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Cast and investigate the characteristics of a high strength aluminium, copper and silver alloy

Couch, J.

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Appendices

A1: Atomic Data

This data was taken from the version of the periodic table published in the book by Askeland, the 'Science and Engineering of Materials' (Askeland 2011). Data on solubility was taken from the phase diagrams appended to this paper (A4).

		atomic number	atomic mass	atomic radius (pm)	electro-negativity [O = 3.5, Cl=3]	Melt [c]	density [g/cm^3]	lattice [at 550c]	max solubility in Al in % weight at Al/Cu binary eutectic (548.2 C)
Aluminium	Al	13	26.98	118	1.61	660	2.7	FCC	100
Copper	Cu	29	63.55	145	1.9	1083	8.9	FCC	5.65
Silver	Ag	47	107.87	165	1.9	961	10.5	FCC	47

A2: Calculating Mass by Volume

To avoid wasting valuable resources, and to improve the efficiency of the casting process, it was desirable to use the minimum quantity of constituents for the given mold size. The method developed is presented here should another wish to calculate percentages by weight based on mold volume.

For any given ternary alloy system;

$$V_m = \frac{m_1}{\rho_1} + \frac{m_2}{\rho_2} + \frac{m_3}{\rho_3} \qquad (A\ 2.1)$$

Where;

$V_m = mold\ volume\ in \frac{grammes}{cm^3}$

$m_1 = mass\ of\ constituent\ 1\ in\ grammes$

$m_2 = mass\ of\ constituent\ 2\ in\ grammes$

$m_3 = mass\ of\ constituent\ 3\ in\ grammes$

It is desirable to find the precise mass of m_3 for a given volume of mold; re-arranging the A 2.1;

$$\alpha\ V_m = \beta\ m_1 + \gamma\ m_2 + \delta\ m_3 \qquad (A\ 2.2)$$

Where;

$\alpha = \rho_1\rho_2\rho_3$

$\beta = \rho_2\rho_3$

$\gamma = \rho_1\rho_3$

$\delta = \rho_1\rho_2$

Constituents, m_1 and m_2 are first expressed in terms of m_3;

$$m_1 = \left[\frac{100 - (\%m_2 + \%m_3)}{\%m_3}\right] \times m_3$$

$$m_2 = \left[\frac{100 - (\%m_1 + \%m_3)}{\%m_3}\right] \times m_3$$

These are then substituted to leave only m_3 as an unknown variable. Before substituting these can be expressed as follows to simplify the equation on the page;

$m_1 = (K - \varepsilon)m_3$

$m_2 = (K - \theta)m_3$

Where;

$$K = \frac{100}{\%m_3}$$

$$\varepsilon = \frac{(\%m_2 + \%m_3)}{\%m_3}$$

$$\theta = \frac{(\%m_1 + \%m_3)}{\%m_3}$$

Substituting into A 2.2 and re-arranging as follows;

$$\alpha\, V_m = \beta\, m_1 + \gamma\, m_2 + \delta\, m_3$$

$$\alpha\, V_m = \beta\, (K - \varepsilon)\, m_3 + \gamma\, (K - \theta) m_3 + \delta\, m_3$$

$$\alpha\, V_m = m_3\, [\beta\, (K - \varepsilon) + \gamma\, (K - \theta) + \delta]$$

$$\boldsymbol{m_3 = \frac{\alpha\, V_m}{[\beta\, (K - \varepsilon) + \gamma\, (K - \theta) + \delta]}} \qquad (\boldsymbol{A\ 2.3})$$

With some alteration to the coefficients, a similar equation can be used to find the weight of any of the three constituents simply by considering it as mass 3.

A spreadsheet was developed based around these equations which allowed the calculations to be carried out easily.

