5-1-1939

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A Thesis Submitted to the Department of Metallurgy
in Partial Fulfillment of the Requirements
for the Degree of Bachelor of Science
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INTRODUCTION

It has been shown by Gregg[1] that a high-copper alloy of the composition Cu-Mn_2Si is susceptible to age hardening. A detailed study of the changes that occur on reheating such alloys which have been quenched from a high temperature was made by Klebba[2], with respect to changes in hardness and electrical conductivity.

The increase in hardness is attributed to the manganese silicide being precipitated from solid solution and deposited between crystal planes. The subsequent softening whichoccurs on prolonging the period of reheating is believed to be due to an agglomeration of the dispersed hardening agent[3].

This thesis deals with the age hardening of copper which contains small amounts of the silicide Mn_2Si.

1) Gregg, J. L. ; "Dispersion Hardening in Copper-base and Silver-base Alloys". Trans. A. I. M. E., Inst. of Metals Div. (1929). 409-413.

2) Klebba, E. L. ; " The Age Hardening of Copper with Manganese Silicide ". Master's Thesis, Montana School of Mines. (1935)

3) Merica, Paul D. ; " The Age Hardening of Metals ". Trans. A. I. M. E., Inst. of Metals Div. (1932). 13.

PREPARATION OF ALLOYS

The following method was used in preparimg alloys for the investigation.

60-gramme charges were prepared by weighing out the theoretical amounts of copper', manganese", and silicon" required to give the desired percentages of copper and manganese silicide (Mn_2Si), assuming a complete combination of the manganese and silicon. The materials were placed in a covered graphite crucible, buried in charcoal, and fused in a carbon resistance furnace. Temperature was measured with an optical pyrometer. The charge was maintained at 1400°C. for at least 30 minutes, which appeared to be sufficient for the combination of the manganese and silicon. The metal was then cast in bar form, using cold graphite molds.

These bars were heated for two hours at 900°C., in a tube resistance furnace, and then quenched in water. Heating was for the purpose of allowing the manganese silicide to form a solid solution with the copper, while quenching was for the purpose of maintaining this condition when the metal was in the cold state.

After filing to remove surface irregularities, the bars were reduced to sheet form by means of hand rolls. A reduction of area of approximately 80% was effected. An intermediate anneal for 30 minutes at 800°C. was required for the 5% Mn_2Si alloy, to prevent cracking, but was not necessary for the 3% material.

' Electrolytic Copper Wire, Anaconda Copper Mining Co.

" From Denver Fire Clay.

The rolled metal was cut into 2" x 1/2" strips for use in the hardening tests. These samples were then heated for 2 hours at 900°C., in a tube furnace, and then quenched in water. This was to assure that the silicide still remained in solid solution, and to reduce the hardness induced by cold work.

Tube furnace temperatures were measured with a platinum resistance thermometer.

HARDENING

In determining hardness changes, the hardness of a quenched strip was measured. The sample was then heated at a constant temperature for a period of 150 minutes, being withdrawn at intervals for furthur hardness measurements. The temperature of tube furnace, as indicated by the platinum resistance thermometer, was maintained with a maximum variation of ± 10°C.

Hardnesses were measured with a Rockwell Superficial Hardness Tester, using a 15 kilogramme load and a T point.(i.e. a 1/16" ball).

RESULTS

Alloys containing 3% and 5% manganese silicide were used in this study. Temperatures of reheating were 300, 400, 500 and 600 degrees Centigrade. The data obtained are presented in both tabular and graphic form. (Tables I & II and Figures 1 & 2.).
The curves of Fig. 1 are for the 3% alloy, and show changes in hardness produced by different times of reheating at 4 given temperatures. Fig. 2 is similar to Fig. 1 , but is for the 5% alloy.

The differences in the initial hardnesses of various test specimens might be attributed to slightly different rates of cooling occurring between the furnace and the quenching bath. Although this period was a matter of a few seconds, some precipitation of the Mn_2Si could occur,as it probably exists in a state of saturation. This would cause a variation in initial hardnesses, as noted.

Although Gregg[1] attributed the hardening to Mn_2Si, it is possible that some silicide of copper might be formed and exert some influence on the hardening process. An equilibrium such as the one listed below could quite possibly exist.

$$Mn_2Si + 2\,Cu \rightleftharpoons Cu_2Si + 2\,Mn$$

1) Footnote 1, Page 1.

TABLE I

Change in hardness with reheating time, for copper containing

3% Mn_2Si. Quenched from 900° Centigrade.

