

38873

OTS: 60-11,843

JPRS: 2953

11 July 1960

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

THE EFFECT OF TERNARY INTERMETALLIC COMPOUNDS ON THE
HEAT RESISTANCE OF DEFORMED ALUMINUM ALLOYS

- USSR -

by B. K. Vul'f and M. N. Chernov

RETURN TO MAIN FILE

19990630 120

Reproduced From
Best Available Copy

Distributed by:

OFFICE OF TECHNICAL SERVICES
U. S. DEPARTMENT OF COMMERCE
WASHINGTON 25, D. C.

U. S. JOINT PUBLICATIONS RESEARCH SERVICE
205 EAST 42nd STREET, SUITE 300
NEW YORK 17, N. Y.

THE EFFECT OF TERNARY INTERMETALLIC COMPOUNDS ON THE
HEAT RESISTANCE OF DEFORMED ALUMINUM ALLOYS

This is a translation of an article written by B. K. Vul'f and M. N. Chernov in Izvestiya Vysshikh Uchebnykh Zavedeniy, Tsvetnaya Metallurgiy, (News of Higher Educational Institutions, Nonferrous Metallurgy), No. 2, Ordzhonikidze, 1960, pages 147-152.

In one of the preceding works (1) the authors investigated the effect of the ternary compound E (Mg₂Al₃Cr) on the heat resistance of deformed aluminum alloys and demonstrated the possibility of obtaining alloys which are characterized by significant long-term resistance.

The present investigation is dedicated to the further development of work in this direction and has as its goal the determination of the high-temperature hardness of certain ternary intermetallic aluminum-containing compounds and an explanation of their effect on the short- and long-term resistance of extruded aluminum alloys.

Seven ternary intermetallic compounds were prepared according to a method described previously (2). Their composition according to the results of a chemical analysis and their extrusion parameters are shown in Table 1.

Table 1

Compositions and extrusion parameters of ternary intermetallic compounds

| Compound | Composition, % | | | | | | | Extrusion Temp, °C | Specific Extrusion Pressure, kg/mm ² |
|---|----------------|------|------|------|------|------|------|--------------------|---|
| | Cu | Mn | Ni | Mg | Zn | Cr | Si | | |
| Cu ₂ Al ₃ Mn ₂ (7) | 15,68 | 19,7 | — | — | — | — | — | 670 | 32,5 |
| Cu ₂ Al ₃ Ni (2) | 46,4 | — | 15,1 | — | — | — | — | 630 | 37,5 |
| Mg ₂ Zn ₃ Al ₃ (7) | — | — | — | 26,0 | 52,2 | — | — | 460 | 43,3 |
| Mg ₂ Al ₃ Cr (E) | — | — | — | 8,1 | — | 16,3 | — | 470 | 25,2 |
| Al ₂ Si ₃ Mn ₂ (7) | — | 41,1 | — | — | — | — | 14,9 | 691 | 28,8 |
| Al ₂ Mn ₃ Ni (X) | — | 24,7 | 8,9 | — | — | — | — | 700 | 39,7 |
| Al ₂ FeNi (2) | — | — | 16,2 | — | — | — | — | 700 | 50,5 |

Before testing, the ternary compounds were made homogeneous by heating the Mg_2Al_3Cr and $Mg_2Zn_3Al_3$ at 400° for 10 days and the others at 500° , after which the alloys were gradually cooled to room temperature over a 24 hour period.

A determination of the microhardness at different temperatures was made using the method of Academician A. A. Bochvar (3) on an apparatus developed at the IMASH of the Academy of Sciences USSR and the VIAM. The time of exposure to the indenter was 30 seconds and 60 minutes with a load of 50 g; the testing temperatures were 20° and 300° . The test data are shown in Table 2 in absolute units and in percentages; the hardness values are averages from four to five determinations.

