JMEPEG (2007) 16:136–141
DOI: 10.1007/s11665-007-9023-5

1059-9495/$19.00

Commercial Airplane Applications of Superplastically Formed AA5083 Aluminum Sheet

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(Submitted April 20, 2006; in revised form October 22, 2006)

This article discusses some of the advances that have been made at Boeing Commercial Airplanes during the manufacture of superplastically formed (SPF) AA5083 aluminum components for aircraft applications. This specially processed material is the lowest cost aluminum alloy that exhibits superplastic properties. Therefore, the use of 5083 would be beneficial to aircraft in forming complicated configurations. Since this aluminum alloy is non-heat treatable and therefore low strength, it is not typically considered a material for use on commercial airplanes. However, applications have been found on the Boeing Commercial fleet that provide lower cost hardware which, in some cases, is lighter weight. Design Engineers have been able to take advantage of the benefits of using SPF sheet metal hardware fabricated from AA5083 in areas where failure of the component during flight would not cause loss of the aircraft. SPF AA5083 components have replaced aluminum castings, fiberglass assemblies, and components fabricated by SPF from other aluminum alloys. Since this alloy is non-heat treatable, the cost of heat treating, quenching, and aging is avoided. Also, there is no contour distortion to straighten due to the solution heat treating and quenching process. Therefore, the quality of the hardware being delivered to the customer is greatly improved.

Keywords aerospace, aluminum, cavitation, finite element modeling, superplastic forming, tube

1. Introduction

The SPF process for aluminum alloys has been used in production for over two decades at various companies around the world including several major aircraft producers in the United States. This monolithic process is expensive to implement compared to conventional aluminum fabrication due to high tooling and raw material costs. However, utilizing the SPF process can actually turn into a significant cost savings due to the reduction in the number of detail parts as well as a reduction in the amount of assembly tooling and labor that is required.

In order to fabricate these SPF aluminum components, care must be taken during the design and fabrication processes to avoid or minimize cavitation which affects the final metallurgical quality of the product. Cavitation is the formation of voids at grain boundary triple points due to the superplastic forming strain not being fully accommodated by grain boundary sliding (Ref 1). There are several factors that influence the amount of cavitation. One of these factors is the amount of elongation that is required for the final geometry. Die design can have an influence on the amount of elongation as well as using a preformed blank which can minimize elongation by getting the starting part blank closer to the final configuration. The next influencing factor is the forming temperature that is used (Ref 2). The final factor is the strain rate used for forming which can be generated by Finite Element Modeling using the appropriate material properties.

If the amount of cavitation being developed is excessive, backpressure can be used in the tool during forming to hold pressure on both sides of the material during forming which minimizes the number of cavities that can occur. Also, after SPF has produced a monolithic configuration, heat treatment is necessary in order to get the strength and corrosion properties required for the particular alloy being utilized. The solution heat treatment and quenching process often introduces distortion into the hardware which must be removed prior to aging. This is accomplished by hand straightening the part to a contour fixture which is a costly, time consuming operation.

The number of available SPF aluminum alloys is fairly limited. There are three main conventional alloys, not including aluminum-lithium alloys, in use today (Ref 3). The highest strength material is 7475, which is specially processed in order to be superplastic. This is the highest strength material available once it is heat treated and aged to the T76 condition. The second alloy is 2004, which was developed by British Aluminium specifically for SPF. It is a medium strength alloy after heat treating and aging to the T62 condition. The last alloy is 5083, which is also specially processed in order to be superplastic. This material is low strength since it is not capable of being heat-treated. Table 1 presents the comparison between typical static properties for the three alloys where strain represents the maximum amount of elongation experienced in the component during SPF.

This article was presented at the AeroMat Conference, International Symposium on Superplasticity and Superplastic Forming (SPF) held in Seattle, WA, June 6-9, 2005.

