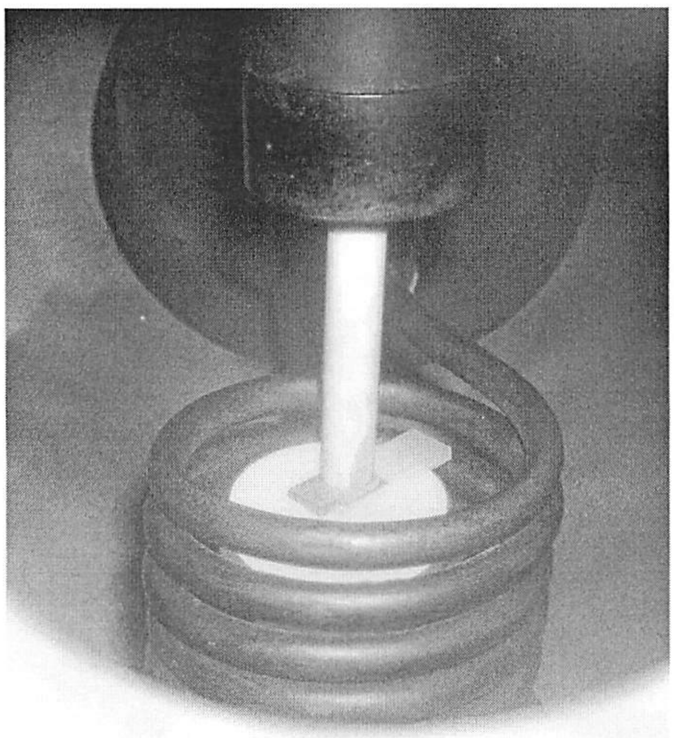


Figure 9. Inconel 718-Laser welded Kovar/Incuro/SiC-SiC composite tensile lap shear specimens.