The data in the following Table 2 are quite interesting, characterizing to a certain extent the long-term heat resistance of ternary compounds. The compound Mg_2Al_3Cr (E) possesses the greatest long-term hardness but the compounds Cu_2Al_6Ni (τ), $Mg_2Zn_3Al_3$ (T) and Al_3FeNi (δ) decrease their high temperature hardness approximately twofold.

Table 2

Microhardness of ternary intermetallic compounds at 20° and 300°

| Compound | Microhardness, kg/mm ² | | | | | | |
|-------------------------|-----------------------------------|--------|----------------------|--------|--------|----------------------|------|
| | 20° | | 300° | | 300° | | - |
| | 30 sec | 30 sec | Decrease in hardness | | 60 min | Decrease in hardness | |
| | | absol- | % | absol- | % | absol- | % |
| $Cu_2Al_6Mn_3$ (T) | 421 | 404 | 17 | 4.0 | 302 | 102 | 25.3 |
| Cu_2Al_6Ni (τ) | 740 | 585 | 155 | 21.0 | 316 | 269 | 46.0 |
| $Mg_2Zn_3Al_3$ (T) | 345 | 225 | 120 | 34.8 | 101 | 124 | 55.0 |
| Mg_2Al_3Cr (E) | 461 | 402 | 59 | 12.8 | 358 | 41 | 11.0 |
| $Al_3Si_3Mn_3$ (T) | 589 | 458 | 131 | 22.3 | 361 | 97 | 21.1 |
| $Al_3Mn_{11}Ni_4$ (X) | 343 | 307 | 36 | 10.5 | 231 | 76 | 24.8 |
| Al_3FeNi (δ) | 860 | 712 | 148 | 17.2 | 414 | 298 | 41.8 |

These data may serve as a useful guide for the development of heat-resistant alloys of the metal-ternary intermetallic compound type for use under conditions of long-term loading.

The hardness at various temperatures had been determined previously for certain ternary compounds (4). The results, in comparison to those obtained in the present study, were higher in all cases probably because in reference (4) a smaller load (10 g) was used on the indenter because of fear of disintegration. Our experiments showed that a load of 50 g, which made it possible to measure with greater accuracy, could be used even at 300° since at this temperature

all the ternary compounds studied are quite sufficiently ductile to exclude disintegration phenomena.

The substantial high temperature hardness of some of the ternary compounds studied made it possible to propose the possibility of using them for increasing the heat resistance of aluminum alloys.

In order to test this, 46 experimental alloy systems were prepared:

| | | | |
|--|-------------------------|-----|---------------------|
| Al—Cu ₂ Al ₂₀ Mn ₃ | with compositions up to | 20% | of ternary compound |
| Al—Cu ₃ Al ₆ Ni | " | 31% | " |
| Al—Mg ₄ Zn ₃ Al ₃ | " | 32% | " |
| Al—Mg ₂ Al ₁₂ Cr | " | 17% | " |
| Al—Al ₅ Si ₃ Mn ₄ | " | 17% | " |
| Al—Al ₆₀ Mn ₁₁ Ni ₄ | " | 16% | " |
| Al—Al ₅ FeNi | " | 13% | " |

The composition of the alloys is given in Table 3.

The ternary compounds in these alloys are found in equilibrium with the corresponding ternary solid solutions. For this reason the amount of alloyed elements in the alloys of certain systems does not quite correspond to the composition of the ternary compound; the percentage of the latter is calculated in such cases according to the content of the element present in least amount.

The solubility of various compounds in solid aluminum is not uniform. So, for example, the solubility of the compounds Al₅Si₃Mn₄ [5], Al₆₀Mn₁₁Ni₄ [6] and Al₅FeNi is quite insignificant in view of the fact that solid solution regions are practically absent in the corresponding ternary composition diagrams. Tempered alloys of these systems do not harden upon subsequent aging. In the system Al—Cu₃Al₆Ni [8] a certain hardening appears upon aging, however the solubility of the ternary compound in aluminum apparently is also quite small; all alloys containing more than two per cent ternary compound after a 48-hour heat soak at 510° and subsequent tempering had a two-phase structure.

