

Precipitation hardening in Cu 1.81 wt % Be 0.28 wt % Co

Part 1 Continuous precipitation

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The structure of the precipitation hardening alloy Cu 1.81 wt % Be 0.28 wt % Co has been studied as a function of ageing temperature and time, by transmission electron microscopy. The continuous precipitation sequence found is:

supersaturated solid solution \rightarrow G.P. zones \rightarrow γ' .

The G.P. zone is an ordered platelet precipitate, which is coherent on $\{100\}$ matrix planes and is nucleated in very high densities ($>10^{24} \text{ m}^{-3}$). The coherency stress fields, due to the misfit of the G.P. zone and matrix, overlap to produce a net matrix contrast along $\{110\} \langle 1\bar{1}0 \rangle$, and give the characteristic "tweed" structure, which can be described by the kinematical theory of diffraction. The semi-coherent γ' intermediate precipitate is nucleated by the G.P. zones and the transformation is characterized from the changes in the "arrowhead" structure produced in the electron diffraction patterns. No transformation of γ' to the γ equilibrium precipitate is found for the ageing times investigated.

1. Introduction

The ageing of precipitation hardening copper-beryllium alloys (with compositions in the range, Be 0.5 to 2.0 wt %, Co 0 to 0.3 wt %) have been investigated by several experimental techniques, which include X-ray diffraction [1-6], transmission electron microscopy [7-22], resistivity [23-25] and calorimetry [26, 27].

From these results the overall decomposition may be described by:

supersaturated solid solution \rightarrow G.P. zones
(or γ'') \rightarrow γ' \rightarrow γ .

However, various interpretations of the precipitation sequence and the precipitate structures have been proposed. Geisler *et al* [4] suggested the formation of an ordered γ'' precipitate (bc monoclinic $a = b = 0.254 \text{ nm}$, $c = 0.324 \text{ nm}$, $\beta = 85^\circ 25'$, coherent on $\{100\}$ matrix planes), followed by the γ' precipitate (bct $a = b = 0.279 \text{ nm}$, $c = 0.254 \text{ nm}$, coherent on $\{112\}$ matrix planes), with the orientation $(112)_\alpha // (120)_{\gamma'}$, $[1\bar{1}0]_\alpha // [001]_{\gamma'}$, and finally succeeded by the ordered equilibrium γ precipitate (bcc $a = 0.270 \text{ nm}$, B2 type) with an

orientation relationship $(111)_\alpha // (110)_\gamma$; $[1\bar{1}0]_\alpha // [001]_\gamma$.

In contrast, Armitage [10] proposed that the intermediate γ' precipitate is nucleated from G.P. zones (although the G.P. zones were assigned a precipitate structure and, hence, are similar to γ'') and has a B2 superlattice ($a = 0.270 \text{ nm}$) with a $\{112\}_\alpha$ habit plane. A similar structure, but with a $\{111\}_\alpha$ habit plane was attributed to the equilibrium γ precipitate. Yamamoto *et al* [21] and Shimizu *et al* [22] made a further distinction between G.P. zones, described as monolayer plates, and γ'' and suggested that γ'' is nucleated by the G.P. zones.

Gruhl and Wassermann [3] differentiated between ageing above and below 325°C . Below 325°C the ageing proceeds by means of G.P. zones and an ordered γ' precipitate (bct $a = 0.250 \text{ nm}$, $c = 0.354 \text{ nm}$, $c/a \sim \sqrt{2}$), whereas above 325°C no transition structure was detected and the equilibrium γ precipitate (B2 type, $a = 0.267 \text{ nm}$) is directly formed. A similar conclusion made by Wilkes and Jackson [19] is that below 320°C the intermediate precipitate γ' is nucleated by G.P. zones,

whereas above 320°C γ' is nucleated heterogeneously and a G.P. zone solvus exists at this temperature.

Support for the γ' structure proposed by Geisler *et al* [4] was obtained from the results of Yamamoto *et al* [21], while Shimizu *et al* [22] obtained a similar γ' structure to that advanced by Gruhl and Wasserman [3].

Most of this previous work was performed on the binary Cu 1.8 to 2.0 wt % Be alloy but it has been demonstrated [10, 24, 28, 29] that the addition of a small amount of cobalt ($\leq 0.3\%$) does not significantly modify the continuous precipitation sequence. Consequently, it provides an appropriate context for the present study, the overall objective of which was to investigate the precipitation process in Cu 1.81 wt % Be 0.28 wt % Co as a function of ageing time and temperature. In this paper, a determination of the structure and orientation of the precipitates formed during continuous precipitation is reported. The mode of discontinuous or grain-boundary precipitation, and the effect of cold work on the precipitation sequence, will be discussed in later publications.

2. Experimental procedure

The alloy investigated was a polycrystalline commercial copper-beryllium alloy (Telcon 250) which had a composition of 1.81 wt % beryllium, 0.28 wt % cobalt. (11.50 at. % Be 0.30 at. % Co).

A supersaturated solid solution was obtained by solution treating the sheet material (1.5 mm thick) for 1 h at 800°C, followed by a water quench. Precipitation was studied as a function of time at ageing temperatures of 175, 250, 315, 360, 400 and 425°C.

