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ROYAL AEROSPACE ESTABLISHMENT

DEFORMATION OF Ti-6Al-4V BAR AND EXTRUSION

UNDER SUPERPLASTIC FORMING CONDITIONS
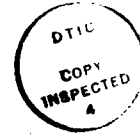
by

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DEFORMATION OF Ti-6Al-4V BAR AND EXTRUSION UNDER SUPERPLASTIC FORMING CONDITIONS

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SUMMARY

There is increasing interest in the use of conventional product forms such as bar and extrusions for superplastic forming (SPF) of pressure vessels and tubular body shells. Tests have been carried out to compare the superplasticity of Ti-6Al-4V bar and extrusion with that reported for sheet. The flow stresses, m-values and plastic anisotropy were measured and related to the microstructure. Resulting anisotropy occurred in specimens machine both parallel (L) and perpendicular (T) to the extrusion major axis. Anisotropy also occurred in specimens machine perpendicular (T), but not parallel (L) to the bar major axis. The anisotropy can be explained in terms of the directionality of the microstructure. It is concluded that for limited strains these conventional product forms, although having non-ideal microstructures can be suitable for superplastic forming of components. GREAT BRITAIN. (TES)

Introduction

The superplastic forming (SPF) of titanium alloys in sheet form is well established and the emphasis has moved towards optimum processing for particular structures [1], and on the post-formed mechanical properties [2]. Meanwhile the need to reduce costs and weight has directed attention to other product forms such as rolled bar and extruded sections for superplastic forming into bottles or pressure vessels. Previous work on textured rectangular rolled bar [3-4] showed texture had negligible effect but the aligned continguous α-microstructure caused stress and strain anisotropy during deformation under superplastic conditions. Further tests have been carried out to compare the behaviour of round bar, and of an extruded U-channel section in Ti-6Al-4V alloy under superplastic conditions. The results obtained are described in the paper.

Experimental Details

The Ti-6Al-4V (IMI 318) extruded section (Fig 1) was produced by conventional extrusion at 950°C and had dimensions of 120 mm wide x 18 mm thick in the web section. The rolled bar was 50 mm diameter. Tensile test pieces aligned parallel to the principal orthogonal directions L and T were machined from the web of the extrusion as shown in Fig 1 and from the axis (L) and diameter (T) of the bar; the gauge lengths of test pieces were 20 mm long and 9 mm diameter. Uniaxial tensile tests were carried out at 925°C at strain rates of 3×10^{-4} s^{-1} (extrusion) and 9×10^{-5} s^{-1} (bar) to elongations up to 400%. The flow stresses and m-values were determined within the range 4-25% elongation and compared with data reported for IMI 318 sheet [5].

Results

The microstructures of the extruded and bar materials were examined after annealing for 2h at 925°C and cooling at 25°C/minute to simulate the thermal cycle experienced under superplastic conditions. The microstructures are shown in Figs 2a and 3a. The α-phase dimensions varied up to 16 μm in the L-direction with the α-phase contiguous and aligned in this direction. The α-phase dimensions were generally much less in the T-directions. The microstructures after deformation to strains of 2.24 (bar) and 1.2 (extrusion) are shown in Fig 2b and 3b; the microstructure was much less aligned and the α-phase appeared to be more equiaxed and broken up into isolated grains.

The shape of the cross-sections in the test piece gauge lengths after deformation to area strains of 2.07-2.24 are shown for the bar in Fig 4; a circular cross-section was obtained for the L-oriented test piece and an elliptical cross-section for the T-oriented test piece, with the maximum diameter parallel to the T-direction. The corresponding cross-section for the extruded material after deformation to strains of 1.2-1.36 is shown in Fig 4; for both L and T orientation test pieces the cross-sections become elliptical during deformation, with the maximum diameter in the T-direction (L oriented test piece) and the L-direction (T oriented test piece). The elliptical shaped cross-section indicated a resistance to deformation in the direction of the larger diameter compared with the orthogonal direction. In all cases the maximum diameter was parallel to the direction of the aligned microstructure in the initial bar and extrusion.

