TECHNICAL REPORT ARCCB-TR-94018

EXPERIMENTAL HEAT TREATMENT OF BERYLLIUM COPPER ALLOY

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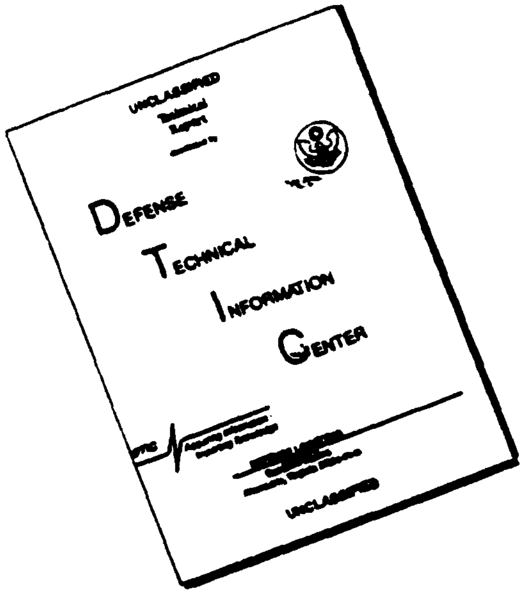

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13. ABSTRACT *(Maximum 200 words)*

A cold-rolled beryllium copper alloy, in bar form, was experiencing deformation (bowing) during machining. Several experimental heat treatments were performed in order to develop a procedure that would alleviate this condition. These treatments consisted of (1) an age-hardening (overaging) and (2) a solution treatment and age-hardening. The minimum desired ultimate tensile strength (UTS) value was achieved in both heat-treating experiments conducted. For the age-hardening experiment, any aging time between one-half hour and two hours would obtain the desired UTS. For the solution treatment and age-hardening experiment, aging for one-half hour or greater at 500°F would fulfill the UTS requirement. Our recommendation for the remaining beryllium copper bars was a one hour age-hardening at 900°F.

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TABLE OF CONTENTS

TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Beryllium copper is used in the manufacture of a rail assembly strip for the 105-mm M119 Lightweight Howitzer. The beryllium copper alloy is procured by Watervliet Arsenal as flat, cold-rolled bars. The strips are then riveted to a steel rail and the assembly is machined to finished dimensions. The beryllium copper strips were reportedly bowing due to imbalanced internal stresses in the material produced during the final machining process. The bowing was causing the bar to lift off the steel rail and result in an unacceptable dimensional condition.

The purpose of our experiment was to develop a thermal treatment procedure that would (1) alleviate the internal stresses causing the deformation, and (2) produce/maintain the desired mechanical properties in the material. The experimental heat treatments were conducted on specimens sectioned from the as-received beryllium copper bars. The specimen size was approximately 2-1/2 x 1/2 x 3/16-inch.

PROCEDURE

The following analyses were performed on the beryllium copper specimens:

- Experimental Heat Treatments

Age-Hardening (Overaging) Experiment

In our "overaging" experiment, four samples were aged at 900°F from the as-received condition. One sample was aged for each of the following times: 1/2, 1, 1-1/2, and 2 hours.

Solution Treatment and Age-Hardening Experiment

In the solution treatment followed by age-hardening experiment, nine samples were solution treated from the as-received condition at 1450°F for 10 minutes immediately followed by a water quench. Eight of the samples were then aged at the times and temperatures shown below in Table 1. Sample 9 was used to examine the microstructure produced solely from the solution-treating process.

Table 1. Solution-Treated and Age-Hardened Samples

	200°F	300°	400°	500°
15 Minutes	--	--	--	Sample 1
30 Minutes	Sample 2	Sample 3	Sample 4	Sample 5
60 Minutes	Sample 6	Sample 7	Sample 8	--

- Metallographic Examination
- Macrohardness Testing

RESULTS

Two heat-treating experiments were conducted on the beryllium copper alloy. In this particular application, the ultimate tensile strength (UTS) desired for the beryllium copper was a minimum of 94.5 Ksi. This strength corresponds to a minimum hardness value of approximately 92 Rockwell B (HRB) (ref 1). During our experiment, hardness was measured on all samples to estimate the UTS. Based on this estimate and the correlation between hardness and tensile strength, we determined whether the desired UTS requirements had been met.