Thin foils were prepared for electron microscope examination by electropolishing. The alloy was first polished to a thickness of 0.5 mm by electrolytic jet machining with Struers D2 electrolyte. Discs, 3 mm in diameter, were subsequently spark machined from the thinned material with a Servomet and then electropolished in a PTFE holder (with stainless steel cathode) with Struers D2 electrolyte. The prepared foils were examined in a JEOL Jem 7 microscope operating at 100 kV, which incorporated a goniometer stage with a tilt of $\pm 10^\circ$.

3. Results

3.1. The supersaturated solid solution

A mottled structure was noted for certain foil orientations of the supersaturated solid solution

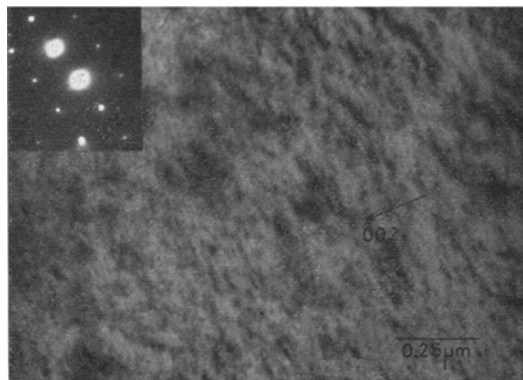


Figure 1 The mottled structure observed in some areas of the solution-treated material.

(Fig. 1) but vacancy loops and helical dislocations were not observed. No rellods were observed in the selected-area diffraction patterns.

No precipitation was observed at the grain boundaries, which indicated an efficient quench [28] and no ageing of the solution-treated material was noted for ageing times up to six months at room temperature or 10 h at 175°C.

3.2. The initial stages of ageing – G.P. zones and related striations

The first observable feature of the decomposition of the supersaturated solid solution was the appearance of regularly oriented markings in the grains, which will be referred to as striations, along the traces of $\{110\}$ planes. In the associated electron diffraction patterns, diffuse scattering effects in the form of rellods passing through the matrix reflections were present. These rellods were produced by the presence of small plate-like precipitates in the matrix, which are designated in this study as G.P. zones (as discussed later).

The striations were first observed after ageing for 12 h at 175°C, and became more distinct with further ageing. The striations and rellods were also found at ageing temperatures of 200, 250, 315, 360, 400 and 425°C, with the ageing time to form the striations decreasing with increasing temperature, e.g. striations were observed after ageing for 2 h at 200°C and after 5 min at 425°C.

Fig. 2a shows a typical striated microstructure after ageing for 20 h at 175°C, with a $g(\bar{2}20)$ active reflection. The striations lie along the $[1\bar{1}\bar{1}]$ and $[1\bar{1}1]$ directions, which are the traces of the $(01\bar{1})$, (101) planes and the (011) , $(10\bar{1})$ planes respectively. The striations com-

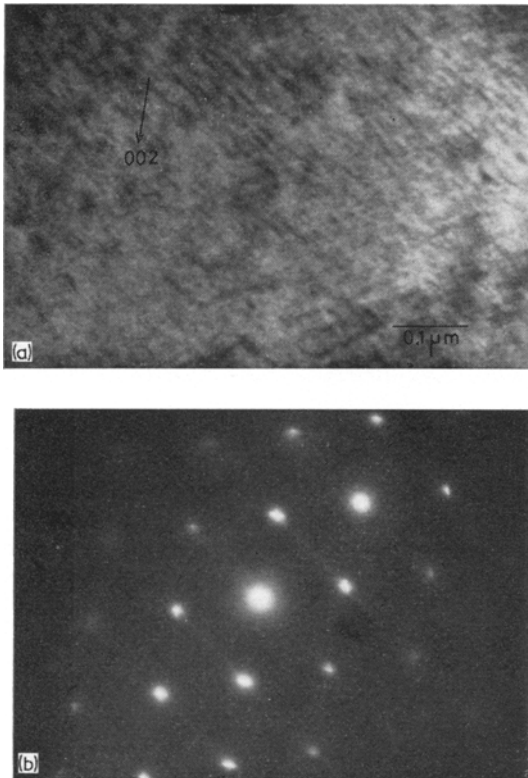


Figure 2 (a) The striations observed in the solution-treated material aged for 20 h at 175°C. $(110)_\alpha$ foil plane. (b) The selected-area diffraction pattern of (a) with $\langle 001 \rangle$ and $\langle 110 \rangle$ relrods present.

prise black-white contrast and have a width and separation of ~ 10 nm. In the associated electron diffraction pattern, Fig. 2b, two distinct types of relrods were present, namely long diffuse $[001]$ relrods which passed through the reciprocal lattice points and the transmitted beam, and shorter, more intense relrods in the $[1\bar{1}2]$ and $[\bar{1}12]$ directions, which were present at reciprocal lattice points, but not at the transmitted beam.

The $[001]$ relrods were symmetrical about the reciprocal lattice points and the transmitted beam. This type of scattering is characteristic of substitutional disorder [30], i.e. clusters of atoms with different scattering factors than those of the matrix were present. These relrods were produced by the presence of plate-like precipitates formed on (001) matrix planes. The relrod length was at least the reciprocal lattice distance from the origin to the (002) reflection and, therefore, the planar discontinuity, or G.P. zone, has a

width of the order of the lattice parameter. From the width of the relrod the diameter of the zone was estimated to be ~ 8.0 nm.

