CANADA

THE METALLOGRAPHY OF CREEP-RUPTURE FRACTURE IN ALUMINUM

by

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ABSTRACT

The evidence presented in this report is interpreted as showing that there is no sharp change from ductile to brittle behaviour in creep-rupture tests of commercially pure aluminum; that all ruptures at less than 100% reduction in area originate in intercrystalline fissures; and that the degree of embrittlement depends upon the extent and number of the fissures.

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MÉTALLOGRAPHIE DE LA FRACTURE PAR FLUAGE JUSQU'AU POINT DE RUPTURE DE L'ALUMINIUM

par

H. H. Bleakney*

RÉSUMÉ

En partant des faits exposés dans le présent rapport, l'auteur prétend qu'il n'y a pas de changement marqué entre le comportement ductile et le comportement cassant au cours d'essais de fluage-rupture d'échantillons d'aluminium commercial pur, que toutes les ruptures qui se produisent dans la masse non encore complètement divisée ont leur origine dans les fissures intercristallines, et que le degré de fragilisation dépend de la gravité et du nombre des fissures.

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INTRODUCTION

A great deal of confusion is found in contemporary discussion of the causes of the intercrystalline fractures observed in creep-rupture tests of most metals and alloys. Servi and Grant(1,2)* proposed that, depending on temperature and strain-rate, points of equicohesion were generated during creep-rupture tests at which the mechanism of fracture changed from trans-crystalline (ductile) to intercrystalline (brittle). Greenwood et al(3) believe that condensation of vacancies at grain boundaries produces cavities which explain the intercrystalline weakness noted. As recently as May 1961, McLean(4) summarized a popular explanation as follows:

> "Cavities form in the grain boundaries, grow, coalesce, and extend until there is too little remaining connected metal to carry the applied load - - - There is strong evidence that the cavities are nucleated by sliding at the grain boundaries which is thought to open up holes at ledges or at inclusions where the cohesion is suitably weak. It is believed that when the cavities have reached a certain size it becomes energetically favourable for vacancies to precipitate in them and thus enlarge them indefinitely".

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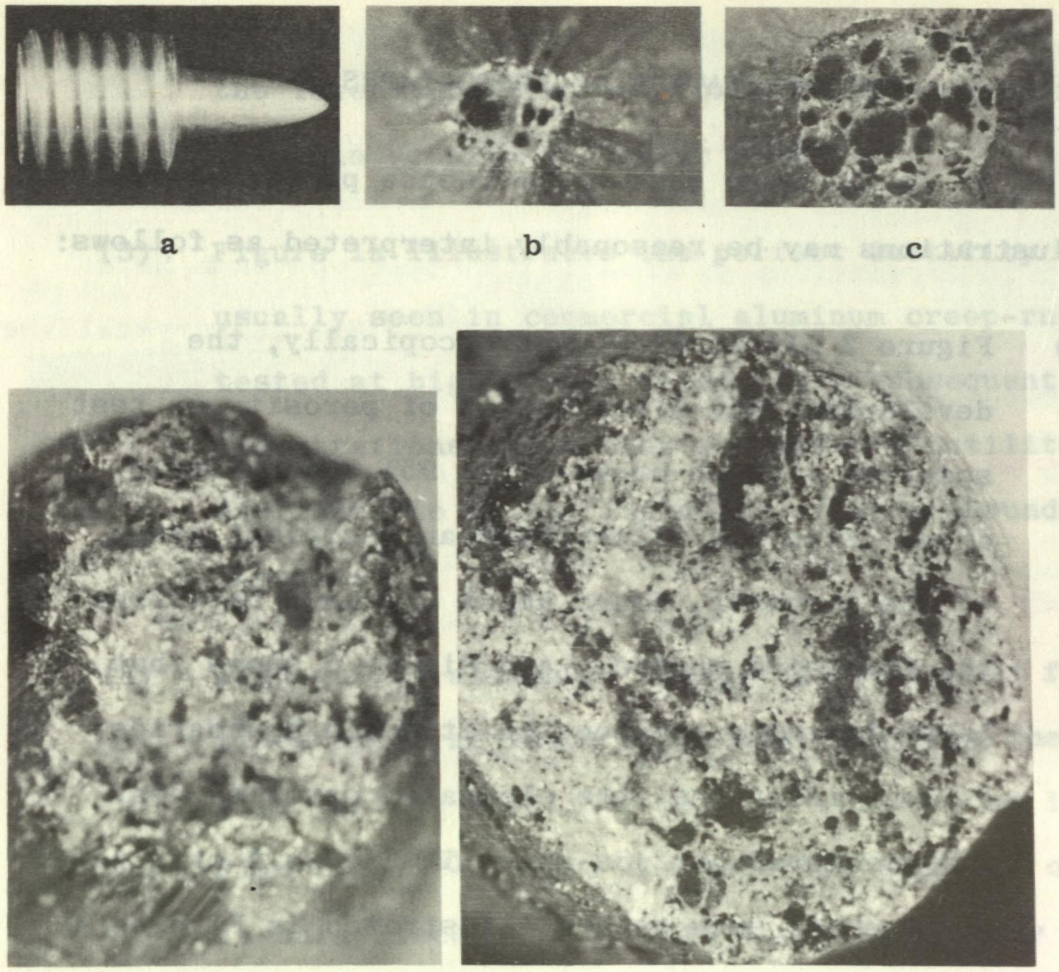
*References are listed at the end of the report in the order in which they are numbered in the text.