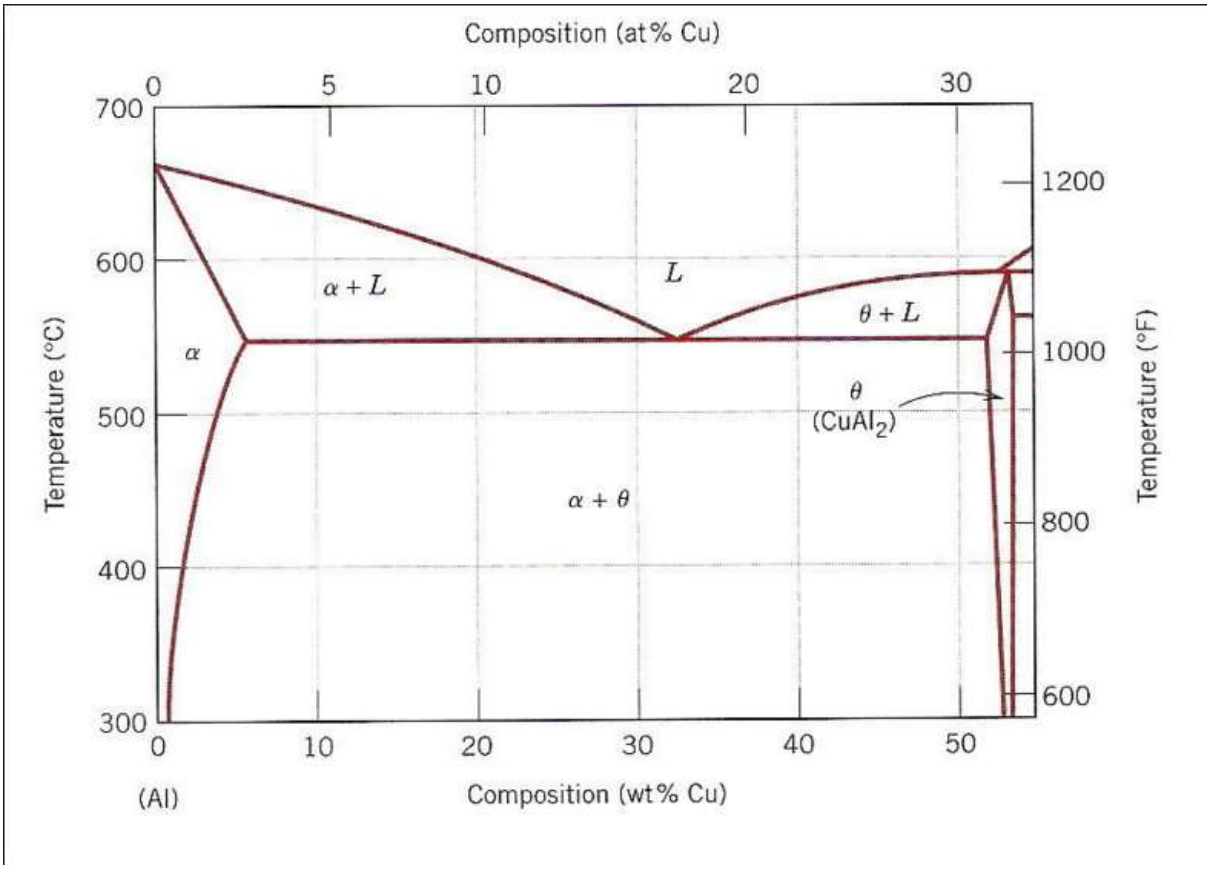
A3: X-ray verification

Verification was conducted using an Olympus XRF hand-held device.

