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SUPERPLASTIC 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. 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 the present investigation, the superplastic deformation capability of the Ti-Al-Mn alloy was studied. Sheets of 1mm thickness were successfully bulge formed to a hemispherical component of 90mm diameter using a superplastic sheet thermoforming route.

Key words: Titanium alloys, superplastic sheet thermoforming, forming pressure.

1. INTRODUCTION

Superplasticity is the ability of a polycrystalline material to exhibit, in relatively uniform manner, very large elongations prior to failure. Typically, large elongations are observed at temperatures above $0.5T_m$, where T_m is the absolute melting point of the alloy and at a rather limited range of relatively slow strain rates. These materials have very fine grain sizes (usually well below 20μm), which remain stable at the temperature of deformation[1-3].

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. However, in these alloys the additions of Vanadium or Molybdenum make them considerably expensive and so, there is a need for developing superplastic titanium alloys with cheaper alloying additions. The Ti-Al-Mn alloy (made as per the Russian specification) 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, and there is virtually little or no information available on its superplastic behavior. In this study, the high temperature superplastic deformation behavior of the alloy was studied and the superplastic forming capability demonstrated.

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 I. Test specimens with their tensile axis parallel to the rolling direction and with gauge dimensions of 12 x 5 x 1 mm, as shown in fig.1 were machined for the high temperature tensile tests[4]. Prior to testing, the specimens were polished to remove fine scratches from the specimen surface, particularly in the gauge portion.

The high temperature tensile tests were carried out using a 250 kN capacity, microprocessor-controlled Schenck-Trebel electromechanical testing machine interfaced with a computer for data acquisition and processing and equipped with a two-zone split furnace. The temperature accuracy was with in $\pm$ 3^0C. Tests were carried out in the temperature range of 1073-1173K (800-900^0C) at different strain rates in the range of 10^{-5} to 10^{-2} s^{-1} with a view to optimise the temperature and strain rate for superplastic forming and to determine the deformation parameters.

A 55-ton hydraulic press was used for the superplastic bulge forming of a hemisphere. A die set-up as shown in Fig. 2 was fabricated and assembled. All components in the die sets were made of austenitic stainless steel of AISI-304/316 quality. The schematic diagram for the gas pipeline used for the forming, capable of with standing 10 MPa, pressure, is shown in Fig. 3. This piping system enabled not only the inert gas flushing of the die-assembly prior to forming, but also for the forming of components under reverse pressure.

A circular sheet (blank) of 116mm diameter was cut from the 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 it reached the set temperature the top chamber was brought down further to effect the required blank holder pressure. About 10 minutes were allowed for thermal equilibriation. 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.

3. RESULTS AND DISCUSSION

The high temperature tensile tests were conducted at different temperatures and different initial strain rates [ISR], where the crosshead velocity was maintained constant and constant true strain rates [CSR], where the true strain rate was maintained constant throughout the duration of the test. Table II and III show the summary of results in terms of the maximum stress and the percentage elongation. These tensile test data showed that the alloy exhibited superplasticity with tensile elongations more than 200% in each of the tests except those at 1173K. In case of the tests carried out constant true strain rates, the crosshead velocity increased as the specimen elongated. The tests were, therefore, of much shorter duration. The elongations to failure were comparatively low and, at the same time, the stress required was higher.

The maximum 450% elongation to failure was observed at 1123K and an initial strain rate of $5.52 \times 10^{-4} s^{-1}$. Fig 4 shows the true stress-true strain plots at this temperature at different initial strain rates. The variation of the flow stress with strain rate at various true strain levels of 0.1 to 0.7 is shown in Fig 5. The *m*-values were obtained as the instantaneous slope of the curve and maximum value of the strain rate sensitivity index of 0.43 was obtained at $5.52 \times 10^{-4} s^{-1}$ at 1123K. From these data the optimal superplastic temperature and strain rate range for superplastic forming (SPF) was determined. Microstructural observations suggest that considerable motion of atoms along the boundary took place and there was no significant grain growth. The results of the microstructural studies are reported else where[5].

The superplastic bulge forming tests were conducted at temperatures of 1098, 1123, 1148 and 1173K and forming gas pressure range of 0.4 to 0.8MPa. The results of the successful forming of a hemisphere under various are given in Table IV. Fig. 6 shows variation of the bulge height with time at 1123K and forming pressure of 0.7MPa. At the temperature of 1098K, with all pressure ranges the full forming will not takes place. As the forming set temperature was increased, the time taken for forming reduced. Similarly with increase in forming pressure the forming time reduced.

Fig. 7 shows a photograph of the sheet specimen and the superplastically bulge formed component formed at a temperature of 1123K and forming gas pressure of 0.7 MPa. The time taken for forming was 85 minutes. This clearly demonstrated the superplastic forming capability of the alloy.

