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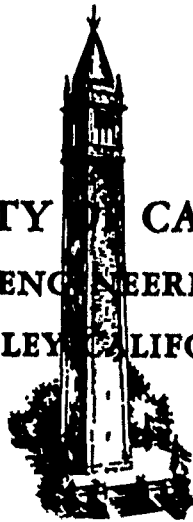
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EFFECT OF COPPER ADDITIONS ON THE  
PLASTIC PROPERTIES OF AN Al-Zn ALLOY

Twenty - Third Technical Report

by

C. D. Starr and J. E. Dorn

23, W7-onr-295, Task Order II,

NR-031-048

SERIES NO.....

ISSUE NO. 23.....

DATE..... January 1, 1953.....

January 15, 1953

Office of Naval Research  
Department of the Navy  
Washington 25, D.C.

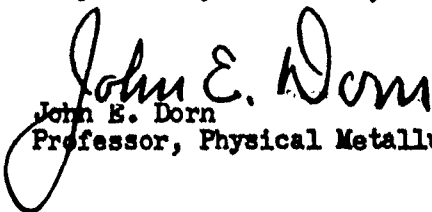
ATTENTION: Dr. O. T. Marzke

Dear Sir:

Attached hereto is the Twenty Third Technical Report on Contract N7-onr-295, Task Order II, Nr-031-048, entitled "Effect of Copper Additions on the Plastic Properties of an Al-Zn Alloy".

The wholehearted cooperation of the Office of Naval Research in making these studies possible is sincerely appreciated.

Respectfully submitted,

  
John E. Dorn

Professor, Physical Metallurgy

JED:bp

EFFECT OF COPPER ADDITIONS ON THE  
PLASTIC PROPERTIES OF AN Al-Zn ALLOY

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## INTRODUCTION

Several investigations reveal that the solid solution strengthening arising from the simultaneous addition of several elements to a host metal is equal to the sum of the individual strengthenings of each element in the binary alloys. Frye and Hume-Rothery <sup>(1)</sup>, for example, have shown that the increase in Meyer's ultimate hardness arising from the additions of Zn and Cd to Ag is equal to the sum of the increases in hardness for the binary Zn-Ag and Cd-Ag alloys. In a more extensive investigation, Lacy and Gensamer <sup>(2)</sup> demonstrated that the increases in the ultimate tensile strengths of ternary and quaternary ferrites are equal to the sum of the increases in tensile strength for each binary ferrite involved. Thus, these investigations suggest that the plastic properties of any alpha solid solution can readily be deduced from the properties of binary alloys.

But the earlier investigations of Schmid and Siebel <sup>(3)</sup> on the critical shear stress for slip in ternary Al-Zn-Mg alloys appear to question the general validity of the additive law, as shown by the data recorded in Table I; the observed value of the critical shear stress for slip was slightly greater than

TABLE I

Critical Shear Stress for Slip in Magnesium Single Crystals

(Data from Schmid and Siebel)

| Alloy | Atomic Percent Composition |      | Critical Shear Stress for slip in gms/mm <sup>2</sup> |            |
|-------|----------------------------|------|-------------------------------------------------------|------------|
|       | Zn                         | Al   | Observed                                              | Calculated |
| A     | 0                          | 0    | 82.9                                                  | ---        |
| B     | 0.36                       | 0    | 159                                                   | ---        |
| C     | 0.38                       | 0    | 168                                                   | ---        |
| D     | 0                          | 2.54 | 441                                                   | ---        |
| E     | 0                          | 5.04 | 875                                                   | ---        |
| F     | 0.36                       | 2.54 | 763                                                   | 517        |
| G     | 0.38                       | 5.04 | 1152                                                  | 960        |

the value calculated from the binary alloys assuming the validity of the additive law. Although this apparent contradiction might have arisen from the well known scatter in evaluating the critical shear stress for slip in the single crystal alloys, it nevertheless deserves further investigation because it suggests that the strengthening due to one solute element might be increased by the presence of some other solute element, thus providing an additional basis for improving the plastic properties of solid solutions over and above that which can be obtained in binary systems alone. For this reason the investigation to be described was initiated to further test the validity of the additive law for ternary alpha solid solutions.

#### MATERIALS AND TECHNIQUES

Aluminum base alloys were selected for this investigation because of the extensive data now available on the plastic properties of their binary alpha solid solutions (4). The chemical composition of the alloys which were studied in this investigation are given in Table II. All alloys were produced from the same high purity aluminum ingots and all major alloying additions were made from the same high purity master alloys. The original alloy ingots were initially hot rolled and finally cold rolled to 0.100 in. thick sheet. Appropriate recrystallization and grain growth treatments were practiced to develop about the same mean grain diameter in each of the various annealed alloys as shown in Table II. No evidence of precipitation could be detected metallographically and no effects of strain aging were noted during the test program.