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Table 1 Comparison of properties after superplastically formed (SPF) and heat treat

Material and condition	0.2% YS, MPa (ksi)	UTS, MPa (ksi)	Elongation, %
7475-T76, <70% Strain, no back pressure	407 (59)	483 (70)	7
7475-T76, 71% to 200% Strain, with back pressure	407 (59)	490 (71)	5
2004-T62, Bare	255 (37)	352 (51)	4
2004-T62, Clad	221 (32)	310 (45)	4
5083	117 (17)	255 (37)	8

2. History of SPF Aluminum at Boeing Commercial Airplanes

The first SPF aluminum part that Boeing fabricated for commercial airplane production was in 1992 (Ref 4). This component, the inner frame for the Blowout Door assembly for the 737, is shown in Fig. 1. Also shown in this figure is the conventional assembly that was replaced. The benefits of the assembly with the SPF inner frame include a 75% decrease in the product cost as well as a reduction in the number of detail parts, from 31 to 6, and a reduction in the number of rivets, from 237 to 137 (Ref 5). The aluminum alloy used for this application is 7475 which, as shown in Table 1, is the highest strength SPF aluminum alloy available after it is heat treated and aged to the T76 condition. The next aluminum product that was incorporated into production was the 737 Auxiliary Power Unit (APU) Air Inlet Duct, which is shown installed on the aircraft in Fig. 2. This product was fabricated from the 2004 alloy. This alloy is medium strength, as shown in Table 1, after it has been processed to the T62 condition.

The solution heat treating process is necessary for the 7475 and 2004 alloys to achieve their associated strength levels. However, this process has the potential to introduce distortion into the product. This distortion has to be removed to meet tolerance requirements prior to aging while the strength is still low enough so that the shape can be manipulated. This distortion issue is a concern for formed aluminum hardware in general, not specifically details that have been superplastically formed. However, due to the capability of SPF to produce more complex shapes than conventional forming, the distortion issue can be a bigger concern for hardware formed by this process.

3. SPF Process

The process of manufacturing an aluminum SPF component consists of fabricating a tool that contains the required part geometry. As previously stated, the geometry of this tool influences the amount of cavitation that will develop during forming. Therefore, care must be taken during design of the die particularly in the areas outside the part periphery so that additional elongation is not introduced to the product. The tool is placed in a press and heated to the appropriate temperature, 455–510 °C (850–950 °F) depending on the alloy being formed. The tool contains provisions for pressurizing the sheet so forming will occur. Also, if required, the die could contain provisions for applying pressure to the backside of the sheet to prevent or minimize cavitation during SPF. Since aluminum does not react with oxygen, as titanium does, at the SPF temperature, an inert gas is not required for forming.

The advantages of using the SPF process are (Ref 5):

1. Replaces multi-piece assemblies with one monolithic component, which saves cost and weight and requires fewer tools.

Fig. 2 2004 superplastically formed (SPF) 737 auxiliary power unit air inlet installed on the airplane

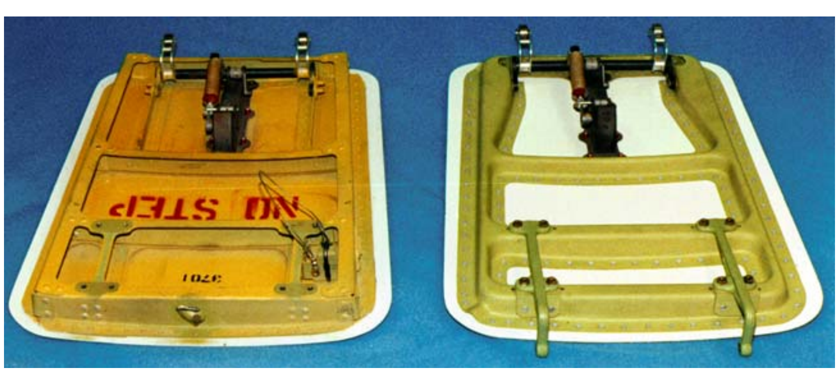

Fig. 1 7475 superplastically formed (SPF) 737 blowout door assembly, right, along with the conventional assembly, left (Ref 5)

Fig. 3 737 wing tip light housing (Ref 6)

Fig. 4 Starting blank fabricated from a rolled and welded piece of sheet

Fig. 5 End caps welded to part blanks

2. Capable of producing complex geometry.
3. Components contain very little, if any, residual stress with no spring back.
4. Less assembly is required, which equates to lower cost and lighter weight along with better dimensional accuracy.