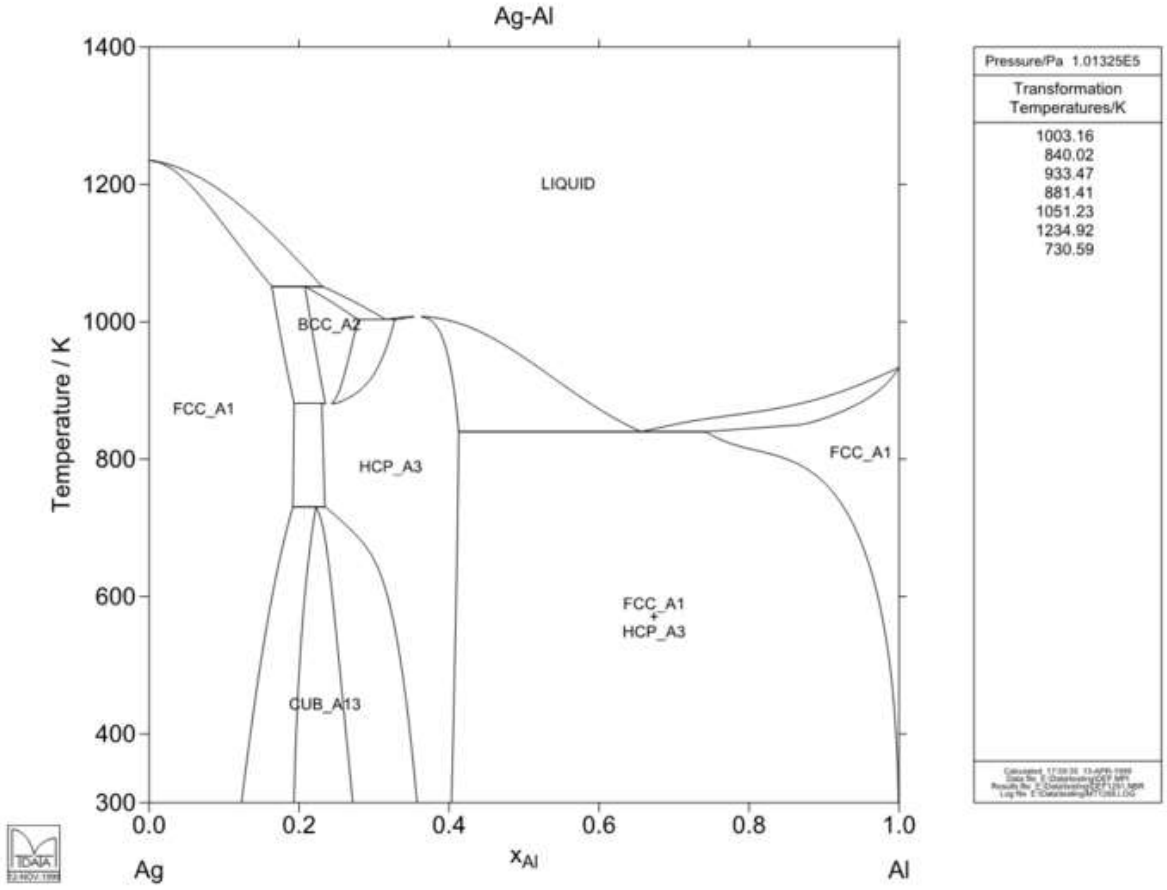
	Intended content	**actual content (verfiied by X-Ray)**									
Code no:					Trace elements also present						
	% Al: %Cu: % Ag	% Al	% Cu	% Ag	% Fe	% Pd	% Si	% Pb	% Cd	% P	% Sn
0	96:04:00	96.06	3.89	0%	0.05	0	0	0	0	0	0
1	95:04:01	94.63	4.19	1.09	0.047	0	0.04	0	0	0	0
2	94:04:02	92.91	4.7	2.16	0.138	0	0.06	0.025	0	0	0
3	93:04:03	91.68	4.16	3.47	0.053	0	0	0.47	0.029	0	0
4	92:04:04	91.03	4.41	4.27	0.29	0	0.12	0.033	0	0	0.048
5	91:04:05	89.44	4.39	6.1	0	0.071	0	0	0	0	0
6	90:04:06	89.44	4.1	6.24	0	0	0.09	0.065	0.035	0.025	0
7	89:04:07	80.74	5.32	13.83	0	0.12	0	0	0	0	0
8	88:04:08	77.04	6.13	16.48	0.043	0	0.06	0.146	0.096	0	0
9	87:04:09	74.03	6.53	18.71	0	0.13	0	0	0	0	0
10	86:04:10	78.49	4.82	16.65	0	0.13	0	0	0	0	0

