Titanium Aluminide Applications in the High Speed Civil Transport

Paul A. Bartolotta and David L. Krause
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
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Glenn Research Center
Cleveland, Ohio 44135

Abstract

It is projected that within the next two decades, overseas air travel will increase to over 600,000 passengers per day. The High Speed Civil Transport (HSCT) is a second-generation supersonic commercial aircraft proposed to meet this demand. The expected fleet of 500 to 1500 aircraft is required to meet EPA environmental goals; the HSCT propulsion system requires advanced technologies to reduce exhaust and noise pollution. A part of the resultant strategy for noise attenuation is the use of an extremely large exhaust nozzle. In the nozzle, several critical components are fabricated from titanium aluminide: the divergent flap uses wrought gamma; the nozzle sidewall is a hybrid fabrication of both wrought gamma face sheet and cast gamma substructure. This paper describes the HSCT program and the use of titanium aluminide for its components.

Introduction

In 1997, the National Aeronautics and Space Administration (NASA) developed an aeronautics and space transportation technology strategic roadmap called the "Three Pillars for Success". As the name suggests, this plan maps out NASA's future efforts and goals through the year 2020. Three categories (or *Pillars*) are described. The Pillar One focus is on Global Civil Aviation. Goals in Pillar One concentrate on increased civilian safety, reduced subsonic exhaust and noise emissions, and increased affordability. Pillar Two: *Revolutionary Technology Leaps* is the location of the HSCT program. Also included in Pillar Two are programs to develop innovative design and manufacturing tools and technology. Finally, Pillar Three concentrates on the access to space. Included in this pillar are efforts to reduce costs of space flight by developing reusable launch vehicles (RLV) and advancing propulsion technologies. To achieve all of the goals listed in each pillar by the year 2020 requires strong partnerships between NASA, industry and academia.

Supersonic Technology (Pillar Two goal)

To maintain the nation's aeronautical leadership, NASA is working in concert with the aircraft industry to develop enabling technologies for a HSCT. The enabling technology goals to be reached within 20 years are: i) reduce overseas travel time by 50 percent, ii) reduce exhaust emissions to well below today's subsonic engines, iii) decrease noise levels slightly below present engines, and iv) achieve this with at most a 15% increase in today's subsonic fares. The focussed program chartered to turn these goals into reality is embodied in the High Speed Research (HSR) program. Present efforts are targeted for a 300 passenger aircraft that flies at supersonic speeds of Mach 2.4 and takes-off and lands at conventional airports (figure. 1). Many enabling technologies are required to meet this target configuration and the most critical are being addressed in the HSR program.

Figure 1: Artist rendering of the 300 passenger High Speed Civil Transport.

The HSR program is a partnership between NASA, Boeing, General Electric (GE), and Pratt & Whitney (PW). Due to the stringent environmental noise and emissions goals, most of this effort is concentrated on the propulsion system. The HSCT engine size is larger than conventional subsonic engines such as the GE90 or Pratt & Whitney PW4000. As shown in figure 2, the engine has two distinct sections. The front half of the engine consists of the turbomachinery and the combustor. The boxed region (figure 2) denotes the exhaust nozzle, which is primarily used for noise attenuation.
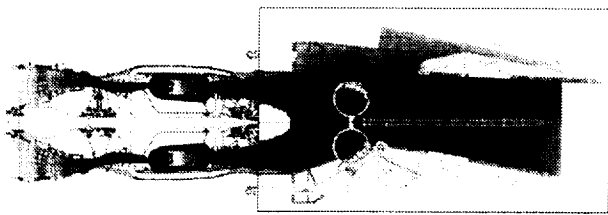
Figure 2: Schematic of the HSCT propulsion system being developed in the HSR program. The boxed area is the exhaust nozzle portion of the engine.

To meet emissions goals, the operating temperature of the engine core reaches supercruise temperatures typical of military jet engines during supercruise, or commercial engines during take-off conditions[1]. The key difference for the HSCT engine is that the major components also need to withstand these temperature extremes for longer periods of time (over 4 hours) and have design lives similar to today's commercial engine components (~18,000 hours). This requirement developed the need for advanced materials that maintain their structural integrity during extreme high temperatures and for long exposure durations.

In addition to their long-term temperature capabilities, the HSCT materials need to be lightweight. According to HSR calculations, for every unit of mass saved in the propulsion system, the Gross Take-Off Weight (GTOW) of the HSCT is reduced by ten times that amount. Weight plays an important role for several reasons. From an economics point-of-view, a low GTOW equates to more passengers and longer cruise range (more passenger-miles). And in order to be an acceptable transportation alternative, the HSCT should not require a drastic change in airport infrastructure (i.e., land and take-off using existing runways). This is also accomplished by maintaining a low GTOW. Finally, from an airframe viewpoint, a low engine weight reduces the structural requirements of the wings and fuselage.

