# AN INVESTIGATION ON THE ISOTHERMAL TRANSFORMATION OF AN ALUMINIUM BRONZE

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## INTRODUCTION

Copper and aluminium, the two most important non-ferrous metals, form a series of complex alloys, of great industrial and theoretical importance. The industrially most important alloys are to be found at the copper and aluminium ends of the series and while the aluminium-rich alloys show pronounced age-hardening characteristics, those predominantly rich in copper are markedly similar to the brasses and bronzes and find much application in the fields where the latter alloys are generally used. A reference to the copper-rich portion of the equilibrium diagram of the Cu-Al system (Fig. 1) indicates that the transformations in the alloys with aluminium between 9·5% and 13·5% are strikingly similar to those occurring in the plain carbon steels, the $\beta$ bronze phase corresponding to the austenite in steel. The $\beta$ phase has no doubt the body centred cubic structure, but the actual transformation on cooling consists in the prior formation of proeutectoid $\alpha$ or $\delta$, followed by the eutectoid formation of $\alpha$ and $\delta$ at the temperature of about 560° C. The transformation of $\beta$ bronze can therefore be well studied by methods developed for the study of the transformation of austenite in steels and in particular by Bain and Davenport's method of isothermal subcritical transformation. Smith and Lindlief[1] in 1933 and several others[2] have carried out such investigations. But it is generally felt that the mechanism of the transformation of the $\beta$ phase is very complex, Raynor[3] reporting that there are at least three distinct transitional phases, each having a different crystal structure. According to him, it is due to the presence of these phases that the mechanical properties of the alloys are susceptible to improvement by heat treatment.

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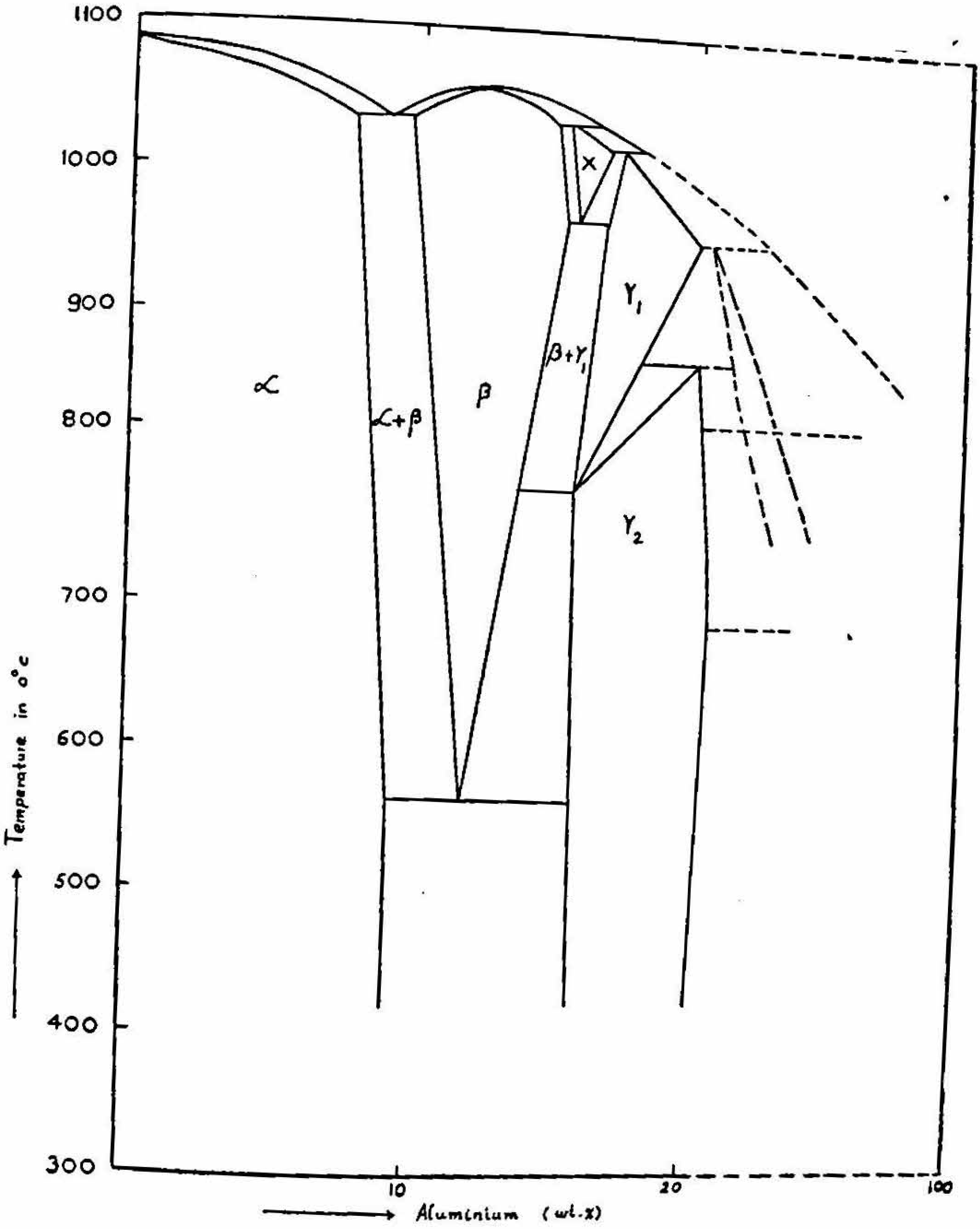