This report presents direct photographic evidence which shows the development and physical characteristics of intercrystalline fissures in aluminum; this evidence confirms the following thesis:(5)

> The chemical impairment of cohesion across grain boundaries by films of embrittling impurities is a necessary and sufficient condition for the development of intercrystalline cracks in creep-rupture tests.

The metallographic features of the fractures observed in creep-rupture tests of aluminum, discussed in this report, were obtained from samples of high-purity aluminum to which had been added 0.17% of iron. All creep-rupture tests were made at 370°C (700°F), and Figure 1 illustrates the observed relationship between embrittlement and strain rate. The honeycomb appearance of the fractures illustrated in Figure 1, b and c, is typical of all creep-rupture fractures of commercial aluminum, seen by the author, in which the reduction in area was greater than about 90%.



a b c

d e

Figure 1. Development of intercrystalline fissures.

	Stress	Time to Failure	Red. in Area	Magnification
a	1440 psi	35 min.	100%	2
b	960 psi	16 hours	99%	25
c	900 psi	37 hours	95%	25
d	840 psi	60 hours	82%	25
e	780 psi	124 hours	60%	25

INTERPRETATION OF PHOTOGRAPHS

It is believed that the evidence presented by the illustrations may be reasonably interpreted as follows:

(1) Figure 2 illustrates, macroscopically, the development and distribution of porosity in test specimen c which broke after 95% reduction in area. Figure 4 illustrates an incipient stage of the porosity, found about 0.1 inch back from the fractured surface, and Figure 6 shows that these fissures are located at grain boundaries. It is evident that the elongated cavities near the fractured surface shown in Figure 2 originated as fissures such as are illustrated in Figures 4 and 6. It is also evident that these fissures did not extend transversely, but were drawn out, as the test specimen became elongated, into the tubular shapes shown in Figure 2. This process clearly explains the appearance of the fractures shown in Figures 1b and 1c.

(2) A comparison of Figures 3, 5 and 7 with Figures 2, 4 and 6 shows that an increasing number of fissures formed at the grain boundaries as the strain rate was decreased. Figure 3 shows that the fissures tend to become drawn out into cavities as deformation proceeds, but that, at

the lower strain rates, fracture occurs before they can acquire a tubular shape.

(3) Figure 1a illustrates the perfect ductility usually seen in commercial aluminum creep-rupture-tested at high strain rates. The subsequent illustrations prove that any lesser ductility is attributable to the incidence of grain-boundary fissures.

(4) High-purity aluminum, creep-rupture-tested for times up to at least 373 hours, displays the same perfect ductility as that illustrated in Figure 1a.(6) Since the material reported on in this discussion differs from high-purity aluminum only by its content of 0.17% iron, the embrittlement illustrated in Figure 3 must be attributable to the influence of iron. That influence has evidently brought about a loss of cohesion across grain boundaries in the sample illustrated in Figure 3.

(5) In Figure 3 the area covered by transverse fissures, on any cross-section of the sample, is much less than the fractured surface; and it appears that the metal between the fissures deforms in the same way as any ductile metal in a notched tension test. However, it is obvious

that the overall reduction in area is much less than the sum of the separate reductions of the individual volumes between fissures. Therefore, the reduction of area of the test specimen is a reliable indicator of the extent of intercrystalline cracking.

(6) The evidence presented in this report shows that there is no sharp change from ductile to brittle behaviour in creep-rupture tests of aluminum (see also reference 7). All ruptures at less than 100% reduction in area originate in intercrystalline fissures, and the degree of embrittlement depends upon the extent and number of the fissures.

