ON SHEAR FAILURE IN ROUND BAR TENSILE TESTS OF Al—Zn—Mg—Cu ALLOYS

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ABSTRACT

Round bar tensile tests of two Al—Zn—Mg—Cu alloys (7010 and 7475) have been carried out in this investigation. The underaged and peak-aged specimens of both alloys exhibit shear failure, whereas the overaged specimens of both alloys exhibit conventional cup-cone mode of failure. Presumably it is due to their different critical values of the ratio of slip plane hardening rate to the tensile stress at that instant for shear localization. Both the underaged and peak-aged specimens have higher critical ratio for shear localization than that of the overaged specimens, so they are easier to attain such localization during the test. Then the shear failure follows immediately after the shear localization.

INTRODUCTION

Shear failure in round bar tensile tests of aluminium alloys has been studied by Forsyth and Smale[1], Embury and Nes[2], Chung et al[3], King, You and Knott[4] and others. However, this phenomenon has not as yet been fully explained. Due to the fact that the fast shear will often result in premature failure[5,6], its effect on the toughness of high-strength materials is important. Thus, the significance of the investigations on this topic is evident. Round bar tensile tests of two Al—Zn—Mg—Cu alloys (7010 and 7475) have been carried out in our investigation and some interesting results have been found.

MATERIALS AND METHODS

The materials used in our investigation were supplied by ALCAN. Their chemical compositions are given in Table 1.

Table 1 Chemical Composition of 7010 and 7475 Alloys

Element wt.%	Zn	Mg	Cu	Cr	Zr	Fe	Si	Mn	Ti
7010	6.2	2.3	1.9	<0.01	0.11	0.09	0.05	<0.01	0.03
7475	5.6	2.2	1.6	0.12	<0.02	0.09	0.05	<0.01	0.03

The heat treatments and identification of specimens are given in Table 2.

Table 2 Specimen Identification and Heat Treatments*

Code	Heat treatment		
	Solid Solution	Quench	Aging
7010(U)			120°C 2h.
7010(P)	470°C 1h	cold water	120°C 24h.
7010(O)			120°C 24h. + 170 °C 16h.
7475(U)			120°C 2h.
7475(P)	470°C 1h.	cold water	120°C 24h.
7475(O)			120°C 24h. + 170 °C 12h.

* U = underaged, P = peak-aged, O = overaged.

Hounsfield No. 13 specimens (diameter 4.5 mm, gauge length 16 mm) machined in the logitudinal orientation were used for tensile tests. The tests were carried out in a 50 KN screw MAND testing machine at a crosshead speed of 1 mm/min at room temperature. For details of the materials and methods are given in the Reference[6].

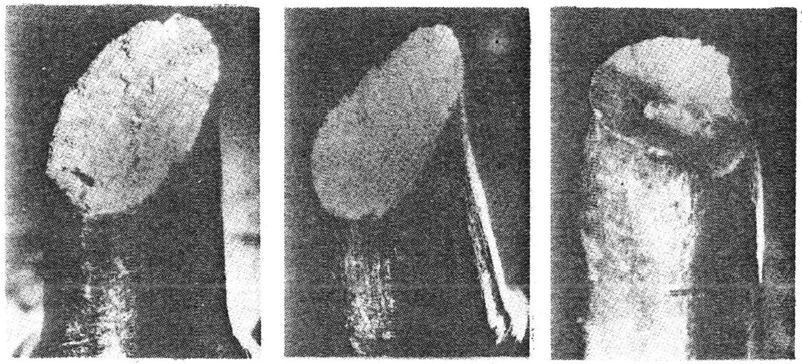
RESULTS

The tensile test results of the alloys are tabulated in Table 3. The reduction of area (q) was measured on the photo taken from the broken specimen. The true fracture strain (ε_f) was calculated based on the reduction of area.

Table 3 Tensile properties of 7010 and 7475 alloys

	σ_u, MNm^{-2}	σ_y, MNm^{-2}	δ,%	q	ε_f
7010(U)	510	430	23.0	0.34	0.42
7010(P)	565	520	15.4	0.24	0.28
7010(O)	520	470	13.5	0.40	0.52
7475(U)	505	405	17.6	0.26	0.30
7475(P)	570	415	14.5	0.21	0.24
7475(O)	485	430	15.6	0.40	0.51

Macroscopic fracture surface of the underaged and peak-aged specimens of both alloys are always slant, whereas the overaged specimens always appear in conventional cup-cone fracture mode. They are shown in Fig. 1.



(a) (b) (c)

Fig. 1. Fracture modes of the specimens, (a) 7475(U), (b) 7010(P), (c) 7475(O)

Microscopic feature of all fracture surfaces is of dimple, ductile mode. In Fig. 2, small dimples are nearly equiaxed and shallow.