The combination of long term durability, high temperatures, and low weight goals make TiAl a viable candidate for several critical components in the HSCT propulsion system. TiAl is being considered in two product forms (cast subcomponents and wrought sheets). Along with these different forms, several compositions of TiAl are being studied. The HSR program is also addressing joining techniques, cast repair methods, and production fabrication processes. This paper shows the progress that the HSR team has achieved in the last several years and addresses future HSR requirements for TiAl in other components of the HSCT propulsion system.

TiAl Applications in the HSCT Propulsion System

Perhaps the most extensive use of TiAl can be found in the HSCT exhaust nozzle. This is where TiAl research was initiated in the HSR program. Originally, cast TiAl was selected for the divergent flap of the nozzle (figure 3).

TiAl was chosen for its high specific stiffness (modulus-to-weight ratio) and its high temperature capability. The divergent flap is a relatively large component (1.8 m X 3.0 m) that is designed for very small deflections.
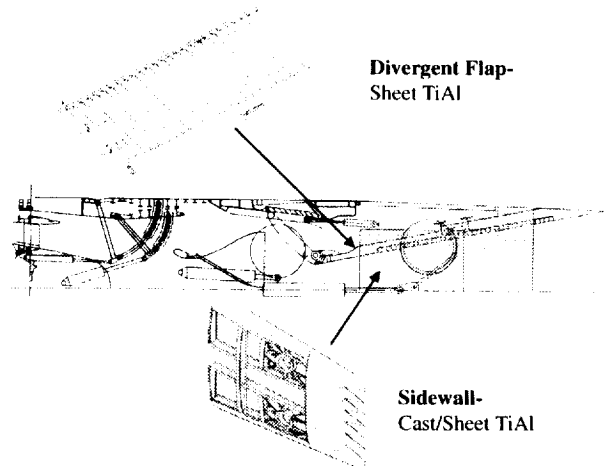

Figure 3: HSCT exhaust nozzle illustrating the use of TiAl for the major nozzle components.

The small deflection requirement is two-fold. First, the performance of the engine is dependent upon certain dimensions of the exhaust nozzle. One critical dimension is the exit area of the exhaust nozzle. Since the width of the divergent flap is relatively large, a small deflection can cause a significant change in that area. From a deflection limited structural viewpoint, the divergent flap is the back-structure of the HSCT engine's acoustic treatment. The acoustic treatment consists of ceramic matrix composite (CMC) tiles and bulk acoustic absorber. The CMC tiles are used to protect the bulk absorber from the turbulent hot exhaust gases. Each tile is connected to the flap via a ceramic fastener. The survival of both the CMC tile and ceramic fastener is directly dependent to the deflection of the divergent flap (i.e., large flap deflections will cause produce high bending stresses in the tiles and fasteners).

In addition to the low deflection criterion, the divergent flap needs to be lightweight and fabricated from high temperature resistant materials. It is estimated that certain regions of the divergent flap will experience temperatures of over 750°C for long exposure times (over 4 hours). Several design concepts and material systems were initially considered (i.e., sheet metal, metal matrix composites, monolithic superalloys and titanium alloys). After an exhaustive study, cast TiAl was chosen as the prime material for the divergent flap.

During the past several years, the HSR program made significant advances in casting technologies for TiAl, and this will be addressed in the next section. However, findings of several HSR studies proved that a cast TiAl flap did not have significant cost and weight savings as

expected. These new studies did show that a divergent flap fabricated from wrought sheet TiAl would have those savings. Fueled by recent successes of Plansee in producing wrought sheets of TiAl, it was decided to concentrate the flap efforts toward sheet TiAl fabrication as shown in figure 3. Here too, the HSR program has made considerable contributions to the wrought TiAl arena in developing forming and joining techniques.

Cast TiAl is still being pursued for other exhaust nozzle applications. These same studies showed that the nozzle sidewall would have significant savings by utilizing a cast TiAl substructure and wrought TiAl face-sheet hybrid sidewall structure (figure 3). Many of the pioneering casting techniques and wrought sheet fabrication methods are being utilized to produce the sidewall subcomponents for the HSCT exhaust nozzle.

Cast TiAl Progress

It has been shown that variability in strength, ductility, and stiffness of TiAl is associated with variations in Al content[2] that can be related, among other factors, to the TiAl microstructure. There are three basic microstructures that can be produced in TiAl depending on the Al content and material processing: equiaxed, duplex and lamellar. TiAl that is composed of either all equiaxed γ grains or all lamellar colonies (γ plus α_2 phase [DO_{19} structure]) has material properties on opposite ends of the spectrum. The equiaxed structure provides for higher room temperature ductility, while the lamellar structure has better fracture toughness and creep properties. The duplex structure can be thought of as a compromise between the lamellar and equiaxed microstructures. Composed of lamellar colonies that form interspersed about equiaxed γ grains, the duplex microstructure leads to higher strength and ductility, but lower fracture toughness. It also has been shown that Al content can influence the amount of lamellar colonies that form about equiaxed γ grains[2].