True stress - true strain curves were obtained from tensile specimens whose axes was selected to be in the rolling direction. All tests were conducted at  $295^{\circ} \pm 1^{\circ}\text{K}$  at a constant strain rate of 0.118 per minute. Strains were

TABLE II

## Chemical Composition and Grain Size

## Chemical Composition\*

| Alloy | Atomic Percent Major Constituents |      | Weight Percent |      |        |        |        |        |        |      | Mean Grain Diam. mm. |
|-------|-----------------------------------|------|----------------|------|--------|--------|--------|--------|--------|------|----------------------|
|       | Cu                                | Zn   | Cu             | Zn   | Mg     | Fe     | Si     | Mn     | Cr     |      |                      |
| A     | -                                 | -    | 0.002          | N.D. | 0.0001 | 0.0007 | 0.0003 | N.D.   | 0.0005 | 0.27 |                      |
| B     | 0.055                             | -    | 0.13           | N.D. | 0.0001 | 0.0008 | 0.0008 | 0.0001 | 0.0005 | 0.29 |                      |
| C     | 0.102                             | -    | 0.24           | N.D. | 0.0002 | 0.0008 | 0.0009 | 0.0002 | 0.0005 | 0.29 |                      |
| D     | -                                 | 0.54 | 0.002          | 1.12 | 0.0012 | 0.001  | 0.0009 | N.D.   | 0.0005 | 0.26 |                      |
| E     | 0.035                             | 0.54 | 0.08           | 1.12 | 0.0002 | 0.0007 | 0.0003 | N.D.   | 0.0005 | 0.27 |                      |
| F     | 0.068                             | 0.54 | 0.16           | 1.12 | 0.0002 | 0.0008 | 0.0009 | N.D.   | 0.0005 | 0.29 |                      |
| G     | 0.089                             | 0.54 | 0.21           | 1.09 | 0.0002 | 0.0007 | 0.0009 | N.D.   | 0.0005 | 0.27 |                      |

N.D. Not Detected

\* Chemical Analysis by Courtesy of Aluminum Company of America Research Laboratories

measured to the nearest  $\pm 0.0002$  and the stresses were measured to the nearest  $\pm 25$  psi.

#### DISCUSSION OF RESULTS

The stress-strain curves, shown in Fig. 1, reveal that the group of alloys form an homologous series which exhibit regular trends of increasing deformation stress and increasing rates of strain hardening with increasing alloy content, in complete harmony with the previously reported results on binary alpha solid solutions (4).

In order to reveal more clearly the effect of alloying composition on the deformation strength, the stress for various stated strains were replotted as a function of the atomic percent Cu as shown in Fig. 2. Thus, the solid solution strengthening is noted to be almost, but not quite, a linear function of the atomic percent Cu. Since the simple additive law for evaluating the plastic properties of ternary alloys can only be valid for cases where the solid solution strengthening is strictly a linear function of the atomic percent of a solute element, it follows that solid solution strengthening in ternary aluminum alloys cannot exactly follow the additive law. This fact was already apparent from the previously reported investigations on binary alpha solid solutions of aluminum.

Since the solid solution strengthening arising from initial additions of a solute element are greater than the strengthening arising from equal subsequent additions, recourse must again be taken to express the solid solution strengthening in terms of the Cu equivalent which proved so helpful in analyses of the previously reported results on binary solid solutions. Thus, as illustrated in

