

Phase Analysis at 660°C of the Gamma Region of the Copper-Aluminium System

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Three closely related phases appear in the region 30–40 atomic % Al in the Cu-Al system. In order of increasing aluminium content they are: the cubic γ phase; the γ_1 phase, of unknown symmetry; and the rhombohedral γ_2 phase, with space group $R3m$. Homogeneity ranges and lattice parameters are given.

Previous X-ray studies on the alloys in the 30–40 atomic % aluminium region of the copper-aluminium system, the most complete of which is the one by Bradley, Goldschmidt and Lipson,¹ have revealed the existence of three closely related structures. The one with the lowest aluminium content is cubic, and its structure, whose ideal composition is Cu_9Al_4 , is well known.^{2,3} The next structure was assumed by Bradley⁴ to be monoclinic, and the conjecture was also made, that the structure with the highest aluminium content might be rhombohedral,^{1,4} in analogy with the distortion from cubic symmetry occurring in $\gamma\text{-Cr}_5\text{Al}_3$.⁵

EXPERIMENTAL

Weighed amounts of copper (J.T. Baker, foil, assay Cu 100.0 %) and aluminium (E. Merck, puriss. ribbons, ≥ 99.99 % Al) were melted together by induction heating in a BeO crucible under vacuum ($< 1 \mu$). The pellets produced in this fashion were crushed in a steel mortar. The powder was annealed at $660 \pm 10^\circ\text{C}$ for ten days in sealed, evacuated silica capsules, which were quenched in water at the end of the heating period.

The alloy samples were analyzed electrolytically for copper. The analyzed copper content was generally found to be around 0.5 atomic % less than the nominal composition. One sample, $\text{Al}_{0.388(2)}\text{Cu}_{0.610(8)}$, was also analyzed by EDTA titration.

X-Ray powder diffraction photographs were taken with a Guinier focusing camera of 80 mm diameter, using monochromatized $\text{CuK}\alpha_1$ radiation and potassium chloride as an internal standard.⁶

Single crystal data have been collected with a Weissenberg camera ($\text{CuK}\alpha$ radiation) and with a General Electric Spectrogoniometer, equipped with a single crystal orienter ($\text{MoK}\alpha$ radiation).

RESULTS

The present investigation confirms the existence of three separate but closely related phases at 660°C in the 30–40 atomic % Al composition range. Following the nomenclature of Bradley *et al.*,¹ these are:

- | | |
|---|-----------------------------|
| a) The cubic γ phase | 31.3 — \geq 35.3 at. % Al |
| b) The γ_1 phase, symmetry not established | \sim 36.5 at. % Al |
| c) The rhombohedral γ_2 phase | \leq 38.3 — 40.6 at. % Al |

Table 1. Lattice parameters of phases present in alloys $\text{Al}_x\text{Cu}_{1-x}$, at 660°C.

x	phases	a (Å)	α
0.304	$\alpha + \gamma$	8.699 ₇	
0.315	γ	8.702 ₃	
0.316	γ	8.703 ₃	
0.323	γ	8.709 ₃	
0.338	γ	8.713 ₃	
0.353	γ	8.714 ₃	
0.365	γ_1		
0.373	$\gamma_1 + \gamma_2$		
0.383	γ_2	8.697 ₁	89.74 ₃
0.389	γ_2	8.689 ₉	89.78 ₃
0.404	γ_2	8.679 ₃	89.86 ₃
0.417	$\gamma_2 + \zeta$	8.674 ₇	89.82 ₀

Results of the phase analysis and the lattice parameter determinations are summarized in Table 1 and Fig. 1.

A rhombohedral indexing of the Guinier photograph of γ_2 ($\text{Al}_{0.389}\text{Cu}_{0.611}$) is given in Table 2. Lattice parameters and their standard deviations have been calculated from the seven unambiguously indexable lines for which the $(\sin^2\theta_o - \sin^2\theta_c)$ differences are indicated. The distortion from cubic symmetry is very small. The deviation of the rhombohedral angles from 90° is of the

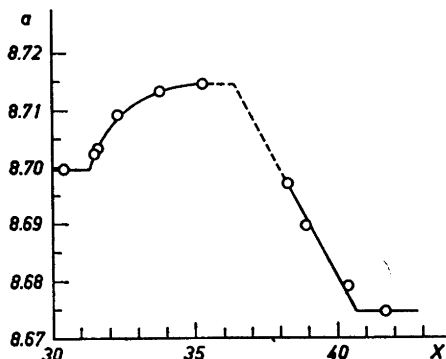


Fig. 1. Edge a (Å) of unit cell versus x , atomic % aluminium.

