# On the Brinell Hardness of the Ternary Alloys consisting of Copper, Zinc and Aluminium as an α-solid solution.

By

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## Introduction.

The hardness of the binary alloys has hitherto been studied by several workers; the results may be summarised as follows:—

1 The hardness increases with the addition of one component to the other, when both are perectly soluble, showing a maximum when the composition is just in the proportion of the atomic weights;[1]

2 When both metals are not completely soluble, the maximum lies in the field of the solid solution, as long as the solubility is relatively large; but with a less solubility, the hardness rises to the saturation point, there cutting the curve as its end value;[2]

3 When one component is soluble in the other, the hardness becomes greater in proportion to the decreasing rate of solubility.[3]

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1 Kurnakow and Zemczuzny, Journ. Russ. Phys.-Chem. Soc., 1908, vol. xl, 1067–1104; Harris, Journ. Inst. Metals, 1922, No. 2, 328.

2 Turner and Murry. Journ. Inst. Metals, 1909, No. 2, 137; Johnson, Journ. Inst. Metals, 1918, No. 2, 233; Haughton, Journ. Inst. Metals, 1918, No. 2, 243; Harris, Journ. Inst. Metals, 1922, No. 2, 330.

3 Norbury, Journ. Inst. Metals, 1923, No. 1, 423; Jeffries and Archer, Sci. Metals, 1924, 257.

It seems, however, that no papers on the ternary alloys as solid solutions have yet been published, so that the present writer has taken up the subject with respect to the alloys consisting of copper, zinc and aluminium as an $\alpha$-solid solution.

## Experiment.

The copper, zinc and aluminium used as materials were of the best quality that could be obtained in the market. They wery melted together in the required proportions, cast, annealed for 2–3 hours at 650°, cut parallel in 2 opposite surfaces and well polished.

The hardness test was made thrice and the mean value taken for each specimen, using a 2 mm ball with a load of 40 kg for one minute, so that the ratio of the load to the diameter of the ball should be 10.[1]

All the results of the experiments are tabulated in Table I, while in Table II, the hardness is given at the position denoted by the weight percentage of zinc as abscissa and that of aluminium as ordinate. The asterisks in the latter Table refer to the specimens containing the $\beta$-phase, the existence of which is obvious from the annexed microphotograms.

The microphotograms, Nos. 11, 19, 27, 34, 40, 44, 47 and 49 represent the specimens consisting of the $\beta$-phase intermixed with the $\alpha$, while Nos. 10, 18, 26, 32, 39, 43 and 46 are those cut from the $\alpha$-field very near to the boundary line.

The curve, Fig. 1, shows the variation of the Brinell hardness due to the addition of aluminium to the $\alpha$-solid solution consisting of Cu and Al. The curve, Fig. 2, shows the hardness variation due to the addition of aluminium to the $\alpha$-soild solution consisting of Cu with 5% Zn. The curves, Figs. 3, 4, 5, 6 and 7 show respectively the variation due to the addition of aluminium to the Cu–alloys consisting of 10, 15, 20, 25 and 30% Zn,

As may be seen from the curves, Figs. 1, 2, 3, 4 and 5, where the solubility–limits are relatively large, the maximum hardness appears within that limit, but from the curves, Figs. 6 and 7, where the solubility–limits are narrower, the hardness rises to the phase boundary, beyond which it still continues to rise in the $\beta$–field. When the maximum points in the $\alpha$–field are connected as in Fig. 8, we obtain a smooth curve drawn in a dotted line, which indicates that the variation of the hardness by the addition of aluminium is continuous, the maximum

1 Brownson, Journ. Inst. Metals, 1923, No. 2, 69.

appearing at 15% Zn–alloy with 3% Al added.

Next, the same result was reached with the Cu–Al–alloys with zinc added. The curve, Fig. 9, shows the variation of the hardness with the increasing amount of zinc in the Cu–Zn-alloys, while the curves, Figs. 10, 11, 12, 13, 14, 15, 16 and 17 show respectively its variation due to the addition of zinc to the Cu–Al–alloys containing 1, 2, 3, 4, 5, 6, 7 and 8% Al. When the maximum points are connected as in Fig. 18, we get a curve drawn in a dotted line, which shows the maximum hardness lies in the alloy consisting of 15% Zn, 3% Al and 82% Cu.

