ON SLIP BANDS OBTAINED BY TENSION ON ALUMINIUM SPECIMENS

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IN RECENT studies[1, 2] we have been able to reveal the fine structure of slip bands; we could also, on the other hand, determine the influence of deformation bands and adjacent crystals on their structure.

In the present paper our aim is to define the mutual relations existing between micro-hardness and slip bands. We are also examining the influence exerted by dimensions of the specimen and state of initial perfection on the development of these slip bands during plastic deformation.

To avoid any ambiguity, we are explaining below what we mean by the following phrases :

"Kink band": unbent zone consisting of two kink bands in opposite ends.

"Kink band in knee": zone of great curvature separating two unbent zones.

"Deformation band": kink band, kink band in knee, secondary slip band.

"Slip line": intersection of the surface of the specimen and only one slip plane.

"Slip band": grouping of parallel slip lines.

I. Specimens studied

We have in general used flat tensile specimens of Chevenard type. They were cut out from commercial variety of annealed aluminium of 1 mm thickness and 99·983% purity, major impurities being silicon 0·007% and iron 0·005%.

In order to avoid any anomaly in shape these specimens were subjected to an initial elongation of 9% followed by an annealing for 2 hours at 600°C to obtain grain uniformity. 30 per cent of the specimens subjected to a second elongation of 13% followed by annealing for 72 hours at 600°C, were monocrystalline between the shackles. Gripped portions remained polycrystalline with fairly large grains. Our experiments were related to such a selection of mono and polycrystalline specimens.

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[Paper translated from French by Mr. J. E. Mannar, Junior Scientific Officer, National Metallurgical Laboratory, Jamshedpur.]

We have also used single crystals of the same aluminium obtained by the method of critical elongation, having considerably larger dimensions: 6 to 7 cm length, 3 mm width and 1 mm thickness.

II. Role of initial micro-hardness in the formation of slip bands

Of the several specimens studied we are considering here the one illustrated in Fig. 1. In this specimen we need only examine the group of 3 crystals formed at the centre. The region which is of interest to us is shown in Fig. 2.

We have numbered each of the three crystals as shown in Fig. 3.

Microhardness measurements determined at the centres of crystals 1–2–3 are inversely proportional to 39, 37, 35 respectively.

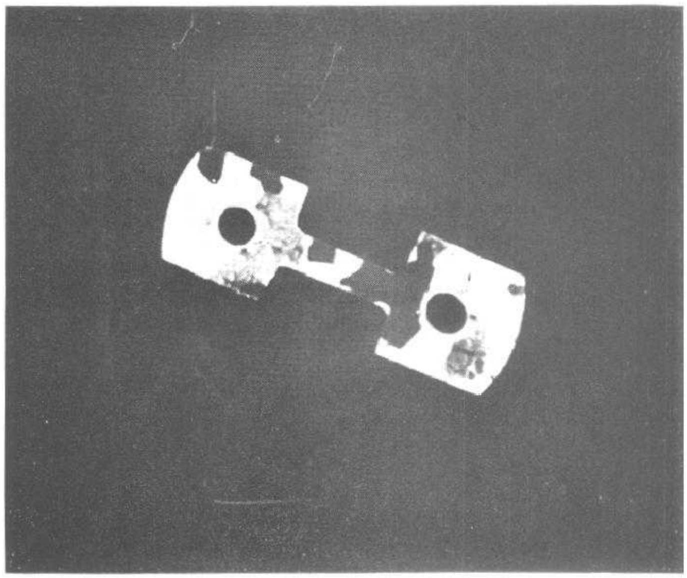

Fig. 1. ×1

Chevenard specimen having at its center the group of three crystals studied.

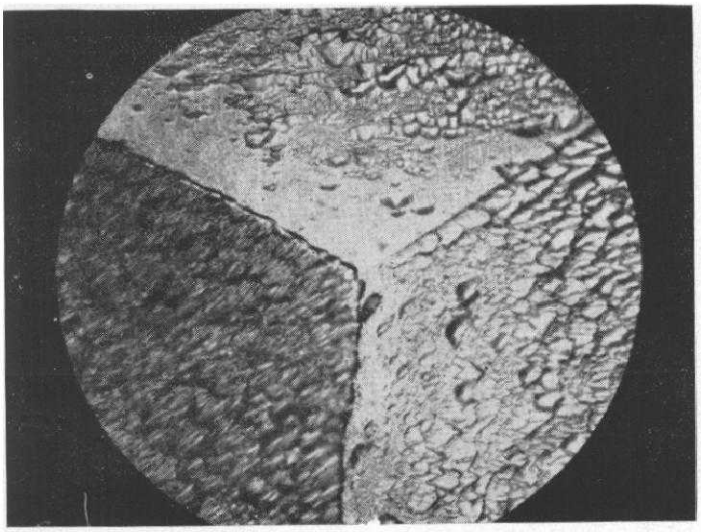

Fig. 2. ×200
Portion subjected to tests.