The beryllium copper is a cold-rolled, full hard (TD04) tempered alloy with a required chemical composition per ASTM B-196 shown below in Table 2:

Table 2. Required Chemical Composition of Beryllium Copper Alloy
(Weight Percent)

Element	Required Chemistry
Beryllium	1.80 to 2.00
Nickel plus Cobalt	0.20 min
Nickel plus Cobalt plus Iron	0.60 max
Aluminum	0.20 max
Silicon	0.20 max
Copper	Balance

Benet's chemical analysis of the beryllium copper alloy is shown in Table 3:

Table 3. Benet's Chemical Analysis of Beryllium Copper Alloy
(Weight Percent)

Element	Chemistry
Beryllium	1.84
Nickel	0.01
Cobalt	0.22
Iron	0.07
Aluminum	--
Silicon	--
Copper	Balance

Based on our analyses, the as-received alloy met compositional requirements.

The as-received sample of beryllium copper was examined in the longitudinal direction and showed an elongated, fine-grained microstructure which is characteristic of a cold-rolled material (Figures 1a and 1b). The transverse direction was also examined and the presence of uniformly dispersed, gamma-2 precipitates, approximately spherical in shape, can be seen in Figure 2. There were also small quantities of gamma-1 precipitates present at the grain boundaries (arrow, Figure 2). The hardness value was approximately 26.5 Rockwell C (HRC) for the as-received alloy.

The four overaged samples were examined for hardness and microstructure. A graphical display of the hardness versus aging time is submitted as Figure 3. This plot shows that the material softened as the time at temperature was increased. Based on the hardness correlation, the UTS requirement was satisfied for any aging time that was experimentally examined. The overaged samples were examined for microstructure as shown in Figures 4 and 5. The beryllium copper precipitate morphologies observed in the samples were consistent with what normally occurs during an overaging process. During overaging, the once coherent precipitates grow, coalesce, and become incoherent with the matrix. Once the precipitates become incoherent, they contribute less to the material's strength. In the 1/2-hour aged sample, the precipitates were small and uniformly dispersed (Figure 4b), but in the 2-hour aged sample, the precipitates had grown and were less uniformly distributed in the copper rich matrix (Figure 5b).

All overaged samples were then machined in a manner similar to the production process. The experimental beryllium copper samples experienced little or no deformation during machining.

In the solution treatment followed by age-hardening experiment, the samples were all examined for hardness after solution treatment. The hardness measurements were relatively consistent ranging from 46.2 to 51.6 HRB. A sample was also examined for microstructure. The microstructure in Figures 6a and 6b shows equiaxed grains with small, spherical beryllium copper precipitates. The solution treatment and water quench retains a supersaturated solid solution of beryllium in copper with small beryllium copper precipitates. The age-hardening process then promotes the growth and eventual coalescence of the beryllium copper precipitates. The effects of this process can be seen in Figures 7 and 8. After aging, the hardness was measured in all samples and is shown in Figure 9. The graph displays the slight hardening that occurred at the lower temperatures and the rapid hardening that occurred at 500°F. The aging for 1/2-hour at 500°F produced the desired hardness value of 92 HRB or greater. Age-hardening data for temperatures higher than 500°F are well documented and therefore were not included in this experiment.

CONCLUSIONS/RECOMMENDATIONS

Both heat-treating experiments, the age-hardening (overaging) experiment and the solution treatment followed by age-hardening experiment, produced the minimum desired UTS value (based on hardness/UTS correlation). For the age-hardening experiment, any aging time that was experimentally examined, as well as the range of times in-between, would satisfy the conditions for hardness. For the solution treatment followed by age-hardening experiment, the aging for 1/2-hour or greater at 500°F would fulfill UTS requirements. The two hardness versus time graphs generated showed the heat-treating parameters needed to obtain a hardness of 92 HRB or greater. The overaged samples were all machined in a manner representative of the machining process and experienced little or no deformation.