## Summary.

1 The variation of the hardness in the ternary alloys shows the same relation as with the binary alloys.

2 When the solubility–limits are relatively large, there exists a maximum in the field of the solid solution.

3 When the limits are relatively narrow, the hardness curve will continue to rise, till it reaches the boundary line.

4 Beyond the boundary line, the curve still continues to rise gradually or very rapidly, as the case might determine.

Table I.

Diameter of ball: 2 mm. Load: 40 kg.

| No. | Weight percent of components | | | Diameter of impression in mm | Brinell hardness |
|---|---|---|---|---|---|
| | Cu | Zn | Al | | |
| 1 | 100 | — | — | 1·108 | 38 |
| 2 | 99 | — | 1 | 1·095 | 39 |
| 3 | 98 | — | 2 | 1·070 | 41 |
| 4 | 97 | — | 3 | 1·025 | 45 |
| 5 | 96 | — | 4 | 0·985 | 49 |
| 6 | 95 | — | 5 | 0·950 | 53 |
| 7 | 94 | — | 6 | 0·950 | 53 |
| 8 | 93 | — | 7 | 0·924 | 56 |
| 9 | 92 | — | 8 | 0·950 | 53 |
| 10 | 91 | — | 9 | 0·968 | 51 |
| 11 | 90 | — | 10 | 0·893 | 60 |
| 12 | 95 | 5 | — | 1·035 | 44 |
| 13 | 94 | 5 | 1 | 1·005 | 47 |
| 14 | 93 | 5 | 2 | 0·975 | 50 |
| 15 | 92 | 5 | 3 | 0.958 | 52 |
| 16 | 91 | 5 | 4 | 0·934 | 55 |
| 17 | 90 | 5 | 5 | 0·923 | 56 |
| 18 | 89 | 5 | 6 | 0·933 | 55 |
| 19 | 88 | 5 | 7 | 0·867 | 65 |
| 20 | 87 | 5 | 8 | 0·708 | 99 |
| 21 | 90 | 10 | — | 1·025 | 45 |
| 22 | 89 | 10 | 1 | 0·995 | 48 |
| 23 | 88 | 10 | 2 | 0·957 | 52 |
| 24 | 87 | 10 | 3 | 0·950 | 53 |
| 25 | 86 | 10 | 4 | 0·897 | 59 |
| 26 | 85 | 10 | 5 | 0·950 | 53 |
| 27 | 84 | 10 | 6 | 0·792 | 77 |
| 28 | 83 | 10 | 7 | 0·720 | 95 |
| 29 | 85 | 15 | — | 0·995 | 48 |
| 30 | 84 | 15 | 1 | 0·950 | 53 |
| 31 | 83 | 15 | 2 | 0·893 | 60 |
| 32 | 82 | 15 | 3 | 0·840 | 66 |

| | | | | | |
|---|---|---|---|---|---|
| 33 | 81 | 15 | 4 | 0·942 | 54 |
| 34 | 80 | 15 | 5 | 0·772 | 82 |
| 35 | 79 | 15 | 6 | 0·650 | 117 |
| 36 | 80 | 20 | — | 0·950 | 53 |
| 37 | 79 | * 20 | 1 | 0·910 | 58 |
| 38 | 78 | 20 | 2 | 0·892 | 60 |
| 39 | 77 | 20 | 3 | 0·925 | 56 |
| 40 | 76 | 20 | 4 | 0·840 | 69 |
| 41 | 75 | 20 | 5 | 0·660 | 114 |
| 42 | 75 | 25 | — | 0·975 | 50 |
| 43 | 74 | 25 | 1 | 0·918 | 57 |
| 44 | 73 | 25 | 2 | 0·864 | 65 |
| 45 | 72 | 25 | 3 | 0·704 | 99 |
| 46 | 70 | 30 | — | 1·024 | 45 |
| 47 | 69 | 30 | 1 | 0·892 | 60 |
| 48 | 68 | 30 | 2 | 0·691 | 104 |
| 49 | 65 | 35 | — | 1·015 | 46 |

Table II.