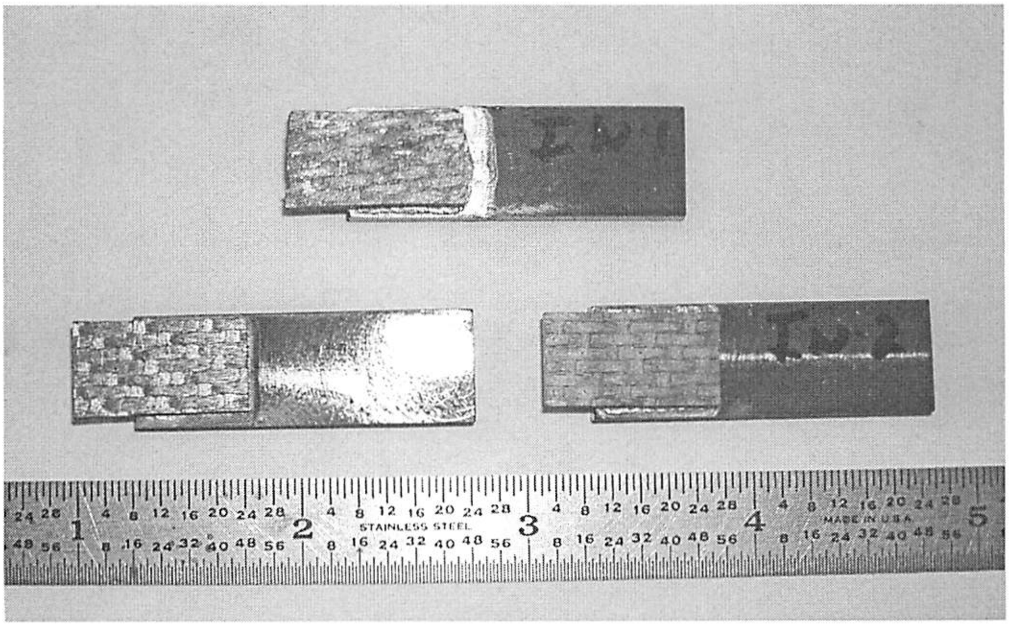
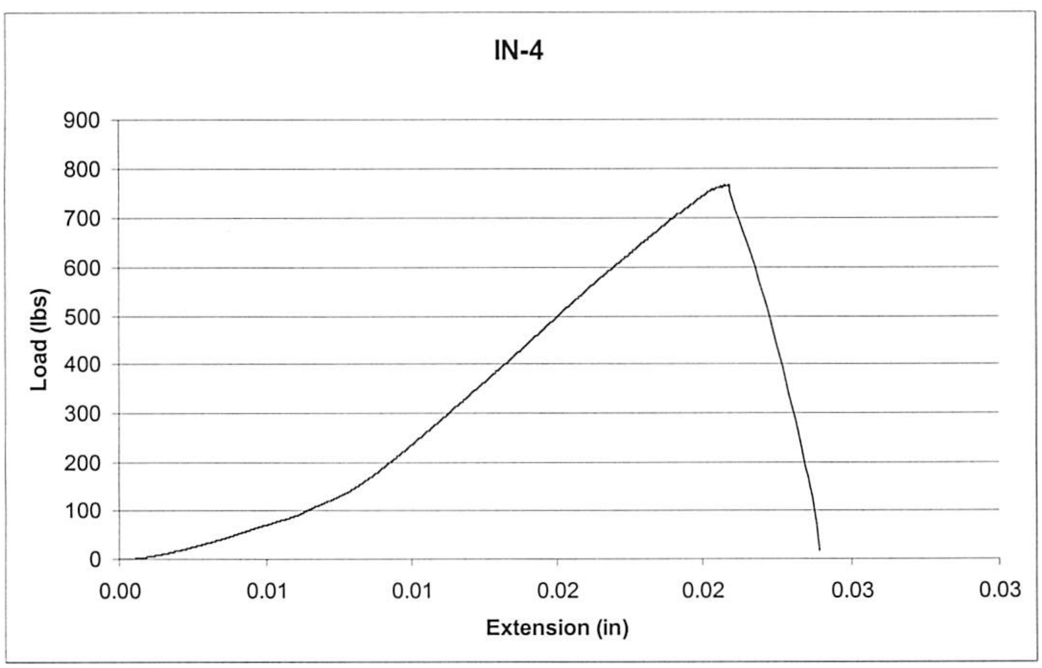


Figure 10. Results of lap shear test on Inconel 718-Laser welded Kovar/Incuro braze/SiC-SiC bonded component. The results show that a strong component was fabricated as it only failed after the application of ~750 pounds of load which corresponded to a bond strength of ~4250psi.



Bonding Process for the Joining of Metals to Ceramic Matrix Composites and Ceramics

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04-18-07

- This invention discloses a bonding processing technique that may be applied to the fabrication of bonds, joints, and/or components consisting of metal to metal, metal to ceramic, metal to glass, metal to composites, and various combinations of these materials.
- The process may utilize intermediate layers of materials that have coefficient of thermal expansions (CTE) between the coefficient of thermal expansions of the two materials that will be joined.
- An example of an intermediate layer is the use of a thin "bonding" sheet material that has an intermediate CTE between many metals that have higher CTE's and many ceramics that have lower CTE's. The metal called Kovar is one such example that has a CTE of ~7 x 10E-6 cm/cm/oC (RT - ~600oC) while many metals have higher CTE's and many ceramics have lower CTE's.
- Another example of an intermediate layer is the use of a thin "bonding" sheet material that has a low CTE between closer to the CTE's of many ceramics. The metal called Invar is one such example that has a CTE of ~<4 x 10E-6 cm/cm/oC (RT - ~500oC) while many metals have higher CTE's and many ceramics have equivalent or slightly higher or lower CTE's.
- These intermediate layers will be bonded to one of the two pieceparts that need to be joined together. Several techniques can be used such as metallizing, brazing, welding, and diffusion bonding.
- An example of a technique for joining an intermediate layer to one of the pieceparts is the application of laser welding. Examples of employing laser welding are described in the Invention Disclosure centered on the welding of a Kovar intermediate layer directly to a piecepart. Various laser processing parameters can be used to accomplish the welding.
- An example of the joining of a Kovar intermediate layer to an Inconel 718 piecepart via a laser welding process is in the Invention Disclosure. Inconel 718 that has a CTE of ~14 x 10E-6 cm/cm/oC (RT - ~600oC) is one of many similar materials that are known as superalloys. Inconel 718 is a nickel-chrome based superalloy, however, other superalloys such as iron-nickel based, cobalt-based and other superalloys could be used.
- Another example of metal that could be joined using the process are iron based steel, stainless steels, and other metals to which an intermediate layer can be attached.
- The application of an intermediate layer to one of the piecepart that will typically but not necessarily be a metal substrate is the first step in the fabricating of the joint between two pieceparts. The second process is to use a solder, braze, glass,