On the other hand, the solubility of the ternary compounds Cu₂Al₂₀Mn₃, Mg₂Al₁₂Cr and Mg₄Zn₃Al₃ in solid aluminum increased noticeably with increased temperature. The values of the specific solubility of the alloying elements in the aluminum, according to the sections studied, are given in Table 4.

Table 3

Amount of alloyed elements in the alloys, % by weight

| Alloy | Cu | Mn | Alloy | Cu | Ni | Alloy | Mg | Zn | Alloy | Mg | Cr | Alloy | Si | Mn | Alloy | Mn | Ni | Alloy | Fe | Ni |
|-------|------|------|-------|------|------|-------|------|------|-------|------|------|-------|------|------|-------|------|------|-------|------|------|
| 1 | 2.27 | 3.37 | 7 | 0.99 | 0.48 | 15 | 0.24 | 0.72 | 22 | 1.98 | 0.05 | 28 | 0.31 | 0.84 | 35 | 0.75 | 0.33 | 41 | 0.30 | 0.23 |
| 2 | 2.40 | 0.62 | 8 | 1.80 | 0.73 | 16 | 1.73 | 4.76 | 23 | 2.00 | 0.14 | 29 | 0.35 | 1.09 | 36 | 1.22 | 0.63 | 42 | 0.46 | 0.46 |
| 3 | 2.74 | 0.84 | 9 | 2.89 | 1.11 | 17 | 2.42 | 6.92 | 24 | 2.24 | 0.24 | 30 | 0.72 | 1.72 | 37 | 1.76 | 0.79 | 43 | 0.72 | 0.66 |
| 4 | 2.90 | 1.30 | 10 | 3.95 | 1.40 | 18 | 3.35 | 8.68 | 25 | 2.30 | 0.63 | 31 | 1.22 | 3.20 | 38 | 2.74 | 1.17 | 44 | 1.22 | 1.39 |
| 5 | 3.38 | 2.04 | 11 | 5.65 | 1.69 | 19 | 4.16 | 11.0 | 26 | 2.72 | 1.18 | 32 | 1.82 | 4.20 | 39 | 3.42 | 1.45 | 45 | 1.70 | 1.63 |
| 6 | 4.58 | 3.96 | 12 | 7.21 | 1.93 | 20 | 5.74 | 14.5 | 27 | 3.66 | 2.12 | 33 | 2.15 | 5.65 | 40 | 6.94 | 1.70 | 46 | 1.83 | 2.15 |
| | | | 13 | 9.54 | 2.98 | 21 | 7.03 | 19.0 | | | | 34 | 2.65 | 6.94 | | | | | | |
| | | | 14 | 14.3 | 4.45 | | | | | | | 35 | | | | | | | | |

Table 4

Greatest solubility of elements in solid aluminum for certain systems

| System | Temperature °C | Specific solubility of alloyed elements, % |
|-----------------|----------------|--|
| A - Cu, Al, Mn | 400 | Cu ≈ 1.4; Mn ≈ 0.1 [9] |
| Al - Mg, Al, Cr | 500 | Mg ≈ 2.0; Cr ≈ 0.3 [10] |
| Al - Mg, Zn, Al | 300 | Mg ≈ 1.5; Zn ≈ 3.8 [11] |

The method for melting and extruding the experimental samples was described in reference (2). For testing the heat resistance of the extruded bars, Gagarin - type samples were cut, tempered and aged artificially before testing. The tempering temperature was selected to be 20°-30° lower than the solidus temperature, and varied from 420° to 600° for different alloys.

Only alloys of the Al-Cu₂Al₃Ni and Al-Mg₂Zn₃Al₃ systems were aged; for these an effect of increased hardness upon aging had been observed earlier (2). Alloys of the first of these systems, after tempering, were heated for 60 hours at 180°; alloys of the second system were heated for 47 hours at 100°, which corresponded to the optimal aging conditions.