FIG. 1

As with the transformation of austenite, a definite " $M_S$ " temperature can be assigned to the subcritical transformation of $\beta$ bronze. At and below this temperature, $\beta$ bronze transforms to a typical martensite-like product, with relatively high hardness and a characteristic acicular microstructure. This temperature has been determined to be at about 400° C.

In this investigation a typical aluminium bronze with 10·63% aluminium has been used. The isothermal transformation of the $\beta$ phase has been studied microscopically and from hardness data at various constant temperatures from 350° C. to 560° C. The results confirm the general existing ideas on the subject.

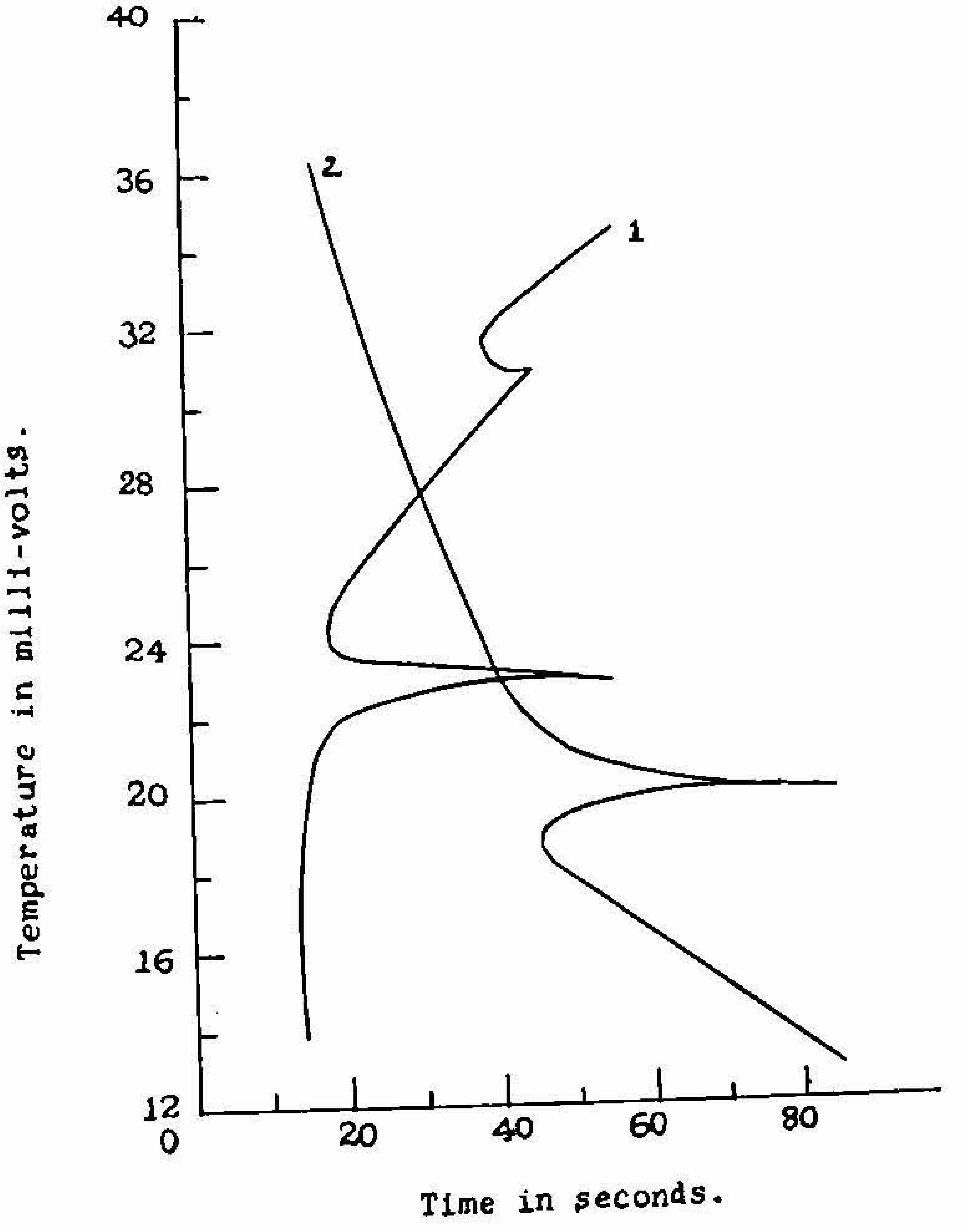
## EXPERIMENTAL

Electrolytic copper and commercially pure aluminium are used to prepare the alloy. Pure copper is first melted in a Battersea crucible, placed in a coke furnace constructed from refractory bricks and with provision for passing a continuous blast of air. The required amount of aluminium is added after copper has melted, using, as flux, borax. A cylindrical ingot, about eight inches long and one inch in diameter is sand-cast and an inch from the top and an inch from the bottom are cut off from the ingot so as to have a material which is reasonably certain to be free from segregation, pipe, etc. The ingot is then hot forged at between 600° C. and 650° C. to eliminate any segregation, blow-holes and other inhomogeneities which may have been present. The ingot is forged to a rod of about $\frac{3}{8}''$ diameter and annealed at 700° C. for six hours. A section is microscopically examined and a chemical analysis of the material carried out, before using the material for further study to ensure that the material is perfectly homogeneous and sound.

The temperature of the eutectoid transformation and of any others which might occur in the alloy, both during heating and during cooling are determined by the " inverse rate " method.