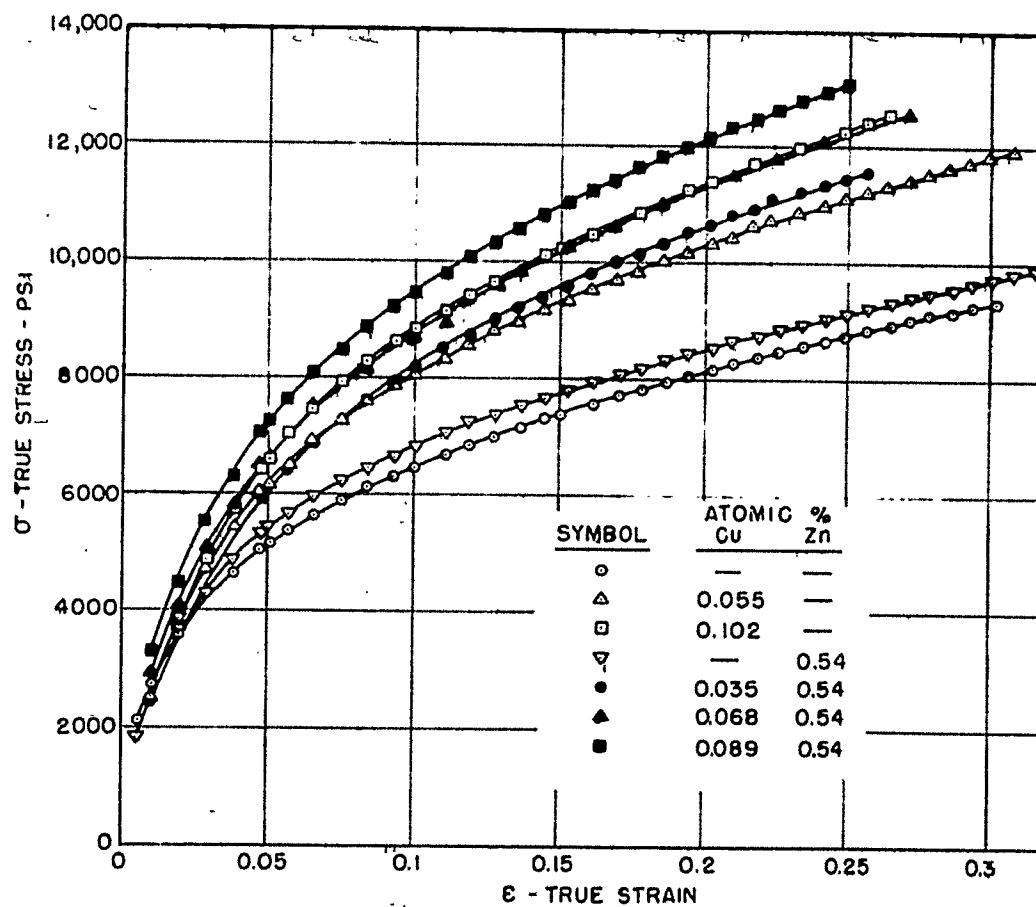


FIG.1 STRESS - STRAIN CURVES FOR PURE Al, Al - Cu, AND  
Al - Cu - Zn ALLOYS AT 295 °K.

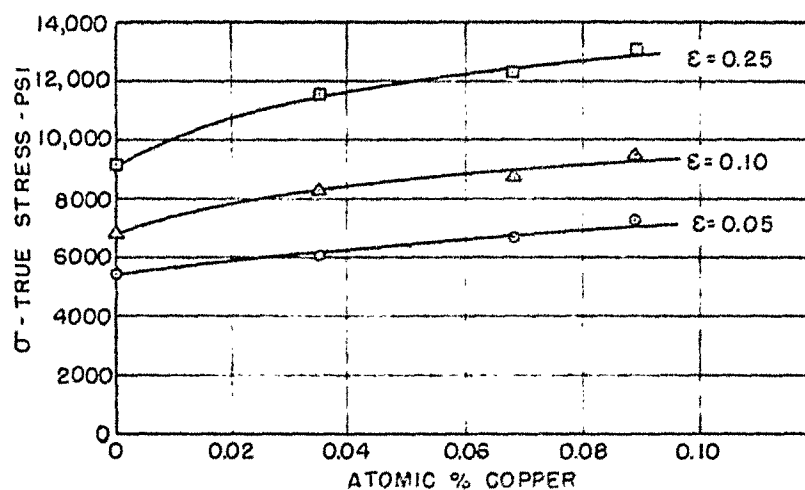


FIG 2a EFFECT OF COPPER ON THE DEFORMATION STRENGTH OF AN 0.54 ATOMIC % ZN - AL ALLOY AT 295 °K.

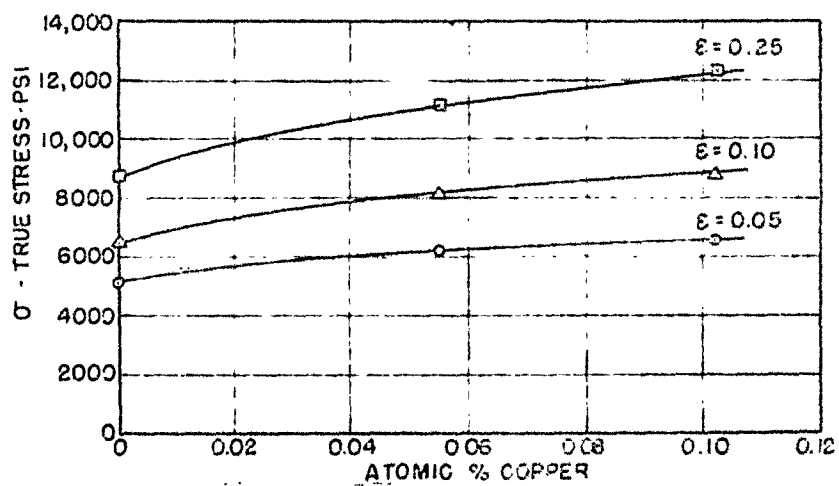


FIG. 2 EFFECT OF COPPER ON THE DEFORMATION STRENGTH OF PURE AL AT 295 °K.

