

Sheet Thermoforming of a Superplastic Alloy

Ordinary metals and alloys have not heretofore been shaped by the sheet thermoforming techniques so advantageously used by the plastics industry. Although a polymeric material may undergo a manifold increase in surface area during vacuum or pressure forming, metal or alloy sheet invariably fails by localized deformation and thinning at relatively low strains when subjected to tensile plastic deformation. Recent reports of "superplastic" behavior in metals and alloys^{1,2} include examples of extraordinary amounts of uniform tensile elongation. This communication reports the initial results of efforts to utilize a superplastic alloy in a laboratory vacuum-forming operation.

As described by Underwood,¹ the superplastic state in a metal or alloy is characterized by its ability to be plastically deformed in very large amounts with anomalously low flow strength. Tensile specimens in this condition may elongate many times their original length without necking or failure.

Superplasticity has been observed primarily in eutectic and eutectoid alloys. The material is heated to a temperature above the invariant temperature, and quenched with adequate severity to suppress the equilibrium phase decomposition. Superplastic behavior is then observed when the alloy is tested at a temperature just below the invariant. The most pronounced superplastic effect is observed in alloys of the invariant composition; off-composition alloys exhibit lower ductility and greater flow stress. Likewise, as the test temperature departs from the invariant temperature, the superplastic effect diminishes.

Backofen et al.² studied the tensile strain rate sensitivity, $m = d \ln \sigma / d \ln \dot{\epsilon}$, in a near-eutectoid, superplastic, 80% Zn-20% Al alloy.³ They determined that an additional characteristic of the superplastic state, at least in this alloy, is a range of m values much higher than previously observed in a metal or alloy. High strain rate sensitivity then was used as a basis for rationalizing the ability of the material to elongate over 1000% without necking or failure. Since localization of deformation necessarily involves increased local strain rate, high m values naturally work against such behavior.

The present work represents an investigation of a practical application of the superplastic Zn-Al alloy in a metal forming operation, first by exploring strain rate sensitivity of the zinc-aluminum alloy at higher defor-

mation rates, and second by trying to use the alloy in a vacuum-forming process. Several heats containing $78 \pm 0.5\%$ Zn and $22 \pm 0.5\%$ Al were melted from 99.99+ % ingot of aluminum and zinc, chill cast, homogenized, and hot rolled to one-inch diameter rod or six-inch wide sheet. Metallographic examination assured that the material was homogeneous and of eutectoid composition. Sheet material was sawed to blanks for vacuum forming; rod was machined into solid, cylindrical torsion specimens. Prior to being tested, each specimen was solution heat treated one hour at 600°F and water quenched to produce the metastable state required for superplastic behavior.

Torsion tests were carried out to determine the variations of m and flow stress with temperature and strain rate. Twist speeds were varied over a range yielding surface shear strain rates from 0.35 to 170/minute, and over a range of temperatures near the eutectoid invariant, 525°F. Test data confirmed the high strain rate sensitivity reported by Backofen² near 525°F, and showed the effect to persist at much higher rates than were available to Backofen.

A small, heated-die, vacuum-forming apparatus was built (Fig. 1). It consists of a female die and clamping ring, a temperature controlled heater surrounding the die, and a vacuum system vented to the die cavity. The die cavity was designed so that a successful draw results in an increase in surface area of the sheet of greater than 200%—a severe stretching operation even for sheet thermoforming in polymer sheet.

Figure 2 shows a typical part formed. Pieces such as this have been readily reproduced in sheet thicknesses from 0.025 inch to 0.100 inch. The shortest forming times and most consistent behavior are found between 520 and 525°F. In this temperature range, 0.025-inch sheet was formed in 4 minutes, and 0.100-inch material, in 34 minutes. The variation of cycle time with thickness is consistent with the variation of stress with strain rate, as determined from torsion tests. The torsion data also indicate that faster cycle times will result from the higher forming stresses that can be obtained by the introduction of pressure forming techniques to supplement or replace the vacuum technique.

Figure 3 presents a cross section of 0.095-inch sheet before and after forming. The ratio of the original sheet

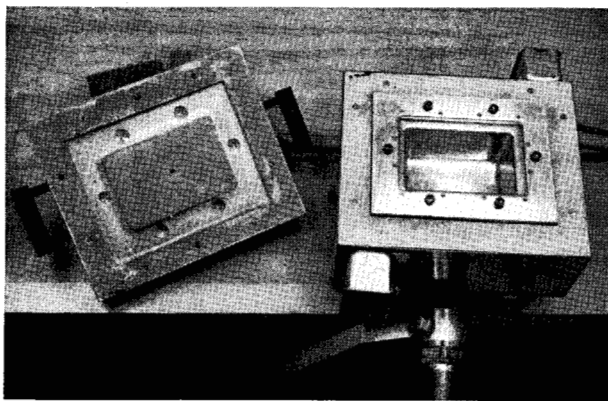


Figure 1 Laboratory vacuum-forming die with clamping ring bolted in place.