Table 1. Tensile Properties of cast Ti-48-2-2 and XD at 25 °C

Property	48-2-2	XD
Yield Strength (MPa)	275-380	400-600
Ultimate Tensile Strength (MPa)	360-500	485-720
Ductility (%)	1-3	0.5-1.5
Modulus of Elasticity (GPa)	160-175	160-175
Fracture Toughness (MPa$\sqrt{m}$)	22	17

Initially, there were two types of TiAl being considered for the cast divergent flap: Ti-48Al-2Nb-2Cr (atomic %) and Ti-45Al-2Mn-2Nb (atomic %) + 0.8 TiB$_2$ (volume %), respectively named Ti-48-2-2 and XD. The addition of TiB$_2$ in the XD inoculates the gamma alloy that results in refined grain sizes[3] ranging from 100 to 150 μm. In contrast, the Ti-48-2-2-cast material has grains approximately 4 times larger than the XD. As seen in

table 1, the refined grain size of the XD gives it a higher strength than the Ti-48-2-2. However, with the increased strength, XD has a lower ductility and fracture toughness.

In general, both cast Ti-48-2-2 and XD TiAl alloys have a duplex microstructure, which consists of γ grains, and $\alpha_2+\gamma$ lamellar structure. XD has a finer microstructure and grain size, which primarily consists of lamellar grains with TiB$_2$ particles. The Ti-48-2-2 alloy has a somewhat larger grain structure and the amount of lamellar structure varies significantly within the casting. In general, the Ti-48-2-2 shows more variation in the grain structure and exhibits textured material properties in thin components[4]. Both alloys have attractive material characteristics; however, the program needed to proceed with only one cast TiAl composition.

To down-select to one TiAl alloy, divergent flap segments were cast from both Ti-48-2-2 and XD alloys (figure 4). The flap section shown in figure 4 is believed to represent the largest TiAl casting yet produced. The divergent flap segments proved to be a challenge in casting TiAl. The flap section shown in figure 4 incorporates all of the cast features of the product flap. Casting defects such as hot tears, porosity, no fill, and shrink were more prevalent in this component configuration than any ever attempted before with TiAl.
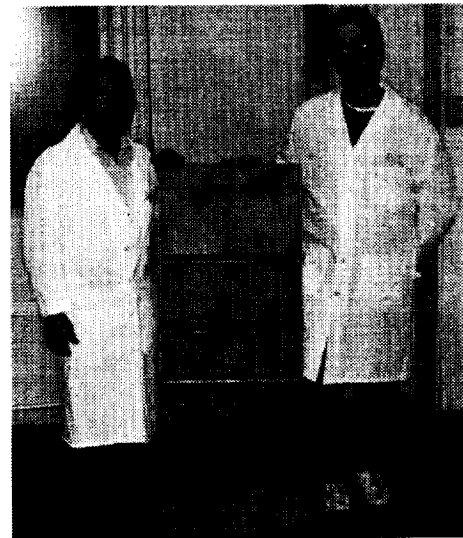

Figure 4: Proposed divergent flap prototype fabricated from cast TiAl (Ti-48-2-2).

There were several factors (size, geometry, material properties, and microstructure) contributing to these problems. The flap segment, being a rib-stiffened component with several rib thicknesses varying between 2 mm to 20 mm, has many features that are difficult to cast. Hot tears and internal porosity occurred at many of the 90° intersections of the egg-crate structure. The majority of these issues were resolved for both TiAl alloys during

the HSR program. After an exhaustive down-selection process (based on castability, repairability, mechanical properties, machinability, and cost), it was shown that Ti-48-2-2 had a slight advantage over XD. Therefore, Ti-48-2-2 was chosen for all cast TiAl nozzle components.

As previously stated, the exhaust nozzle sidewall (figure 3) is a hybrid structure utilizing both a cast TiAl substructure and wrought TiAl facesheets. The sidewall substructure is comprised of tapered and curved cast TiAl I-beams. The average I-beam dimensions are 70 cm in length, over 10 cm in depth, and 2-10 mm in thickness. The I-beams will be electron beam welded together to form the sidewall. Subsequently, the TiAl facesheet is brazed on to the cast I-beam substructure to finish the fabrication of the sidewall.

In an effort to demonstrate and optimize the casting process prior to a final sidewall design, I-beams were cast in several configurations incorporating different salient features of the sidewall. One of the configurations is shown in figure 5. The most prevalent defect during the initial casting trials was hot tears located at the intersection of the flange and web of the I-beam. After several iterations the gating was optimized to eliminate these hot tears.
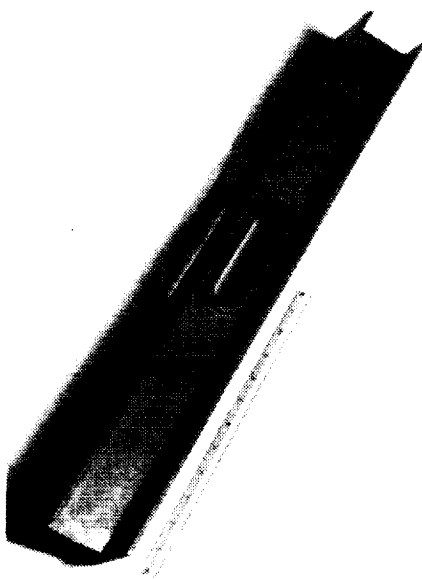

Figure 5: Cast Ti-48-2-2 I-beam and track illustrating salient features of the nozzle sidewall beams.