Following the procedure proposed by Hirsch *et al* [31] the direction made by relrods in a given reciprocal lattice plane was calculated. It was found that the short relrods in Fig. 2b, lying along the $[1\bar{1}2]$, $[\bar{1}12]$ directions, are the projection of the $[101]$, $[01\bar{1}]$ and $[011]$, $[10\bar{1}]$ relrods respectively, onto the (110) reciprocal lattice plane. These relrods were produced by the presence of planar discontinuities on $\{110\}$ matrix planes which were estimated to have a thickness of twenty $\{220\}$ atomic planes, i.e. 2.6 nm.

Fig. 3a and b are micrographs and selected area diffraction patterns taken of the same specimen as in Fig. 2 for different degrees of tilting of the goniometer stage, and analysis of these micrographs is summarized in Table I. In all cases, the striations were found to be along the traces of $\{110\}$ planes, with the type of

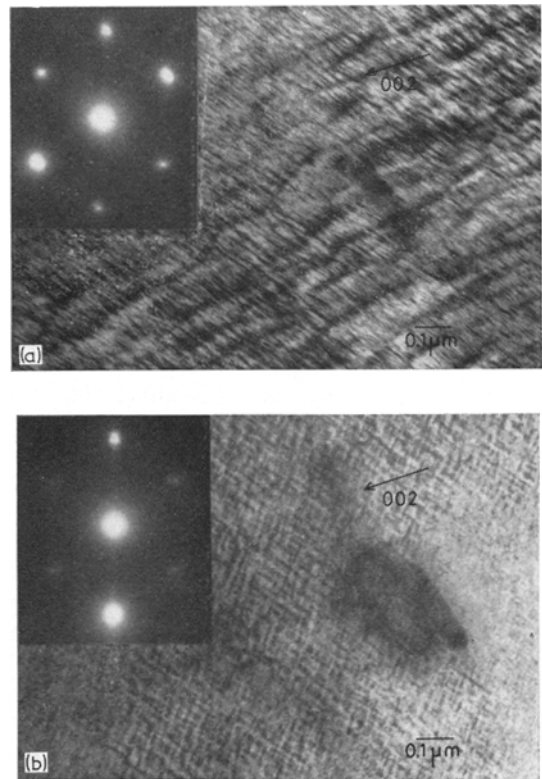


Figure 3 (a) and (b) The striations observed in the solution-treated condition aged for 20 h at 175°C.

TABLE I The phase factor $\alpha_{\langle 110 \rangle}$ for different foil planes and active reflections

Figure	Foil plane	Active reflection	Striations	Phase factor, α
2a	(110)	$g(\bar{2}20)$	Present along $[1\bar{1}\bar{1}]$, $[1\bar{1}1]$ directions, the traces of (101), (01 $\bar{1}$) and (10 $\bar{1}$), (011) planes respectively. Produced by G.P. zones on (001) planes, i.e. parallel to electron beam.	$\alpha_{[101]} = \alpha_{[011]} = \alpha_{[101]} =$ $\alpha_{[011]} = 2\pi\sqrt{2} \mathbf{R}_{[101]} $
3a	(110)	$g(1\bar{1}\bar{1})$	Present along $[1\bar{1}\bar{1}]$ directions, the trace of (101), (01 $\bar{1}$) planes. Produced by G.P. zones on (001) planes which also gives displacements on (10 $\bar{1}$), (011) planes.	$\alpha_{[101]} = \alpha_{[011]} = 2\pi\sqrt{2} \mathbf{R}_{[101]} $ $\alpha_{[101]} = \alpha_{[010]} = 0$
3b	(110)	$g(00\bar{2})$	Present along $[1\bar{1}\bar{1}]$, $[1\bar{1}1]$ directions, the traces of (101), (01 $\bar{1}$) and (10 $\bar{1}$), (011) planes respectively. Produced by G.P. zones on (001) planes.	$\alpha_{[101]} = \alpha_{[011]} = \alpha_{[101]} =$ $\alpha_{[011]} = 2\pi\sqrt{2} \mathbf{R}_{[101]} $
4a	(210)	$g(00\bar{2})$	Present along $[1\bar{2}\bar{2}]$, $[1\bar{2}2]$ directions, the trace of (01 $\bar{1}$) and (011) planes respectively.	$\alpha_{[011]} = \alpha_{[0\bar{1}1]} = 2\pi\sqrt{2} \mathbf{R}_{[011]} $

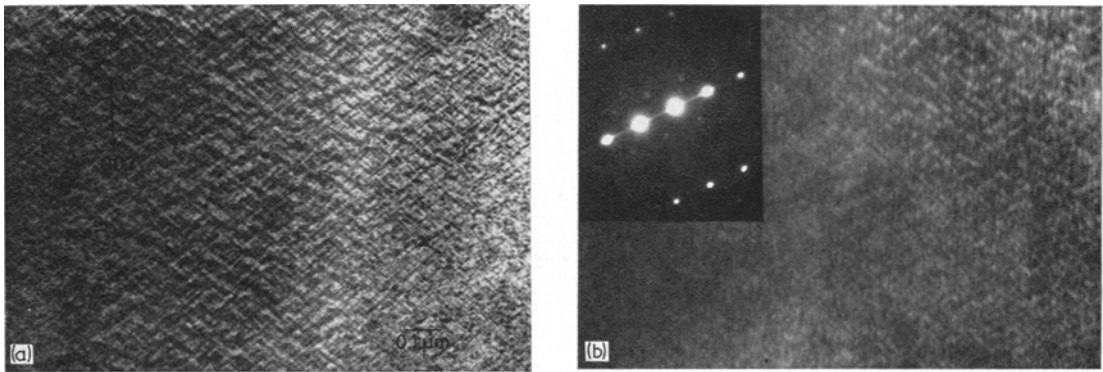


Figure 4 (a) The striations observed in the solution-treated condition aged for 20 h at 175°C. (210) foil plane. (b) The dark-field micrograph of the (002)_α reflection which reveals the striated microstructure.

contrast obtained depending on the active reflection.