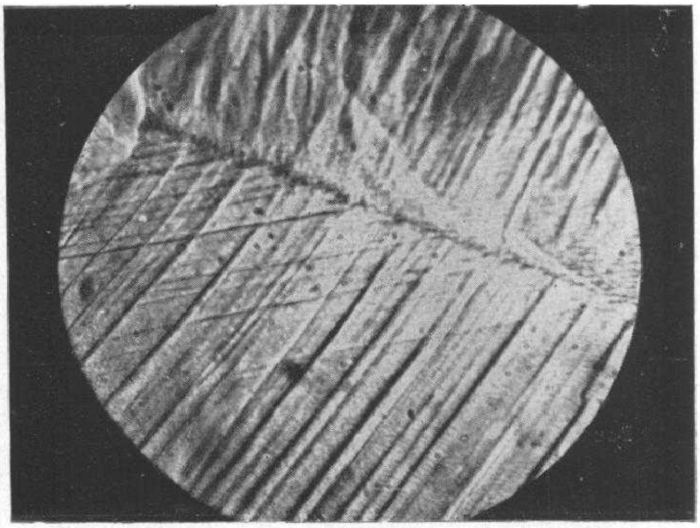

Fig. 4. ×500
Double slip system in the soft crystals adjacent to a harder crystal.

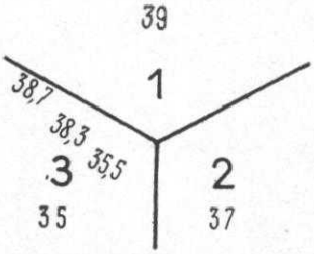

Fig. 3.
Diagram of the study of initial micro-hardness.

Besides, we have also studied the micro-hardness of crystal 3 by carrying out several measurements from the boundary 1–3. Micro-hardness was found to be lower in the neighbourhood of the boundary (it was successively inversely proportional to 38·7, 38·3 and 35·5).

The hardness value of a crystal harder than an adjacent one, therefore, decreases near the boundary.

The consequences of the above observations on the evolution of slip bands formed during plastic deformation by tension are as follows :

We observe a supplementary system of slip bands in grain 1, but only in the boundary region between grain 1 and grain 3 (Fig. 4).

From these observations we conclude that when a crystal is oriented such that its micro-hardness is greater than that of an adjacent grain it can bring about a second system of slip in the latter and in its neighbourhood.

III. Role of slip bands in the evolution of micro-hardness

1. *The micro-hardness of a zone increases with the density of junctions of its slip bands:* We have examined at its centre and near the boundary evolution of slip bands of a crystal after each of the following three elongations : 3%–12%–30%.

(*a*) After the first elongation we have observed only one system of slip near the boundary (Fig. 5—crystal at the right). It is also observed at the centre (Fig. 6). But in addition to this a second system of slip also appears in this figure.

(*b*) Whereas both the slip systems develop intensely at the centre (Figs. 8 and 10) after the second and third elongations, only the second system is developed near the boundary (Figs. 7 and 9).

We have measured the micro-hardness in both these regions at the initial state and after each elongation. Each time, a series of indentations were made on a horizontal line. Thus, on Figs. 5 and 6 the bottom line corresponds to the initial micro-hardness ; the second line from bottom corresponds to micro-hardness after the first elongation. On Figs. 7 and 8 the bottom two lines are those already seen in Figs. 5 and 6, and the third line from the bottom corresponds to the micro-hardness after the second elongation and so on. We thus observe in Figs. 6, 8 and 10 that micro-hardness clearly increases. The horizontal diagonals of the indentations decrease even after the first elongation. Hardness then slowly increases with the later elongations.

Summarizing the above facts it can be said that in the particular case considered, the boundary has prevented the development of one of the two systems which developed at the centre of the crystal. Near the boundary, the metal, therefore, remains softer after deformation.