Weight per-cent of aluminium.

Weight per cent of zinc.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 38 | 39 | 41 | 45 | 49 | 53 | 53 | 56 | 53 | 51 | 60* |
| 5 | 44 | 47 | 50 | 52 | 55 | 56 | 55 | 65* | 99* | | |
| 10 | 45 | 48 | 52 | 53 | 59 | 53 | 77* | 95* | | | |
| 15 | 48 | 53 | 60 | 69 | 54 | 82* | 117* | | | | |
| 20 | 53 | 58 | 60 | 56 | 69* | 114* | | | | | |
| 25 | 50 | 57 | 65* | 99* | | | | | | | |
| 30 | 45 | 60* | 104* | | | | | | | | |
| 35 | 46* | | | | | | | | | | |

Fig. I.
Brinell hardness of copper-aluminium alloys.

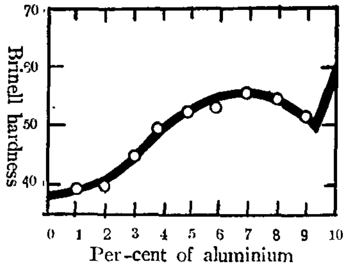



Fig. 2.
Brinell hardness of copper-zinc-aluminium Alloys, containing 5% zinc:

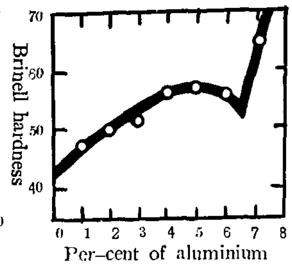



Fig. 3.
Brinell hardness of copper-zinc-aluminium alloys, containing 10% zinc.

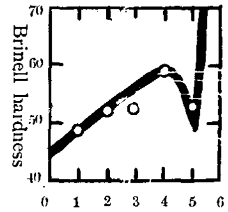



Fig. 4.
Brinell hardness of copper-zinc-aluminium alloys containing 15%zinc.

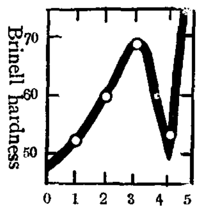



Fig. 5.
Brinell hardness of copper-zinc-aluminivm alloys containing 25% zinc.

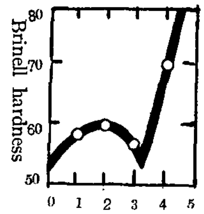



Fig. 6.
Brinell hardness of copper-zinc-aluminium alloys containing 25% zinc.

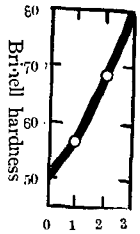



Fig. 7.
Brinell hardness of copper-zinc-aluminium alloys containing 30% zinc.

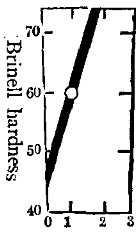



Fig. 8.
Brinell hardness of copper-zinc aluminium alloys.

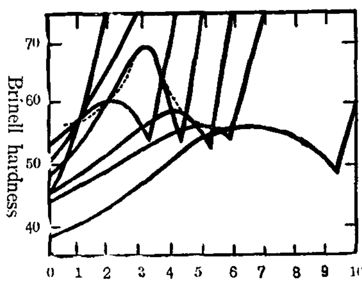


Fig. 9.

Brinell hardness of copper-zinc alloys.

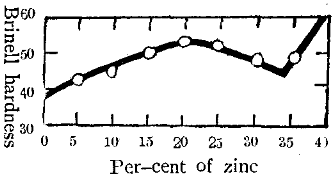



Fig. 10.

Brinell hardness of copper-zinc-aluminium alloys, containing 1% aluminium.

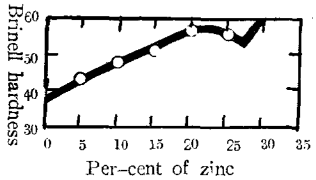



Fig. 11.