A4: Equilibrium Binary Phase Diagrams

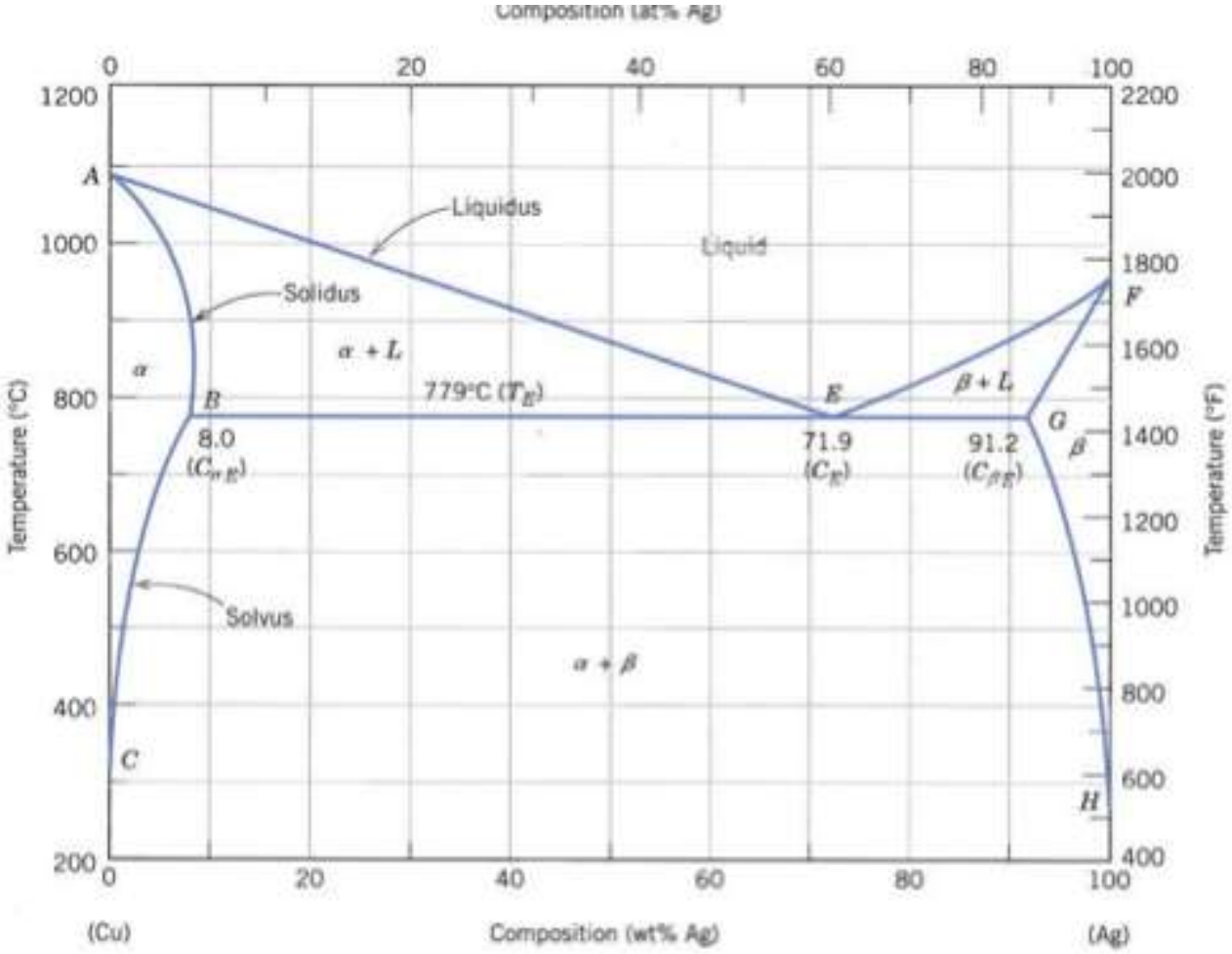
A 4.1; Alumninium/ Copper



A 4.2; Aluminium/ Silver



A 4.3; Silver/ Copper



A5: Calculation of Atomic %

From authoritative versions of the periodic table one mole (that's $6.022\ X\ 10^{23}\text{atoms}$) of each of the elements in the alloys under investigation are as follows;

$$one\ mole\ of\ Ag = 107.87\ grammes$$

$$one\ mole\ of\ Cu = 63.55\ grammes$$

$$one\ mole\ of\ Al = 26.98\ grammes$$

Following this;

$$1\ gramme\ Ag = \frac{6.022\ \times 10^{23}}{107.87} = 5.583\ \times\ 10^{21}$$

$$1\ gramme\ Cu = \frac{6.022\ \times 10^{23}}{63.55} = 9.476\ \times\ 10^{21}$$

$$1\ gramme\ Al = \frac{6.022\ \times 10^{23}}{26.98} = 2.232\ \times\ 10^{22}$$

That is, for the same mass there are approximately 58.92% more copper atoms than silver.

In the context of this investigation this is significant as it is not until the silver content exceeds around 8% by weight (actually just under this) that there is approximately an equal number of silver and copper atoms present in the alloy. However, the alloy manufactured with 8% silver by weight has twice as much silver in it when considered by weight due to the silver having a higher density than copper.

Diffusion, the mechanism by which precipitates form, depends on the atomic concentration and in nearly all of the alloys investigated the copper atoms are in greater abundance than silver, although the silver content is more by weight.

A6: Process Parameters

No data was available on optimising process parameters for the specific alloy system in question. Therefore, parameters at each of the stages were chosen carefully by consulting authoritative sources on parameters used for similar alloy systems; namely 2000 and 6000 series aluminium alloys (Couper, Cooksey & Rinderer).