Hardness of a given crystalline region, therefore, increases with the density of intersections of the slip bands. It is clear, in fact, that the defects accumulated during slips hinder subsequent slips and hardening is still greater when the slip bands cross each other.

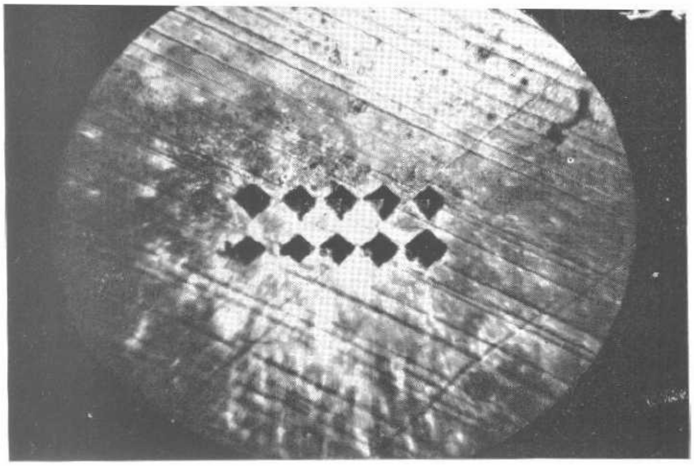

Fig. 5. ×200
Boundary region of a crystal after an elongation of 3%.

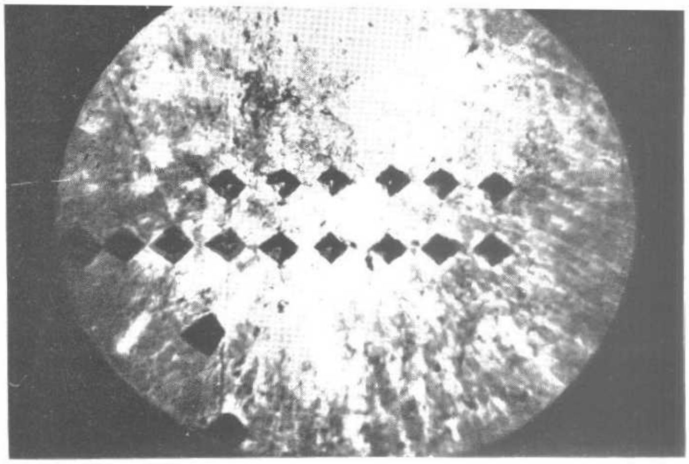

Fig. 6. ×200
Central region after an elongation of 3%.

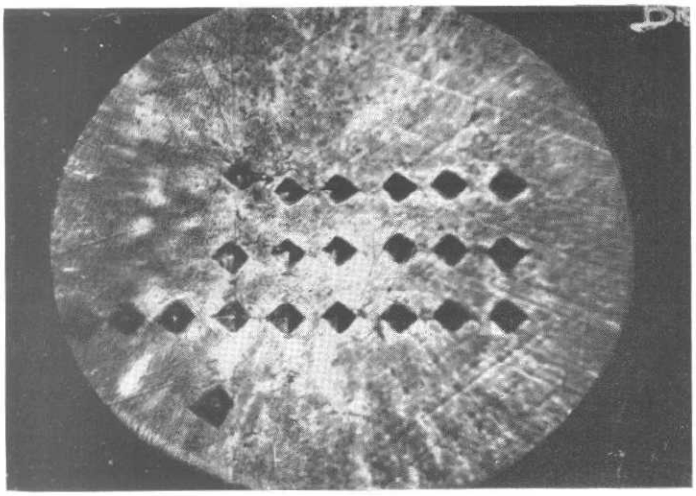

Fig. 7. ×200
Boundary region after an elongation of 12%.

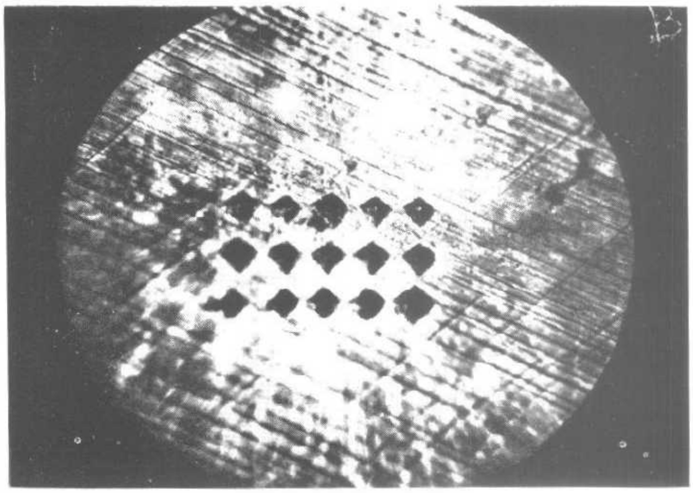

Fig. 8. ×200
Central region after an elongation of 12%.