Either heat-treating process examined could be used to recover the beryllium copper bars since each (1) effectively eliminated the internal stresses in the as-received, cold-rolled material, and (2) produced acceptable mechanical properties. We recommend that a 1-hour aging process at 900°F be performed on the remaining beryllium copper bars. The age-hardening process would be less expensive to perform and also less time-consuming.

REFERENCES

1. *Metals Handbook*, Ninth Edition, Volume 2, American Society for Metals, Metals Park, OH, 1978, p. 304.

(a) 100X.

(b) 1000X.

Figure 1. Elongated, fine-grained microstructure in the as-received, cold-rolled beryllium copper material.

Figure 2. Photomicrograph of fine, spherical gamma-2 beryllium copper precipitates dispersed in the copper matrix, at 1000X. The arrows point to large gamma-1 precipitates present at the grain boundaries.

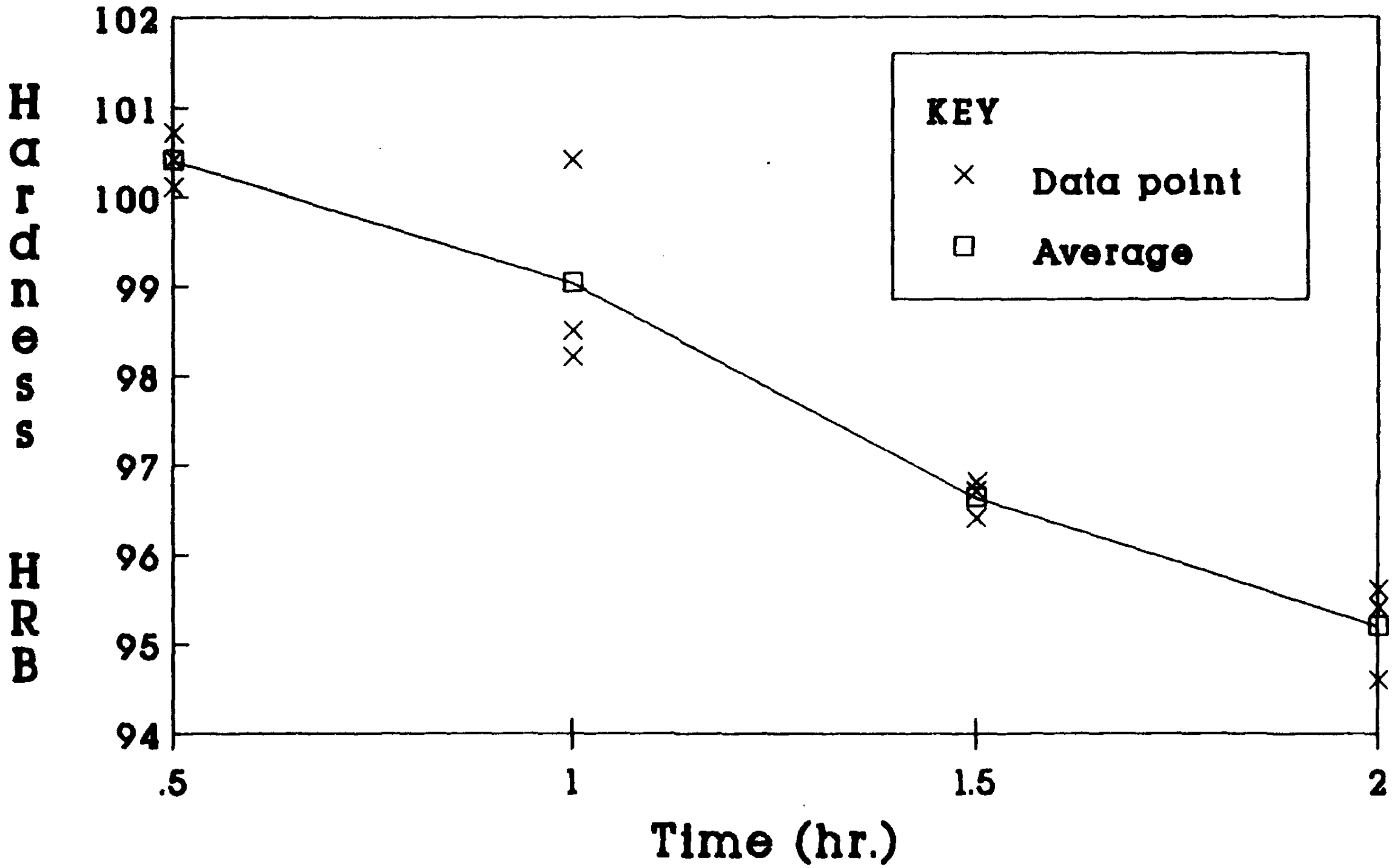
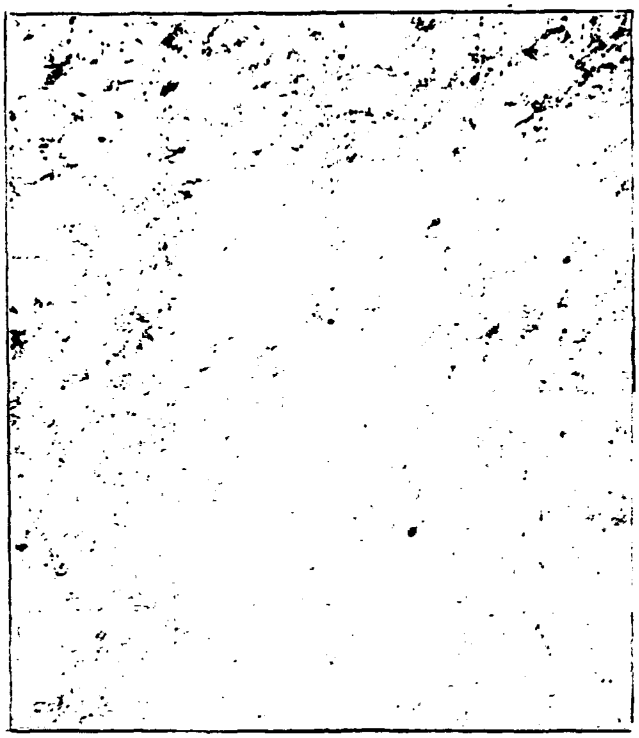


