
Bachelors Theses

Student Theses and Dissertations

1940

X-ray data concerning some manganese-copper alloys

George Lester Mitsch

Follow this and additional works at: https://scholarsmine.mst.edu/bachelors_theses



Part of the [Metallurgy Commons](#)

Department: **Materials Science and Engineering**

Recommended Citation

Mitsch, George Lester, "X-ray data concerning some manganese-copper alloys" (1940). *Bachelors Theses*. 127.

https://scholarsmine.mst.edu/bachelors_theses/127

This Thesis - Open Access is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in Bachelors Theses by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

X-RAY DATA CONCERNING SOME MANGANESE-COPPER ALLOYS

BY

GEORGE LESTER MITSCH

A

THESIS

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the work required for the
Degree of
BACHELOR OF SCIENCE IN METALLURGICAL ENGINEERING

Rolla, Mo.

1940

Approved by Paul G. Herold
Professor of Ceramic Engineering

56331

TABLE OF CONTENTS

	Page No.
INTRODUCTION.....	1
RESULTS OF PREVIOUS INVESTIGATIONS.....	2
DESCRIPTION OF APPARATUS USED.....	10
SOURCE OF MATERIALS.....	11
MECHANICS OF THE INVESTIGATION	
1. Preparation of Samples.....	12
2. Exposure.....	12
3. Development and Measurement.....	12
PROCEDURE AND DATA.....	13
SUMMARY.....	23
CONCLUSIONS.....	24
SUGGESTIONS FOR FURTHER RESEARCH.....	25
ACKNOWLEDGMENTS.....	25
BIBLIOGRAPHY.....	26

LIST OF ILLUSTRATIONS AND TABLES

	Page No.
Table I: Summary of Data on Allotropism of Mn.....	3
FIG. I: VOLUME vs. LATTICE STRUCTURE, BAIN.....	5
FIG. II: PHASE DIAGRAM PROPOSED BY PERSSON, 1930.....	6
FIG. III: PHASE DIAGRAM PROPOSED BY U.S.B.M.	7
FIG. IV: PHASE DIAGRAM PROPOSED BY U.S.B.M., 1940....	9
FIG. V: X-RAY EQUIPMENT.....	10
Table II: Composition of Alloys.....	11
Table III: Data for Gamma Manganese.....	14
Table IV: Data for Alpha Manganese.....	15
Table V: Data for Electrolytic Copper.....	15
Table VI: Data for Alloy 1, cast.....	15
Table VII: Data for Alloy 2, cast.....	15
FIG. VI: DIFFRACTION PATTERNS,--ALPHA MN, ALLOYS 1, 2, AND 3.....	16
Table VIII: Data for Alloy 3, cast.....	16
Table IX: Data for Alloy 4, cast,.....	16
FIG. VII: DIFFRACTION PATTERNS FOR ALLOYS 5, 6, 7, 8, and 9.....	17
Table X: Data for Alloy 5, cast.....	17
Table XI: Data for Alloy 6, cast.....	17
Table XII: Data for Alloy 7, cast.....	18
Table XIII: Data for Alloy 8, cast.....	18

Table XIV: Data for Alloy 9, cast.....	18
FIG. VIII: DIFFRACTION PATTERNS FOR ALLOYS 1, 2, 4, 8, and 9, SLOW COOLED.....	19
Table XV: Data for Alloy 9, Slow Cooled.....	19
Table XVI: Data for Alloy 8, Slow Cooled.....	19
Table XVII: Data for Alloy 2, Slow Cooled.....	20
Table XVIII: Data for Alloy 1, Slow Cooled.....	20
FIG. IX: COMPARISOM OF QUENCHED AND SLOW COOLED SPECIMENS.....	21
Table XIX: Data for Alloy 1, quenched.....	22
Table XX: Data for Alloy 9, quenched.....	22
Table XXI: Summary of Data.....	24

X-ray Data Concerning Some Manganese-Copper Alloys

INTRODUCTION

Until recently the only commercial method of producing metallic manganese in large amounts was a pyrometallurgical process. Producing a metal of about 97% purity, it was not very satisfactory. With the advent of a process for producing a metal of 99.9 plus % purity electrolytically, introduced by the United States Bureau of Mines, for the first time was there a sufficient quantity of pure manganese available for alloy use.

The manganese-copper system was chosen for study because of the inconsistencies in the reports of previous investigators, and because of the properties alloys of these components possess, such as magnetism, high damping capacity, and good electrical resistance, coefficient of expansion and heat conductivity. Several ordered lattices and compounds have been reported by some investigators and work is now being done to determine their effect on the properties.

To date, very little work has been done on alloys made from electrolytic manganese and, as they promise to be of prime importance in future non-ferrous metallurgy, it is felt that the structure should be more thoroughly investigated.

RESULTS OF PREVIOUS INVESTIGATIONS

1. Copper

The crystal structure of pure copper has long been known to be of the face-centered cubic system and of the O_h^5 , containing four atoms in the unit cube. Its a_0 value has been controversial for a considerable length of time but recent work by Owen and Pickup¹, Obinata and Wasserman², and Weibke³ has indicated that this value must be $3.608 \pm .001$. This value is substantiated by the author who, without being painstakingly accurate, calculated a value of 3.608.

2. Manganese

Concerning the structure and size of the three manganese atoms, alpha, beta, and gamma, there is considerable discussion. Beginning with the recognition of allotropic transformation by

-
1. Owen, E. A. and Pickup, L., X-ray Study of Copper-Cadmium Alloys. Proc. Royal Society of London, (A) 139, 1933 (526-541)
 2. Obinata, J. and Wasserman, G., Rontgenographische Untersuchung der Löslichkeit von Aluminium in Kupfer. Naturwiss, 21, 1933 (382-385)
 3. Weibke, F., Das Zustandsdiagramm des Systems Kupfer-Gallium. Z. Anorg. Allg. Chem., 220, 1934 (293 - 311)

Gayler⁴ in 1927, who published a table of thermal points for pure manganese, several sets of conflicting data were presented. Most of this work was accomplished by use of the microscope and dilatometer. As this paper is concerned with neither microscopic data nor elementary manganese most of this work may be overlooked. However, an excellent discussion may be found in the U.S. Bureau of Mines, Reports of Investigations 3477. It suffices to say that the allotropy of manganese was confirmed and three allotropic phases identified as summarized in table I.

