

Fabrication of Titanium Aerospace Hardware using Elevated Temperature Forming Processes

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ABSTRACT

Titanium is a difficult material to fabricate into complex configurations. There is several elevated temperature forming processes available to produce titanium components for aerospace applications. The processes to be discussed are Superplastic Forming (SPF), hot forming and creep forming. SPF uses a tool that contains the required configuration and seals around the periphery so inert gas pressure can be used to form the material. Of the processes to be discussed, this is the one that can produce the most complex shapes containing the tightest radii. A variation of the process combines an SPF operation with diffusion bonding (SPF/DB) of two or more pieces of titanium together to produce integrally stiffened structure containing very few fasteners. Another process for shaping titanium is hot forming. In this process, matched metal tools, offset by the thickness of the starting material, are used to form the part contour at elevated temperature. The required part geometry usually contains no sharp features that have to be formed. Starting blanks are often preformed in order to get the material as close as possible to the required shape to minimize thickness variation in the final part. The final forming process to be discussed will be creep forming. In this process, there is only a lower tooling surface. The starting material is placed on the tool and weights are then placed on the part, in the areas where forming needs to occur, and this set-up is placed in a piece of equipment for heating, which is typically a vacuum furnace. At elevated temperatures, the weights force the material down to the tool. Since the only forming force comes from the applied weights, only simple shapes can be achieved.

INTRODUCTION

Typically, the SPF process uses standard titanium alpha-beta alloys, like 6Al-4V, and the forming temperature is between 900° and 925°C (1650° to 1700°F). This forming temperature

causes tool wear and oxidation as well as shortens the life of press components, such as heaters and platens. A recent innovation in this technology has been the introduction of fine grain alloys that allow the forming temperature to be reduced to around 775°C (1425°F). This temperature range allows the tool to maintain a smooth surface and generates less alpha case on the part surface that has to be removed. Production hardware is currently being fabricated at Boeing using this material and the company received a patent in 2009 for SPF and SPF/DB processing using this alloy. For hot forming, the temperature is typically around 730°C (1350°F). In this process, matched metal tools, offset by the thickness of the starting material, are used to form the part contour. While this is typically a sheet (less than 4.75 mm (0.187 inch) thick) forming process, plate (thicker than 4.75 mm (0.187 inch)) can be formed and this is often used to pre-form plates that will be subsequently machined to the required configuration. The forming process allows a thinner plate of starting material to be used which lowers the buy-to-fly ratio, how much material starts to how much material is contained in the final part, as well as reduces the amount of time for machining which leads to lower cost products. The final forming process to be discussed will be creep forming. This technique is typically used to straighten parts that do not meet contour requirements or the desired forming is not very challenging. In this process, there is only a lower tooling surface. The starting material is placed on the tool and weights are then placed on the part, in the areas where forming needs to occur, and this set-up is placed in a piece of equipment for heating, which is typically a vacuum furnace. At an elevated temperature similar to hot forming, 730°C, the weights force the material down to the tool. Since the only forming force comes from the applied weights, only simple shapes can be achieved.

All three of these processes are capable of forming titanium. However, each process is used for different applications

based on the limitations as to how complex of a configuration can be achieved. Since all of these processes involve temperatures that are above the annealing point of the material, which is around 700°C (1300°F), there is little to no spring back after the part cools down which is important for fabrication of aerospace hardware.

SUPERPLASTIC FORMING [1]

Superplastic forming is an elevated temperature process for forming certain metal alloys. The process can produce components of complex geometry by means of applying inert gas pressure to form the required configuration. The parts are fabricated without excessive material thinning or rupture and typical elongations are usually 300% or less. The SPF temperature for standard titanium 6Al-4V with a grain size of about 8 μm , and other standard grain alpha-beta alloys such as 6Al-2Sn-4Zr-2Mo, is between 900° to 925°C. At these temperatures, die life and surface finish are issues that have not found cost effective solutions. Stainless steel alloys have been developed that successfully withstand oxidation at 900°C in air, however, it is apparent that under the SPF conditions of combining titanium, graphite and boron lubricants along with a low partial pressure of oxygen, as well as other factors, the die surface is preferentially attacked, so that dies have to be regularly cleaned in order to maintain the required surface finish. This is required to ensure the surface finish on the SPF part is within allowable limits. Eventually, the prolonged thermal cycling of the dies results in degradation of the tool surface that normal clean-up will not be able to remove, as shown in [Figure 1](#). Since the titanium surface is easily marked at elevated temperature, these imperfections in the die surface will cause surface irregularities in the titanium during the SPF operation. Also, the design of an SPF die inevitably has both thick and thin sections, and the stresses caused by repeated thermal cycling to 900°C eventually cause the die to develop cracks. These conditions result in having to replace the dies at specific intervals.

In order to lower the forming temperature of the 6-4 titanium alloy, collaborative research between Boeing and Verknaya Salda Metallurgical Production Association (VSMPO) in Russia, yielded a fine grain version of this material with a grain size of about 1 μm that was capable of being superplastically formed at around 775°C. The chemistry of the alloy was kept within the limits of the AMS4911 specification in order to keep the designation familiar to engineers and manufacturing. Also, this assisted in minimizing any mechanical property testing that would be required to qualify the material after SPF since the properties already existed for standard grain material. Forming at this lower temperature reduces the amount of alpha case, a brittle, oxygen rich layer on the surface that affects fatigue, which has to be removed by chemical milling. Development lots of

the material were tested on current production parts, such as the one shown in [Figure 2](#).



Figure 1. Typical SPF die surface after numerous thermal cycles at 900°C.