The contrast obtained for a (210) foil surface, with a (002) active reflection, is shown in Fig. 4. The striations lie along the $[1\bar{2}\bar{2}]$ and $[1\bar{2}2]$ directions and are the traces of the (01 $\bar{1}$) and (011) planes respectively. A dark-field micrograph of the (002) reflection is shown in Fig. 4b in which the striations are revealed by a strain contrast mechanism, i.e G.P. zones on (001) planes produce strain contrast effects on $\{110\}$ planes at 45° to the plane of the zone.

A consistent feature of the areas examined was

the absence of dislocations, which indicated that any dislocation contrast effects were masked by the presence of the striations. Using the kinematical theory of diffraction, the phase factor, $\alpha = 2\pi \mathbf{g} \cdot \mathbf{R}$ has been calculated for the areas shown in Figs. 2 to 4 in terms of the displacement produced on $\{110\}$ planes in $\langle 1\bar{1}0 \rangle$ directions, $| \mathbf{R} \langle 1\bar{1}0 \rangle |$, by the coherency stress fields of the G.P. zones on $\{100\}$ planes. The results are tabulated in Table I, from which it can be seen that the kinematical theory adequately describes the observed contrast effects.

The striations revealed a net matrix contrast

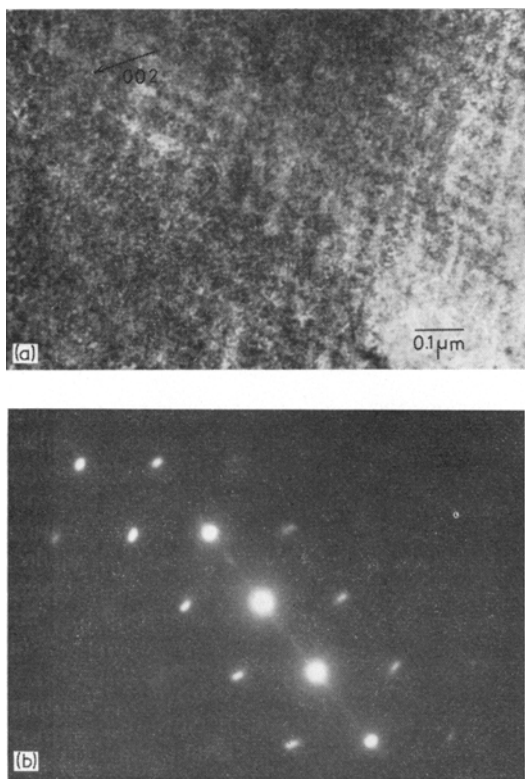


Figure 5 (a) The "tweed" structure observed in the solution-treated material aged for 30 min at 315°C. (b) The selected-area diffraction pattern of (a) with the presence of a diffuse maxima along the [001] relrod at position (004/3).

rather than the strain around an individual G.P. zone, due to the strain fields of adjacent zones overlapping. The estimation of zone density was difficult as no individual G.P. zones were imaged, but a value of $>10^{24} \text{ m}^{-3}$ was calculated assuming that ~ 1.0 at. % of the beryllium was in the form of zones, 8.0 nm in diameter and one atom thick.

As ageing proceeded the zones grew in size and the coherency strain fields increased. Eventually a stage was reached when it was energetically favourable for the zone to lose coherency and transform to the semi-coherent intermediate precipitate γ' .

3.3. The intermediate γ' precipitate

On further ageing, the striations became more diffuse. The progressive disintegration of the striations was accompanied by the formation of a second type of plate-like precipitate which was identified as the intermediate γ' precipitate.

A diffuse "tweed-like" structure was observed

after ageing for 30 min at 315°C, as shown in Fig. 5a with the diffuse striations lying along the $[\bar{1}\bar{1}\bar{1}]$ and $[1\bar{1}\bar{1}]$ directions, which are the traces of the $(10\bar{1})$, (011) and $(01\bar{1})$, (101) planes respectively. In the corresponding selected-area diffraction pattern, Fig. 5b, $\langle 001 \rangle$ relrods indicated the presence of G.P. zones on $\{001\}$ planes. In addition an important feature of the relrods was an intensity maximum which was present along the relrod and extended from d -spacings corresponding to $d = 0.362 \text{ nm}$ to $d = 0.270 \text{ nm}$. No $\langle 110 \rangle$ relrods were observed due to the breakdown in the coherency of the G.P. zones and the subsequent formation of the semi-coherent precipitate γ' .