Table 2. Guinier powder pattern of γ_2 -Al_{0.3892}Cu_{0.6108}. $a = 8.6899 \pm 0.0009$ Å; $\alpha = 89.782 \pm 0.011^\circ$; $\sin^2\theta = 0.0078566 (h^2 + k^2 + l^2) - 0.0000595 (hk + kl + lh)$.

<i>I</i>	<i>h k l</i>	$\sin^2\theta_o$	$\sin^2\theta_c$	$10^5 \times \Delta\sin^2\theta$
w	2 1 0	0.03915	0.03916	-1
vw	$\bar{2}$ 1 0	0.03932	0.03940	-8
w	2 1 1	0.04699	0.04684	+ 15
w	$\frac{2}{2}$ $\bar{1}$ 1	0.04726	0.04720	
	$\frac{2}{2}$ 1 1		0.04732	
vw	3 0 0	0.07087	0.07071	+ 16
vw	$\frac{3}{3}$ $\bar{1}$ 1	0.08667	0.08648	
	$\frac{3}{3}$ 1 1		0.08672	
vw	$\frac{3}{3}$ $\bar{2}$ 2	0.13398	0.13380	
	$\frac{3}{3}$ 2 2		0.13404	
vs	4 1 1	0.14092	0.14088	
vs	3 3 0	0.14153	0.14148	
vs	$\frac{4}{4}$ 1 1	0.14197	0.14184	
vvs	$\frac{3}{3}$ 3 0	0.14197	0.14195	
vw	4 2 2	0.18772	0.18737	
vw	$\frac{4}{4}$ $\bar{2}$ 2	0.18894	0.18880	
	$\frac{4}{4}$ 2 2		0.18927	
vw	4 4 2	0.28089	0.28093	-4
m	6 0 0	0.28286	0.28284	+ 2
	4 4 $\bar{2}$			
vw	$\bar{4}$ 4 2	0.28376	0.28379	-3
vw	$\bar{4}$ 4 4	0.37821	0.37807	
m	6 3 3	0.42192	0.42158	
m	$\bar{7}$ 2 1	0.42526	0.42533	

order of 0.2° , decreasing somewhat with increasing aluminium content. Single crystal Weissenberg photographs and spectrogoniometer data indicate that the space group of this phase is $R\bar{3}m$ (No.160), which is a subgroup of $P\bar{4}3m$, the space group of the cubic γ phase. A complete structure investigation is in progress.

The powder photograph of γ_1 , which appears to be present as a single phase in the 36.5 atomic % Al sample only, has not yet been satisfactorily indexed. The distortion of the unit cell from cubic symmetry seems to be even smaller than in γ_2 .

The 37.3 atomic % Al preparation appears to be in the γ_1 - γ_2 two phase region. None of the samples have been observed to contain the two phases $\gamma + \gamma_1$ in equilibrium.

The phase homogeneity ranges observed are in complete accord with the findings of Bradley *et al.*,¹ but the lattice parameter values obtained in the present work are generally higher by the order of 0.01 Å, as well as more precise. The systematic difference may be due to the older values being given in kX units. The unit of measurement was not, however, explicitly stated in that work.

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REFERENCES

1. Bradley, A.J., Goldschmidt, H.J. and Lipson, H. *J. Inst. Metals* **63** (1938) 149.
2. Bradley, A.J. and Jones, P. *J. Inst. Metals* **51** (1933) 131.
3. Westman, S. *Acta Chem. Scand.* **19** (1965) 1411.
4. Bradley, A.J. *Nature* **168** (1951) 661.
5. Bradley, A.J. and Lu, S.S. *Z. Krist.* **96** (1937) 20.
6. Westman, S. and Magnéli, A. *Acta Chem. Scand.* **11** (1957) 1587.

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