Joining of cast TiAl components is not trivial. Although mechanical fastening of cast TiAl has been successful, special expensive machining operations are required and the required reinforcing features for the mechanical fasteners add additional weight to the component. A less costly attachment method is electron beam welding. Electron beam welds of cast Ti-48-2-2 up to 25 cm in length and 15 mm thickness have been successfully made

as shown in figure 6. This type of weld requires special handling and unique weld procedures. To electron beam weld cast TiAl, the parts are heated in a controlled atmosphere to a prescribed temperature[5]. The parts are then slowly removed from the furnace and welded. As the weld is placed, the parts are simultaneously returned to a second furnace at the same prescribed temperature as the first and receive a final heat treatment. Following this process crack free electron beam welds have been produced in Ti-48-2-2 on a regular basis without difficulty. When properly heat treated, the all-weld metal room temperature tensile properties are generally better than the base metal's, while the creep and fracture toughness are equivalent.
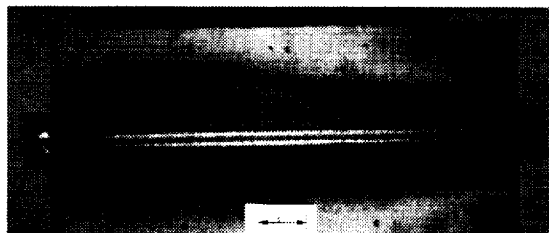

Figure 6: Defect free electron beam weld of cast Ti-48-2-2.

Conventional large structural titanium castings typically exhibit numerous defects. Depending on their location in the part, many of these defects are repairable. It is more cost effective to repair a large casting than to scrap it out. Typically, the castings are repaired by grinding out the defect and filling in by Gas Tungsten Arc Welding (GTAW) deposition. A repair technique was also developed for cast Ti-48-2-2 using GTAW[5]. These repairs are done in an inert atmosphere while the part is held at a uniform, elevated temperature. Simple castings of Ti-48-2-2 have been successfully repaired by GTAW. More complex geometry parts like rib-stiffened faceplates and sections from the prototype flap (figure 4) also have been repaired. Examples of relatively complex repair welds using GTAW of a 13-mm thick plate are shown in figure 7.
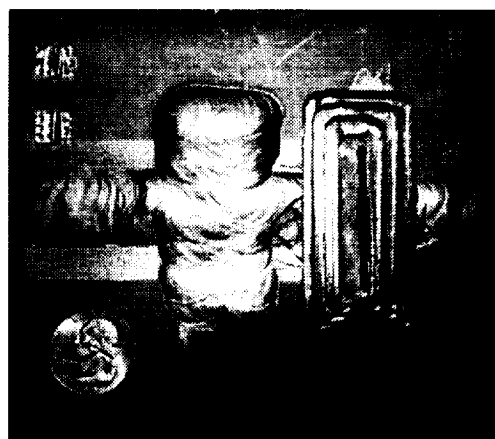

Figure 7: GTWA repair on cast Ti-48-2-2 slab.

Further HSCT applications of cast TiAl

Present applications have been limited to the relatively large exhaust nozzle components where the weight benefits of cast TiAl are substantial. Since the conception of the HSR materials development program, cast TiAl technologies have matured, and this has prompted HSCT engine designers to look at other applications for cast TiAl. Even though maximum use temperatures for long term exposures are approximately 760°C, designers have targeted ancillary components in the engine's combustor region for cast TiAl. The back-structure of the combustor liner is a prime candidate for cast TiAl. The weight advantage of cast TiAl over conventional superalloys makes it very attractive for this application in spite of TiAl's shortcomings.

Other applications are extensions of what is already demonstrated in present commercial aircraft engines. For example, GE is currently evaluating Ti-48-2-2 compressor cases (figure. 8). The T700 compressor case has a much smaller diameter than what will be required for the HSCT, but still similar casting technologies can be applied. Here again, the anticipated weight savings justify the development costs for a larger diameter casing.
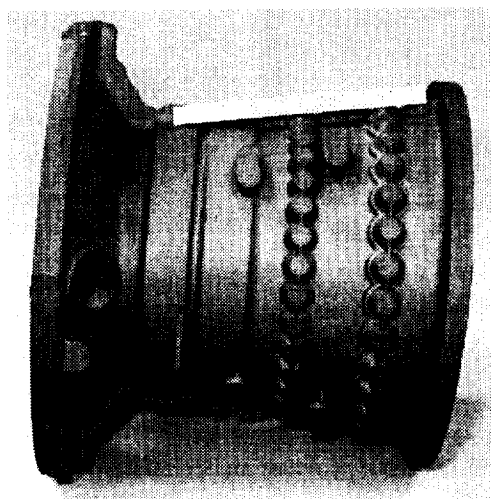
Cast Ti-48Al-2Cr-2Nb
T700 Compressor Case

Figure 8: T700 Compressor case fabricated from cast Ti-48-2-2. The HSR program is considering Ti-48-2-2 for a similar application in the HSCT engine.