Table I*

Summary of Data on Allotropism of Manganese

Density	Form	Stability Range	Crystal Structure
7.4	Alpha	Below 740°C.	Cubic, 58 atoms to unit cell. $a_0 = 8.901 \text{ \AA}$.
7.29	Beta	740 to 1070°C.	Cubic, 20 atoms to unit cell. $a_0 = 6.305 \text{ \AA}$.
	Beta	1070 to 1160°C.	Cubic, body-centered or face-centered.
7.2	Gamma	1160°C to M.P.	Tetragonal, 4 atoms to unit cell. $a_0 = 3.767 \text{ \AA}$. $c/a = .934$

4. Gayler, Dr. Marie, Alloys of Iron Research Part VI, Preparation of Pure Manganese. Journal Iron and Steel Institute, 113, 1927 (393-411)

* Reprinted from United States Bureau of Mines, Reports of Investigations 3477.

It is to be noted that the a_0 values do not agree very closely with those published by Zeitschrift für Kristallographie, Ergänzungsband II and those published in the Handbook of Chemistry and Physics, Vol. 22, 1937, nor with the results of other investigators, but are $.007\text{\AA}$ higher in the case of the alpha and gamma phases and $.006\text{\AA}$ in the case of beta manganese. This difference, however, is within the allowable range of error.

Bradley⁵, Westgran and Phragmen⁶, and Persson and Ohman⁷ have recognized the structure of high temperature manganese (gamma) as of the same structure as electrolytically deposited manganese. Bradley also advanced the theory that two forms of manganese exist together in a state of isodynamic isomerism between temperature intervals of $650\text{--}850^\circ\text{C}$. Persson and Ohman found no trace of this and suggested inaccurate quenching or that if such a field did exist, it was very narrow. Persson and Ohman also stated in their paper that heating electrolytic manganese to 150°C , or allowing it to stand at room temperature for several days, would transform it to the alpha state.

5. Bradley, A.J., The Allotropy of Manganese. Philosophical Mag., Vol. 50, 1925 (1018-1030).

6. Westgren, Arne and Phragmen, G., The Crystal Structure of Manganese. Ztsch. Physik, Vol. 33, 1925 (777-788)

7. Persson, E. and Ohman, E., A High Temperature Modification of Manganese. Nature, Vol. 124, 1929 (333-334)

3. Copper-Manganese Alloys

E. C. Bain⁸ in his study of the crystal structure of solid solutions used copper-manganese alloys as an excellent example of a continuous solid solution series presenting a minimum in fusion temperature. He showed (Fig. I) a range of overlapping patterns between 60-40% and 90-10% manganese-copper, the changing point being at about 75% Mn.

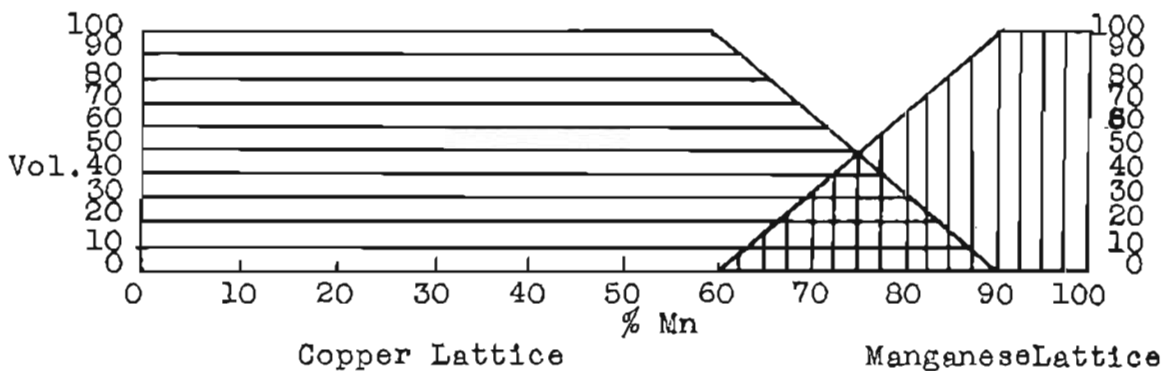


Fig I

Patterson⁹ found solid solution occurring up to 30% Mn, the lattice changing from 3.60 Å. to 3.70 Å with the increase in manganese. Above 30% little effect on the lattice was noted. Another lattice began to appear at 50% Mn to which, he reported, most Mn atoms attached themselves. At 90% Mn the size of the lattice had increased to 3.74 Å. He rejected complete miscibility from 35% on. He found that the minimum melting point was between 30 and 35% and stated that this agreed with Rosehain's conception that the straining of the lattice by the substitution of new atoms lowers the melting point.