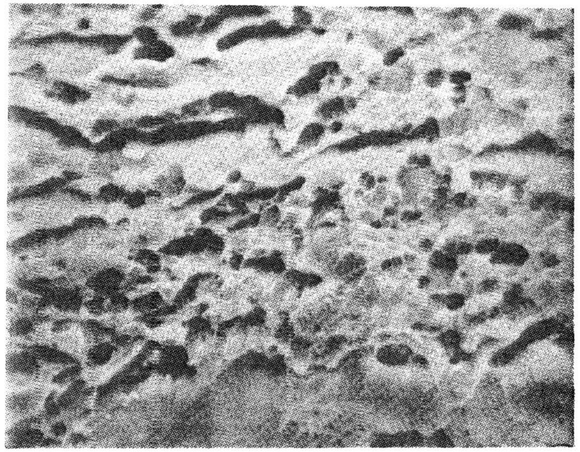


Fig. 2 Scanning electron micrograph, 7010(U),X960

DISCUSSION

The macroscopic shear failure is a widespread problem[2]. Some interesting works have been done on Al-Cu precipitation hardening single crystals by Beevers and Honeycombe[7], Price and Kelly[8], and Chang and Asaro[9]. These crystals often show shear localization. Asaro et al[10,11] discussed this phenomenon from the viewpoint of crystal slip theory and found that the macroscopic shear localization appears whenver the low critical value of the ratio of slip plane strain-hardening rate (h) to the tensile stress (σ) at that instant is attained, i.e. $(h/\sigma)_{crit.}$ is reached. For θ' containing crystals (Al-2.8 wt.% Cu), the average value of $(h/\sigma)_{crit.}$ was 0.032 which is in close agreement with their theoretical models.

In our study the shear failure immediately followed the macroscopic shear localization, and the failure process is catastrophic. Therefore, it is reasonable to assume that the criterion of the shear failure is approximately same as the criterion of the onset of macroscopic shear localization.

The power law $\sigma=k\varepsilon^n$ has been used here to express the true stress-true

strain curves, where n is the strain-hardening exponent and K is the strength coefficient. The n and K values of different specimens are shown in Table 4. The true fracture stress σ_f is also listed in Table 4. $(\frac{\partial\sigma}{\partial\varepsilon})_{\varepsilon_f}$ is the strain hardening rate at ε_f calculated by the power law.

Table 4 Some Flow Parameters of 7010 and 7475 Alloys

	n	K, MNm^{-2}	σ_f, MNm^{-2}	$(\frac{\partial\sigma}{\partial\varepsilon})_{\varepsilon_f}$, MNm^{-2}	h, MNm^{-2}	$(h/\sigma)_{crit.}$
7010(U)	0.11	716	776	172	17.9	0.023
7010(P)	0.08	746	707	196	20.4	0.029
7010(O)	0.09	706	713	116	12.1	0.017
7475(U)	0.18	830	663	406	42.2	0.064
7475(P)	0.09	764	704	253	26.3	0.037
7475(O)	0.11	701	645	140	14.6	0.023

Following Taylor[12], $\sigma=\bar{m}\,\tau$, $\gamma=\bar{m}\varepsilon$, where τ is shear stress and γ is shear strain, $\bar{m}$ is the mean orientation factor. For aluminium, $\bar{m}$ = 3.1, so $(\frac{\partial\sigma}{\partial\varepsilon}) = \bar{m}^2(\frac{\partial\tau}{\partial\gamma}) = 9.61h$, where $h = (\frac{\partial\tau}{\partial\gamma})$ is the slip plane hardening rate. Then, we obtain the critical values of the ratio $(h/\sigma)_{crit.}$ of slip plane hardening rate to the tensile stress, now σ_f, at that instant. It is also listed in Table 4.

By comparison, it is found that the $(h/\sigma)_{crit.}$ of the underaged and peak-aged materials are higher than that of the overaged materials. Obviously, the high value of $(h/\sigma)_{crit.}$ is much easier to attain during the test, because the $(\frac{\partial\sigma}{\partial\varepsilon})$ decreases and the flow stress σ increases as the strain ε increases. Therefore, the underaged and peak-aged specimens are apt to show shear localization, and in turn to shear failure. When the overaged specimens are tested, the center crack forms before attaining its critical value $(h/\sigma)_{crit.}$, thus the failure usually are of cup-cone mode.

SUMMARY

The $(h/\sigma)_{crit.}$ for underaged, peak-aged and overaged materials are different. The underaged and peak-aged materials give higher values of $(h/\sigma)_{crit.}$ than that of overaged materials in both alloys, so they are easy to attain the $(h/\sigma)_{crit.}$ during the test and produce shear failure as the

result. For overaged materials, center cracks forms before $(h/\sigma)_{crit.}$ so that they show conventional cup-cone mode.

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