GE is also developing a Ti-48-2-2 low-pressure turbine (LPT) blade for the GE90 engine (figure 9). These blades are similar in dimension to the LPT blades being designed for the HSCT. Casting techniques for the GE90 blades can be directly applied to the HSCT blades. Here the weight savings potential is two-fold. Obviously, the TiAl blades will lighter than the conventional superalloy blades. However, the real weight saving will be in the turbine disk.

The lower blade weight decreases the centrifugal force exerted on the disk, thereby decreasing the associated stresses and consequently the mass of the superalloy disk.

GE90 Cast-to-Size Gamma LPT Blade

Figure 9: Cast Ti-48-2-2 Low Pressure Turbine (LPT) blade prototype for the GE90 engine. Similar size and geometry of the HSCT LTP blades.

As can be seen from the previous discussion, significant progress in the advancement of cast TiAl technologies has been made via the HSR program. With these advancements, cast TiAl is being considered in many critical applications of the HSCT propulsion system. The opportunities for further applications in commercial aircraft are limited by the lack of understanding by the engine designers of cast TiAl capabilities and by its high temperature capabilities. The prior can be resolved by successes as seen in the HSR program. The latter will require new compositions of TiAl to be developed and verified. These new compositions must have temperature capabilities approaching superalloys (over 850°C).

Wrought Sheet TiAl Progress

Wrought sheet TiAl was down-selected over cast TiAl as the prime divergent flap material for the HSCT exhaust nozzle. The divergent flap (figure. 3) is comprised of two superalloy box beams supporting a series of sheet TiAl subelements (figure. 10). The fabrication of the sheet TiAl subelements required a significant international effort with contributions from industry, academia, and government. Sheet TiAl fabrication processes were optimized, forming methods were developed, and joining techniques were evaluated.
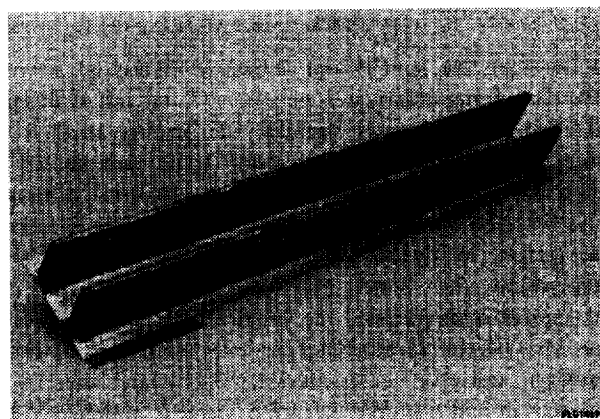

Figure 10: Sheet TiAl subelement of the Divergent Flap concept for the HSCT with salient features of the full-scale flap. [Material: Ti-46.5Al-4(Cr-Nb-Ta)-0.1B]

Prior to HSR involvement with wrought TiAl, Plansee of Austria had developed rolling techniques for TiAl as a subcontractor with a DoD program in the early 90's[6]. The original DoD program focussed on diffusion bonding and superplastic forming (SPF) methods of fabricating components from sheet TiAl[6]. Therefore, much of Plansee's efforts were concentrated on the ingot material (IM) process of TiAl sheet manufacturing. In the IM process, an ingot of TiAl is forged into a pancake prematerial. This pancake is then machined into a rectangular shape, canned, and hot rolled into thin sheets. The thin TiAl sheets are trimmed and surface ground to the final thickness. In their IM efforts, Plansee had selected a composition for the TiAl ingot that optimized certain material properties for the SPF process. This composition was Ti-46.5Al-4(Cr-Nb-Ta)-0.1B and was used for the HSR program too. The IM process is very costly and has high material rejection rates. This is due to the forging step of the IM process. However, the properties of the IM sheet TiAl are exceptional and have proven to be an excellent material for SPF.

With the aid of the HSR program, Plansee developed a new powder metal (PM) processing method for wrought sheet TiAl. The PM process starts with TiAl powders that have a composition the same as the IM material. The powder is then consolidated into a prematerial rectangle, canned, and hot rolled, similar to the IM process. Again after rolling, the sheets are de-canned, trimmed to final shape and surface ground to final thickness. According to HSR estimates, there is a significant cost saving with PM TiAl sheets because the forging step is eliminated. However, the PM TiAl sheet has a slight disadvantage over IM TiAl. Areas of micro-porosity are found in the PM sheets, and consequently this slightly limits the strength of the material. For the HSCT application, strength is not a primary design requirement, and therefore this is not an issue for the HSCT designers. All of the results described in this section are based on PM TiAl sheet material that has been hot rolled in only one direction.