8. Bain, E.C., Crystal Structure of Solid Solutions. Trans. A.I.M.E., Vol. 68, 1923 (623)

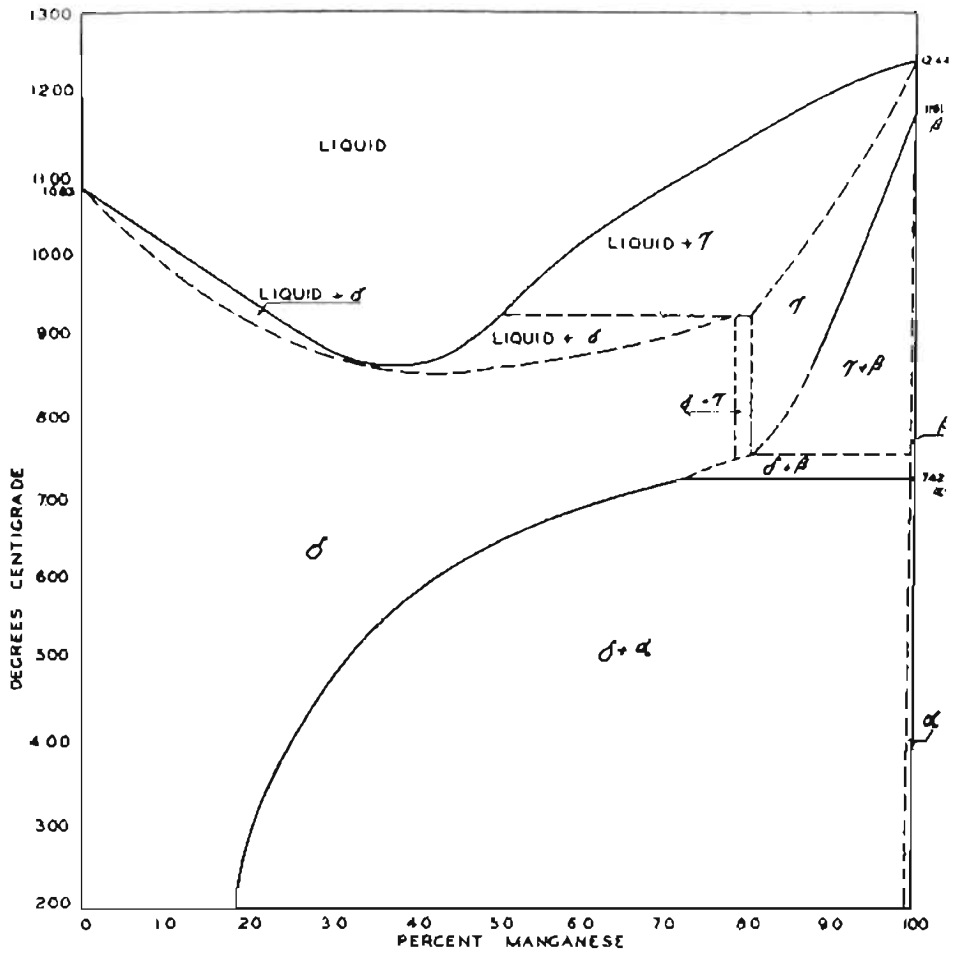


Fig. II

Phase Diagram Proposed by Persson, 1930

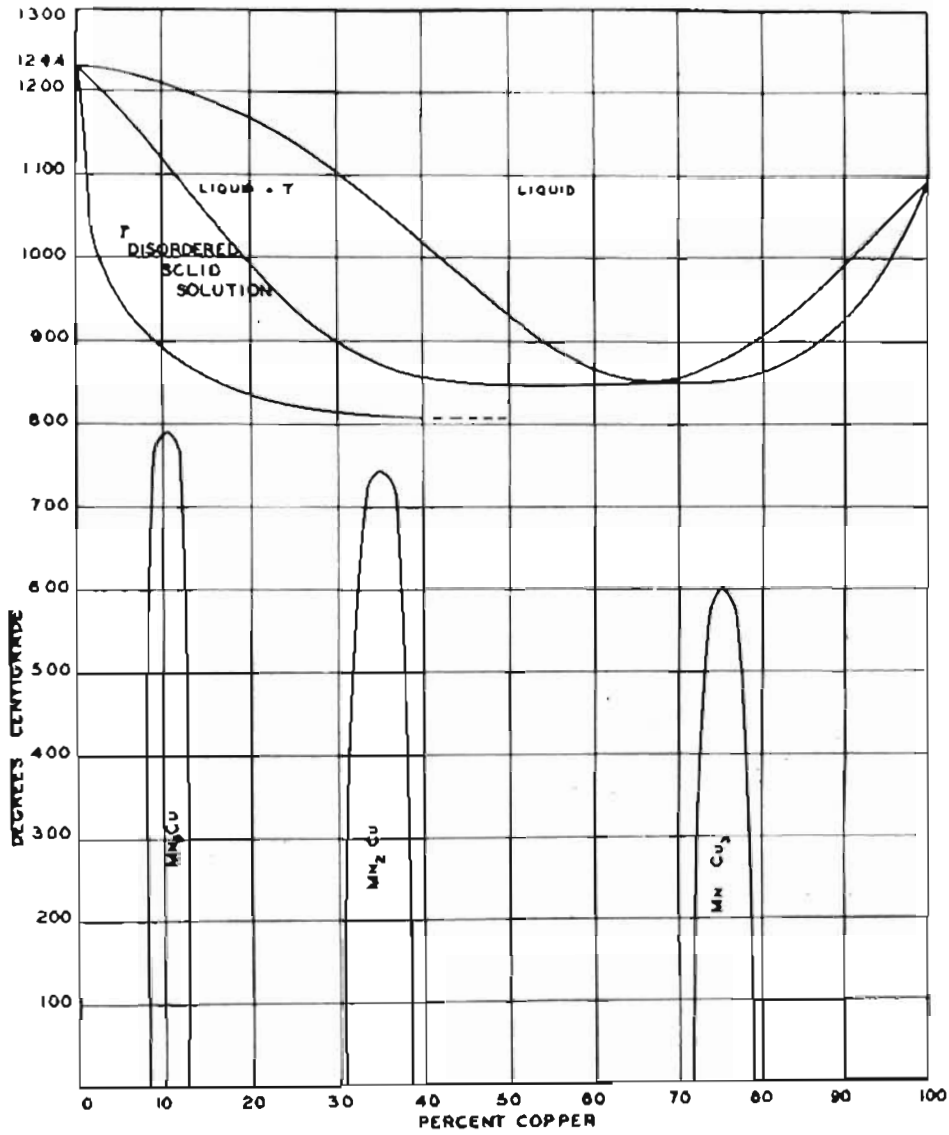


Fig. III

Phase Diagram Proposed by U. S. Bureau of Mines, 1939

Persson and Ohman stated that copper is not soluble to any great extent in alpha or beta manganese. They reported that alloys containing 5% copper or more showed no resemblance to alpha and beta manganese and as the copper content was increased to 20% the lattice became more cubical in nature. Extrapolation of one of his curves showed that at 24% Cu the c/a ratio was one.