4. SPF Applications of AA5083 at Boeing

Due to the fabrication issues with heat treatable SPF aluminum alloys, such as heat-treat distortion and raw material cost, the emphasis at Boeing has focused on developing applications for the 5083 alloy. Because it is non-heat treatable,

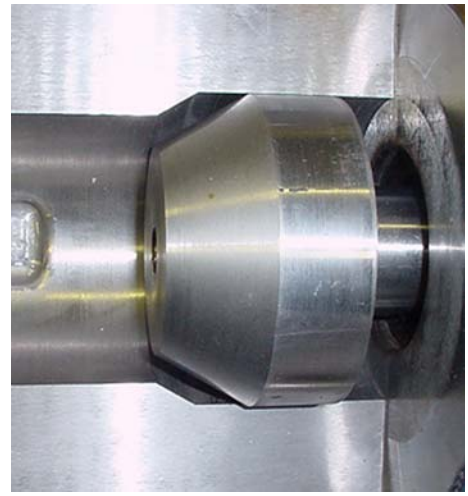

Fig. 6 Tapered plug for sealing the end of the tube (Ref 6)

and therefore, low strength, the applications have to be carefully chosen so the properties of the material will meet the structural requirements. The 5083 alloy is weldable which offers advantages where components need to be attached to the SPF detail.

4.1 737 Wing Tip Light Housing

The initial 737 Next Generation models went into production with an aluminum casting for the Wing Tip Light Housing, which is shown in Fig. 3.

However, there were issues with the quality of the casting being delivered, which included inconsistent surface finish and unreliable delivery of the product. A proposal was developed for a SPF aluminum component to replace the casting. Since a titanium prototype of this product had previously been fabricated, it was felt that an aluminum part was feasible. However, since there were no seamless aluminum tubes available in the SPF alloys, the part blank would need to be a rolled piece of sheet that was welded down the length, as shown in Fig. 4. Due to the geometry of the component, and the desire not to solution heat treat and quench, Engineering was tasked to determine if the strength level of AA5083 would meet the structural requirements for this product. The analysis showed that since the casting was produced from a lower strength alloy and a high strength material was not necessary for the component, 5083 would meet the structural requirements for the product. Since a welded tube would need to be fabricated, a weldable alloy was needed and AA5083 met this requirement. Also, the weldability of the alloy was required for attachment of the forward end cap after the formed part had been trimmed.

Initially, the plan was to fusion weld end caps on each end of the tube, as shown in Fig. 5, with a gas tube attached to one end. However, testing showed that it was possible to seal the ends with tapered plugs, shown in Fig. 6, and pressurize the tube through one of the plugs thus eliminating the non-value added operations of welding on the end caps and gas tube.

Since the SPF titanium torque tube previously prototyped had been preformed in a separate operation, this was the original plan for the SPF aluminum product. However, Finite Element Modeling (FEM) showed that it was possible to preform the part in the SPF tool as the upper die was closing.

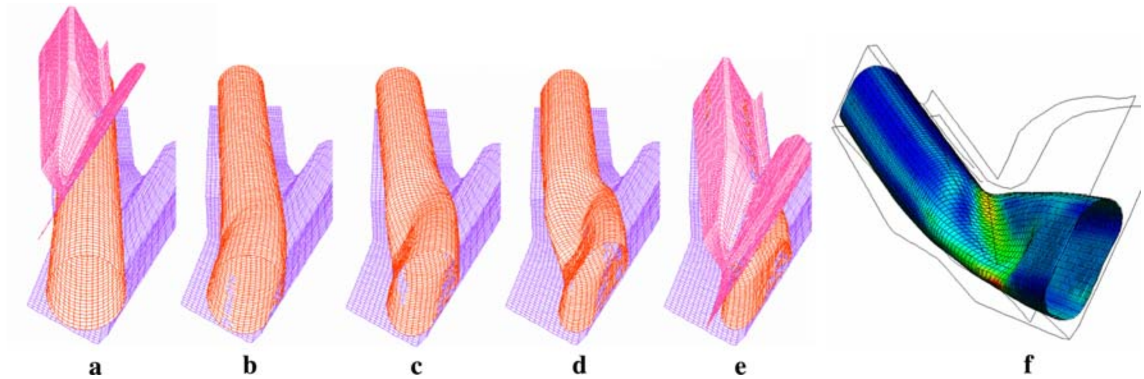

Fig. 7 Finite element modeling of preforming during closing of the final form die

Fig. 8 737 superplastically formed (SPF) AA5083 light housing after processing (Ref 6)

Fig. 9 Superplastically formed (SPF) free-expansion testing of AA5083 seamless tube samples

Figure 7 shows the Finite Element Modeling progression of the die closing: (a) unformed tube resting on lower die ready to start forming sequence, (b), (c), (d) shows the forming progression as the upper die closes, upper die not shown for clarity, (e) and (f) final preformed configuration before SPF begins.