Determination of the heat resistance consisted of short term and long term tests under elongation at 300°. The short term tests were carried out by the standard method determining the resistance limit (σ_s) and the specific elongation (ϵ) lengthwise $l_0 = 5d$. Tests of long term resistance were carried out as a rule under a load of 4 kg/mm² with a determination of the time elapsing until fracture (τ). The results are shown in Fig. 1-6. Each value determined was the average from three tests.

No diagrams are shown for the Al-Al₃Si₃Mn₃ system since the heat resistance of these alloys is quite low; their short term resistance at 300° was about 6 kg/mm² and elapsed time before fracture under a load of 3 kg/mm² was less than one hour for all of the samples.

It is possible to draw a number of conclusions from an analysis of the results obtained.

In all the systems studied the heat resistance of the alloys increased up to a certain limit of ternary intermetallic compound content.

In the Al-Mg₂Zn₃Al₃, Al-Cu₂Al₃Mn₃ and Al-Mg₂Al₃Cr systems, which are characterized by noticeable solubility of the ternary compound in aluminum, a maximum long term resistance was reached at a particular composition. This maximum is found in alloys in whose structure there are, after tempering, solid solutions that can undergo dispersion hardening (which also explains their hardening effect on aging). At the long-term resistance test temperature (300°) such alloys (Nos. 4, 20 and 25) must have a heterogeneous twophase structure, according to the data of Table 4. This is in agreement with the characteristic regularities in heat resistance variation that were determined in references (12-14) where it was shown that alloys with maximum heat resistance at high temperatures are found in the region of unsaturated solid solutions, those with maximum heat resistance at average temperatures correspond to the area where the saturation limit has been reached

and those with maximum heat resistance at lower temperatures lie in the two-phase region of the composition diagram. Apparently alloys 4, 20 and 25 which we studied correspond to the last case since they show a maximum heat resistance while possessing a heterogeneous structure (Figs. 7, 8 and 9). [not shown].

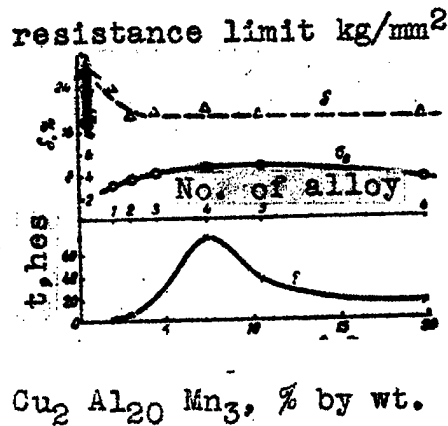


Fig. 1 - Relationship of the heat resistance of the alloys $\text{Al-Cu}_2\text{Al}_{20}\text{Mn}_3$ to composition. Tests were made of the short-term resistance at 350° , long-term resistance at 300° with a load of 4 kg/mm^2 .

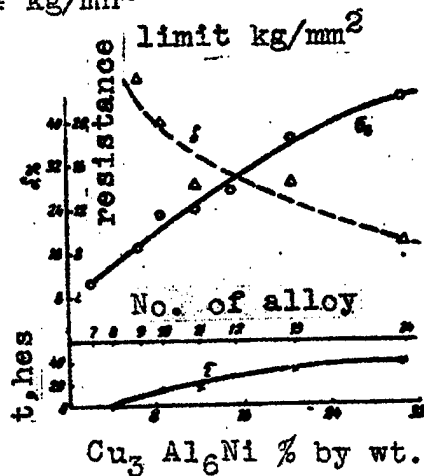


Fig. 2 - Relationship of the heat resistance of the alloys $\text{Al-Cu}_3\text{Al}_6\text{Ni}$ to composition. Tests were made of the short-term resistance at 300° , long-term resistance at 300° with a load of 4 kg/mm^2 .