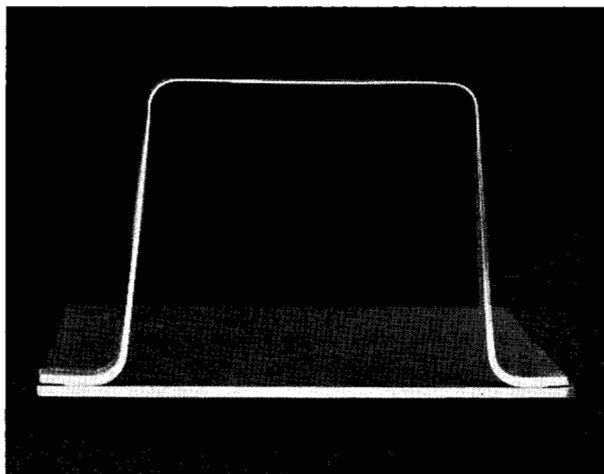


Figure 3 Sections through formed part and original 0.095-inch blank.

thickness to its minimum final thickness was 4.6:1 in this sample.

The ability of sheet to form around intricate contours and to reproduce fine surface detail is shown in Fig. 4, an experimental sample formed over an unplated IBM SELECTRIC typehead. The sample in Fig. 5 was formed over plastic letters on wire mesh placed in the bottom of the die cavity. Figure 6 shows a collection of specimens removed from the die at successively later points during forming, and illustrates the development of a part such as that in Fig. 4.

Additional heats of this eutectoid zinc-aluminum alloy have been cast from lower quality base metal, yielding a 99.8% purity alloy. Vacuum forming results were almost identical with those from the 99.99% purity alloy, with respect both to surface quality and to forming cycle times.

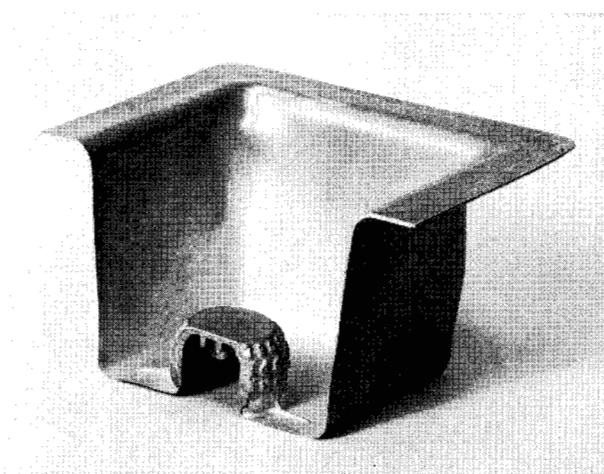


Figure 4 Sections through vacuum-formed part, showing entrapped plastic IBM SELECTRIC typehead used as a pattern.

Figure 2 Typical part vacuum-formed in superplastic 78% Zn-22% Al sheet.

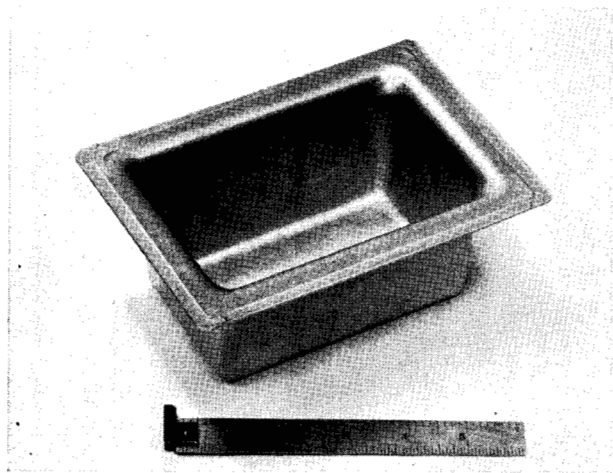
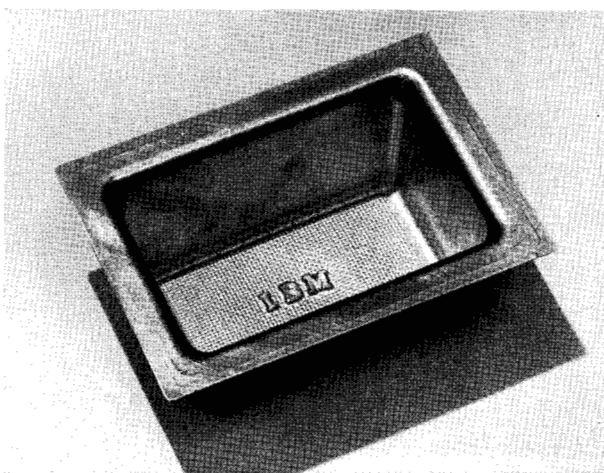


Figure 5 Vacuum-formed part with bottom surface developed over wire mesh and plastic characters.