Figure 3. Graph showing overaging times with corresponding hardness values. Samples age-hardened at 900°F.



(a) 100X.

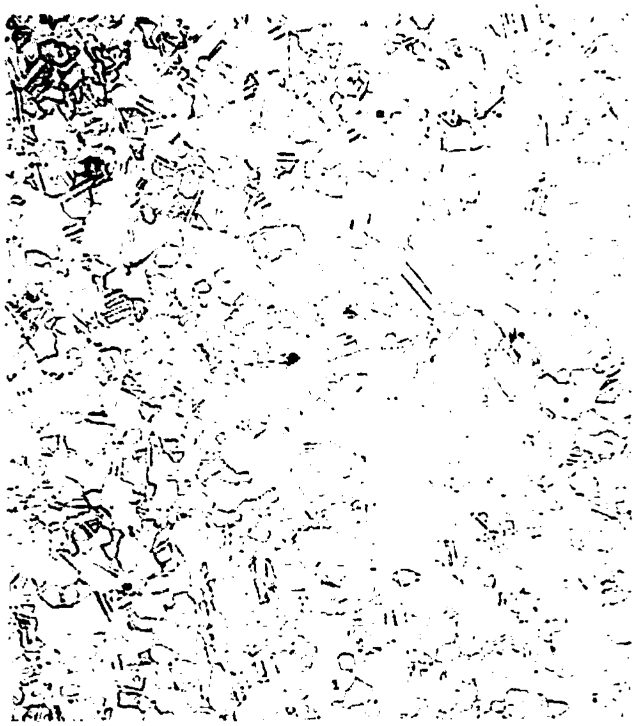
(b) 1000X.