In a later paper by Persson¹⁰ alone he published a phase diagram of the system (Fig. 2).

In the Reports of Investigations 3477 of the Bureau of Mines a tentative phase diagram (Fig. III) was proposed that was quite different from Persson's in that it proposed several compounds whereas Persson's diagram showed none.

In a new paper proposed by the Bureau of Mines¹¹ and as yet unpublished a third diagram is advanced (Fig. IV). This diagram was developed from microscopic study and contains several of the main features of Persson's diagram while proposing even more compounds than shown in the Bureau's first diagram.

9. Patterson, R., Crystal Structure of Copper-Manganese Alloys. Physical Review, Vol. 23, 1923 (552).

10. Persson, E., X-ray Analysis of Copper-Manganese Alloys. Ztschr. Physik Chem. Abt. B, Vol. 9, 1930 (25-42).

11. Dean, R.S.; Anderson, C.T.; and Jacobs, J.H., The Alloys of Manganese and Copper. U.S. Bureau of Mines. (Unpublished)

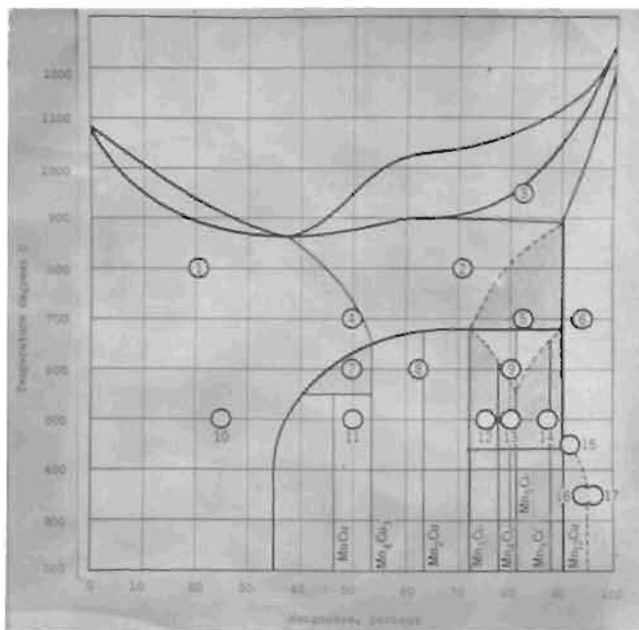


Fig. IV

Phase Diagram Proposed by U.S. Bureau of Mines, 1940

DESCRIPTION OF APPARATUS USED

The X-ray tube (Fig. V) used in this work was of the "gas" variety, designed to operate continuously at 40 kilovolts and 10 milliamperes. It was built at the Missouri School of Mines and Metallurgy by Dr. Paul G. Herold, Head of the Department of Ceramic Engineering. The vacuum is maintained by means of a mercury diffusion pump.

Two Debye diffraction cameras, each equipped with a fluorescent screen and rotating device, and having a diameter of 11.4 cm. were used.

The targets were made of copper with an iron inset. Both the cathode and the target were water-cooled.

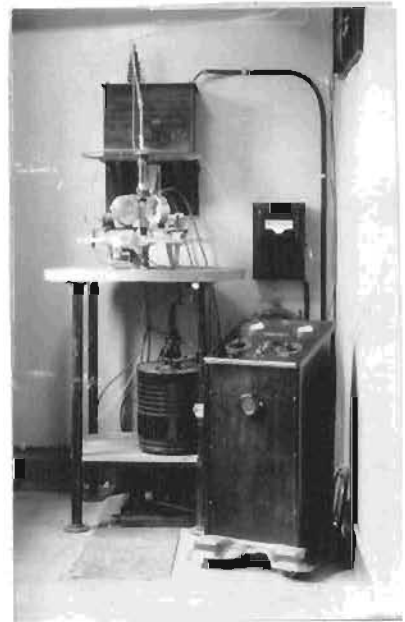


Fig. V
X-ray Equipment Showing
Debye Cameras in Position.

SOURCE OF MATERIALS

A series of nine alloys, varying in chemical composition between 96 and 50% manganese were prepared by the Bureau of Mines.

Table II

Composition of Alloys Furnished (to the nearest %)

Alloy No.	% Mn	% Cu
1	96	4
2	94	6
3	92	8
4	90	10
5	82.5	17.5
6	75	25
7	70	30
8	60	40
9	50	50

The alloys were melted and cast into molds and cooled. After solidification while still at red heat, between 400 and 500°C., the molds were taken apart and the alloys water quenched.

All heat treatment operations were performed at Rolla by J. H. Jacobs* who heated the specimens in a hydrogen atmosphere. Slow cooling was attained by heating to temperature and furnace cooling in the hydrogen atmosphere.

* Research Metallurgist, U. S. Bureau of Mines.

MECHANICS OF THE INVESTIGATION

1. Preparation of Samples for X-ray Analysis

Attempts were made to secure samples by means of filing the specimens but this method was rejected because the variable hardnesses did not allow particles of uniform size to be obtained. In the case of the harder alloys impurities from the iron file were introduced while the softer specimens gave flakes too large for convenient mounting. It was found much easier to produce particles of small and uniform size by sawing.

The powders were mixed with a quick drying, acetone soluble cement and mounted as thinly as possible on a tightly stretched silk thread.

2. Exposure

The samples were mounted in the Debye camera and exposed to Fe - K radiation for an average of 9 - 10 milliampere hours at 30 kilovolts. Cr - K radiation was tried but the faintness of the few lines that did appear on the film, due to the great absorption which air shows for the long wave length radiation from Cr, made it impractical to continue with this radiation in the limited time allowed for exposure.

3. Development and Measurement

The films were not developed under any standard conditions as to time or temperature but extreme care was taken to secure clear, distinct films.

A standard measuring device was used to measure the films

to the nearest .002 cm.

The intensities were measured visually and are comparative to the strongest and weakest lines on the film, number one being the strongest line and number ten the weakest.