glass-ceramic, or other "bonding material" to form the final joint between the intermediate layer and the second piecepart.

- An example of bonding materials such as a braze is Incuro, another example is Nioro, still another example is Nioro ABA, and still another example is Ticuni. These are brazes from Wesgo Metals which also makes a large number of braze materials such as Cusil, Nicusil, and still other brazes. Other brazes from other companies besides Wesgo Metals could also be used.
- Various other bonding materials such as glasses such as an example 7052, or glass-ceramics such as S-glass-ceramic and many other examples could be employed as the bonding material.
- The bonding material will form a bond between the intermediate layer and the second piecepart in several ways including utilizing heating in an oven, furnace, heat lamp or other heating apparatus. The application of epoxies or some other self-curing or drying materials may not require a heating process.
- The second piecepart could be the same or another metal as the first piecepart, or it could be a ceramic such as alumina, or a composite material such as Silicon Carbide/Silicon Carbide or SiC/SiC.
- One example as outlined in the Invention Disclosure of one aspect of the described process consists of first laser welding a thin sheet of Kovar to an Inconel 718 piecepart. Next the bonding material which may be a braze which may be Incuro is placed on top of the welded Kovar. The second piecepart which in this case was SiC/SiC composite (CTE of ~4 x 10E-6 cm/cm/oC RT - ~600oC) was placed on top of the bonding material. The assembly was placed in this case inside a vacuum furnace and heated to ~1000oC for 10 minutes. Lap shear tests on the specimen confirmed a strong bonded component was fabricated between the high CTE. The described processing techniques were successfully practices in the fabrication of a high strength joint between the high thermal expansion superalloy and a low thermal expansion CMC.
- Heating temperatures, heating soak times, or the thermal profile is a function of the materials being joined.
- The commercial and/or government use of this invention is varied and includes many fields but is not limited to aerospace, automotive, medical and other applications where there is a need to bond two materials that may or may not have a large CTE differential.
- An example is the need of jet engine manufacturers who desire to operate at higher temperatures than the metals they presently employ will withstand. By fabricating for example Inconel 718-SiC/SiC joined components, the jet engines may be able to operate at higher temperatures due to the higher temperature capability of the SiC/SiC compared to the Inconel 718. This would result in improved engine performance and due to higher temperature operation high fuel efficiencies that can be easily shown via the Carnot equation.
- Another example of improved performance of being able to bond a Ceramic Matrix Composite such as SiC/SiC composite to a metal substrate such as a superalloy such as Inconel 718, is that the resultant component will be able to withstand more hostile operating environments due to greater erosion, corrosion, chemical stability of many CMC's over metals.

- This disclosure describes a processing technique that has successfully allowed the joining of a high thermal expansion superalloy to a low thermal expansion CMC. This disclosure employs the application of a unique interlayer that readily facilitates bonding to the CMC.
- Specimens have been successfully fabricated between a high CTE superalloy and a low CTE CMC using the invention. Lap shear tests have been performed on the components with the results demonstrating high strength bonds.