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Superplastic hemispherical Bulge Forming of a Ti-Al-Mn Alloy

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Abstract— Superplastic sheet thermoforming has been identified as a standard processing route for the production of complex shapes, especially in the aerospace industry. Ti-Al-Mn (OT4-1) alloy is currently being used for aero engine components as well as other aerospace applications by forming through a conventional route which is typically cost, labour and equipment intensive. The Ti-Al-Mn alloy (made as per the Russian specification, OT4-1) is a candidate material for aerospace applications. However, there is virtually little or no information available on its superplastic forming behavior. In this paper the superplastic deformation capability of the Ti-Al-Mn alloy was studied. Sheets of 1 mm thickness were successfully bulge formed to a hemispherical component of 90 mm diameter using a sheet thermoforming route.

Index Terms — Ti-Al-Mn (OT4-1) alloy, superplastic forming, bulge forming, forming pressure.

1 Introduction

Superplasticity is the ability of a polycrystalline material to exhibit, in relatively uniform manner, very large elongations prior to failure [Langdon (1982)]. Typically, large elongations are observed at temperatures above 0.5Tm, where Tm is the absolute melting point of the alloy and at a rather limited range of relatively slow strain rates [Padmanabhan et al. (1980) and Pilling et al. (1989)]. These materials have very fine grain sizes (usually well below 20µm), which remain stable at the temperature of deformation.

Titanium alloys such as Ti-6Al-4V find extensive use in aerospace applications, not only because of their specific high temperature strength, but also because of the fact that a large number of these alloys exhibit superplastic behavior and are amenable to superplastic forming (SPF) [Boyer (1996)]. However, in these alloys the additions of Vanadium make them considerably expensive and so, there is a need for developing superplastic titanium alloys with cheaper alloying additions. The Ti-Al-Mn alloy could be such a candidate material. Based on the microstructure, this alloy can be classified as a near alpha alloy. This alloy shows significant post-uniform deformation at ambient and near-ambient temperatures [Bhattacharya (1989)], and there is virtually little or no information available on its superplastic forming behavior. In this paper, the high temperature superplastic bulge forming of the alloy was studied and the superplastic forming capabilities are demonstrated.

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2. Experimental

The Ti-Al-Mn (OT4-1) alloy was available in the form of a 1 mm thick cold-rolled sheet. The chemical composition of the alloy is shown in Table 1. A 35-ton hydraulic press was used for the superplastic bulge forming of a hemisphere. A die set-up was fabricated and assembled with the piping system enabling not only the inert gas flushing of the die- assembly prior to forming, but also for the forming of components under reverse pressure, if needed. The schematic diagram of the superplastic forming set-up used for bulge forming with all necessary attachments is shown in Fig.1 and the photograph of the top (left) and bottom (right) die for SPF is shown in Fig.2.

Table 1 Chemical composition of the alloy.

Element	Al	Mn	Zr	Fe	C	Ni	Ti
Weight %	2.2	1.50	0.25	0.078	0.035	0.024	Balance

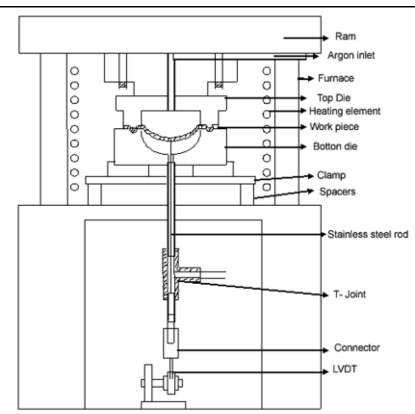

Fig. 1 Schematic of the experimental setup.

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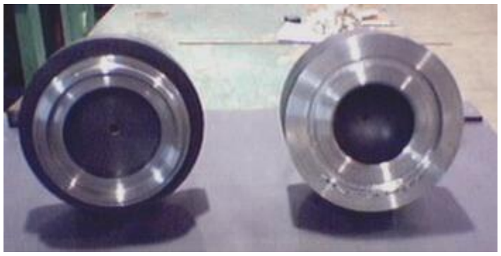

Fig.2 A picture of the top (left) and bottom (right) die for SPF.