Brinell hardness of copper-zinc-aluminium alloys, containing 2% aluminium.

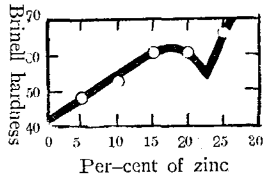



Fig. 12.

Brinell hardness of copper-zinc aluminium alloys, containing 3% aluminium.

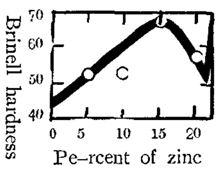



Fig. 13.

Brinell hardness of copper-zinc-aluminium alloys, containing 4% aluminium.

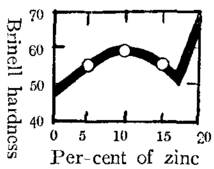



Fig. 14.

Brinell hardness of copper-zinc-aluminium alloys, contaning 5% aluminium.

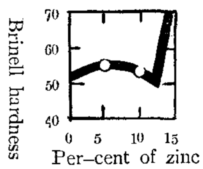



Fig. 15.

Brinell hardness of copper-zinc-aluminium alloys, containing 6% aluminium.

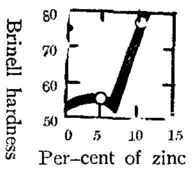



Fig. 16.

Brinell hardness of copper-zinc-aluminium alloys, containing 7% aluminium.

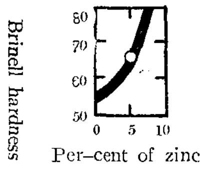



Fig. 17.

Brinell hardness of copper-zinc-aluminium alloys, containing 8% aluminium.

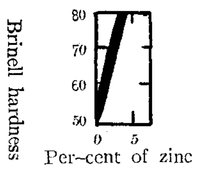
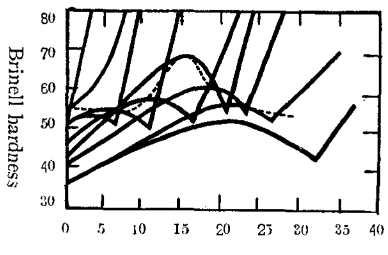
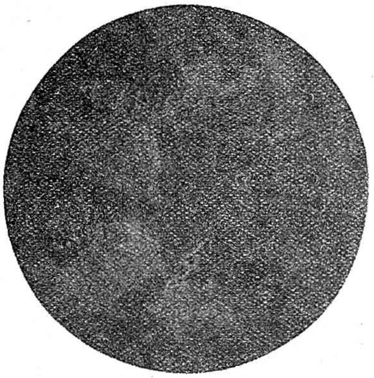



Fig. 18.

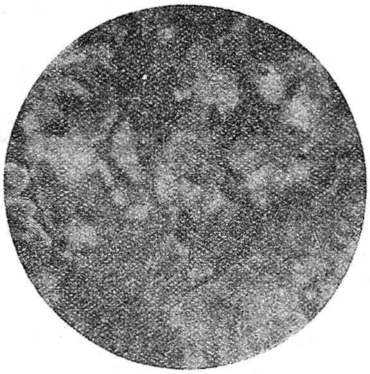
Brinell hardness of copper-zinc-aluminium alloys.



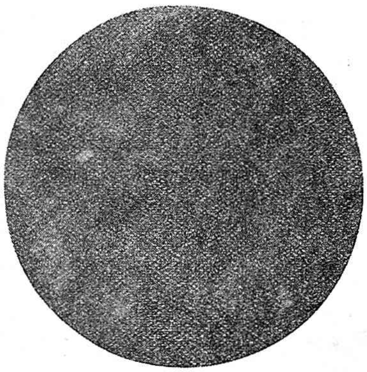


No. 11. Copper-zinc alloy, containing 10 % Zn, annealed for 2 hours at 650.°

No. 16. Copper-zinc aluminium alloy, containing 5 % Zn and 7 % Al, annealed for 2 hours at 650.°