Testing showed that the FEM analysis had accurately predicted the geometry of the tube while the die was closing. Therefore, production components are produced in a single process where preforming and final forming operations are performed in a single tool. The final product, which is shown in Fig. 8, has approximately 70% elongation at the maximum strain location. This product saves approximately 20% in cost and weight compared to the aluminum casting it replaced (Ref 6).

In order to eliminate the non-value added operation of welding the rolled sheet down the length to produce the starting blank, a seamless tube is desired. Seamless tubes in AA5083 material have been produced by a couple of companies. In order to determine the forming properties of the tube, PNNL tested prospective samples by expanding them superplastically without the use of a die, free-expansion, at the SPF temperature of 500 °C (930 °F) as shown in Fig. 9. Successful light housing prototype parts have been fabricated using seamless tubes. If implemented into production, an additional four percent cost savings would be realized for this product.

Fig. 10 767 superplastically formed (SPF) moisture shroud assembly comprised of two SPF AA5083 components

Fig. 11 Superplastically formed (SPF) 737 wing outboard leading edge strakelet

Fig. 12 Location of the superplastically formed (SPF) AA5083 strakelet on the 737 wing leading edge

Fig. 13 Superplastically formed (SPF) AA5083 777 wing tip light housing

4.2 767 Moisture Shroud

The 767 project had a requirement to increase the stiffness of a moisture shroud that protects the electronics under the cockpit. The current Fiberglass assembly, which was composed of 40 detail parts which had to be assembled and then sealed to prevent moisture from reaching the electronics, was unable to meet the increased stiffness requirement. Also, due to the number of sealed joints, service failures often occurred which had to be repaired in order to maintain the integrity of the electronics. The solution was to convert the product to a two-piece SPF AA5083 assembly. Even though this alloy is low strength, the stiffness of the material was sufficient to meet the structural requirements. Integrally stiffened SPF panels were developed to eliminate the detail components previously required. The SPF assembly, which is shown in Fig. 10, is approximately 0.25 m (98 in.) long and eliminates about 0.9 linear m (30 linear ft) of sealant. The SPF 5083 assembly saves both cost and weight compared to the Fiberglass assembly.

4.3 737 Outboard Leading Edge Strakelet

The 737 wing contains a SPF aluminum detail, approximately 61 cm (24 in.) long by 38 cm (15 in.) wide, which is shown in Fig. 11. The component is located where the engine strut joins the wing box as shown in Fig. 12. This product was originally fabricated from the 2004 alloy. However, forming issues arose due to the complexity of the required geometry. Structural analysis showed that changing the material to 5083 would satisfy the requirements for this product. Therefore, 5083 was implemented for this product. This material change has resulted in a cost savings for the component due to the use of a lower cost alloy as well as eliminating the heat treatment and aging processes.

4.4 777 Wing Tip Light Housing

The light housings on several Boeing commercial airplanes are currently fabricated from SPF 2004 aluminum components. However, this alloy is costly and requires heat treatment after forming. Also, due to the geometry of the 777 component, distortion during heat treat and quench was a concern. The 777 project structurally analyzed their light housing and determined that the 5083 material would meet the requirements for the component. This product on the 777, which is approximately 122 cm (48 in.) long and 61 cm (24 in.) wide, is being fabricated as a SPF AA5083 detail which is shown in Fig. 13.

5. Conclusions

Even though AA5083 is not typically considered an aircraft quality material, SPF 5083 products have been implemented on various Boeing commercial airplanes. The applications show that this material can meet the structural requirements for certain products even though it is a low strength alloy. Since this material does not require heat treatment and is the lowest cost superplastically formable alloy, cost savings have been realized for the implemented products. Weight savings have also been realized for some of the applications due to monolithic components replacing multi-piece assemblies. Finally, since solution heat treatment and quenching is not required, distortion due to this process is eliminated, and therefore, a higher quality product is delivered to the airplane customer.

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