A circular sheet (blank) of 118 mm diameter was cut from the alloy sheet and the cut surfaces polished to remove burrs. The blank was placed on the die and the top chamber brought in contact. The furnace was switched on to the set temperature. Once the set temperature was reached the top chamber was brought down further to effect the required blank holder pressure. About 10 minutes were allowed for thermal equilibration. The argon gas cylinder was opened to the set pressure gradually. Simultaneously, the LVDT, fitted at the bottom of the die, was set for recording the sheet bulge. Once the LVDT reached 45 mm (radius of bottom die), gas pressure was stopped and the furnace switched off. The formed components were taken out when the temperature of the die set had dropped to 600 °C. Easy removal of the component was possible at this stage.

Superplastic bulge forming of hemispheres were carried out at temperatures of 1098, 1123, 1148, 1173, 1198 and 1223 K (825, 850, 875, 900, 925 and 950 °C) at forming pressures of 0.2, 0.4, 0.6 and 0.8 MPa. As the bulge forming process progresses, significant thinning in the sheet material becomes obvious. An ultrasonic technique was used to measure the thickness distribution on the profile of the formed component. The components were analysed in terms of the thickness distribution, thickness strain and thinning factor. Post deformation microstructural studies were conducted on the formed components in order to analyse the microstructure in terms of grain growth, grain elongation, cavitation, etc.

3. Results and Discussion

The microstructure of the as-received material with a 2 dimensional grain size of 14 μm is shown in Fig.3. The grain size was determined using the linear intercept method in both the longitudinal and transverse directions of the rolled sheet.

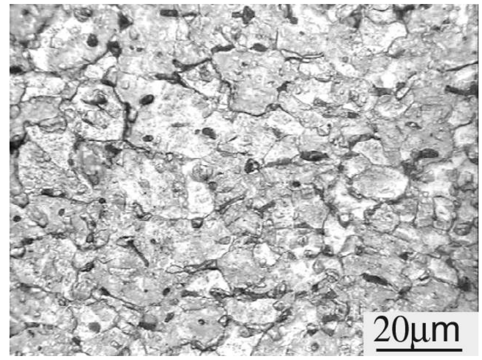

Fig.3 Microstructure of the as-received alloy. The 2D grain size is 14 μm.

Successful superplastic forming of hemispheres were carried out at temperatures of 1098, 1123, 1148, 1173, 1198 and 1223 K and argon gas forming pressures of 0.2, 0.4, 0.6 and 0.8 MPa. A maximum time limit of 250 minutes was given for the complete forming of the hemispheres. This cut-off time of 250 minutes was given for practical reasons. Fig.4 shows a photograph of the blank (specimen) and a bulge formed component (temperature of 1123 K and a forming gas pressure of 0.6 MPa).

Fig.4 SPF component (right) and the blank (left) before forming.

Table 2 shows the forming times of successfully formed components at different forming temperatures and pressures. From the travel of the LVDT fitted at the bottom of the die (which measured the bulge height/depth) an estimate of the rate of forming was obtained. It was seen that the rate of forming was rapid initially and decreased gradually for all the temperature and pressure ranges as reported in Table 2. At a particular temperature, the forming time reduced as the forming pressure was increased. Similarly at a given forming pressure, forming time decreased with an increase in temperature.

The thickness of the bulge profile was measured at 7 points including the periphery (base) and pole. These points were selected by taking the line between center of the hemisphere and base point as reference and offsetting by 15° until the pole point was reached. Hence the points 1, 2, 3, 4 and 5 subtend an angle of 15, 30, 45, 60 and 75° respectively with the base of the hemisphere as Shown in Fig.5. The thickness was measured at each of these points on the bulge profile by using an ultrasonic technique. The thickness values for each of the successfully formed hemispherical components are also reported in Table 2.