Plate-like precipitates were observed after ageing for 3 h at 315°C, as shown in Fig. 6a. The original striations were still visible, but with the small plate-like precipitates, $\sim 10 \text{ nm}$ in diameter interspersed between them. In the selected area diffraction pattern, Fig. 6b, the appearance of a curved reflection corresponding

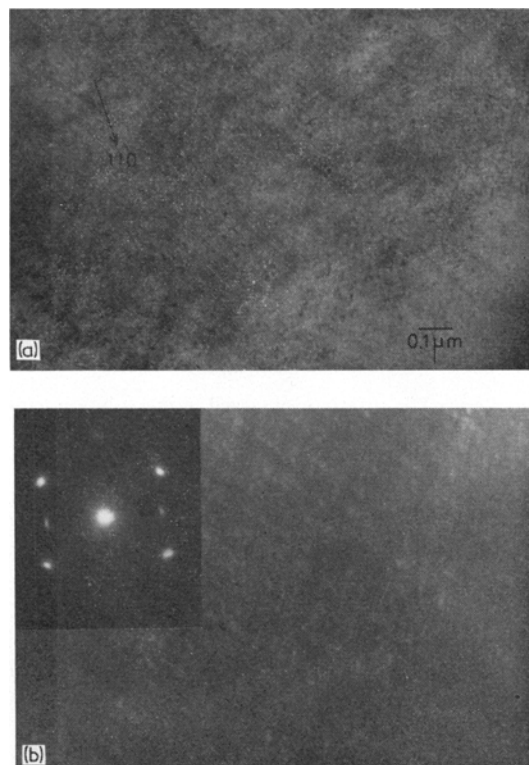


Figure 6 (a) The solution-treated material aged for 3 h at 315°C. (b) The dark-field micrograph of the $(010)_{\gamma}$ reflection which reveals the presence of the "tweed" structure.

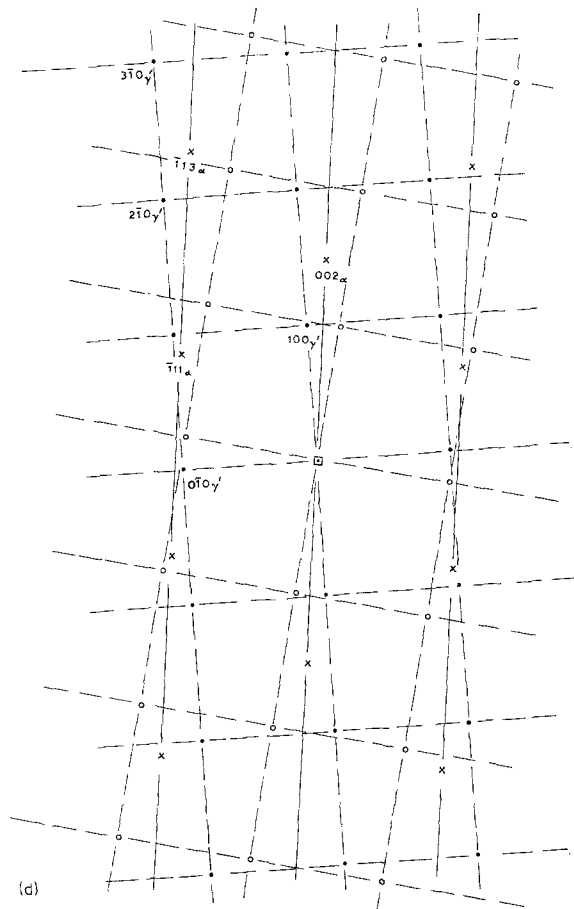
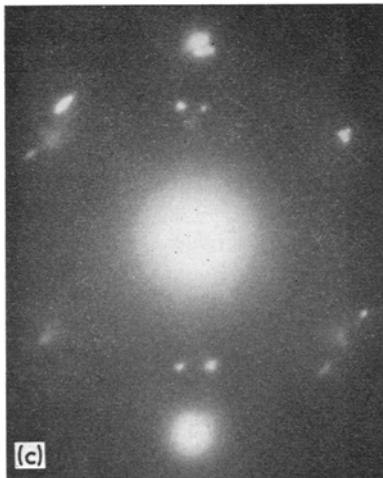
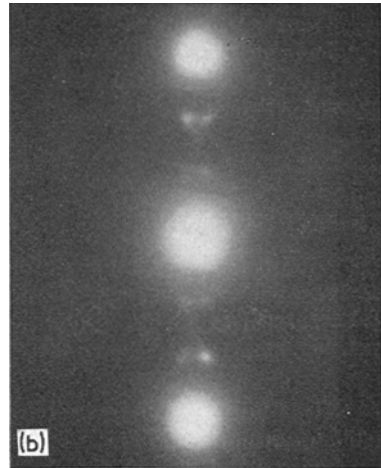
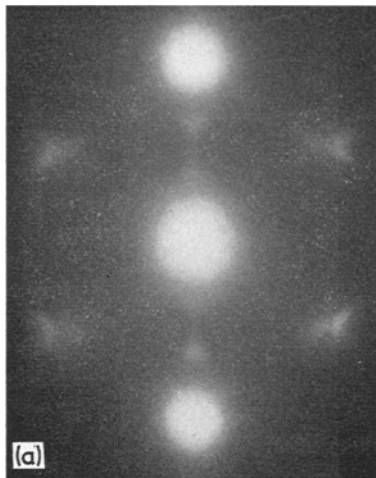


Figure 7 The change in the selected-area diffraction pattern of a $[110]_{\alpha}$ zone as a function of ageing time at 315°C , for the solution-treated material. The diffraction patterns represent ageing for (a) 8 h at 315°C , (b) 24 h at 315°C , (c) 168 h at 315°C ; (d) is a diagrammatic representation of (c). \times $[110]_{\alpha}$ zone, \bullet $[001]_{\gamma'}$ zone, \circ $[001]_{\gamma'}$ zone.

to a d -spacing of 0.270 nm was noted and attributed to the γ' precipitate. A dark-field

micrograph of this reflection is shown in Fig. 6b which reveals the traces of $\{110\}_{\alpha}$ planes.