The material for study contained 88·53% copper and 10·63% aluminium and the inverse-rate curves, shown in Fig. 2, indicate that the eutectoid transformation occurred at 584° C. on heating and at 518° C. on cooling.

Specimens $\frac{1}{4}''$ long were used for the isothermal transformation studies. Prior to transformation at the various subcritical temperatures, the specimens were soaked at 900° C. for half an hour. The specimens were suspended in a tube furnace, constructed by winding suitably Kanthal 'D' wire of 20 S.W.G. over a silica tube, one foot in length and one inch internal diameter. The furnace was designed to permit continuous working at 900° C. and suitably lagged and fixed in a specially constructed stand in a vertical position. This facilitates easy and very rapid dropping of the specimens into a salt bath furnace, kept below the tube furnace (Fig. 3). The temperature distribution inside the tube furnace is first determined by moving the hot junction of a thermocouple to various positions inside it, that portion of the furnace at which a steady temperature of 900° C. prevails is marked off and care is taken to see that all the specimens are within this zone while being soaked prior to transformation.




1. Heating.

2. Cooling.

FIG. 2

The salt bath furnace is constructed by winding nichrome wire of 28 S.W.G. over an iron pot, the windings being separated from the iron pot by mica sheets. The pot with the windings is placed inside a small G.I. bucket and the space between the two packed with asbestos. A simmerstat control switch is incorporated as seen in Fig. 3 and this permits the regulation of the operating temperature of the bath at any desired temperature. A mixture of equal proportions of sodium nitrite and potassium nitrate is used as the operating range provided by this mixture is between about 250° C. to about 600° C.