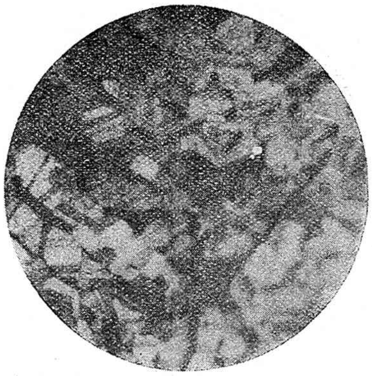


No. 27. Copper-zinc-aluminium alloy, containing 10 % Zn and 6 % Al, annealed for 2 hours at 650.°



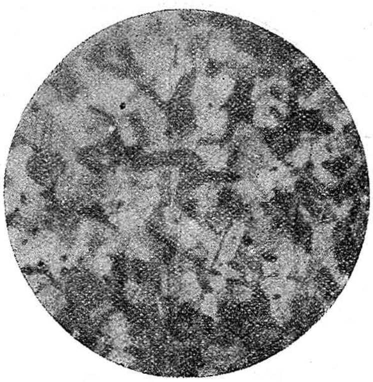
No. 34. Copper-zinc-aluminium alloy, containing 15 % Zn and 5 % Al, annealed for 2 hours at 650.°

No. 40. Copper-zinc-aluminium alloy, containing 20 % Zn and 4 % Al, annealed for 2 hours at 650.°

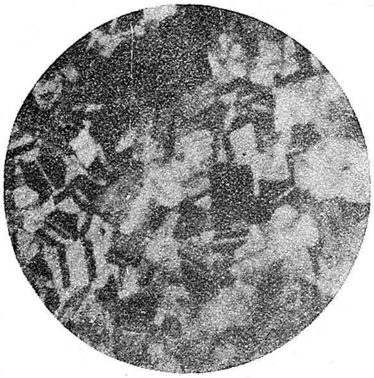


No. 44. Copper-zinc-aluminium alloy, containing 25% Zn and 3 % Al, annealed for 3 hours at 650.°

No. 47. Copper-zinc-aluminium alloy, containing 30 % Zn and 1 % Al, annealed for 3 hours at 650.°



Ny. 49. Copper-zinc alloy, containing 35 % Zn, annealed for 3 hours at 650.°

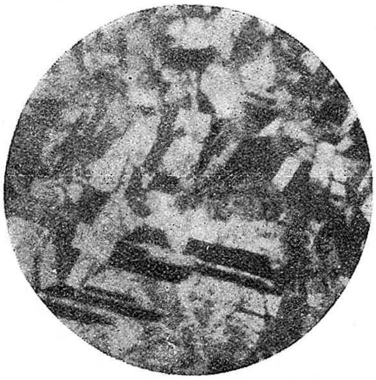


No. 10. Copper-aluminium alloy, containina 9 % Al, annealed for 2 hours at 650.°

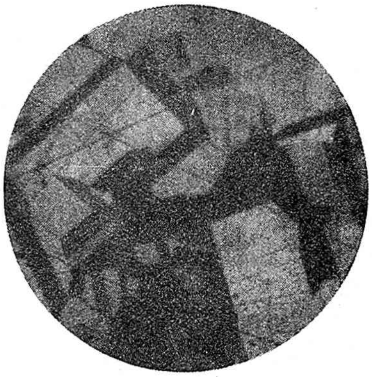
No. 18. Copper-zinc-aluminium alloy, containing 5% Zn and 6 % Al, annealed for 2 hours at 650.°

No. 26. Copper-zinc-aluminium alloy, containing 10 % Zn and 5 % Al, annealed foı 2 hours at 650.°

No. 32. Copper-zinc-aluminium alloy, containing 15 % Zn and 4 % Al, annealed for 2 hours at 650.°



No. 39. Copper-zinc-aluminium alloy, containing 20 % Zn and 3 % Al, annealed for 2 hours at 650.°



No. 43. Copper-zinc-aluminium alloy, containing 25 % Zn and 1 % Al, annealed for 3 hours at 650.°

No. 46. Copper-zinc alloy, containing 30 % Zn, annealed for 3 hours at 650.°