The formation of the intermediate precipitate γ' can be studied by means of the selected-area diffraction patterns and the change in the diffraction pattern as ageing proceeds at 315°C is shown in Fig. 7 for a $[110]_{\alpha}$ zone.

The diffuse maximum of Fig. 5a was found to transform into a diffuse "arrowhead" which pointed towards the origin, with its "tip" at the position of the $(001)_{\alpha}$ reflection and its "base" at $(004/3)_{\alpha}$ i.e. corresponding to a d -spacing of 0.270 nm, as shown in Fig. 7a. The diffuse "arrowhead" at the $(002/3)_{\alpha}$ position was interpreted as being produced by double diffraction of the $(002)_{\alpha}$ beam.

The "arrowhead" was formed by the diffuse scattering of the γ' precipitates which had a wide range of orientations, indicating a change in the habit plane from that of the G.P. zone. The "tip" of the "arrowhead" corresponded to the forbidden $(001)_{\alpha}$ reflection and the diffuse reldrod along $[001]_{\alpha}$ represented the initial transformation from a G.P. zone to γ' . The "arrowhead" had its sides bounded by reldrods along the $[\bar{1}13]_{\alpha}$ and $[1\bar{1}3]_{\alpha}$ directions, which were the projection of the $[\bar{1}13]_{\alpha}$, $[1\bar{1}\bar{3}]_{\alpha}$ and $[1\bar{1}3]_{\alpha}$, $[\bar{1}\bar{1}\bar{3}]_{\alpha}$ reldrods respectively. Hence, the "arrowhead" may be considered as produced by γ' precipitates with a range of habit planes from $\{001\}_{\alpha}$ to $\{113\}_{\alpha}$.

For longer ageing times, the diffuse interior of the "arrowhead" disappeared leaving two discrete reldrods about the $d = 0.270$ nm reflection, in the $[\bar{1}13]_{\alpha}$ and $[1\bar{1}3]_{\alpha}$ directions, as shown in Fig. 7b. No $[001]_{\alpha}$ reldrods were present, which suggested that the transformation to γ' was complete, that γ' had a $\{113\}_{\alpha}$ habit plane and that the reldrods were produced by small γ' precipitates along these planes. On further ageing, two discrete diffraction spots were formed at $d = 0.270$ nm, as shown in Fig. 7c, which indicates that two variants of the γ' orientation were present.

Fig. 8 shows the change in the diffraction pattern as a function of ageing time at 315°C, for a $[1\bar{1}0]_{\alpha}$ zone. A curved reflection corresponding to a d -spacing of 0.270 nm, was present about the $[220]_{\alpha}$ direction and was attributed to a range of γ' orientations. In many cases, a double diffracted image was found adjacent to this reflection, as shown in Fig. 8b and c.

From an analysis of the diffraction patterns, a cubic structure was determined for γ' with $a = 0.270$ nm and a B2 superlattice structure, with copper atoms at the corners of the cubic

unit cell and a beryllium atom at its centre. The orientation of γ' was found to be:

$$(\bar{1}13)_{\alpha} // (130)_{\gamma'}; [110]_{\alpha} // [001]_{\gamma'}$$

This relationship can be seen by an inspection of the electron diffraction patterns. Fig. 7d is a diagrammatic representation of the $[110]_{\alpha}$ zone of Fig. 7. Two $[001]_{\gamma'}$ zones are found to be present, with an angle between the $[002]_{\alpha}$ direction and the two $[010]_{\gamma'}$ directions of $6.5^{\circ} \pm 0.5^{\circ}$.

Ageing for 24 h at 315°C produced a further decomposition of the striations and the growth of γ' to ~ 40 nm in diameter, as shown in Fig. 9. The striations were along the traces of $\{110\}$ matrix planes and an analysis of the habit plane of γ' revealed it to be close to $\{113\}$. Evidence to support this conclusion was provided by the projection of $\langle 113 \rangle$ reldrods onto the foil plane, as in Fig. 7b.

After ageing for 100 h at 315°C, as shown in Fig. 10 the striations had disappeared and the γ' precipitate, with a $\{113\}$ habit plane had increased in size (~ 100 nm diameter).

For a specimen aged 285 h at 315°C, the γ' precipitates along two different $\{113\}$ matrix planes were distinguished (Fig. 11a and b) by dark-field micrographs of the two variants of the $(010)_{\gamma'}$ reflection.

The orientation relationship and structure for γ' noted after ageing at 315°C was also found after ageing at 360, 400 and 425°C.