Several specimens suspended from a retort stand (by nichrome wire), are lowered into that portion of the tube furnace where a temperature of 900° C. prevails. After soaking for half an hour, seven specimens are smartly

| Specimen No. | Isothermal transformation temperature | Time of holding at the transformation temperature before quenching in water | Vickers Hardness Number | Remarks |
|---|---|---|---|---|
| 4 | Cooled inside the furnace from the soaking temperature (900° C.) | | 142 | Well defined proeutectoid $\alpha$ regions and matrix of barely resolved eutectoid (Fig. 4). |
| 3 | 560° C. | 1 minute | 142 | The structure is similar to that of the annealed bronze, definitely showing that this temperature is near the eutectoid temperature and that the transformation is completed within 1 minute. The hardness is also the same as in the annealed sample (Fig. 5). |
| 7 | 520° C. | 10 seconds | 158 | Proeutectoid and eutectoid regions seen as before, pronounced Widmanstätten distribution of $\alpha$. The eutectoid unresolved (Fig. 6). Hardness increase indicates that transformation is partly incomplete after 10 seconds. |
| 13 | 470° C. | 30 minutes | 171 | Transformation of $\beta$ phase apparently over. The structure differs from that of annealed bronze. Hardness has also increased appreciably (Fig. 7). |
| 15 | 460° C. | 5 seconds | 205 | Relatively lesser amounts of free proeutectoid as compared to the others transformed at 560° C. and 520° C. (Fig. 8). |
| 33 | 425° C. | 30 seconds | 199 | Same as above, with however, finer distribution of constituents, due presumably to the lower transformation temperature. Transformation of $\beta$ appears to be completely over (Fig. 9). |
| 26 | 395° C. | 10 seconds | 209 | Structure similar to water quenched bronze structure. The temperature of transformation is accordingly concluded to be near the "Martensite" transformation temperature of $\beta$ bronze (Fig. 10). |
| 19 | 350° C. | 10 seconds | 225 | Structures practically same as the above one (Fig. 11). |
| 22 | Directly quenched in water from 900° C. | | 272 | Same as above (Fig. 12). |