To fabricate the subelement shown in figure 10, several different joining techniques were considered and evaluated. Diffusion bonding was initially the joining method of choice. Preliminary diffusion bond trials[7] are shown in figure 11. In figure 11a, the first attempt of a diffusion bond between two PM TiAl sheets exhibits a visible bond line (arrow in figure 11a). After optimizing the bond temperature the bond line disappears (figure 11b). Subsequent tests showed the bond strength to be greater than the parent sheet material, indicating the diffusion bonding was very successful. However, the bond preparation and required fixturing made it impractical for the large divergent flap application.
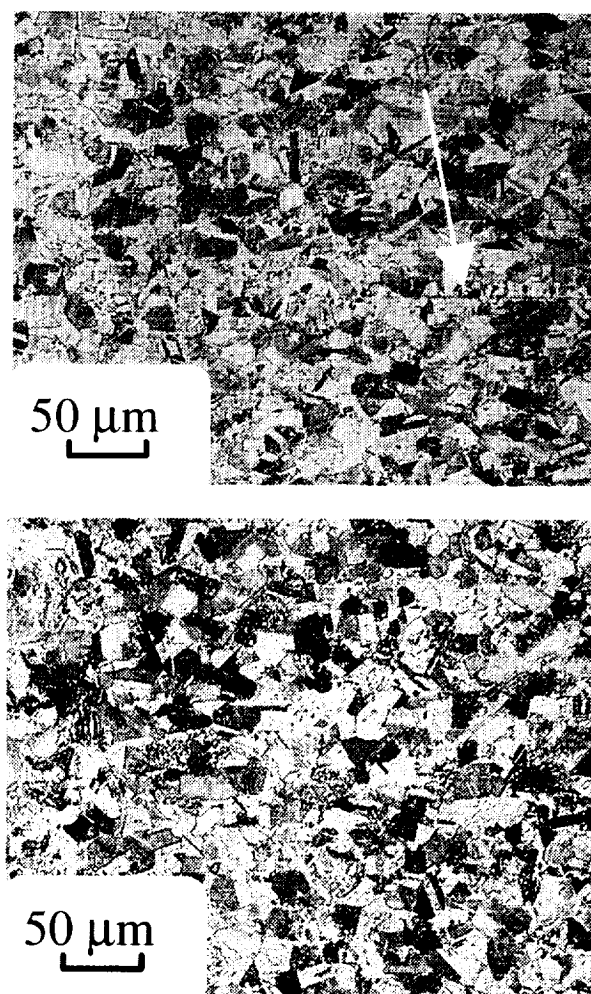

Figure 11: Microstructure of diffusion bond trial (a) initial attempt showing bond line, and (b) optimized diffusion bond process with no bond line[7].

An alternative joining method for the HSCT flap application is brazing. Brazing is not as strong as a diffusion bond but provides an economical option. Brazed joints using TiCuNi70 brazing film were successfully demonstrated in the laboratory[7]. An example of the brazed joint is shown in figure 12. As implied by the micro-hardness indicators (diamond marks in figure 12), the braze and its two reaction zones are more brittle than the parent TiAl material. This could be a problem in low cycle fatigue (LCF) situations; however, for this application, LCF does not limit the design life. Initial strength tests indicate the brazed joint to be structurally sound and providing full coverage within the joint area. These results provide confidence in using the TiCuNi70 braze, the primary joining method for the divergent flap.
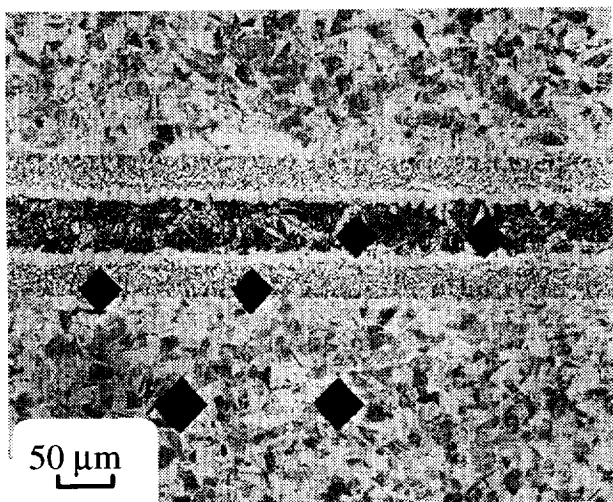
Figure 12: TiCuNi70 braze of Gamma TiAl sheet [Ti-46.5Al-4(Cr-Nb-Ta)-0.1B[7].

Mechanical fasteners will be required to attach the TiAl sheet subelements to the box beams of the divergent flap (figure 3). As a part of the effort to evaluate mechanical joining methods for sheet gamma, a series of room temperature and 700°C static tensile tests were conducted on riveted specimens (figure 13 a&b). The specimens were fabricated by joining two 13 mm X 64 mm X 1mm sheets with a 6 mm "Cherry max" stainless steel rivet. The holes for the rivets were drilled using water jet machining and subsequently honed to final dimensions. Initial test results showed smaller than expected failure loads[7] and failures initiating within the sheet TiAl at the rivet hole (figure 13a). No rivet failures occurred in any of the specimens. It was hypothesized that the drilling still produced some residual stresses. Therefore, a stress relieving heat treatment was prescribed on subsequent test samples. Results from subsequent tests with the heat treatment showed a marked increased in failure loads, and the majority of the failures occurred with the stainless rivet.