Fig. 2a, the flow stress of the 0.54 at. % Zn plus 0.015 at. % Cu alloy is identical with that for the 0.032 at. % Cu alloy shown in Figure 2b. This suggests that the 0.54 at. % Zn in the 0.015 at. % Cu alloy is equivalent in solid solution strengthening to  $0.032 - 0.015 = 0.017$  at. % Cu. In this way the Cu Equivalent for 0.54 at. % Zn was obtained as a function of the Cu content of the ternary alloy as shown in Fig. 3. Since these equivalents are independent of the strain at which they are evaluated, they do exhibit the necessary internal consistency demanded of true equivalents. The interpretation of Figure 3 is therefore obvious, namely that the Cu - Equivalent of 0.54 at. % Zn increases with the atomic percent Cu in the ternary alloy. Thus, the solid solution strengthening of Zn in Al is increased by the presence of Cu. This implies the anticipated conclusion that the strain energy and electronic interaction between a solute atom and a dislocation depends upon the modification of the strain energy and electronic fields arising from the surrounding solute atoms.

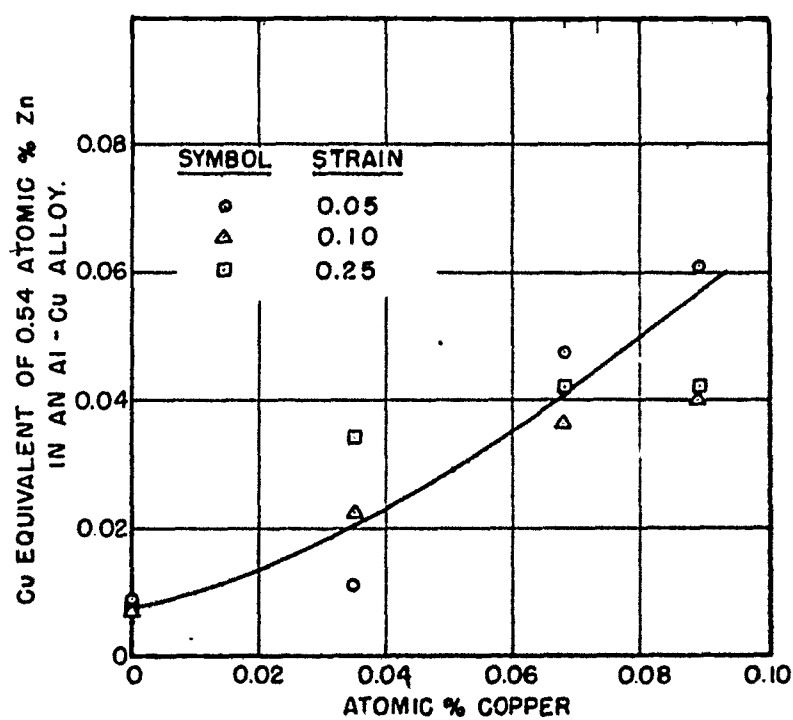


FIG. 3 EFFECT OF COPPER ON THE COPPER EQUIVALENCE OF 0.54 ATOMIC % Zn IN AN Al-Cu-Zn ALLOY AT 295 °K.

### CONCLUSIONS

1. The stress-strain curves for ternary aluminum alpha solid solutions containing Zn and Cu are homologous with those for the binary aluminum alloys.
2. The plastic properties of ternary aluminum alpha solid solutions do not obey a simple additive law.
3. The concept of Cu - Equivalents can be extended to ternary aluminum alloys.
4. The Cu Equivalent of Zn in a ternary aluminum alloy increases with the Cu content.

#### ACKNOWLEDGMENTS

This investigation was sponsored by the Office of Naval Research. The authors wish to thank the ONR staff for its continued interest and support during this investigation. They also wish to express their appreciation to the Aluminum Research Laboratories for furnishing the alloys and their chemical analyses.

In addition, appreciation is expressed to O. D. Sherby for his assistance, suggestions and advice, and to C. Wiseman for his assistance in conducting the tests.

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