During the homogenisation and solution treatment stages it was crucial not to exceed the alloy's solidus line as this would have meant partial melting. A temperature of $510\ ℃$ was chosen for homogenisation as this gave 'room for error' to allow the kiln controller damping system to over shoot the target before settling down.

<u>The controller was programmed with the following temperature time profile used for homogenisation*;*</u>

Ramp up; $22 - 510℃$ at a rate of $1000℃$ per hour $(30$ minutes$)$.

Hold at $510℃$ (120 minutes)

Ramp down; $510 - 400\ ℃$ at a rate of $220\ ℃$ per hour $(30$ minutes$)$.

Total time was 180 minutes.

<u>The controller was programmed with the following temperature time profile used for solution treatment*;*</u>

Ramp up; $22 - 548℃$ at a rate of $1052℃$ per hour $(30$ minutes$)$.

Soak at $548\ ℃$ (240 minutes)

Ramp down; $548 - 22\ ℃$ at quenched in water at room temperature.

Total time was 270 minutes.

A7: Further Research Topics

1) It is not known what conditions will cause these alloys to over-age, this has implications for how the alloys may be employed under service conditions; a duraluminium type alloy (4% Wt Cu) will overage in around 6 minutes at 240 ℃ (Askeland 2011). The parameters used in this investigation appear to show that over-ageing did not occur (evidence for this is that the material is strongest in the aged 4 hour condition).
2) Further work is needed to provide data on the material's specific strength; due to silver's relatively high density the specific strength may place the material at a disadvantage.
3) Further work is needed to determine how strain hardening will affect the cast alloy's strength in comparison to the wrought state; significant further improvements to strength are to be expected by working the alloy.
4) Research is needed to determine a suitable etchant (other than Kellers) that will not attack the silver so aggressively.