Temperature (K)	Pressure (MPa)	Time (min)	Point 1	Point 2	Point 3	Point 4	Point 5	pole
1098	0.8	145	0.73	0.56	0.45	0.34	0.32	0.27
1123	0.8	95	0.73	0.6	0.52	0.4	0.34	0.29
	0.6	205	0.79	0.64	0.55	0.45	0.41	0.4
1148	0.8	75	0.79	0.66	0.58	0.49	0.41	0.39
	0.6	95	0.74	0.59	0.48	0.39	0.34	0.31
	0.4	200	0.74	0.6	0.5	0.38	0.35	0.3
1173	0.8	50	0.72	0.63	0.49	0.38	0.32	0.24
	0.6	65	0.72	0.6	0.49	0.41	0.38	0.31
	0.4	120	0.76	0.62	0.52	0.44	0.39	0.35
1198	0.8	24	0.71	0.6	0.45	0.35	0.3	0.24
	0.6	40	0.67	0.56	0.45	0.37	0.34	0.27
	0.4	54	0.71	0.6	0.49	0.41	0.38	0.32
	0.2	240	0.69	0.57	0.48	0.43	0.39	0.35
1223	0.8	15	0.74	0.58	0.49	0.38	0.29	0.26
	0.6	23	0.74	0.59	0.6	0.52	0.37	0.29
	0.4	40	0.71	0.59	0.49	0.43	0.37	0.29
	0.2	155	0.7	0.61	0.54	0.48	0.4	0.37

Table 2: Results of successfully formed hemisphere at different forming temperatures and pressures. The forming time and thickness at selected points on the profile are also tabulated

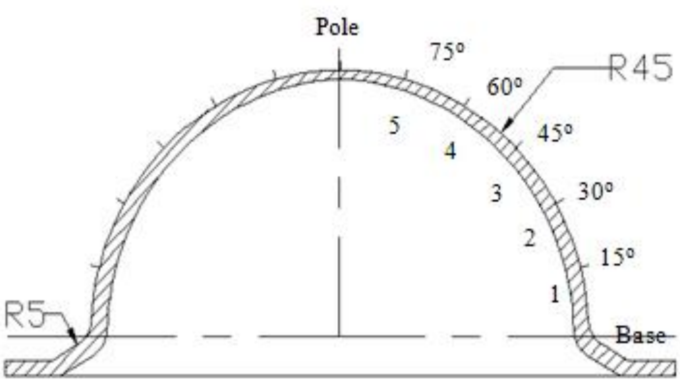

Fig.5 Points selected for thickness measurement on bulge profile

Fig.6 shows the pole thickness of fully formed hemispheres as a function of forming pressure at different temperatures. At a particular temperature the pole thickness reduced as the forming pressure was increased. For all the cases studied the pole thickness lay in the range of about 0.3 to 0.4 mm from the original blank thickness of 1 mm.

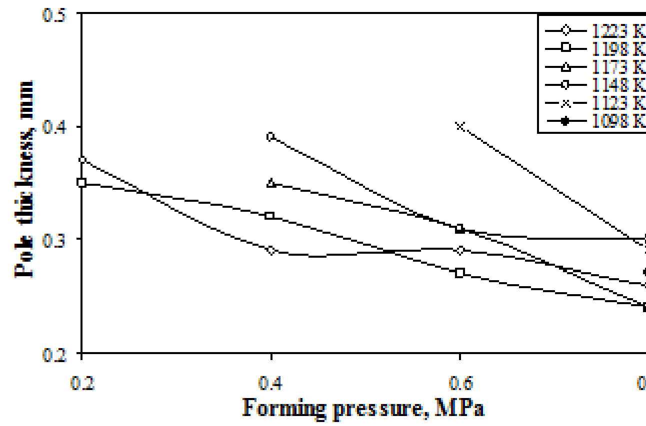

Fig. 6 Pole thickness as a function of forming pressure at different temperatures

The thickness strain, ln(S/So), where S is the local thickness and so is the initial thickness, was calculated at different locations for all the successfully formed components. For a particular pressure the thickness strain reduced as the forming temperature was increased. Fig.8 shows the thickness strain, ln(S/So) as a function of position along the dome cross section in case of a component formed at 1123 K at a forming pressure of 0.6 MPa.