The flow stress v strain rate curves for the extrusion and bar L-oriented test pieces are shown in Fig 5. Over the whole strain rate range the flow stresses were in the order σ_f extrusion > σ_f bar > σ_f sheet. The corresponding m-values v strain rate curves are plotted in Fig 6. The coarser microstructure in the bar and extrusion caused a shift in the peaks of the curves to lower strain rates compared with the curve for sheet. The extruded material

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also showed a sharper peak compared with the other materials. Although for
extrusions the uniaxial tests were carried out at strain rates corresponding
to maximum m-value for the sheet (3×10^{-4} s^{-1}) whilst the bar was tested at
a lower strain rate (9×10^{-5} s^{-1}) which gave a similar m-value to that of
sheet (m > 0.70); anisotropic deformation occurred for bar and extrusion
under both test conditions.

Discussion and Conclusions

The results show that for bar and extrusions high m-values and low flow
stresses can be obtained with microstructures which were not ideal for super-
plasticity. To obtain the same flow stress as used for superplastic sheet,
with m > 0.6 the ratio of the strain rates ($\dot{\varepsilon}$) would be $\dot{\varepsilon}$ sheet : $\dot{\varepsilon}$ bar :
$\dot{\varepsilon}$ extrusion = 2.4 : 2.1 : 1. A fivefold increase in forming time for the
extruded material is likely to impose a severe cost penalty on processing.
The other characteristic of the bar and extruded material was the tendency
to deform anisotropically under superplastic conditions. This behaviour has
also been reported in thin sheet test pieces when the microstructure was
strongly aligned [6]. This is illustrated in Fig 7 for sheet test pieces
machined from rolled bar [6] the non-uniform deformation in Fig 7a was caused
by the banding shown in Fig 7b; note the minimum transverse strain occurred
at the position of the aligned microstructure at A. This behaviour has been
explained in terms of the resistance to sliding in α/α phase grain boundaries
compared with β/β grain boundaries [3,4,7].

Although isotropic strain and high m-values can be obtained in conven-
tionally processed material in a particular direction of stressing, eg rolled
bar in the L-direction, for more homogeneous deformation at higher strain rates
some modification to the rolling, extrusion or heat treatment operations will
be required. This may involve some cost increases in exchange for subsequent
reduced component manufacturing costs by SPF.

