

STRUCTURES OBTAINED IN A CU 11.8 at% SN ALLOY
QUENCHED FROM THE MELT

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Introduction

As it is well known that liquid quenching often allows primary solid solutions to be extended to a higher solute content (1), two splat cooling methods were used with a Cu-11.8 at% Sn alloy in order to try to extend the α phase (FIG.1). This composition was chosen because it corresponds to an

electron concentration 1.35 which is below the limit 1.4, proposed by Hume-Rothery(2). However, none of the two techniques yielded the supersaturated α phase. On the contrary, a structure was obtained which is derived from the undersaturated β phase.

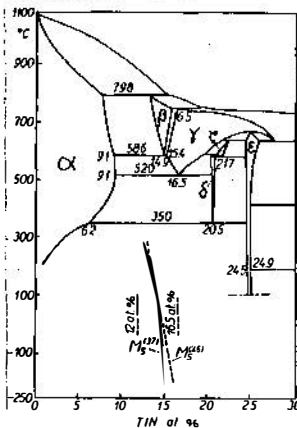


FIG. 1
Cu-Sn diagram

Results and Discussion

a. Gun method

At first a gun method, similar to that described in (3) was used. The structure of the splat-cooled alloy was examined by X-ray diffraction (FIG.2a). Apart from a uniform peak shift this pattern is identical to the diffractogram of β' martensite, obtained by quenching the equilibrium β phase to room temperature.

Therefore the phase giving rise to the observed pattern will be called β'_g . The indexing on figure 2a is done on the basis of the ABCBCACABAB stacking. Besides β'_g small quantities of the Cu-Sn α and β phases are present. If these small amounts are neglected the rest of the alloy (β'_g) must have the original composition of the liquid which is located in the two phase $\alpha + \beta$ region (FIG.1).

The fact that β'_g has the same structure as β' is already a strong evidence that it has also been formed martensitically from the β (bcc) phase. The appearance of the β phase (further called β_g to distinguish it from equilibrium β) at a

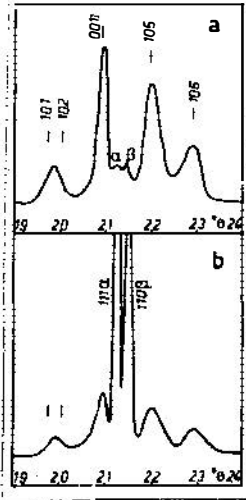


FIG. 2

- a. gun method
b. piston and anvil method

composition which is normally two phase can be understood if it is accepted that solidification occurs at high undercooling because of the high cooling rate. Figure 3 shows the hypothetical free energy vs. composition curves for a temperature below the peritectic point. It can be seen that for the composition 11.8 at% Sn diffusionless formation of β'_s is the process which most rapidly lowers the energy of the alloy. On further cooling the β'_s phase may transform martensitically in the same way as equilibrium β . The presence of small amounts of α and β is readily understood when considering the results obtained with the second cooling method.

b. Piston and anvil method

The technique used is the classical piston and anvil set up. Pressurized gas was used to simultaneously expel the metal from the furnace and move the piston.

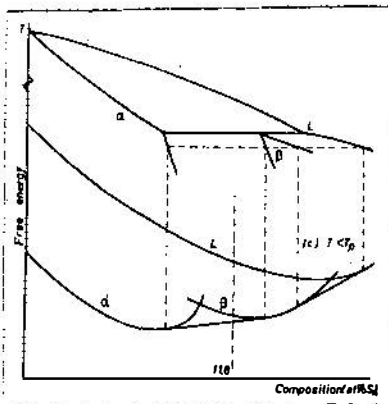


FIG. 3

Free energy curves

Figure 2b shows a diffractogram of a specimen. Now three phases are present in substantial amounts: α with about 11.8 at% Sn, β with about 16 at% Sn and β'_s with about 11.8 at% Sn. The latter composition follows from the coincidence of the peak positions with those of β' obtained with the gun method. The compositions of α and β were determined from lattice parameter measurements.

Fig.4 shows a metallographic section parallel to the plane of a disc. After electrolytic thinning the different phases could be identified by means of selected area diffraction in the electron microscope. It appeared that the den-



FIG. 4

Metallographic section parallel to surface of disc



FIG. 5

Electron micrograph of β'_s region

drites (α_D) and particles (α_P which elsewhere in the specimen are more differently different from α_D) consist of the α phase. The interdendritic phase is either martensite or β . The other regions consist of pure martensite which must be the β'_s phase. The β'_s regions are subdivided by a network of the α phase. Metallographic examination of the entire surface of the specimen showed that the β'_s domains are inhomogeneously distributed throughout the specimen



FIG. 6

α dendrites in β'_s matrix

FIG. 5 is an electron micrograph of a β'_s region. The lamellar morphology of β'_s is further evidence that it formed martensitically from another phase and did not solidify directly from the melt.