PROCEDURE AND DATA OF THE INVESTIGATION

Part 1

At the very beginning of the investigation standard films were made of electrolytic copper and alpha manganese which had been electrolytically produced some months previously.

An attempt was made to produce gamma manganese electrolytically by the following method:

Catholyte: 250 gms. MnSO_4 plus 1000gms. $(\text{NH}_4)_2\text{SO}_4$ / liter
in water.

Anolyte: 200 gms. $(\text{NH}_4)_2\text{SO}_4$ / liter in water.

Both solutions were made free of sulphur and other potential impurities and brought to a pH value of 6 - 6.5. Manganese was plated both on an aluminum and stainless steel cathode. At this point the apparatus was broken and it was ten days before it could be completely repaired. During this time the manganese specimens were kept at a low temperature in an electric ice box. Diffraction patterns were made of both cathode products and showed nothing but alpha Mn. We, therefore, may assume that at least one of three possibilities was responsible for the results obtained:

1. The transformation of gamma Mn to alpha Mn occurs, even at low temperatures, more rapidly than suspected by Persson.

2. The crushing of the sample at room temperature causes a rapid recrystallization.

3. Manganese does not always deposit in the gamma phase.

As time did not permit repeating the experiment, data for gamma Mn, as reported by Westgren, was used throughout the work as a standard for the identification of gamma Mn.

Table III

Data for Gamma Mn as Reported by Westgren

Intensity	Reflecting Plane	Radiation	d Value
med.	111	beta	2.34
strong	111	alpha	2.13
weak	200	beta	2.08
weak	002	beta	1.94
medi	200	alpha	1.885
med.	002	alpha	1.77
v. weak	220	beta	1.47
weak	202	beta	1.418
med.	220	alpha	1.335
strong	202	alpha	1.29
weak	131	beta	1.241
weak	113	beta	1.185
weak	222	beta	1.17

Table IV

Alpha Manganese		
Intens.	Reflecting Planes	d Value
6	822,660	1.0488
2	722,633,552	1.2120
5	543,710,550	1.2571
6	444	1.2866
4	510,431	1.7441
5	422	1.8145
3	332	1.8969
1	411,330	2.0980
6	400	2.2223

Table V

Electrolytic Copper		
Intens.	Reflecting Plane	d Value
4	420	0.8060
4	331	0.8268
6	400	0.9009
5	222	1.0400
3	311	1.0858
3	220	1.2739
2	200	1.8029
1	111	2.0835

Part 2

The next procedure was to run the nine alloys as cast.

The data secured is given in the following tables:

Table VI

96% Mn-4% Cu		
Intens.	Reflecting Plane*	d Value
2	202	1.297
3	220	1.323
2	200	1.869
1	111	2.144

Table VII

94% Mn-6% Cu		
Intens.	Reflecting Planes*	d Value
3	312	1.0729
3	311,131	1.1320
4	202	1.2993
4	220	1.3292
5	102	1.8029
2	200	1.8830
1	111	2.1377

* Gamma Mn.

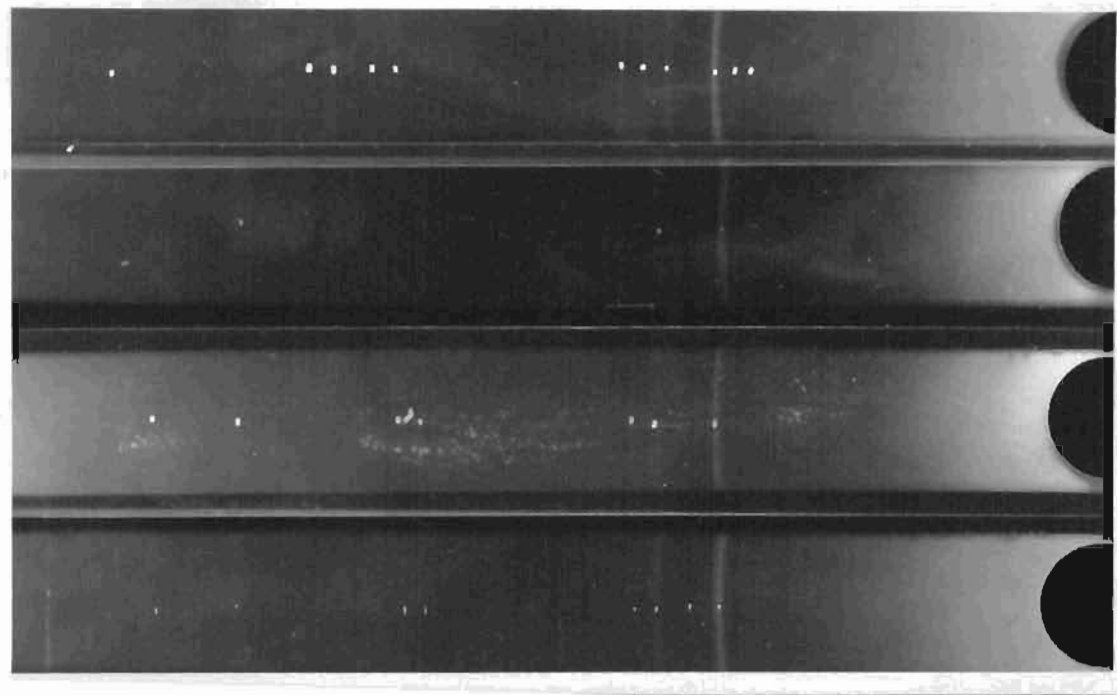


Fig. VI

Diffraction Patterns for, top to bottom, Alpha Mn,
and Alloys 1, 2, and 3, Respectively.

Table VIII

92% Mn-8% Cu*

Intens.	Reflecting Plane**	d Value
2	200	1.8571
1	111	2.1379

Table IX

90% Mn-10% Cu

Intens.	Reflecting Planes**	d Value
7	312	1.073
3	311,131	1.130
4	202	1.305
4	220	1.333
6	002	1.806
2	200	1.878
5	411,330***	2.040
1	111	2.1417

* Cr radiation.