References

1. D. Stephen, Designing with Titanium, Inst.Metals, (1986), 108

2. P. G. Partridge et al, Superplasticity, AGARD Lecture Series No 154,
   (1987), 6

3. D. S. McDarmaid et al, J.Mater.Sci., 19, (1984), 2378

4. D. S. McDarmaid et al, J.Mater.Sci., 20, (1985), 1976

5. C. D. Ingelbrecht, Designing with Titanium, Inst.Metals, (1986), 252

6. C. D. Ingelbrecht, P. G. Partridge, J.Mater.Sci., 21, (1986), 4071

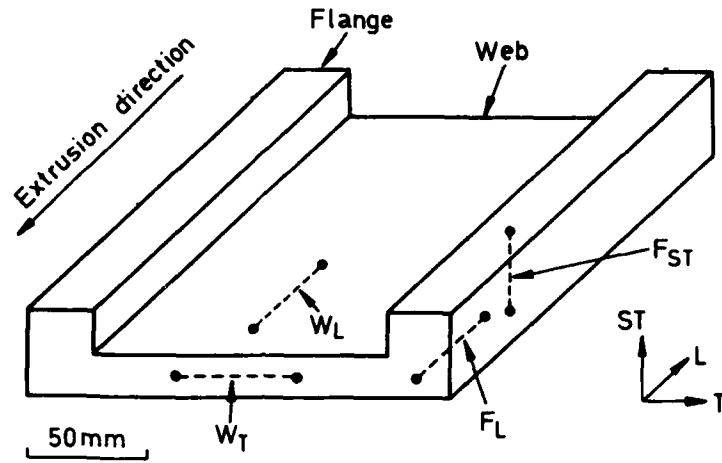7. P. G. Partridge et al, Acta Met., 33, (1985), 571
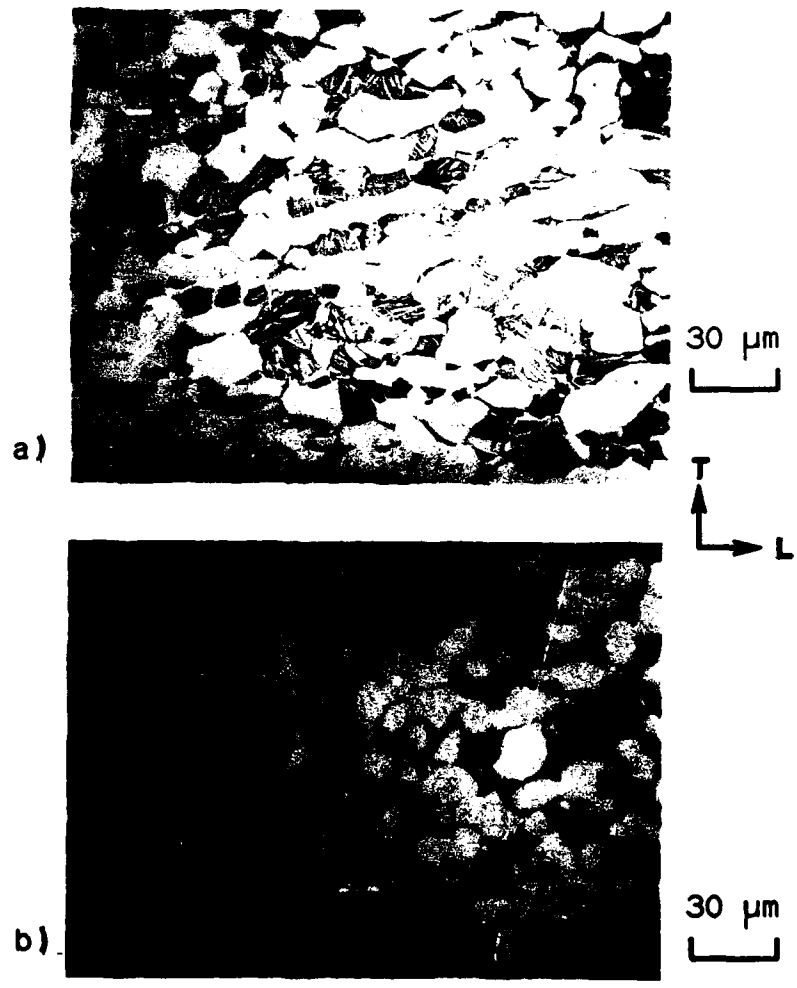
Fig 1 Position of test piece in extruded section

Fig 2 Microstructures of IMI 318 bar (a) after thermal cycle,
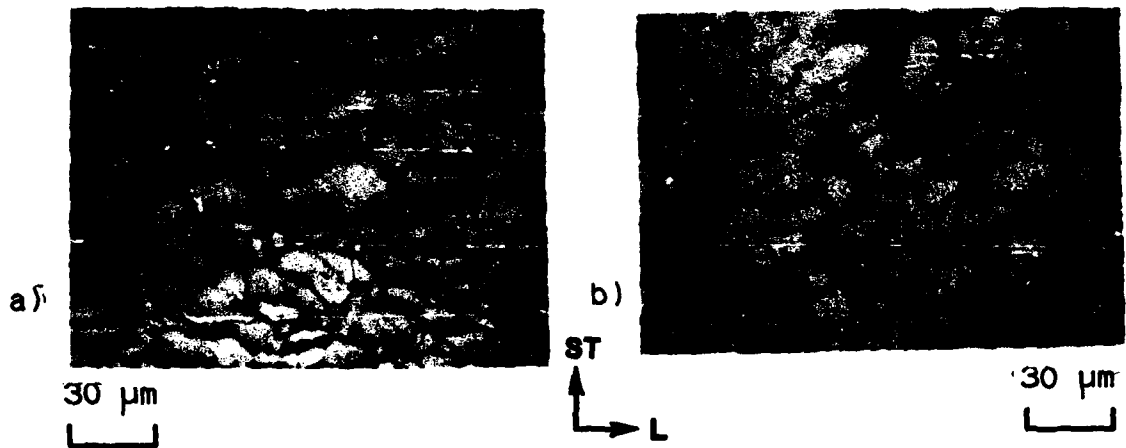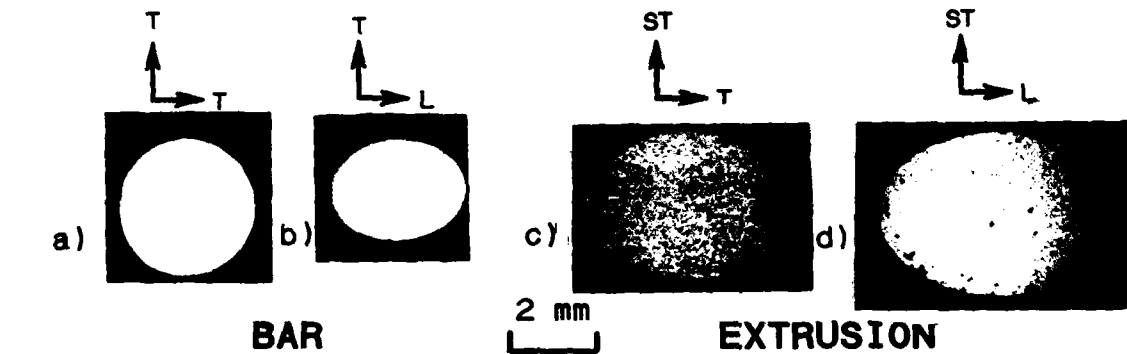(b) after superplastic strain (area strain, $\bar{\varepsilon} = 2.24$)