In order to explain the presence and distribution of the α and β phases in these discs it must be accepted that most of the solidification occurs under conditions of much less undercooling than with the gun method. The smaller undercooling is probably due to a greater amount of alloy being spread over a smaller cooling surface. Therefore solidification almost

8.4

occurs according to the equilibrium diagram and α dendrites will form first. However, due to the closing movement of the cooling plates, the dendrites break away and new ones are formed. This explains the absence of a preferred orientation of the dendrites. Solidification of α continues until the temperature becomes lower than the peritectic temperature. From then on the β phase starts forming. The mean composition of β proves that the peritectic reaction does not take place, probably because of the high cooling rate. The β phase formed at the highest temperature has a composition with M_{β} point above room temperature (FIG.1) and transforms to β' on further cooling. This explains the presence of martensite between the α dendrites. In order to account for the presence of β'_g it must be assumed that some parts of the liquid still have the original composition at the later stages of solidification. At that moment the layer between the cooling plates becomes thin and the cooling rate increases. Therefore the last parts of the liquid solidify diffusionless to β_g as with the gun method. The α network has probably precipitated along the β_g grain boundaries in the high temperature region before cooling to room temperature. It provides another piece of evidence for the assumption that it is the β_g phase that forms diffusionless from the melt. Indeed, if it were α that formed directly from the melt, one would expect β to precipitate.

The sequence of solidification described above (formation of α and β followed by undersaturated β , i.e. slow cooling followed by rapid cooling) is further supported by the fact that often α dendrites are observed in the β'_g regions (FIG.6). This is only possible if α is formed before β_g . These dendrites are probably brought there by turbulence in the liquid. The presence of the numerous small α particles which often occur in the martensite may also be explained by convection of α dendrites followed by dendritic remelting (4).

The α and β phases found in specimens obtained with the gun method are probably formed by one of the processes described above due to a locally slower quench.

Conclusions

Quenching with the gun method (fast quenching) of a Cu-11.8 at% Sn alloy results in an almost single phase structure. This consists of martensite which is formed from a bcc phase which solidifies diffusionless from the melt.

During quenching of the same alloy with the slower piston and anvil method the solidification occurs initially close to the equilibrium conditions by forming

α and β . Subsequently solidification occurs diffusionless and the same phases are formed as with the gun method.

References

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2. W. Hume-Rothery, G.V. Raynor, The structure of metals and alloys, The Institute of Metals, London, (1954).
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DISCUSSION :

- M. Païć : I think that your diagram showing the cooling of the globule between the plates represents a rather very rare case.
- W. Vandemeulen: The drawing is only intended to give a schematic view. (The drawing in question is not in the text)
- K. Löhberg : Could it be possible, that in the last case you have shown, that primarily β crystallized and that the melt was reheated by released heat of fusion. So, the equilibrium conditions may nearly be reached and crystallisation of dendritic α followed. That is the inverse explanation of that you have given, if I have understood you rightly.
- W. Vandemeulen: In that case the α dendrites, dendritic regions or particles (in text) must be surrounded by a grain boundary delineating the interface $\beta_2 \rightarrow \alpha + \beta$. This was never observed (Fig. 6). If such a boundary existed it must be visible in figure 6 for immediately adjacent to the dendrite indicated, the α network precipitated at the boundary of two β_2 (11.8 at% Sn) grains is visible. This would not be so if this zone belonged to the $\alpha + \beta$ region.
- H. Müller : It is possible that you had a relatively low cooling rate for central parts of the thin foil because there is no diffusionless transformation liquid solid for your α -phase. These diffusionless transformations we found in our experiments with Cu + 5 wt% Sn. This was confirmed by the work of Kamenenskaya et al.
- W. Vandermeulen: If it is accepted that the presence of dendrites and particles: (see text and discussion with prof. Löhberg) in β_2 regions is due to turbulence, the α -phase must have formed before β_2 (11.8 wt% Sn). As solidification is supposed to start at the regions with the lowest temperature (i.e. the parts in contact with cooling plates) α is thought to start forming there and not in the central parts. As to their rate of solidification, it must be relatively slow.