** Gamma Mn.

*** Alpha Mn.

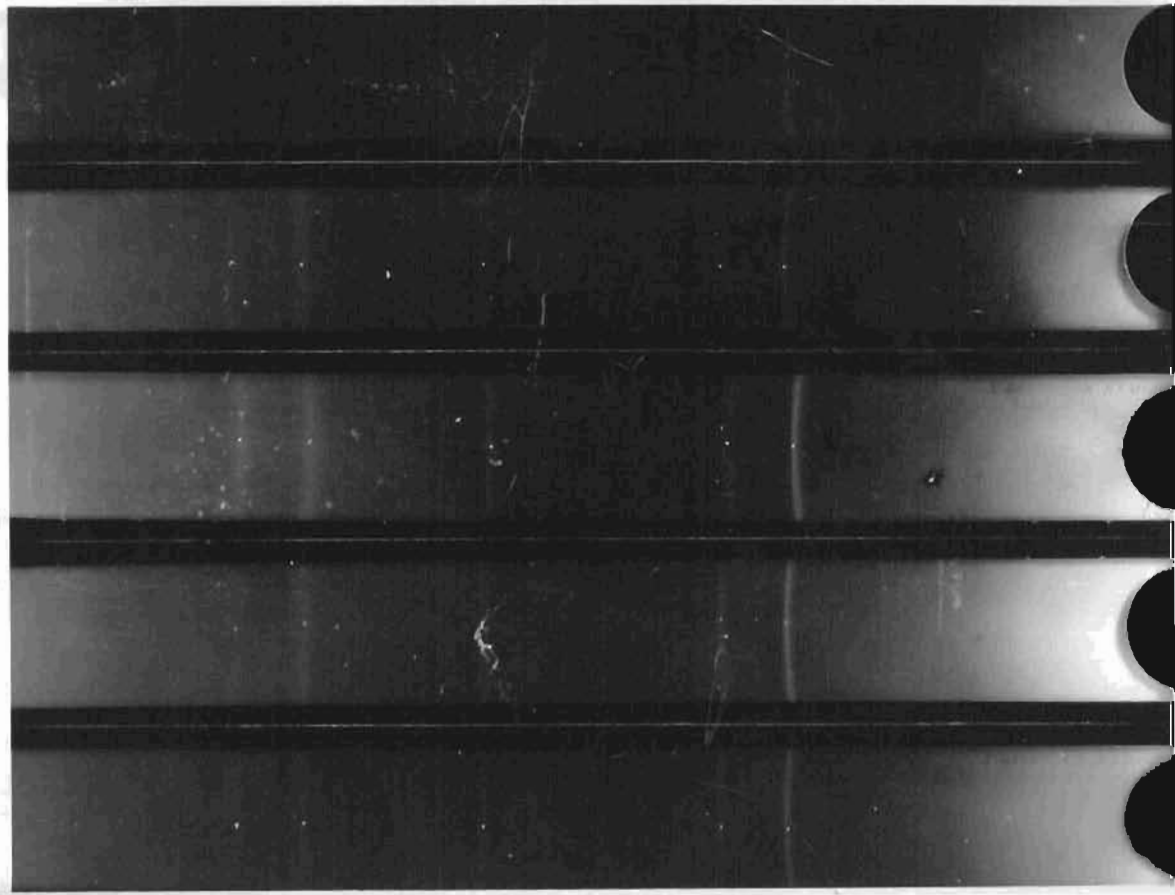


Fig. VII

Diffraction Patterns for, top to bottom, Alloys
5, 6, 7, 8, and 9, Respectively

Table X

82.5% Mn-17.5% Cu

Intens.	Reflecting Planes	d Value
6	311,131*	1.067
5	222**	1.089
3	311**	1.129
3	220** 202*	1.290
6		1.449
4	002*	1.782
2	200**,200*	1.881
1	111**,111*	2.134

Table XI

75% Mn-25% Cu

Intens.	Reflecting Plane**	d Value
4	311	1.129
3	220	1.316
2	200	1.862
1	111	2.148

** Cu lattice.

* Gamma Mn lattice.

Table XII

70% Mn-30% Cu

Intens.	Reflecting Plane*	d Value
4	222	1.082
4	311	1.175
3	220	1.325
2	200	1.872
1	111	2.155

Table XIII

60% Mn-40% Cu

Intens.	Reflecting Planes	d Value
3	222*	1.081
3	311*	1.130
2	220*	1.322
2	200*	1.865
4	411, 330**	2.009
1	111*	2.156

Table XIV

50% Mn-50% Cu

Intens.	Reflecting Plane*	d Value
3	222	1.080
3	311	1.133
2	220	1.325
2	200	1.872
1	111	2.164

Part 3

Several of the alloys that had been heated and slow-cooled were run next.

* Cu lattice.