4. Discussion

The continuous precipitation sequence found in the present study for Cu 1.81 wt % Be 0.28 wt % Co, aged between 175 and 425°C is: supersaturated solid solution \rightarrow G.P. zones $\rightarrow \gamma'$. The concept of a G.P. zone in the present investigation is that of a metastable coherent precipitate, which is the first stage of the continuous precipitation sequence. As a result, such a G.P. zone can be assigned a unit cell and identified from its associated diffuse electron diffraction effects. Alternatively, this precipitate could be considered as the γ'' precipitate, following the notation of Geisler *et al* [4]. This interpretation is not the same as that of Guinier [30] who stated that in the initial stages of ageing no real precipitate was formed, but instead small heterogeneities of the solid solution, called zones, were formed which were coherent with the matrix and did not have a characteristic

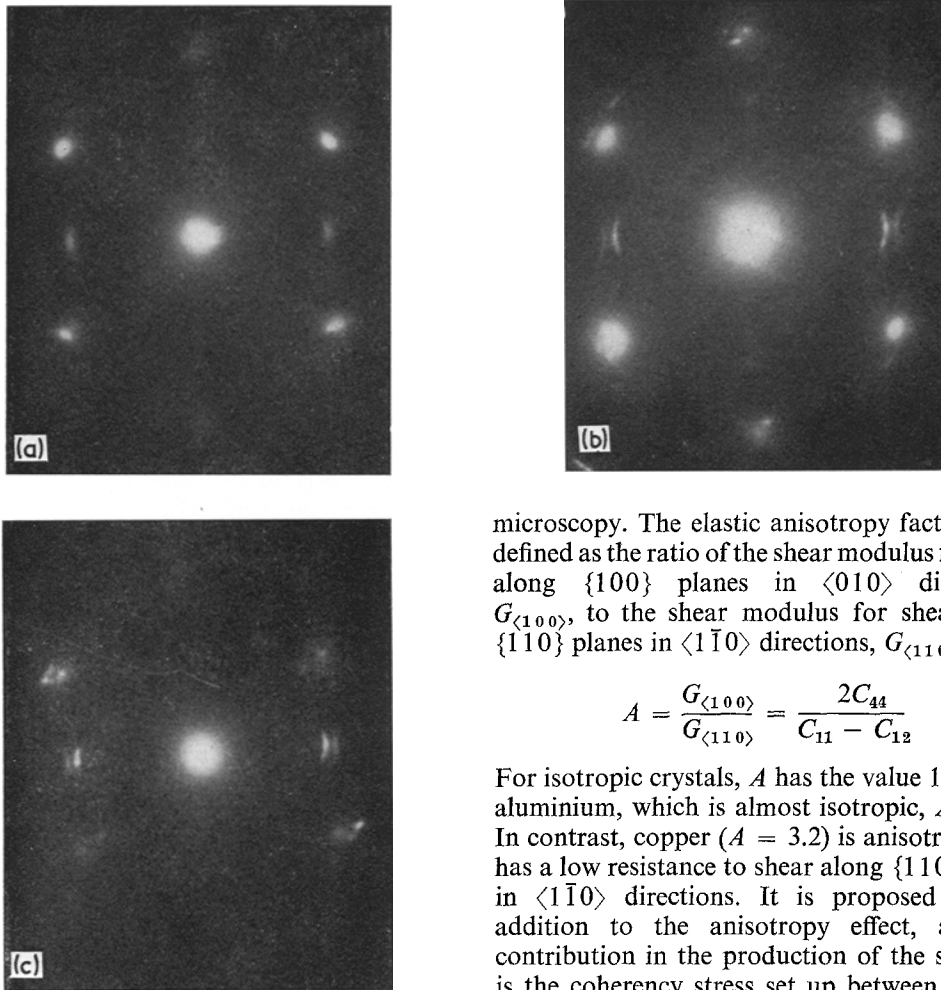


Figure 8 The change in the selected area diffraction pattern of a $[110]_{\alpha}$ zone, as a function of ageing time for the solution-treated material aged for (a) 3 h at 315°C , (b) 168 h at 315°C , (c) 285 h at 315°C .

crystalline lattice. In the present investigation, Guinier's concept of "zones" may be identified with the beryllium-vacancy clusters which form during the quench.

The results of Table I indicate that the striations associated with the G.P. zones result from a strain contrast effect and that the phase contrast can be adequately described by the kinematical theory. Tyapkin [6] proposed that the $\langle 110 \rangle$ refores, noted in X-ray studies of the early stages of ageing, resulted from the anisotropy of the copper lattice. Tanner [14] and Sorokin [15] applied the same argument to the diffuse scattering and striations observed with electron

microscopy. The elastic anisotropy factor, A , is defined as the ratio of the shear modulus for shear along $\{100\}$ planes in $\langle 010 \rangle$ directions, $G_{\langle 100 \rangle}$, to the shear modulus for shear along $\{110\}$ planes in $\langle 1\bar{1}0 \rangle$ directions, $G_{\langle 110 \rangle}$, i.e.

$$A = \frac{G_{\langle 100 \rangle}}{G_{\langle 110 \rangle}} = \frac{2C_{44}}{C_{11} - C_{12}}$$