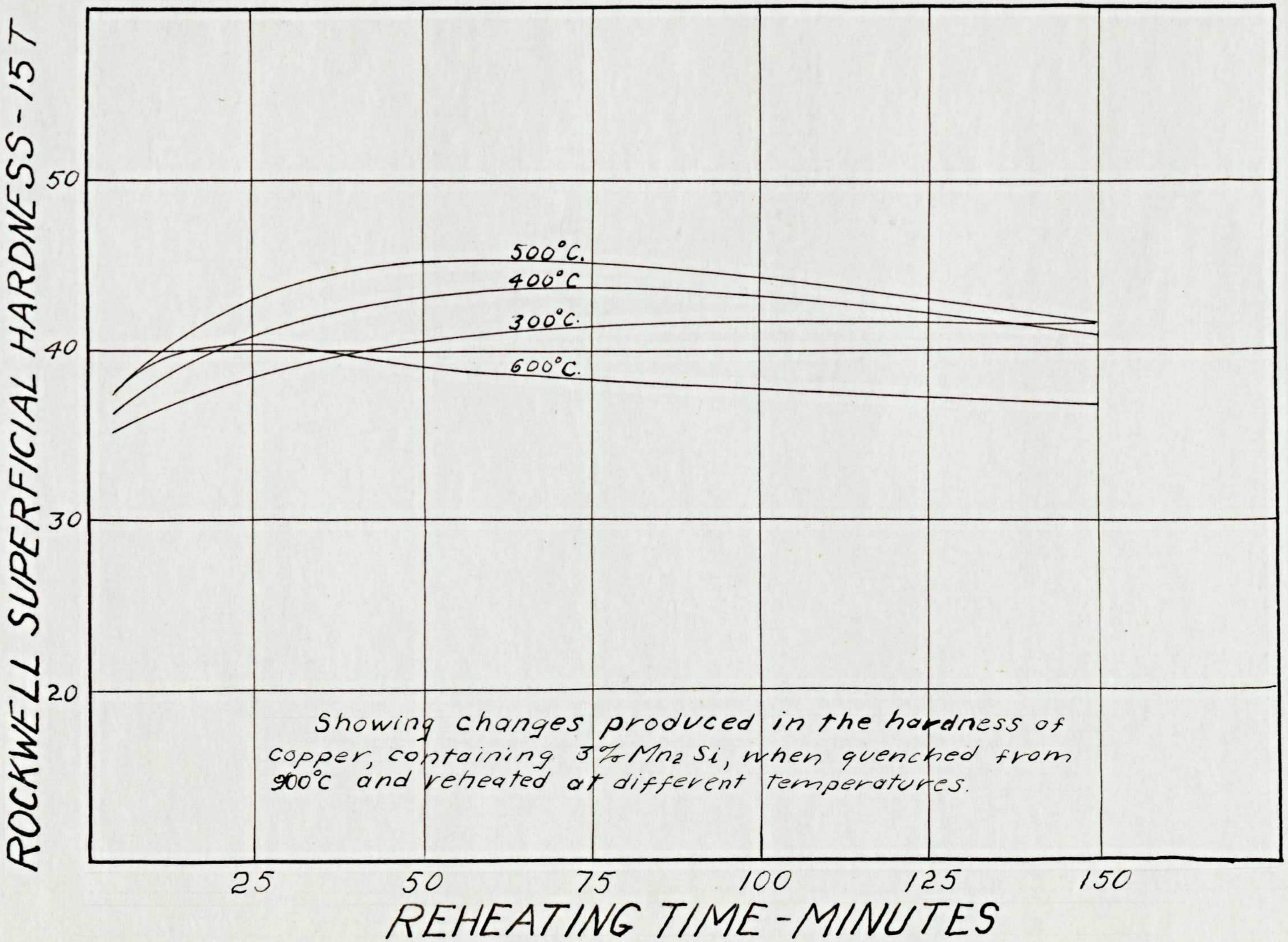
Reheating Temperature °C.	Reheating Time Minutes	Rockwell Superficial Hardness 15-T
300	0	34
300	10	37
300	25	38
300	50	40
300	100	41
300	150	42
400	0	12
400	10	38
400	25	40
400	50	43
400	100	43
400	150	41
500	0	35
500	10	39
500	25	43
500	50	45
500	100	44
500	150	42
600	0	35
600	10	39
600	25	40
600	50	39
600	100	38
600	150	37

TABLE II

Change in hardness with reheating time, for copper containing

5% Mn_2Si. Quenched from 900°Centigrade.

Reheating Temperature °C.	Reheating Time Minutes	Rockwell Superficial Hardness 15-T
300	0	54
300	5	56
300	10	58
300	25	62
300	50	64
300	100	67
300	150	66
400	0	59
400	5	61
400	10	63
400	25	63
400	50	63
400	100	60
400	150	59
500	0	66
500	5	68
500	10	70
500	25	70
500	50	69
500	100	68
500	150	64
600	0	64
600	5	66
600	10	66
600	25	62
600	50	59
600	100	58
600	150	57



Showing changes produced in the hardness of copper, containing 3% Mn_2Si, when quenched from 900°C and reheated at different temperatures.

Fig. 1.