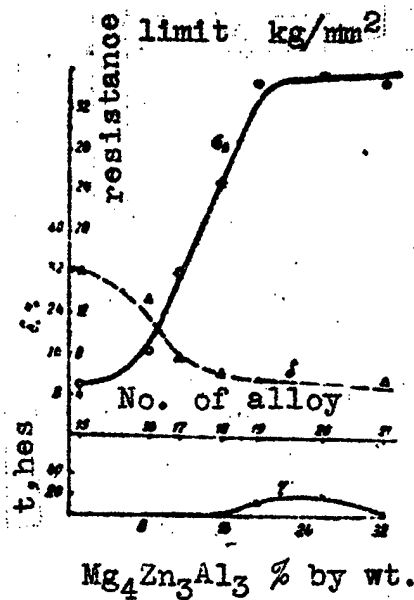


Fig. 3 - Relationship of the heat resistance of the alloys $Al-Mg_4Zn_3Al_3$ to composition. Tests were made of the short-term resistance at 300° , long-term resistance at 300° , with a load of 4 kg/mm^2

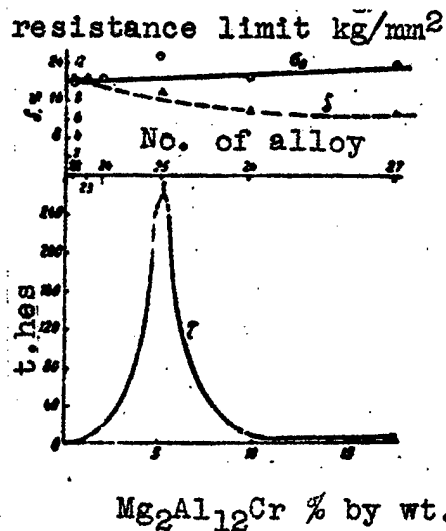


Fig. 4 - Relationship of the heat resistance of the alloys $Al-Mg_2Al_{12}Cr$ to composition. Tests were made of the short-term resistance at 300° , long-term resistance at 300° with a load of 4 kg/mm^2

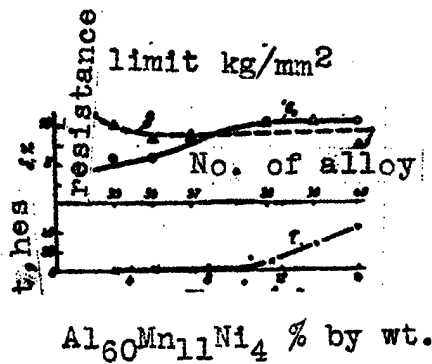


Fig. 5 - Relationship of the heat resistance of the alloys Al-Al₆₀Mn₁₁Ni₄ to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 300° with a load of 4 kg/mm².

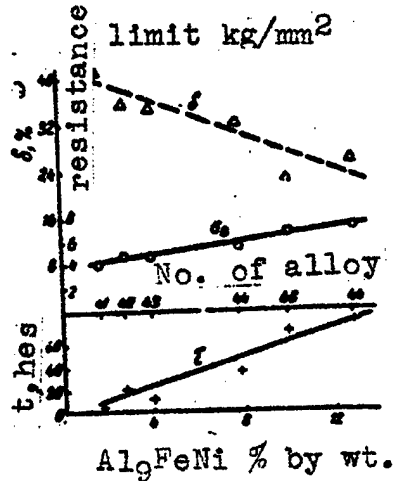


Fig. 6 - Relationship of the heat resistance of the alloys Al-Al₉FeNi to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 270° with a load of 3 kg/mm².

This does not contradict the work of M. V. Zakharov (15) who showed that in a number of cases the greatest heat resistance was encountered in slightly heterogeneous ternary alloys lying in the quasi-binary sections or close by.

For various systems of this type the higher the maximum of long-term resistance, the greater the high-temperature hardness of the ternary compound and the less the relative decrease in the latter upon increasing the time of exposure to the indenter.