For isotropic crystals, A has the value 1, and for aluminium, which is almost isotropic, $A = 1.2$. In contrast, copper ($A = 3.2$) is anisotropic and has a low resistance to shear along $\{110\}$ planes in $\langle 1\bar{1}0 \rangle$ directions. It is proposed that in addition to the anisotropy effect, a major contribution to the production of the striations is the coherency stress set up between the unit cells of the G.P. zone and that of the copper lattice. A proposed model for the unit cell of the

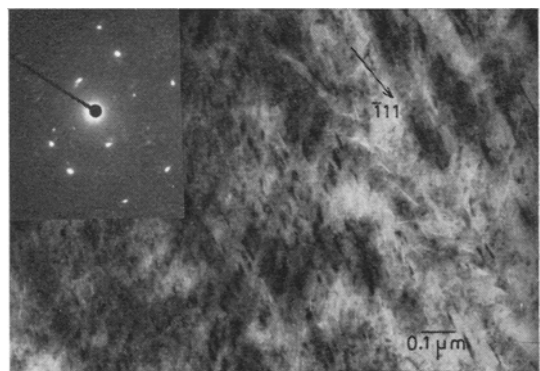


Figure 9 The solution-treated material aged for 24 h at 315°C , with the presence of striations along the traces of $(110)_{\alpha}$ planes and the intermediate precipitate γ' .



Figure 10 The solution-treated condition aged for 100 h at 315°C, with the intermediate precipitate γ' present. (The large regular particles are a Cu-Be-Co compound [18].)

G.P. zone, which is consistent with the transformation to γ' noted in this study, is shown in Fig. 12. The suggested cell has a L1₀ superlattice structure with $a = 0.253$ nm, $c = 0.322$ nm and an orientation $(\bar{1}11)_\alpha // (110)_{G.P.}$; $[110]_\alpha // [001]_{G.P.}$. Hence the coherency stress fields of these zones result in deformation of the matrix along $\{110\} \langle 1\bar{1}0 \rangle$ and produce the characteristic tweed structure. The proposed orientation relationship could also explain the abutting of the G.P. zones reported recently by Phillips and Tanner [20], as the stress field surrounding one zone produces co-operative interaction of adjacent zones to minimize the compressive and tensile stresses imposed on the matrix.

The intermediate precipitate γ' is nucleated

by G.P. zones on $\{100\}_\alpha$ planes. As the γ' precipitate grows, a rotation of the habit plane to $\{113\}_\alpha$ occurs, which produces the arrowhead structure in the electron diffraction patterns. An approximate orientation relationship for γ' is found to be: $(1\bar{1}3)_\alpha // (130)_{\gamma'}$; $[110]_\alpha // [001]_{\gamma'}$, as shown in Fig. 12, which disagrees with the previously proposed orientation relationships [3, 4, 10]. A B2 superlattice structure is determined for γ' with $a = 0.270$ nm, which is in agreement with the results of Armitage [10].

The transformation to the equilibrium precipitate γ was not observed during the continuous precipitation range of temperature and time covered in the present investigation. However, a transformation of $\gamma' \rightarrow \gamma$ is feasible, requiring only a change in the habit plane, and is discussed in a later paper [32].

5. Conclusions

1. The continuous precipitation sequence for Cu 1.81 wt % Be 0.28 wt % Co is: supersaturated solid solution \rightarrow G.P. zones $\rightarrow \gamma'$.
2. G.P. zones are ordered platelet precipitates which are coherent on $\{100\}$ planes. The coherency stress fields set up due to the misfit of the zones and matrix produce displacements along $\{110\} \langle 1\bar{1}0 \rangle$, resulting in the characteristic "tweed" structure. The zones are nucleated in very high densities $>10^{24} \text{ m}^{-3}$, with the stress fields of the zones overlapping, producing a net matrix contrast which can be described using the kinematical theory of diffraction.
3. The intermediate precipitate γ' is nucleated by the G.P. zones. The transformation can be

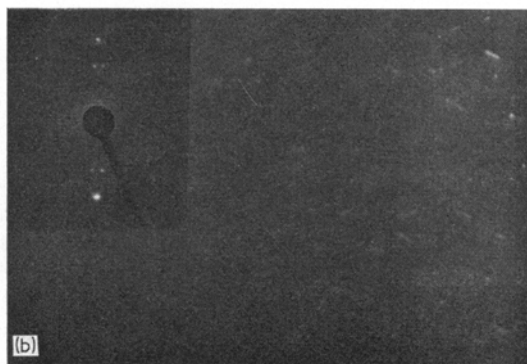
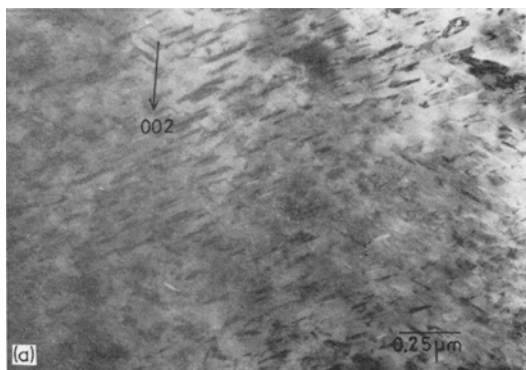


Figure 11 (a) The solution-treated material aged for 285 h at 315°C, with the intermediate precipitate γ' present. (210) foil plane. (b) The dark-field micrograph of the two variants of the $(100)_{\gamma'}$ reflections, revealing two different orientations of γ' .

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