4. CONCLUSION

The high temperature deformation behavior of a Ti-Al-Mn alloy was studied. Tensile tests conducted in the temperature range of 1073 –1173K at a strain rate range of 10^{-5} –10^{-2} s^{-1} showed elongations to failure of more than 200% in most cases. An elongation of more than 450% could be obtained at 1123K at a strain rate of $5.52x10^{-4}$ s^{-1}. The strain rate sensitivity index values were greater than 0.3 for deformations at 1098 and 1123K. This coupled with the large elongations obtained clearly indicated superplastic behavior of the alloy. The optimal strain rate range for superplastic deformation was found to be $1.38x10^{-4}$ to $1.38x10^{-3}$ s^{-1} at the temperature range of 1098 to 1123K. Hemispherical components of 90mm diameter was successfully formed in the temperature range of 1123 to 1173K at forming gas pressures in the range of 0.4 to 0.8MPa by the superplastic bulge forming technique.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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TABLES

Table I. 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

Table II. High temperature, initial strain rate (ISR) tensile test results in terms of the maximum stress and the percentage elongation obtained.

Sl. No	Temper-ature (K)	Strain Rate (s^{-1})	Stress MPa	Elong-ation (%)
1	1073	$1.38x10^{-5}$	18.4	159
2		$6.94x10^{-5}$	21.4	186
3		$1.38x10^{-4}$	30.6	270
4		$5.52x10^{-4}$	41	252
5		$1.38x10^{-3}$	51.4	267
6	1098	$1.38x10^{-5}$	14.4	201
7		$6.94x10^{-5}$	14.6	260
8		$1.38x10^{-4}$	20.4	263
9		$5.52x10^{-4}$	29.87	307
10		$1.38x10^{-3}$	36.8	370
11	1123	$1.38x10^{-5}$	15.6	100
12		$6.94x10^{-5}$	15.8	233
13		$1.38x10^{-4}$	19.92	320
14		$5.52x10^{-4}$	26.57	450
15		$1.38x10^{-3}$	37.61	368
16	1148	$1.38x10^{-5}$	17.4	131
17		$6.94x10^{-5}$	17.62	210
18		$1.38x10^{-4}$	18.2	245
19		$5.52x10^{-4}$	19.79	293
20		$1.38x10^{-3}$	24.68	250
21	1173	$1.38x10^{-5}$	16.2	108
22		$6.94x10^{-5}$	16.2	150
23		$1.38x10^{-4}$	18.4	120
24		$5.52x10^{-4}$	16.8	109
25		$1.38x10^{-3}$	25	160

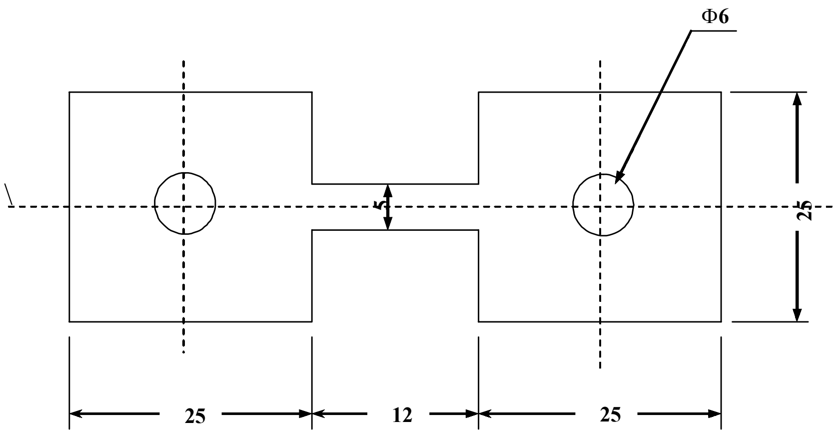
Table III. High temperature, constant strain rate (CSR) tensile test results in terms of the maximum stress and the percentage elongation obtained.