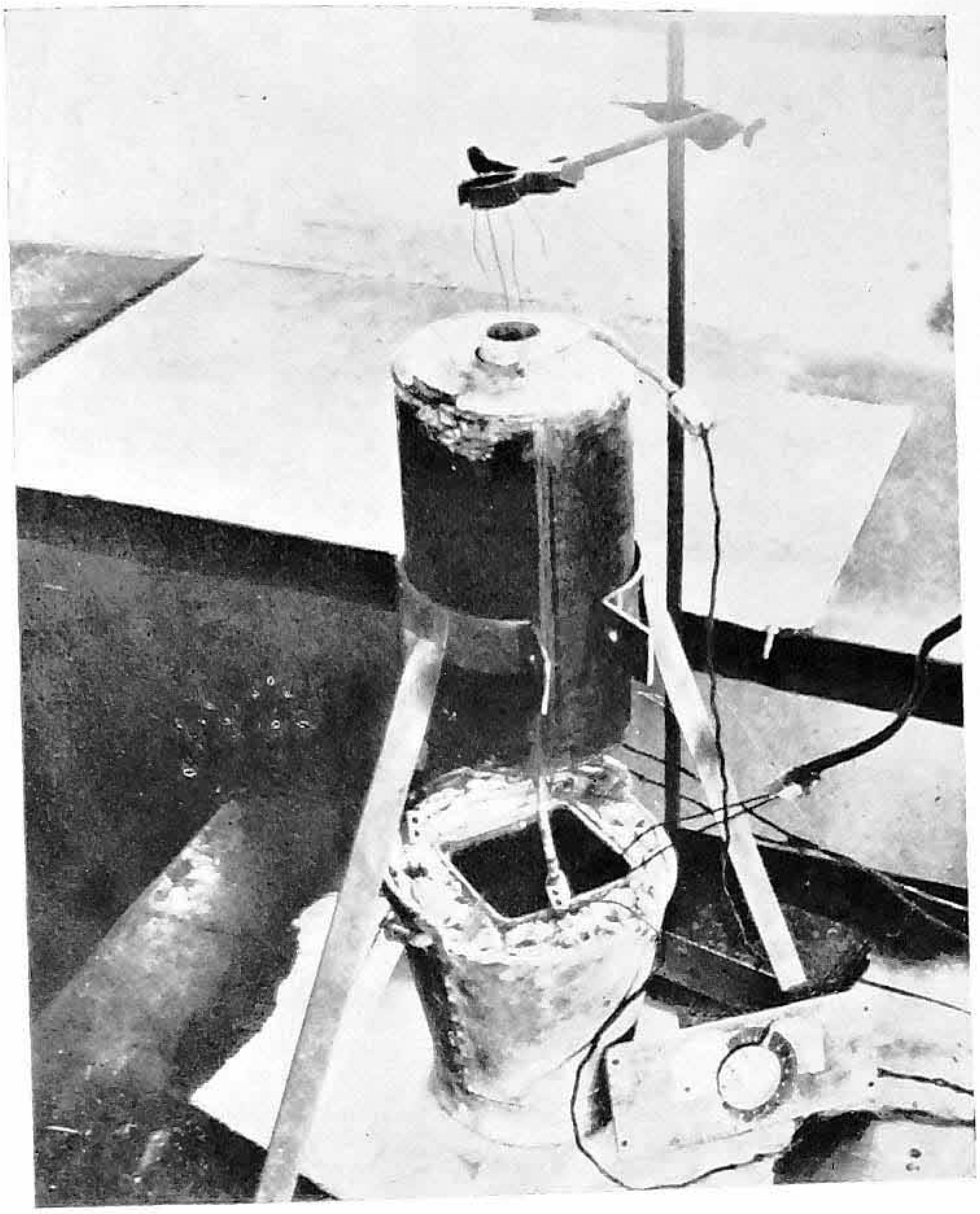


FIG. 3

FIG. 4

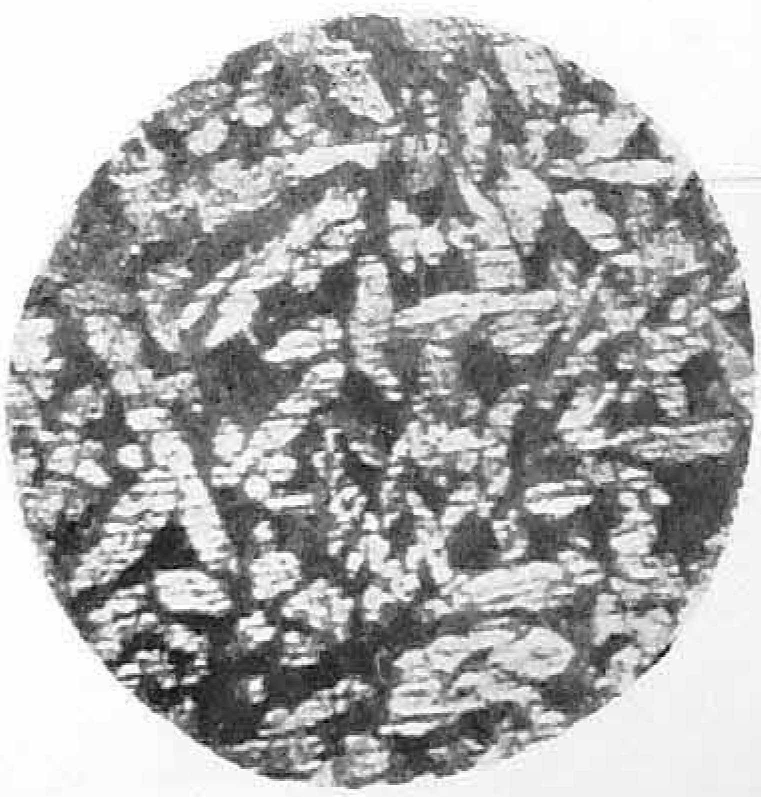


FIG. 5

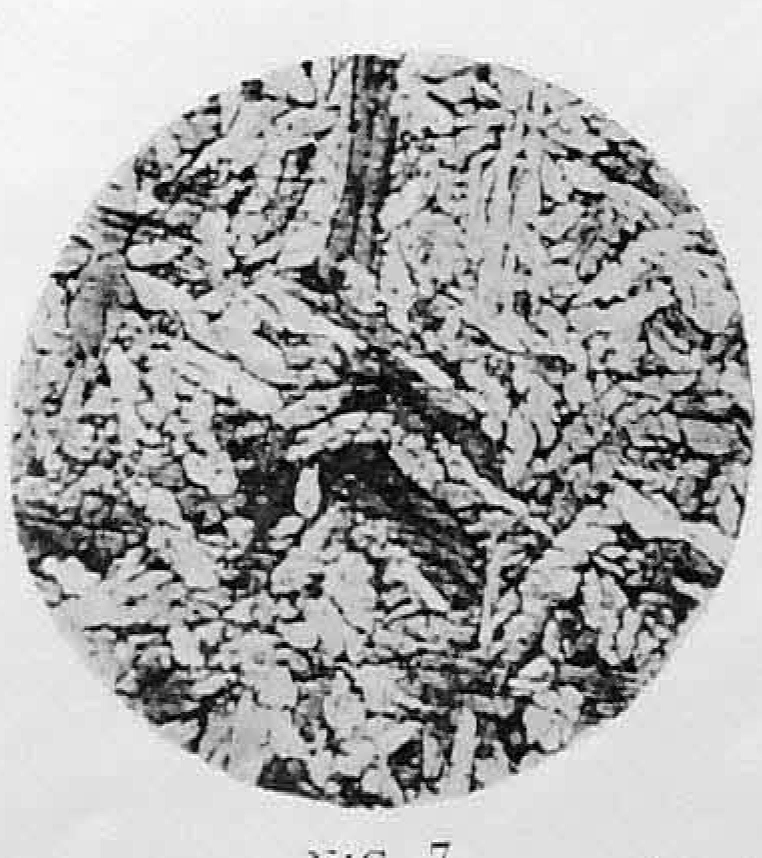


FIG. 7

FIG. 8

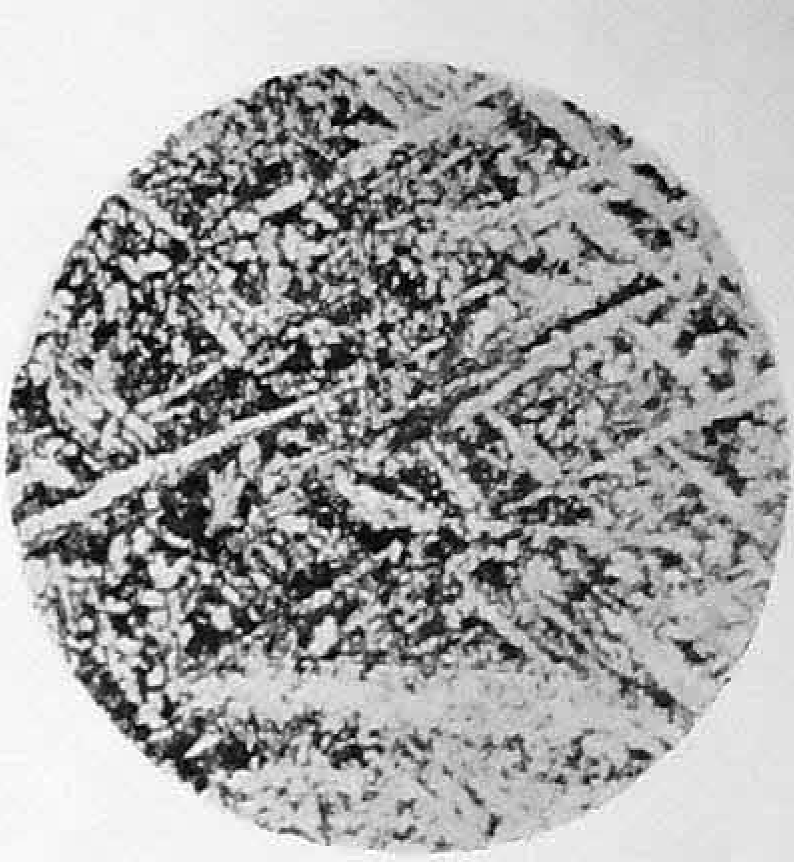


FIG. 9

FIG. 10

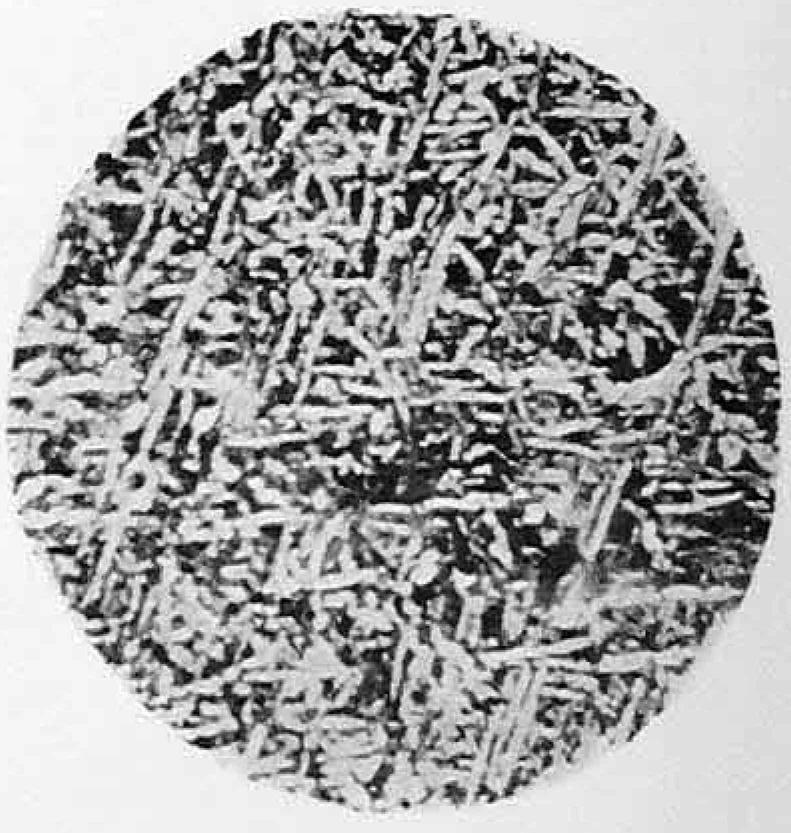


FIG. 11

FIG. 12

dropped into the salt bath furnace kept below and maintained at 560° C. and the times at which the specimens are immersed are noted. At the end of 3, 5, 10 and 30 seconds and 6, 15 and 30 minutes respectively (and some times, at the end of other suitable time intervals) the specimens are very quickly transferred to a vessel containing ice-cold water, to arrest the further transformation of the $\beta$ phase. One of the specimens is slowly cooled from 900° C. in the tube furnace itself while another is quenched from the soaking temperature direct in ice-cold water. The specimens, after the heat treatment, are rapidly polished and etched