Fig 3 Microstructures of IMI 318 extrusion, W_T test piece
(a) after thermal cycle, (b) after superplastic strain
(area strain, $\bar{\epsilon}$ = 1.20)

BAR   **EXTRUSION**

$\bar{\epsilon}$	2.07	2.24	1.36	1.20
$\dfrac{d_{min}}{d_{max}}$	1.0	0.74	0.68	0.69

Fig 4 Cross-sections after deformation. Round bar
(a) L-direction, (b) T-direction and extrusion
(c) W_L test piece, (d) W_T test piece. Minimum
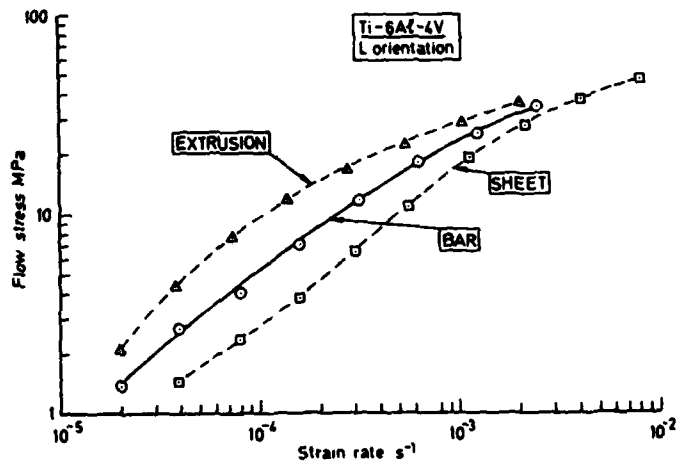diameter, d_{min}, maximum diameter, d_{max}

Fig 5 Flow stress v strain rate for IMI 318 bar,
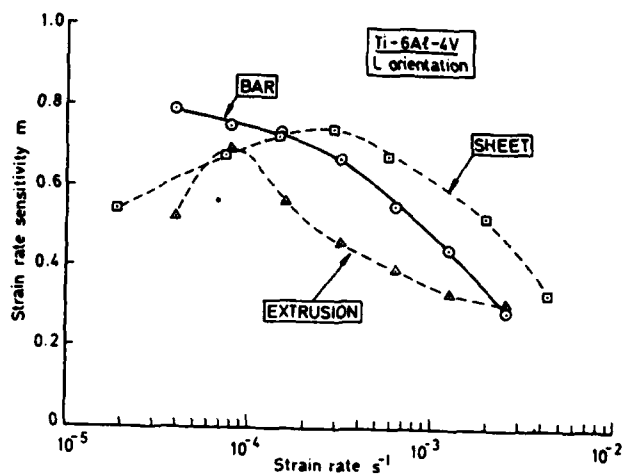extrusion and sheet at 925°C

