Superplastic forming (SPF) of titanium 6Al-4V, with a standard grain size of about 8 μm, is typically performed between 900°C and 920°C. Verkhnaya Salda Metallurgical Production Association in Russia has developed a fine-grain version of the 6-4 alloy, with a grain size of about 1 μm, which can be superplastically formed at around 775°C. Since this material diffusion bonds to itself as well as other standard grain size titanium alloys at this temperature, superplastically formed and diffusion bonded (SPF/DB) hardware can be produced. There are several advantages to using this lower forming temperature, including a smaller amount of alpha case developed on parts, longer press platen and heater life, and less oxidation of the tool surface. This fine-grained 6-4 material is currently being used in the production of SPF and SPF/DB aerospace components due to these advantages.

INTRODUCTION

The superplastic forming (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°C and 920°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 the late 1990s, Nippon Kokan K.K. (NKK) Corporation in Japan, now part of JFE Steel Corporation in Japan, introduced a fine-grain titanium alloy known as SP700 (Ti-4Al-3V-2Mo-2Fe) that was capable of being superplastically formed at 760°C. RTI International Metals, Inc. in Ohio manufactured the alloy under license from 1998 until 2003. The mechanical properties of the material were evaluated after SPF and found to be similar to the properties for 6Al-4V. In order to demonstrate the value of SPF at this lower temperature, the door threshold corners for the Boeing 757 were converted from standard grain 6Al-4V to SP700 in 2000. Since the thermal expansion factor at the SPF temperature was very close between 6Al-4V and SP700, the same die was able to be used. A typical door threshold corner can be seen in Figure 2. These parts continued to be fabricated using SP700 until the end of the Boeing 757 production, in 2004. After several years of production, the dies were in very good condition with no surface pitting or wear and the parts had a very smooth finish as required for aerodynamic and aesthetic reasons. Since the parts were formed at a lower temperature, there
was less alpha case to remove, reducing the time spent in a chemical acid bath, and minimizing the chances of non-uniform etching as well as hydrogen pick-up. Since a full mechanical property testing program had not been performed, other parts were not converted to this material. With the only application ending with the Boeing 757 production and other producers of SPF products not having applications for this material, a decision was made to stop manufacturing this alloy.

FINE-GRAIN TITANIUM 6Al-4V

Since the benefits of SPF of titanium at lower temperatures had been shown with the SP700 material, another material was sought that had similar lower-temperature forming properties. As a result of discussions and collaborative research between Boeing and Verkhnaya Salda Metallurgical Production Association (VSMPO) in Russia, the latter developed a fine-grain version of titanium 6Al-4V 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 as well as minimizing any mechanical property testing that would be required to qualify the material after SPF since the properties already existed for standard grain material. Development lots of the material were tested on current production parts, as shown in Figure 3.

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 4, 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°C to 920°C in order to fully diffusion bond. In 2009, Boeing was granted a U.S. patent covering SPF and SPF/DB of fine-grain 6Al-4V titanium.

PRODUCTION USING FINE-GRAIN 6Al-4V

Due to the benefits of the lower forming temperature, 6Al-4V titanium from VSMPO was selected for parts that have been designed recently for aircraft structures.

Heat Shields for a Twin-aisle Aircraft

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 be-

Figure 1. Typical surface of a die used for SPF of standard grain titanium 6Al-4V after numerous thermal cycles.

Figure 2. SP700 titanium Boeing 757 door threshold corner installed on an airplane. The part is approximately 18 cm by 18 cm.

Figure 3. Test parts from a production die using fine-grain 6Al-4V developed by VSMPO. (a) A formed sheet containing four identical parts each approximately 30 cm long. (b) Two parts, the top one being approximately 117 cm long.

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