SPF Model Applications for Aluminum

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Abstract. A closed-form, plane strain model (PS2) is compared with a finite element model (SUPFORM3) in analyzing the forming of rectangular pans from 2090-OE16 aluminum sheet. The errors introduced by improperly using a plane strain model are quantified. Some preliminary verification of SUPFORM3 is shown, and the effect of friction on the distribution of thickness in the superplastic forming (SPF) of a rectangular pan is presented.

SUPFORM3 is used to predict thickness distribution of male formed access doors, selecting proper starting gauges, assessing producibility, estimating forming time, and developing pressure time cycles. SUPFORM3 will be used to form complex parts and flat-bottomed pans such that post-SPF properties samples can be cut from the flat areas of the flat-bottomed pans, yet have the same strain and strain rate history as the critical areas in the complex part.

It is concluded that SUPFORM3 is a useful tool for predicting thickness distributions resulting from and pressurization schedules for superplastic forming.

INTRODUCTION

Some metals, produced under special conditions and deformed at a carefully controlled low strain rate and high temperature, exhibit extreme ductility, called superplasticity. This extreme ductility allows components formerly produced by joining many pieces together into an assembly to be redesigned into a single component which performs the same structurally, lowering total manufacturing cost. Superplastic forming (SPF) is accomplished by using gas pressure to blow the hot sheet into a female die cavity or over a male form, in a process very similar to the vacuum forming or blow molding of polymer sheet.

Superplastic formability and post-SPF service properties are strongly affected by strain rate, and the resulting distribution of thickness in the formed part is dependent upon part geometry and friction. Because of the high strain rate sensitivity, it is important to use a pressurization schedule during forming which will lead to acceptable formability and post-SPF properties.

Strain rate affects the final service properties by affecting the tendency of the metal to form micro pores during forming. This formation of intergranular voids, called cavitation, is one of the limits to the superplastic forming of high strength aluminum alloys. Figure 1 shows the voids on a cross section taken through a highly deformed region of a superplastically formed part. These voids reduce the post-SPF properties and their number/size must be held below some critical value if a component is to be used in a structural application.

Fortunately, cavitation can be suppressed by properly controlling key SPF process variables. Although other variables also affect cavitation, the most important process variables are strain rate, total strain in the component, and back pressure. As shown in Figures 2 and 3 for 7475-02, cavitation increases with strain and strain rate and decreases with back pressure. Any factor, such as increasing strain rate or decreasing forming temperature, which increases the flow stress during forming will increase the degree of difficulty in suppressing the formation of pores through the proper control of other process variables. At the optimum forming conditions for 7475-02 of 960F and 0.0002 1/sec, cavitation is suppressed at a relatively low back pressure [1], as shown in Figure 2.

Mathematical models of the SPF process are used to predict the pressurization rate which will result in optimum superplastic formability and minimum porosity, and to predict the distribution of thickness in the formed part so that producibility can be assessed. Modeling also yields an estimate of forming time, which is needed to estimate the cost of an SPF operation. Closed form and finite element method (FEM)
dicted and measured thickness distributions in a superplastically formed rectangular pan, to quantify the errors introduced when a plane strain model is used for a rectangular pan, and to present some early uses of SUPFORM3.

**MODEL DESCRIPTIONS**

PS2, a plane strain, closed form model [1], assumes that only unsupported metal deforms, that it thins uniformly in the unsupported region, and that the profile of the unsupported metal for a long rectangular pan is cylindrical. The forming process can be considered in three geometrical phases, as shown in Figure 4. The first phase consists of bulging the initially flat sheet into a cylindrical profile, with no contact with the die walls. The radius of curvature decreases rapidly and the contact angle increases rapidly with time during this phase. The second phase begins when the sheet first becomes tangent with the die sidewall. The radius of curvature decreases slowly and the contact angle remains constant with time during this phase. The sticking which occurs when the sheet touches the die wall results in a tapered wall thickness. The third phase begins when the sheet first touches bottom. During this final phase a “filling in” of the corners occurs. Radius of curvature decreases more rapidly.