In the remaining systems studied, which are characterized by the absence of noticeable regions of solid solutions, the long term resistance increased linearly with the increase in ternary compound content in the alloy.

The greatest values for short term resistance at 300° were obtained with alloy No 14 of the Al-Cu₃Al₆Ni system ($\sigma_B = 22 \text{ kg/mm}^2$; $\delta = 17\%$), and alloys Nos. 19-21 of the Al-Mg₄Zn₃Al₃ system ($\sigma_B = 35 \text{ kg/mm}^2$; $\delta = 9-11\%$), exceeding significantly the resistance of standard heat-resistant deformed alloys (Ak 4-1, VD 17) for which at 300° $\sigma_B \approx 16-17 \text{ kg/mm}^2$ and $\delta \approx 8-21\%$.

Alloy No 25 of the Al-Mg₂Al₁₂Cr system had the greatest long-term resistance; with a load of 4 kg/mm² and a temperature of 300° it held for more than 250 hours before fracturing.

Alloys of the Al-Al₉Si₃Mn₄ system showed the lowest heat resistance under the test conditions.

Bibliography

1. B. K. Vul'f, M. N. Chernov. ZhNKh AN SSSR, (Journal of Inorganic Chemistry of the Academy of Sciences USSR, Vol 1, 158 (1956)
2. B. K. Vul'f, M. N. Chernov, Izv. VUZ, Tsvetnaya Metallurgiya, (News of Higher Educational Institutions, Non-ferrous Metallurgy), No 4, 153 (1958)
3. A. A. Bochvar Izv. AN SSSR, OTN, (News of the Academy of Sciences USSR, Department of Technical Sciences), No 10, 1947.
4. G. V. Zakharova, Sb Metody kontrolya metallov u splavov, (Collection of methods for control of metals and alloys), Oborongiz, 1951
5. H. Bückle. Aluminium - Arch., 13, 1 (1938)
6. G. Raynor. J. Inst. Metals, 70, 507, (1944)
7. G. Raynor, P. Pfeil. J. Inst. Metals, 73, 397, (1947)
8. D. A. Petrov Voprosy teorii splavov alyuminiya. (Questions on the theory of aluminum alloys), Metallurgizdat 1951
9. W. Hofmann, Z. Metallkunde, 41, (12) 477 (1950)
10. W. Hofmann, R. Herzer, Metallwirtschaft, 19, 141, (1940)
11. V. I. Mikheyeva. Splavy magniya s alyuminiyem u tsenkom. (Magnesium alloys with aluminum and zinc. Publ. House of Academy of Sciences USSR), Izd AN SSSR 1946.
12. I. I. Kornilov, L. I. Pryakhina. Izv. AN SSSR, OTN (News of the Academy of Sciences USSR, Department of Technical Sciences), No 9, 85 (1954)
13. I. I. Kornilov, V. V. Kosmodem'yanskiy. Izv. AN SSSR OTN (News of the Academy of Sciences USSR, Department of Technical Sciences), No 2, 90, 1955.

14. I. I. Kornilov, F. M. Titov, Izv. AN SSSR, OTN (News of the Academy of Sciences USSR, Department of Technical Sciences), No 10, 117 (1956).
15. M. V. Zakharov. Sb. Prochnost' metallov, Izd AN SSSR, (Resistance of metals, collected data. Publ. House of Academy of Sciences USSR, 1956).

END

FOR REASONS OF SPEED AND ECONOMY
THIS REPORT HAS BEEN REPRODUCED
ELECTRONICALLY DIRECTLY FROM OUR
CONTRACTOR'S TYPESCRIPT

THIS PUBLICATION WAS PREPARED UNDER CONTRACT TO THE
UNITED STATES JOINT PUBLICATIONS RESEARCH SERVICE
A FEDERAL GOVERNMENT ORGANIZATION ESTABLISHED
TO SERVICE THE TRANSLATION AND RESEARCH NEEDS
OF THE VARIOUS GOVERNMENT DEPARTMENTS