In the course of this work it was found that a mechanical polish, applied with careful delicacy, was needed to expose the true appearance of the fissures. Electrolytic polishing, by preferentially attacking the exposed edges of the cracks, so enlarged and rounded the openings as virtually to erase the characteristics of the fissures and substitute an appearance characteristic of cavities.

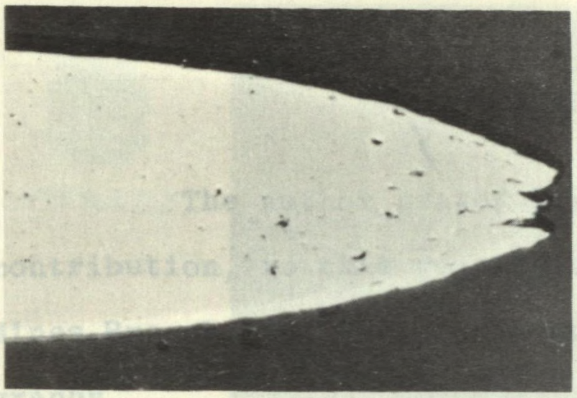


Figure 2. Longitudinal section of c, Figure 1. X9.

Figure 3. Longitudinal section of brittle sample that showed 48% reduction in area after 143 hours under 780 psi. X9.

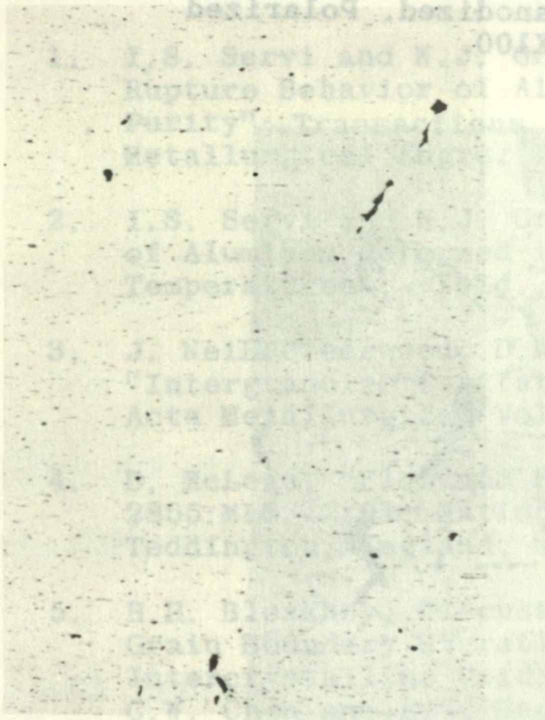


Figure 4. Same section as Figure 2, anodized. Polarized light. X100.

Figure 5. Same section as Figure 3, unetched. Mechanical polish. X100.

Figure 6. Same field as Figure 4, lightly anodized. Polarized light. X100.

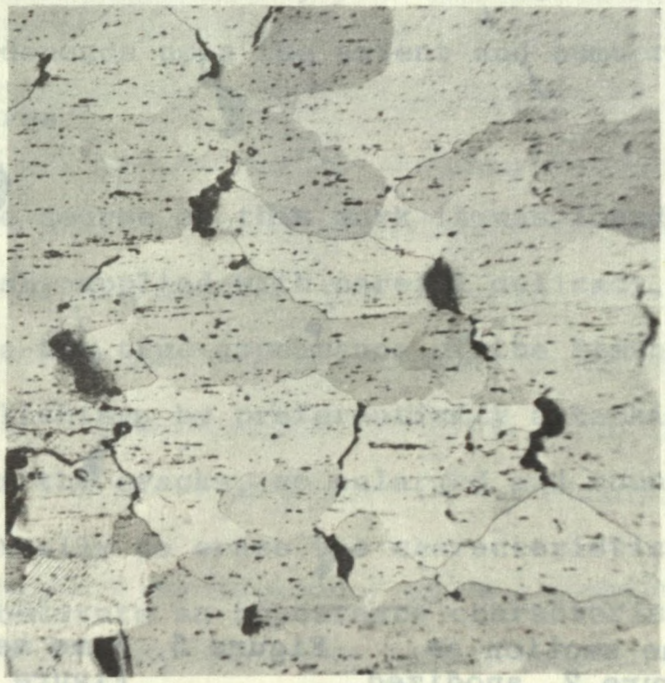


Figure 7. Same field as Figure 5, lightly anodized. Polarized light. X100.

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