To evaluate wrought gamma TiAl as a viable material candidate for the exhaust nozzle, a divergent flap subelement was fabricated using 1-mm thick sheets of TiAl (figure 10). This subelement is the largest structure fabricated out of sheet TiAl. The subelement was approximately 85 cm in length and has 10-cm corrugations. Incorporated into the subelement were features that might be used in the fabrication of a full-scale divergent flap. These features included the use of i) shear clips to join together sections of corrugations, ii) multiple face sheets, iii) double corrugation sections and iv) brazed joints. Fabrication processes of double corrugation forming and face-sheet-to-corrugation brazes were extremely successful. Shear clip brazes were not as successful. Due to an incorrect process interpretation from laboratory to production unit, the braze coverage in the shear clip area only averaged between 70 to 85 percent. However, it was

shown that the braze coverage was not as important as the stress concentration caused by the shear clip itself.
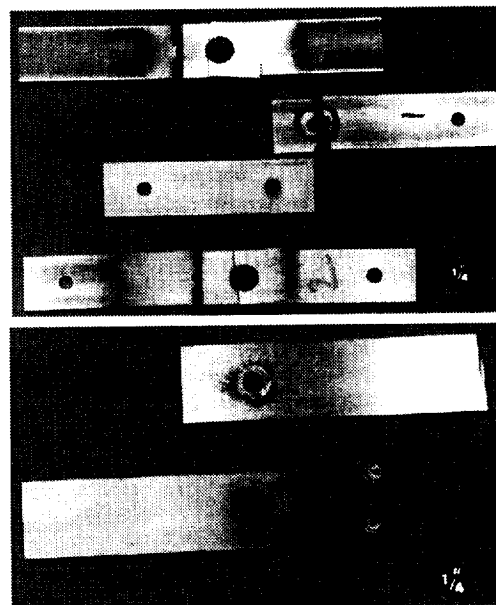

Figure 13: Mechanical fastening of sheet Gamma TiAl by rivet (a) as received, and (b) stress relieved conditions[7].

It was decided to cut the subelement in half (lengthwise) and test only one corrugation at a time. The subelement was tested at room temperature in a three-point bend using a uniform pressure instead of a point load (figure 14). The subelement had epoxy potted ends to ensure that the corrugations would not buckle due to the point load reactions at the roller supports.
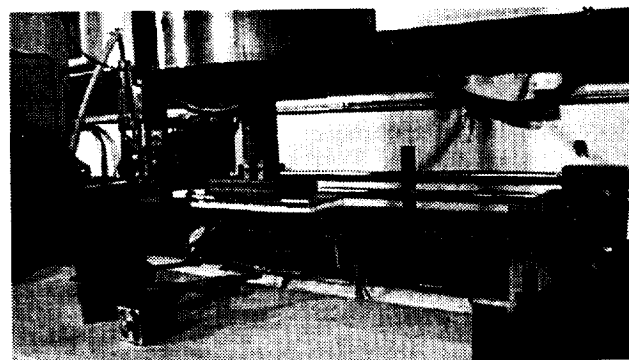

Figure 14: Static test of subelement. Load at 3.35 kN. Predicted failure load of 1.95 kN.

Periodically during the load-up, the subelement was examined for any external damage. Only a small crack in one of the brazed shear clips in the braze material was observed (note: this location was NOT the failure location). The beam deflection was noticeable with the naked eye at 3.35 kN (figure 14). Failure occurred shortly after reaching 3.75 kN, which was 90% higher than the predicted failure load. The subelement initially failed at the center shear clip edge within the stress concentration area (figure 15).

Pretest finite element analysis (FEA) results accurately predicted measured corrugation strains/stresses. Corrugation stresses were within 4% of predicted stresses. Post-test FEA using the failure load of 3.75 kN shows the stress at the failure location was 520 MPa. Since this is within 5% of the sheet gamma's ultimate tensile strength (UTS) of 550 MPa, it can be stated that the fabrication process of hot forming and brazing did not significantly affect the materials structural capability. The final conclusion from this test is that sheet gamma TiAl has a tremendous potential for the HSCT propulsion system.
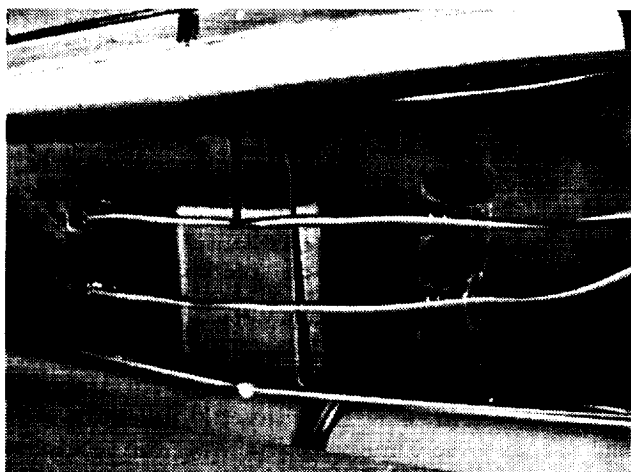

Figure 15: Failure of subelement at 3.75 kN, which is 190% of predicted failure load. Failure initiated at the edge of the center shear clip towards the apex of the TiAl corrugation.