Figure 4. Photomicrographs of overaged samples showing precipitate growth progression.

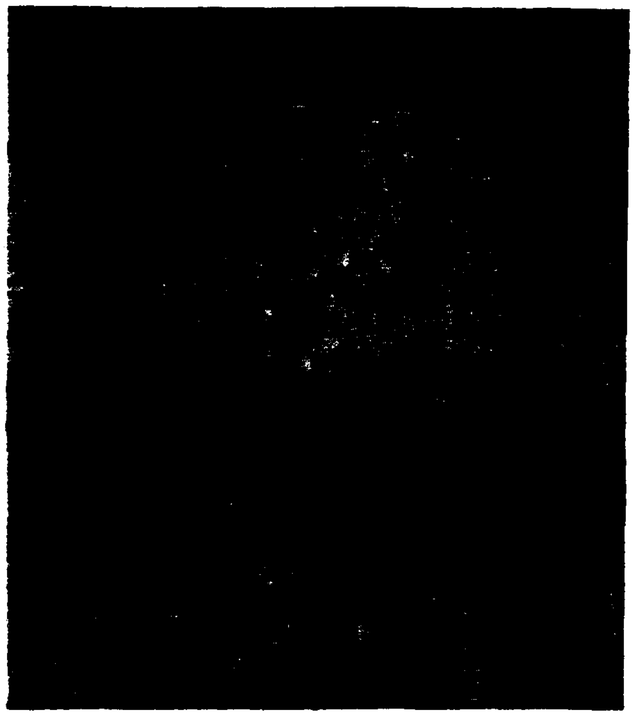
(a) 100X.

(b) 1000X.

Figure 5. Photomicrographs of overaged samples showing precipitate growth progression.



(a) 100X.



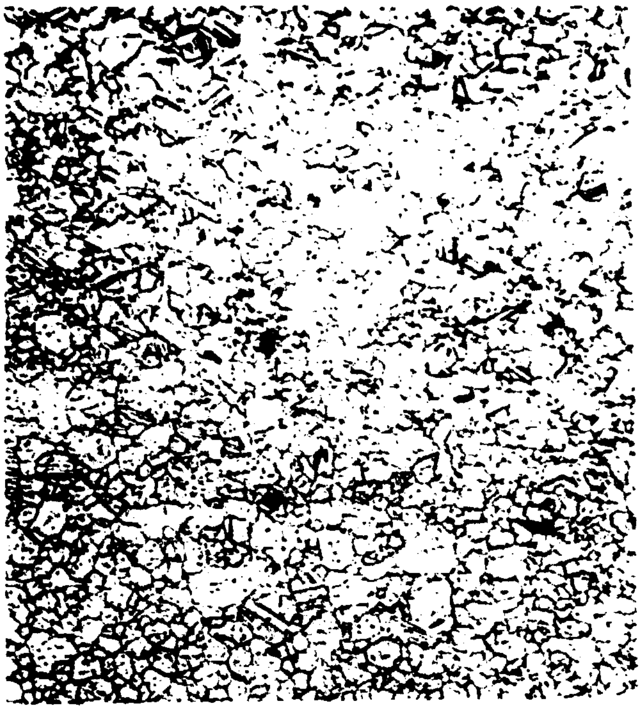
(b) 2000X.

Figure 6. Solution-treated sample depicting equiaxed grains and small, spherical beryllium copper precipitates.

(a) 100X.

(b) 2000X.

Figure 7. Photomicrographs of samples after solution treatment with age-hardening. Beryllium copper precipitates are present both in the grains and at the grain boundaries.



(a) 100X.

(b) 2000X.

Figure 8. Photomicrographs of samples after solution treatment with age-hardening. Beryllium copper precipitates are present both in the grains and at the grain boundaries.