** Alpha Mn lattice.

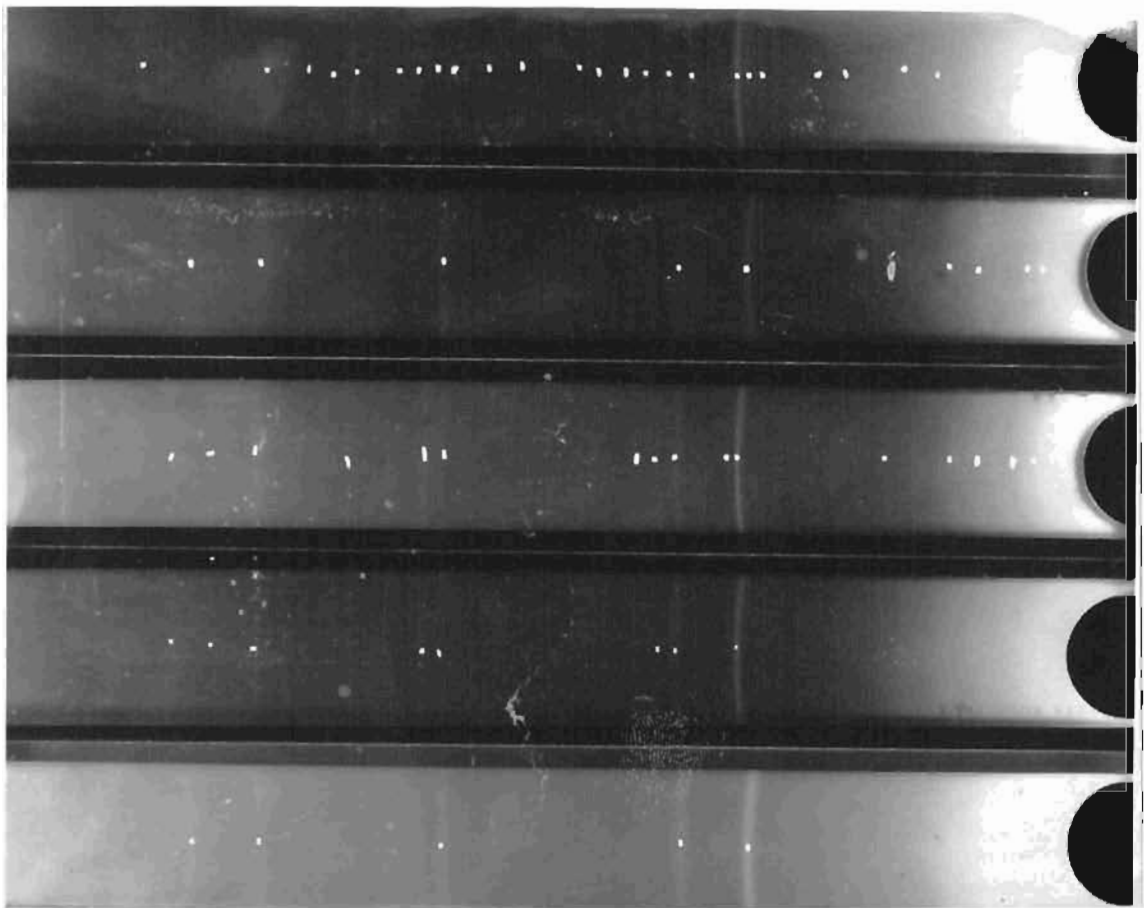


Fig. VIII

Diffraction Patterns for, top to bottom, Alloys
1, 2, 4, 8, and 9, Respectively, Slow-Cooled.

Table XV

50% Mn-50% Cu

Intens.	Reflecting Plane*	d Value
4	222	1.0796
3	311	1.1268
3	220	1.3209
2	200	1.8667
1	111	2.1588

Table XVI

60% Mn-40% Cu

Intens.	Reflecting Plane*	d Value
3	222	1.0788
3	311	1.1270
4	220	1.3270
2	200	1.8622
1	111	2.1488
		5
		3.3881
		5
		4.2731
		5
		5.3010

* Cu lattice

Table XVII

90% Mn-10% Cu

Intens.	Reflecting Planes	d Value
4	312*	1.0714
5		1.0965
4	311,131*	1.1272
7	722,633,552**	1.2107
4	202*	1.3023
5	220*	1.3310
7	510,431**	1.7404
6		1.7996
2	200*,332**	1.8711
1	111*,411,330**	2.1228
7		3.3247
3		4.4654
3		5.5580
3		6.9016
3		8.2431

* Gamma MN lattice.

** Alpha Mn lattice

Table XVIII

96% Mn-4% Cu

Intens.	Reflecting Planes	d Value
3	822,600**,312*	1.0488
6	311,131*	1.1296
7		1.1891
2	722,633,552**	1.2115
5	543,710,550**	1.2583
7	444**,202*	1.2846
7	220*	1.3338
7		1.3874
7		1.4452
7		1.6196
7		1.6787
3	510,431**,002*	1.7442
4	422**,102*	1.8137
2	332**,200*	1.8987
1	411,330**	2.0968
2	111*	2.1513
4	400**	2.2344
5		2.5788
5		2.8029
5		3.4837
5		4.1035