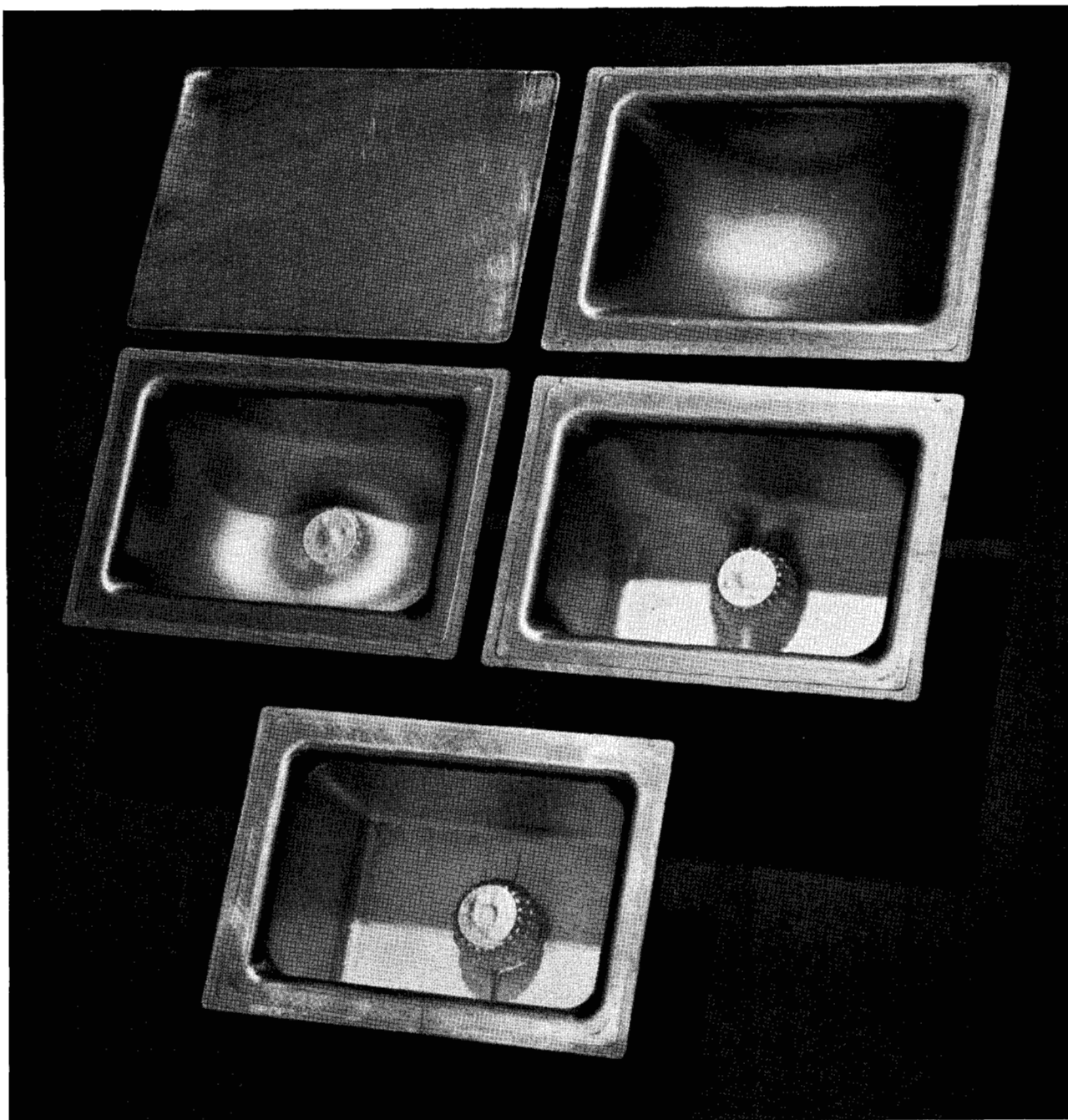


Figure 6 A collection of sample parts obtained by interrupting the forming process after successively longer intervals.

Acknowledgments

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References and footnotes

1. E. E. Underwood, "A Review of Superplasticity," *Journ. of Metals* 14, 914 (1962).
2. Backofen, Turner and Avery, "Superplasticity in an Al-Zn Alloy," *Trans. Am. Soc. Metals* 57, 980 (1964).
3. Values of stress, σ , are taken from test results for various strain rates, $\dot{\epsilon}$. Stress, in this state, was found to be almost independent of strain.

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