Sl. No	Temper-ature (K)	Strain Rate (s^{-1})	Stress MPa	Elong-ation (%)
1	1073	$3.5x10^{-3}$	74.2	145
2		$1.0x10^{-3}$	44	272
3	1098	$3.5x10^{-3}$	41.3	118
4		$1.0x10^{-3}$	45.6	280
5	1123	$3.5x10^{-3}$	30.8	77
6		$1.0x10^{-3}$	32.6	274
7	1148	$3.5x10^{-3}$	23.1	73
8		$1.0x10^{-3}$	29.9	273
9	1173	$3.5x10^{-3}$	21	75
10		$1.0x10^{-3}$	31.2	94

Table IV. Experimental data details of hemispherical superplastic bulge forming.
Initial thickness- 1.00mm
Soaking time - 10 min

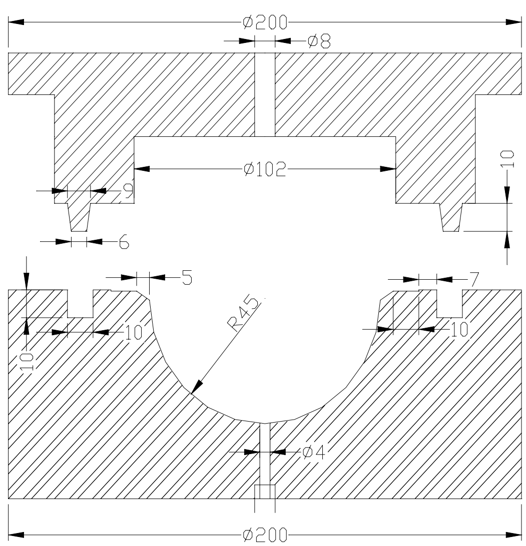
Sl. No	Temper-ature (K)	Pressure MPa	Time (min)
1	1123	0.38	140
2	1123	0.7	85
3	1148	0.7	74
4	1173	0.44	120
5	1173	0.7	66

FIGURES



All dimensions in mm.

Fig.1 High temperature tensile test sample.



All dimensions are in mm

Fig. 2 Schematic diagram of the superplastic forming set-up

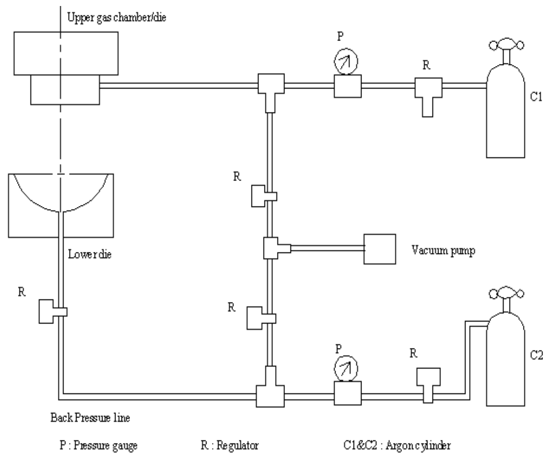


Fig. 3 Schematic diagram for the gas pipeline used for the forming

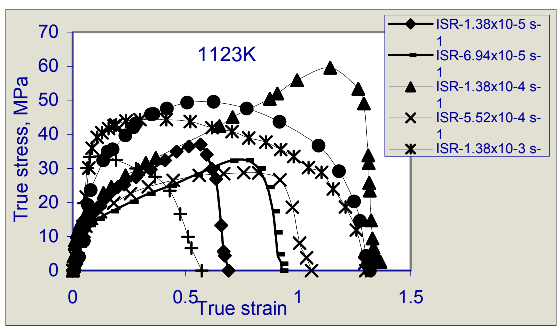


Fig. 4 True stress - true strain plots at 1123K

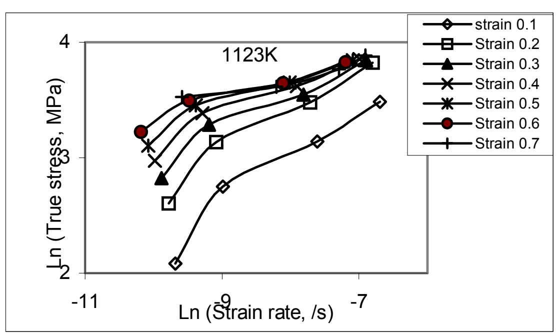


Fig. 5 Variation of flow stress with strain rate at intervals of 0.1 true strain at 1123K

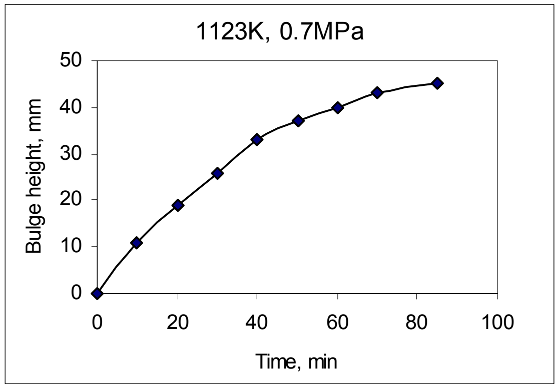


Fig. 6 Variation of the bulge height with time at 1123K and forming pressure of 0.7MPa

Fig. 7 superplastically bulge-formed component (right) and the blank before forming (left).