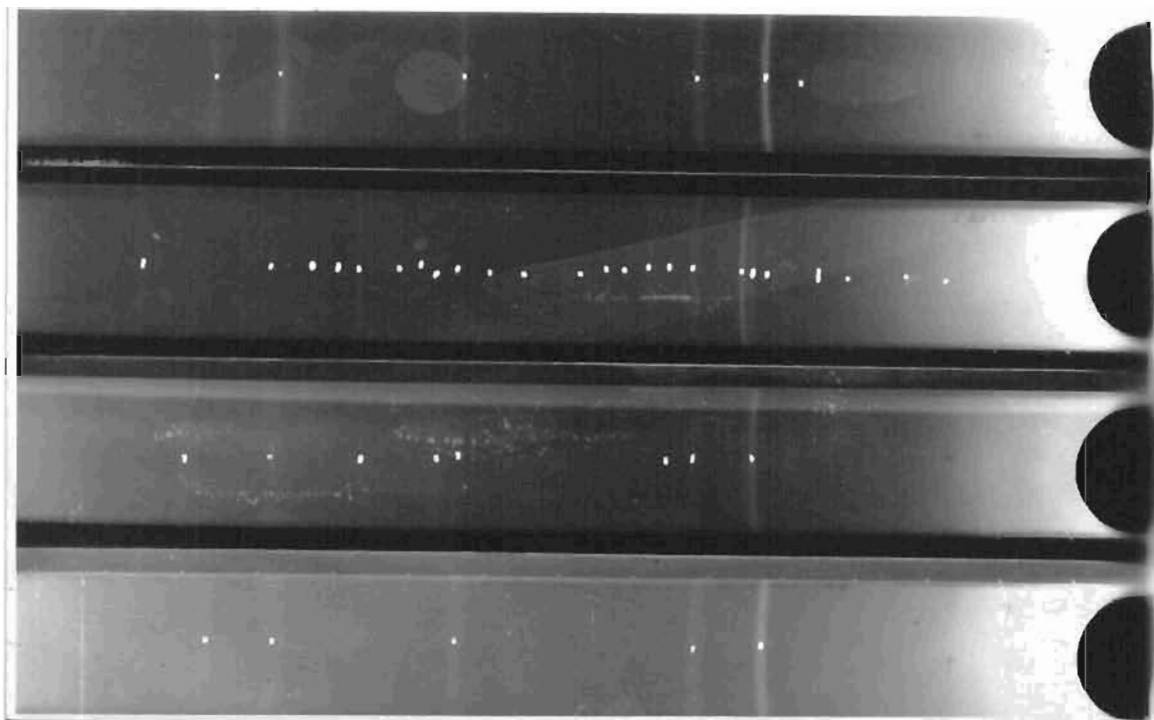


Fig. IX

Comparison of Quenched and Slow Cooled Specimens

Part 4

Diffraction patterns were secured of alloy 1 which had been heated to 1040°C and quenched (top film, Fig. VIII) and alloy 9 which had been heated to 840°C . and quenched. Figure VIII shows, top to bottom, alloy 9 quenched and slow cooled, and alloy 1 quenched and slow cooled, respectively.

Table XIX

96% Mn-4% Cu

Intens.	Reflecting Planes*	d Value
4	222	1.0862
3	311,131	1.1348
3	220	1.3325
2	200	1.8830
1	111	2.1778

Table XX

50% Mn-50% Cu

Intens.	Reflecting Planes*	d Value
6	222	1.0693
6	311	1.1306
6		1.2150
3		1.300
4	220	1.3303
5		1.7939
2	200	1.8848
1	111	2.1352

* Cu lattice.

SUMMARY

From the data, as obtained, the following table may be constructed:

Table XXI

Alloy	% Mn	% Cu	Discussion
1, cast	96	4	Gamma Mn structure, no solid solution.
2, cast	94	6	Gamma Mn structure exactly.
3, cast	92	8	Gamma Mn structure, solid solution.
4, cast	90	10	Gamma Mn structure, solid solution, plus a very small amount of alpha Mn.
5, cast	82.5	17.5	Cu structure and some gamma Mn, sol solution.
6, cast	75	25	Cu structure with solid solution.
7, cast	70	30	Cu structure with more solid solution.
8, cast	60	40	Cu structure with slightly less solid solution, alpha Mn present.
9, cast	50	50	Cu structure with solid solution as in 8 but no alpha Mn present.
* * * * *			
1, slow cooled	96	4	Alpha Mn and gamma Mn (perhaps some Cu) with large lattice.
4, slow cooled	90	10	More alpha Mn, less gamma Mn (large lattice but different than 1).

Table XXI con't.

Alloy	% Mn	% Cu	Discussion
8, slow cooled	60	40	Cu structure with considerable solid solution, other large pattice materials.
9, slow cooled	50	50	Cu structure with considerable solid solution.
* * * * *			
1, quenched	96	4	Apparently Cu structure.
9, quenched	50	50	Cu structure, some unidentified lines indicating compound

CONCLUSIONS

1. Solid solutions, both of the substitutional and interstitial types, are formed between copper and gamma manganese.
2. The presence of compounds, ordered lattices and superlattices is indicated.
3. A change in structure occurs between 96 and 90% Mn alloys but not within the limits as set forth in Fig. IV.
4. There is no indication of compounds between 90 and 60% Mn alloys.
5. There is a structural change at elevated temperatures between 50% and 60% Mn alloys.

SUGGESTIONS FOR FURTHER RESEARCH

For further research in this field I suggest a more thorough study of the alloys in which the presence of compounds, ordered lattices, and superlattices are indicated. Work should also be done to determine accurately the new limits suggested in conclusions 3, 4, and 5.

ACKNOWLEDGMENTS

I wish to take this opportunity to thank Prof. Charles Y. Clayton of the Metallurgical Engineering Department for suggesting the research into these alloys, Mr. James H. Jacobs for heat treating the specimens, and Dr. Paul G. Herold of the Ceramic Engineering Department for his helpful suggestions and indispensable aid throughout the work.

G. L. M.

BIBLIOGRAPHY

1. Bain, E. C., Crystal Structure of Solid Solutions. Trans. A. I. M. E., Vol 68, 1923 (625).
2. Patterson, R., Crystal Structure of Copper-Manganese Alloys. Physical Review, Vol. 23, 1923 (552).
3. Bradley, A. J., The Allotropy of Manganese. Philosophical Mag., Vol 50, 1925 (1018-1030).
4. Westgren, Arne and Phragmen, G., The Crystal Study of Manganese. Ztschr. Physik., Vol 33, 1925 (777-788).
5. Persson, Elis and Ohman, Einar, A High Temperature Modification of Manganese. Nature, Vol. 124, 1929 (333-334).
6. Persson, Elis, X-ray Analysis of Copper-Manganese Alloys. Ztschr. Physik. Chem., Abt. B, Vol. 9, 1930 (25-42).
7. United States Department of the Interior, Bureau of Mines. Reports of Investigations 3477, November, 1939.
8. Dean, R. S., Anderson, C. T. and Jacobs, J. H., The Alloys of Manganese and Copper. United States Bureau of Mines (Unpublished).
9. Clark, George, Applied X-rays, Sec. Ed. New York, McGraw Hill Book Co., 1932.
10. Wyckoff, R. W. G., The Structure of Crystals, Sec. Ed. New York, Chemical Catalog Co., 1931.

11. Wyckoff, R. W. G., The Structure of Crystals, Supplement to Sec. Ed. New York, Chemical Catalog Co., 1935.
12. Zeitschrift für Kristallographie, Strukturbericht, Ergänzungsband 1, 2, and 3. Leipzig, Akademische Verlagsgesellschaft M. H. B., 1931, 1937.
13. Internationale Tabellen zur Bestimmung von Kristallstrukturen, Vol. 1 and 2. Gebrüder, Germany, 1935.
14. Industrial and Engineering Chemistry, Analytical Ed., Vol. 10, No. 9, September 15, 1938.

56331