and their micro-structures examined (all at a magnification of $\times 250$) and their hardness determined on the Vickers Hardness Testing Machine. Similar procedures are carried out with other specimens, varying the temperature of isothermal transformation, *i.e.*, of the salt bath, to 520° C., 470° C., 425° C., 395° C. and 350° C.

The microstructure and hardness data are discussed below:

## Discussion

An examination of the microstructures of the specimens transformed at 560° C. and 520° C. and also of their hardness values indicates that the transformation at these temperatures is of the eutectoid type, yielding structures similar to that of the annealed material. This confirms the value of the temperature of eutectoid transformation, determined from thermal analysis (518° C.).

The microstructures and hardness data for the transformations at 460° C. and 425° C. indicate that the transformations commence after a finite interval, but proceed rather quickly, once started. This would appear to correspond to the region of the 'S' curve between the "knee" and the "nose" corresponding respectively to the solid solution and eutectoid transformations. The structures obtained at 395° C. and at 350° C. appear to indicate that the '$M_s$' temperature has been crossed.

It is thus seen that the $\beta$ bronze transforms to an acicular constituent similar to martensite at about 400° C. This conclusion is in conformity with the existing knowledge of the subject.

## Acknowledgement

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## References

1. *Transactions of the American Institute of Mining & Metallurgical Engineer*, 1933, 104. For abstracts of this paper see *Journal of the Institute of Metals*; 1933, 53.
2. *Metals Technology*, Sept. 1947.
3. *Annotated Equilibrium Diagram Series*, No. 4, Sept. 1944, Institute of Metals, London.