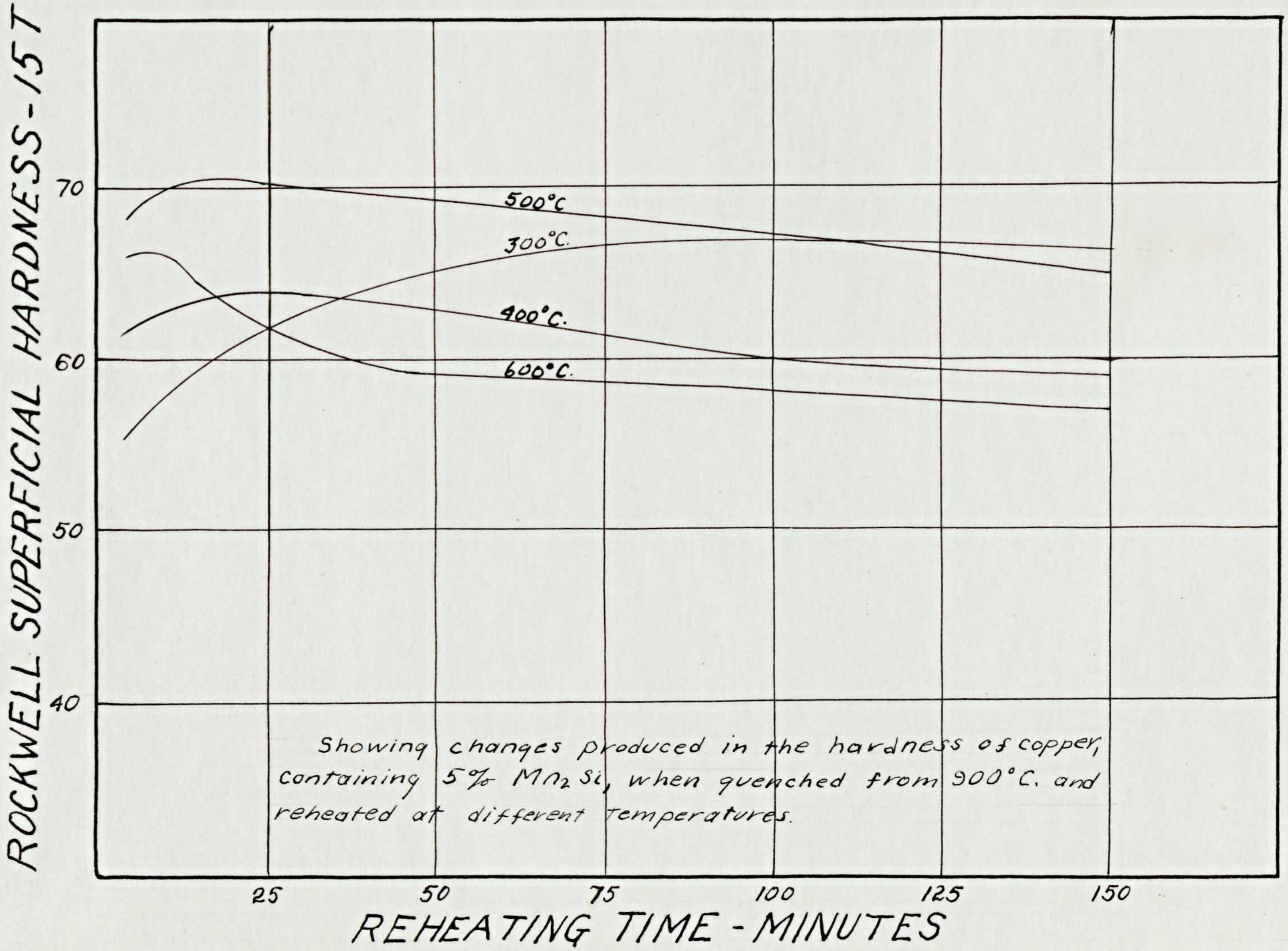

ROCKWELL SUPERFICIAL HARDNESS - 15 T
70
60
50
40
500°C
300°C.
400°C.
600°C.
Showing changes produced in the hardness of copper, containing 5% Mn_2Si, when quenched from 900°C. and reheated at different temperatures.
25
50
75
100
125
150
REHEATING TIME - MINUTES

Fig. 2.

CHROMIUM SILICIDE

With a view to seeing if Cr_2Si would act as a hardening agent for copper, it was attempted to produce an alloy containing 5% Cr_2Si and the rest copper. The procedure for the preparation of the alloy was essentially the same as that used to prepare the copper-manganese silicide. Elemental copper', silicon'' and chromium''' were used. The charge was allowed to solidify in the crucible.

Microscopic examination showed that the chromium did not combine with the silicon, but was distributed throughout the copper.

' Electrolytic Copper Wire, Anaconda Copper Mining Company.
'' From Denver Fire Clay.
''' From Eimer and Amend.

CONCLUSIONS

1) For both alloys studied, the maximum hardness is obtained with a reheating temperature which is in the neighborhood of 500°C. Temperatures of 600°C. and higher cause softening to become appreciable.

2) Alloys containing 5% manganese silicide are harder than alloys containing 3% manganese silicide, regardless of the time or temperature of reheating.

3) Reheating the 5% alloy at 300°C. produced a hardness greater than that obtainable at 400°C. but which was less than that obtainable at 500°C. Therefore it would seem that there are two, or possibly more, reheating temperatures which will produce maximum hardening, these maxima not necessarily being equal to each other.

ACKNOWLEDGMENTS

For assistance given me during this work, I wish to express my thanks to Dr. Curtis L. Wilson and to Dr. E. A. Peretti.