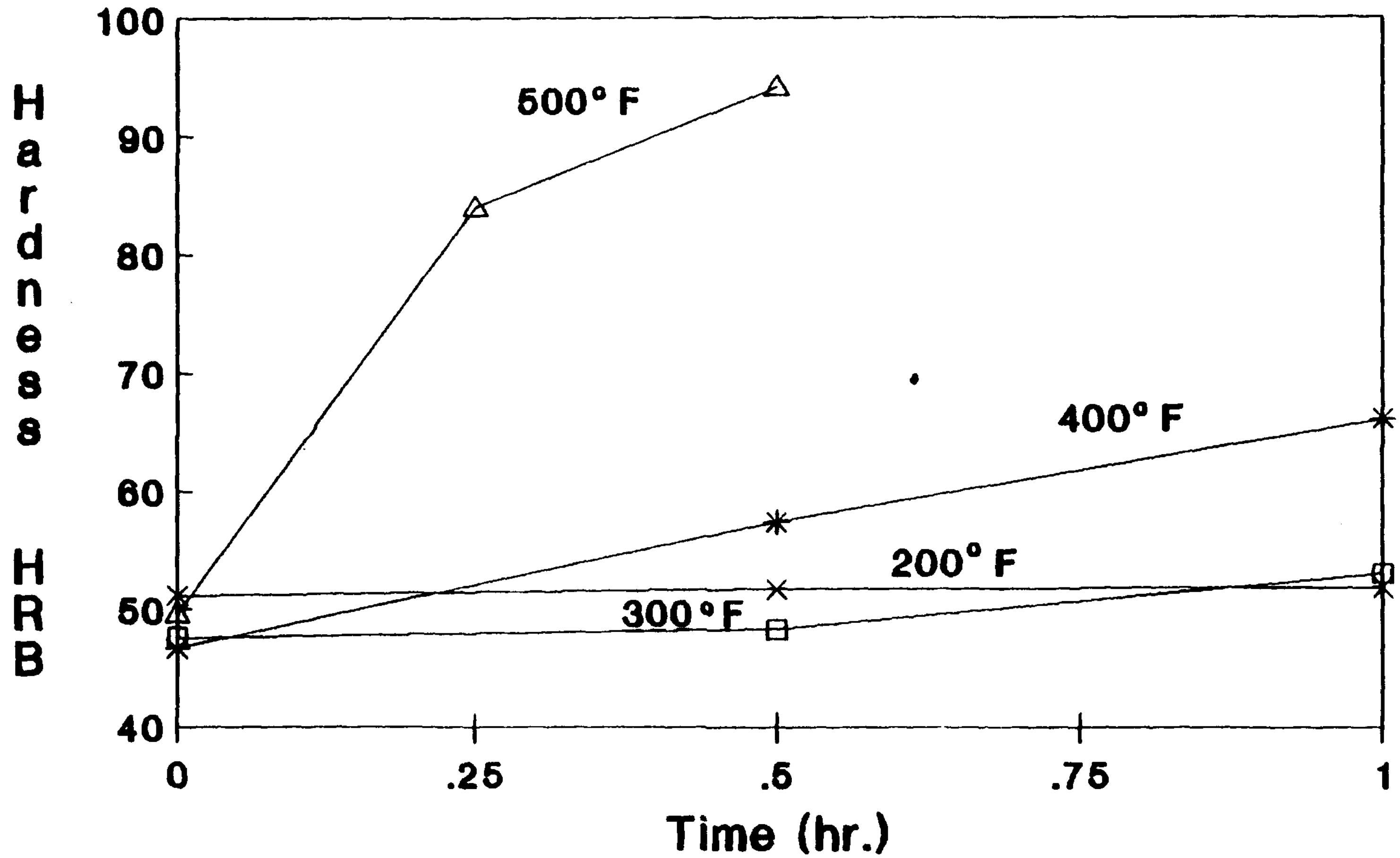


Figure 9. Graph showing age-hardening temperatures and times with corresponding hardness values.
Samples solution treated at 1450°F for 10 minutes.

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