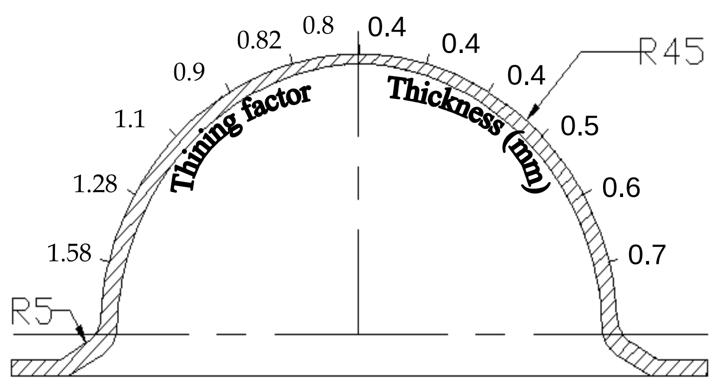

Fig.7 Thinning factor on bulge profile, forming temperature and pressure of 1123 K and 0.6 MPa.

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The post-formed microstructure revealed that there was no significant change in grain size. Fig.9 shows the microstructure of the bulge formed component at the base and the pole for a component formed at a temperature of 1148 K and forming pressure of 0.6 MPa. These microstructures show no significant change in grain size.

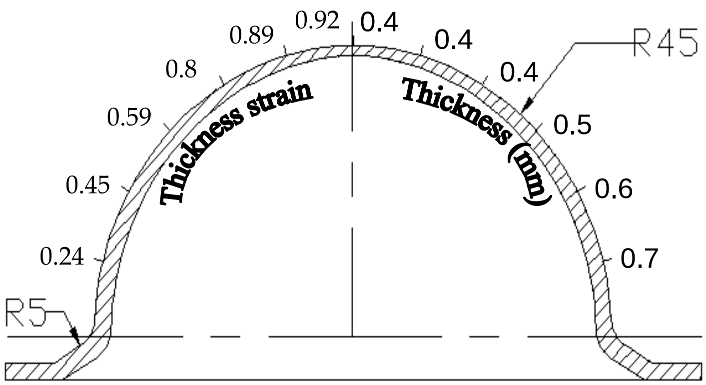

Fig.8 Thickness strain on bulge profile, forming temperature and pressure of 1123 K and 0.6 MPa.

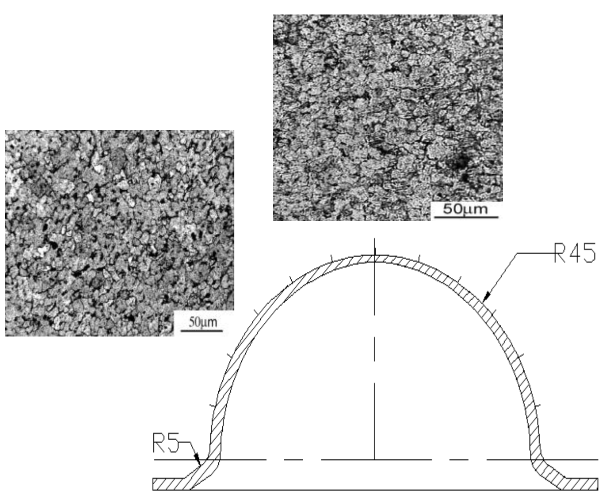

Fig.9 Microstructure near the base and the pole of a component formed at a temperature of 1148 K and pressure of 0.6 MPa.

4. Conclusions

The high temperature deformation behavior and superplastic forming capability of a Ti-Al-Mn alloy was studied. Successful forming of 90 mm diameter hemispheres using the superplastic route were carried out at the temperature range of 1098 to 1223 K and forming pressure range of 0.2 to 0.8 MPa. The following conclusions could be drawn:

1. The forming time decreased steeply when the gas pressure or temperature was increased. The rate of forming was initially high, but reduced progressively with time.
2. At a particular temperature the pole thickness reduced as the forming pressure was increased. For all the cases studied the pole thickness lay in the range of about 0.3 to 0.4 mm from the original blank thickness of 1.0 mm.

The thinning factor and thickness strain increased as one moved from the periphery to the pole. The post-formed microstructures show no significant change in grain size

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