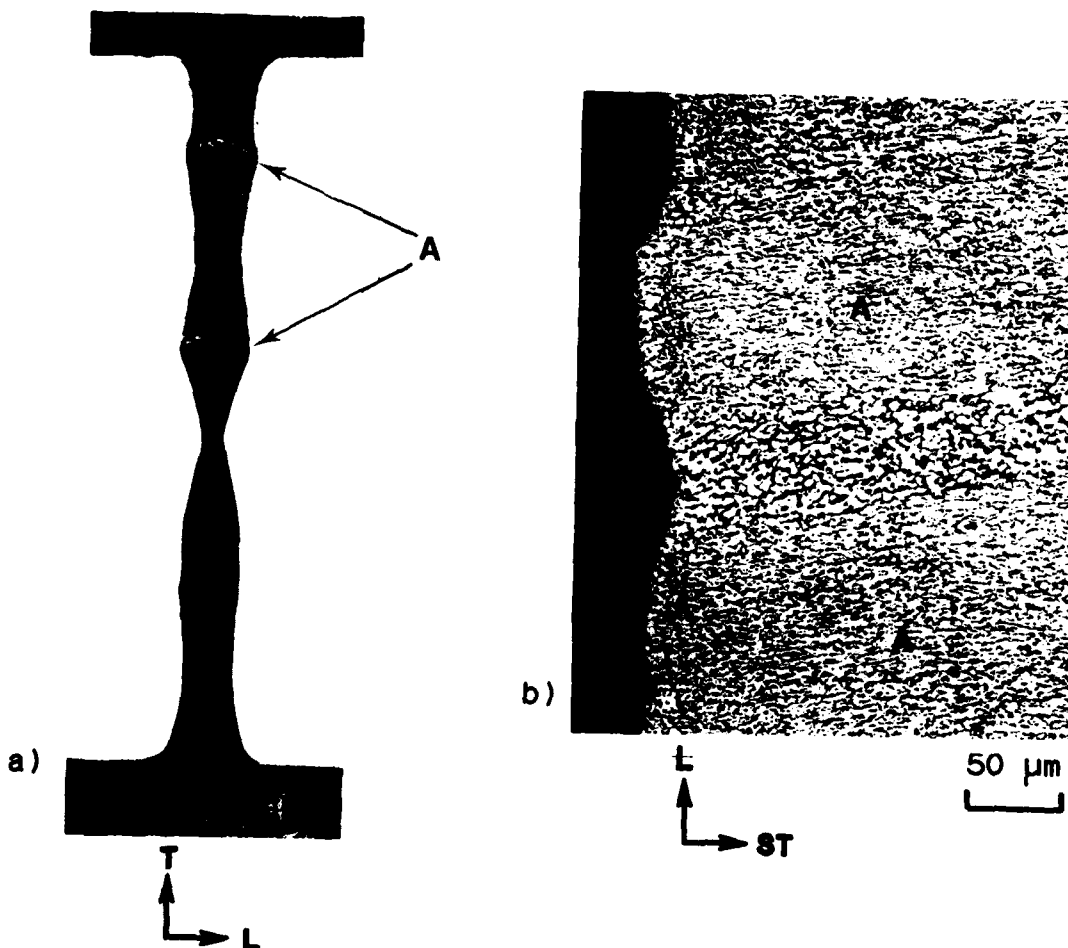Fig 6   m-values v strain rate for IMI 318 bar,
extrusion and sheet at 925°C

Fig 7   Ti-6Al-4V sheet machined from bar (a) test piece,
(b) microstructure,after 273% extension at 875°C,
$\dot{\varepsilon} = 3 \times 10^{-4}$

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16. Descriptors (Keywords)   (Descriptors marked * are selected from TEST)

Titanium alloy. Superplastic deformation. Bar. Extrusion. Sheet.

17. Abstract
     There is increasing interest in the use of conventional product forms such as bar and extrusions for superplastic forming (SPF) of pressure vessels and tubular body shells. Tests have been carried out to compare the superplasticity of Ti-6Al-4V bar and extrusion with that reported for sheet. The flow stresses, m-values and plastic anisotropy were measured and related to the microstructure. Resulting anisotropy occurred in specimens machine both parallel (L) and perpendicular (T) to the extrusion major axis. Anisotropy also occurred in specimens machine perpendicular (T), but not parallel (L) to the bar major axis. The anisotropy can be explained in terms of the directionality of the microstructure. It is concluded that for limited strains these conventional product forms, although having non-ideal microstructures can be suitable for superplastic forming of components.