Superplastic Forming for Aerospace Applications

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1. Introduction

In superplastic forming (SPF) process, one or multiple sheets of superplastic materials are forced onto or into single surface tools in superplastic forming conditions [1]. Since superplasticity is diffusion controlled process, the forming temperature is usually above half the melting temperature in absolute temperature scale. At elevated temperatures, dynamic recovery and dynamic recrystallization becomes active and flow stress and hardening rate decrease with increasing temperature. It is assumed that there is equilibrium between recovery and hardening at these temperatures so that the metal does not strain harden [2,3]. This is important in practical application because the metal must maintain similar grain size during superplastic forming process. Therefore the material must have a small (usually less than 10 microns) and equiaxed grain size and consists of multiple phases or single phase with fine secondary particle to suppress grain growth. Examples of multiple phases are Ti-6Al-4V, which is well known alpha-beta alloy, and duplex stainless steel with austenite and ferrite. It can describe the ability of the metal to resist necking. During superplastic deformation, the strain rate sensitivity of the flow stress is used as an index of the degree of superplasticity to be expected at a given temperature. The higher the value of the strain rate sensitivity the more superplastic the alloy [2,4].

This paper presents an innovative superplastic forming method to produce various parts of space launcher with superplastic forming by low gas pressure. The results demonstrated that superplastic forming process with titanium, and stainless steel can be applied to manufacturing lightweight integral structures of space launcher and rocket propulsion components.

2. Combustion Chamber Jacket with Stainless Steel

In a combustion chamber of liquid propellant launch vehicle, the inner shell of the chamber is copper with cooling channels for regenerative engine and outer jacket is stainless steel to keep high pressure inside the chamber. Duplex stainless steel (SUS329J1) was received in the form of 11mm thick sheet. Since this alloy consists of two phases, ferrite and austenite with average grain size of about 10 micron, superplasticity of this duplex steel has been exhibited over a narrow range of strain rates. The flow stress behavior was obtained from a series of tensile tests with strain rates ranged from 10^{-4}/sec to 10^{-2}/sec and at several temperatures from 900℃ to 1050℃. It is interesting to notice high values of strain rate sensitivity obtained are 0.36-0.47 at 980℃. At a strain rate of 10^{-4}/sec, the elongation was 552% and UTS was 13MPa at 980℃. After determining high temperature tensile characteristics of materials, the forming profile was prepared from a finite element analysis (FEM) with MARC (MSC Software Corp.). The finite element model was discretized using 4 node membrane elements with full integration starting with an initial plate thickness of 11.0mm and the geometrical symmetry is included. The pressure profile was obtained from the simulation applied to superplastic forming machine shown in Figure 1 [6].

Figure 2 shows the contact status between the plate and the mold surface according to the forming time [7,8]. From this figure, it can be seen that the contact between the plate and mold starts at center part, and then the contact in the left part of the throat progressively spreads. When t = 6000 sec, the plate has been almost formed to the extending zone. Thus, it is concluded that 6000 sec is enough to obtain the required forming part. It is noted that the minimum thickness at 6000 sec is thicker than the minimum requirement of 5.0 mm and this is due to the excessive metal flow from surrounding flange region.

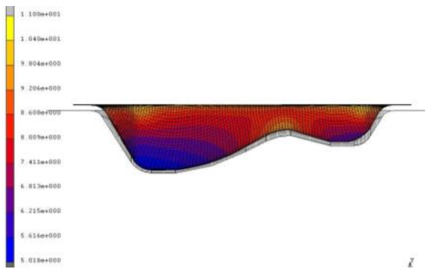
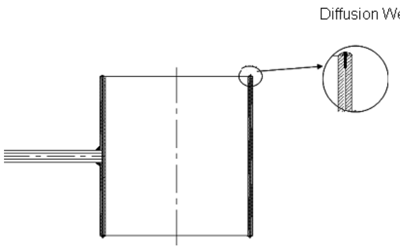


Fig. 1. Thickness distribution analysis according to forming time of 6000 sec [7,8].

Fig. 2. Steel outer skin article after superplastic forming [7,8]

3. Toroidal Fuel Tank with Ti-6Al-4V

Fuel tank is one of the largest components in launcher vehicle structure. For a lightweight and space efficiency, toroidal fuel tank shows advantage over cylindrical tank. Typical manufacturing methods include spinning, bending, hot stamping and welding. These several steps can be reduced by using superplastic forming process.
The forming profile of toroidal configuration was analyzed and the finite element model was successfully demonstrated to predict forming behavior. In this process the end of two sheets are diffusion welded together and dome and cylinder parts were formed in a single step from a double layer tube. The diffusion bonding condition is 875℃/4MPa/one hour [9,10]. The gas pressure profile was obtained from the finite element simulation and the gas pressure increases almost linearly [10]. Based on the gas pressure profile obtained from the finite element simulation, the forming of toroidal tank was performed at 875℃ and the maximum pressure of 1.5MPa. The final shape was obtained at 4,000 sec. The forming tool and formed article were shown at Figure 4 (c). The result shows that the forming of complicated shape of toroidal tank has been successful with superplastic forming technology.



(a)

(b)

Fig. 3. (a) Schematic view of diffusion welded region of a double layer titanium tube, and (b) titanium toroidal tank [9,10].

4. Summary

In summary, superplastic forming technology for space launcher is presented. Discussion focused on application of advanced aerospace materials, duplex stainless steel and Ti-6Al-4V with practical information for industrial application.

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