Future applications for wrought sheet TiAl

With the success of the sheet TiAl subelement fabrication and test, sheet TiAl is gaining support as a potential replacement material for other components in the HSCT. Some candidate components are hot ducts and chute doors. Mentioned in the cast TiAl section, sheet TiAl is the primary material for the sidewall facesheet of the HSCT exhaust nozzle. As confidence continues to build and more successes arise, sheet TiAl may be considered as a lightweight replacement for sheet superalloys in other areas within the HSCT engine.

Like cast TiAl, wrought sheet TiAl is hindered by its high temperature capabilities. Improvements in TiAl compositions to increase its use temperatures to above 850°C would enhance its likelihood to be used as a superalloy replacement. Likewise, an increase in ductility and fracture toughness would make it more attractive to design engineers. Even with the success of braze joining methods, more work is needed to improve high temperature durability of these joints. Joining methods such as transient

liquid phase (TLP) bonding for sheet TiAl would be a great benefit to the aerospace community. With the HSR hot forming methods and a TLP bond, advanced concepts like TiAl honeycomb (figure 16) could be produced for the HSCT engine.
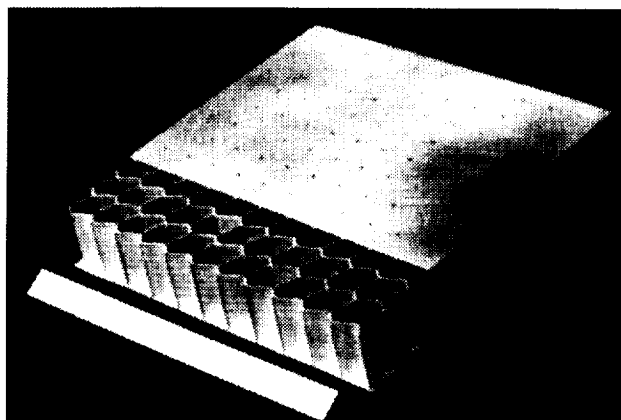

Figure 16: Example of advanced concept for sheet TiAl applications in HSCT engine.

Honeycomb structures have saved weight in conventional aircraft and could save weight in the HSCT. If successfully developed, TiAl honeycomb panels could be used in hot ducts and doors within the HSCT engine. TiAl honeycomb panels could also replace the sheet TiAl being used in the divergent flap and sidewall of the HSCT nozzle.

Presently, NASA's reusable launch vehicle (RLV) program is bookkeeping TiAl honeycomb as the primary thermal protection system (TPS) for the leeward side of the VentureStar™ (figure 17). The pioneering HSR fabrication and joining techniques have been transferred to the RLV program, representing a synergistic use of technology between space and aeronautics applications.
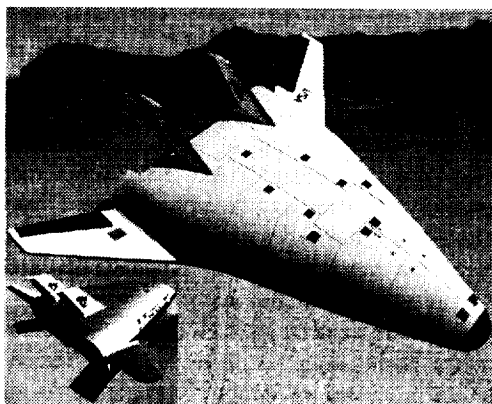

Figure 17: TiAl Honeycomb panels are being considered in the Reusable Launch Vehicle (RLV) program.

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13. ABSTRACT (Maximum 200 words)

It is projected that within the next two decades, overseas air travel will increase to over 600,000 passengers per day. The High Speed Civil Transport (HSCT) is a second-generation supersonic commercial aircraft proposed to meet this demand. The expected fleet of 500 to 1500 aircraft is required to meet EPA environmental goals; the HSCT propulsion system requires advanced technologies to reduce exhaust and noise pollution. A part of the resultant strategy for noise attenuation is the use of an extremely large exhaust nozzle. In the nozzle, several critical components are fabricated from titanium aluminide: the divergent flap uses wrought gamma; the nozzle sidewall is a hybrid fabrication of both wrought gamma face sheet and cast gamma substructure. This paper describes the HSCT program and the use of titanium aluminide for its components.

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Summary

Many of the presented advancements in casting, fabrication and joining technologies for TiAl are attributed to the HSR program. Much more work is required to achieve acceptance of this material system within the design community. However, the potential weight savings of TiAl over conventional superalloys have enticed design engineers to consider this material for high temperature applications where high stiffness is required. Each successful accomplishment in programs such as RLV and HSR creates an optimistic future for TiAl in aerospace applications. To truly capitalize on the potential for this class of material, more research is required. Areas for improvement include low cost material production, robust joining methods, and increased materials property database.

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