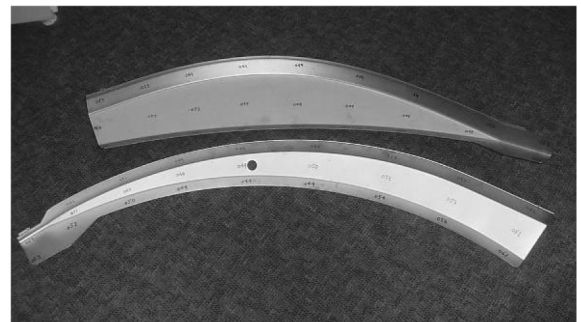
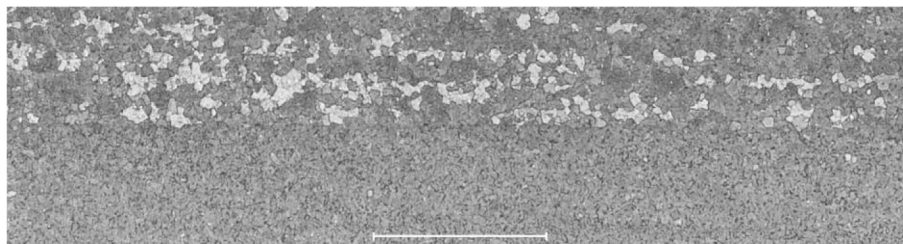


Figure 2. Test part from a production die using fine grain 6Al-4V developed by VSMPO, the top detail being approximately 117 cm (46 inches) long.

Two, or more, sheets of clean titanium are capable of being diffusion bonded together so it was also of interest to have a material that would diffusion bond at this lower temperature of 775°C. Testing showed that the fine grain 6Al-4V material would diffusion bond to itself at this temperature using the same times and pressures typical for standard grain sheet. It was also discovered that this material would diffusion bond to standard grain alpha-beta titanium alloys, as shown in [Figure 3](#), at this same temperature using the same time and pressure profiles. This is an important innovation since standard grain alpha-beta materials require temperatures around 900 to 925°C in order to fully diffusion bond [2]. In 2009, Boeing was granted a U.S. patent covering SPF and SPF/DB of fine grain 6Al-4V titanium [3].



125 μm

Figure 3. Diffusion bond between fine and standard grain 6A1-4V titanium.

HEAT SHIELDS FOR A TWIN AISLE AIRCRAFT [1, 4, 5]

Titanium heat shields are used to protect the structure above the engine exhaust from the high temperature gases. In the past, these components were typically castings. However, on recent aircraft, the heat shields have been fabricated using titanium sheet metal details to save cost and weight. On some aircraft, the heat shields are simple bent components fabricated by hot forming. However, on twin aisle aircraft, the geometry no longer allows this type of fabrication. When heat shields were being developed for a twin aisle airplane, castings were the first choice. However, to save cost and weight, assemblies of single sheet SPF details as well as two-sheet SPF/DB components were designed as shown in Figure 4. A portion of these details are produced using the fine grain 6A1-4V alloy from VSMPO.

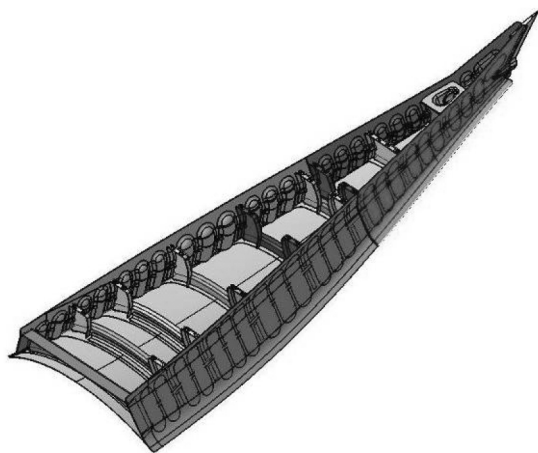


Figure 4. Titanium sheet metal heat shield assemblies containing SPF and SPF/DB components.

Fabrication of SPF Components

The SPF components for the heat shield assemblies were fabricated in multi-cavity dies in order to get the best utilization of the starting material. The parts to be nested together were chosen so the amount of strain would be similar and the pressure cycle would form all the parts at

close to the same strain rate. Representative sheets of details produced using the fine grain 6A1-4V material is shown in Figure 5. After several years of production and numerous thermal cycles, the die surfaces of these tools is still very smooth and show little signs of usage as can be seen in Figure 6.

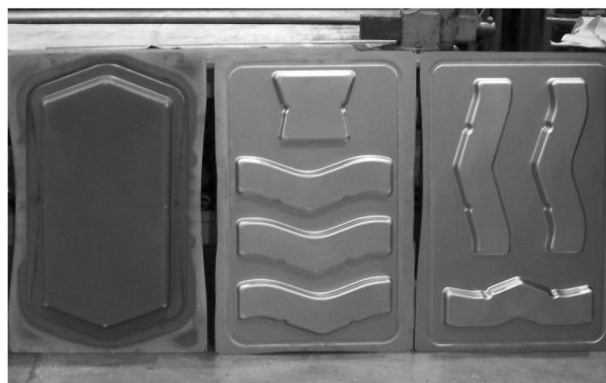


Figure 5. Representative SPF heat shield details produced using fine grain 6A1-4V. Sheet size for the starting blanks is 61 cm by 91 cm (24 inches by 36 inches).



Figure 6. Surface of SPF die for forming fine grain 6A1-4V after several years of production and numerous thermal cycles [1].