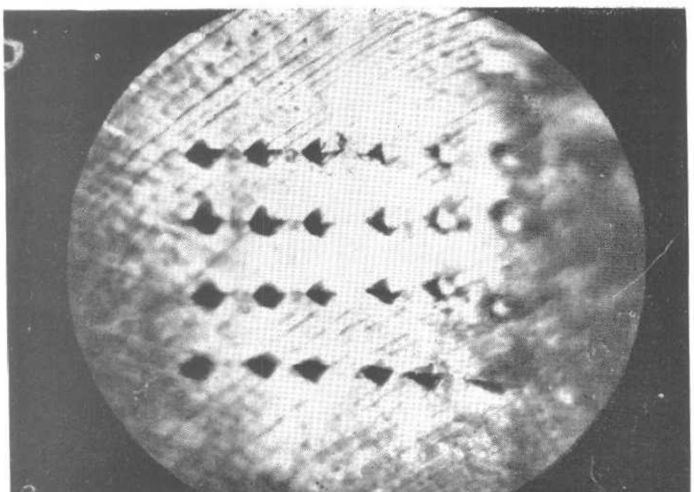

Fig. 9. ×200
Boundary region after an elongation 30%.

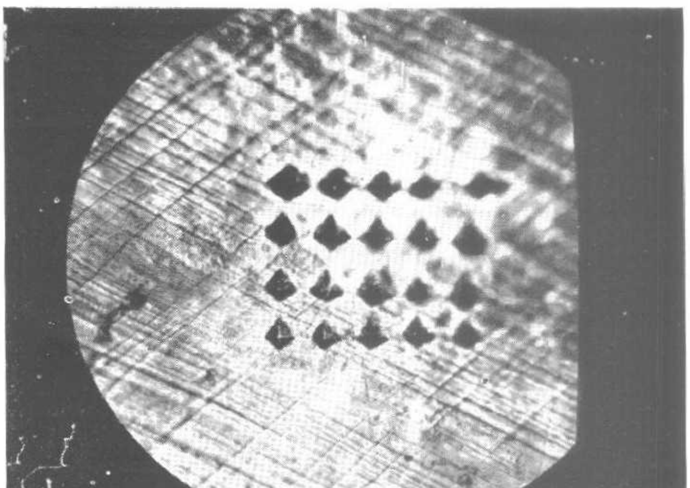

Fig. 10. ×200
Central region after an elongation of 30%.

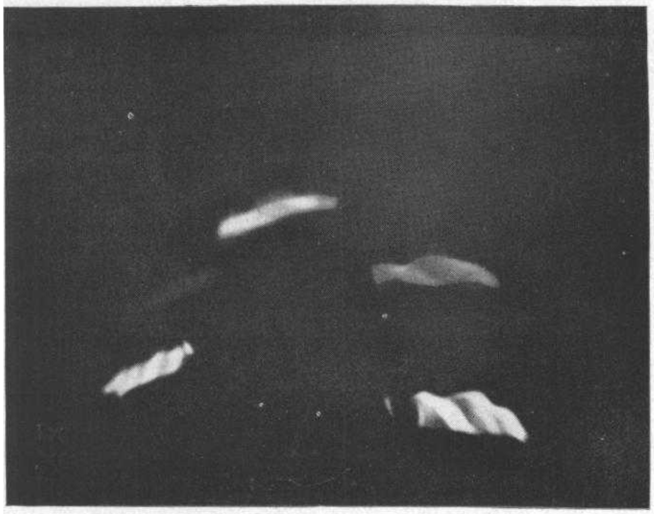

Fig. 11. ×1

Photographs of the double film chamber.
Distance : Source-Specimen, 13·2 cm.;
Specimen-Film, 5 cm.;
Monocrystal of great initial perfection stretched by 3%.

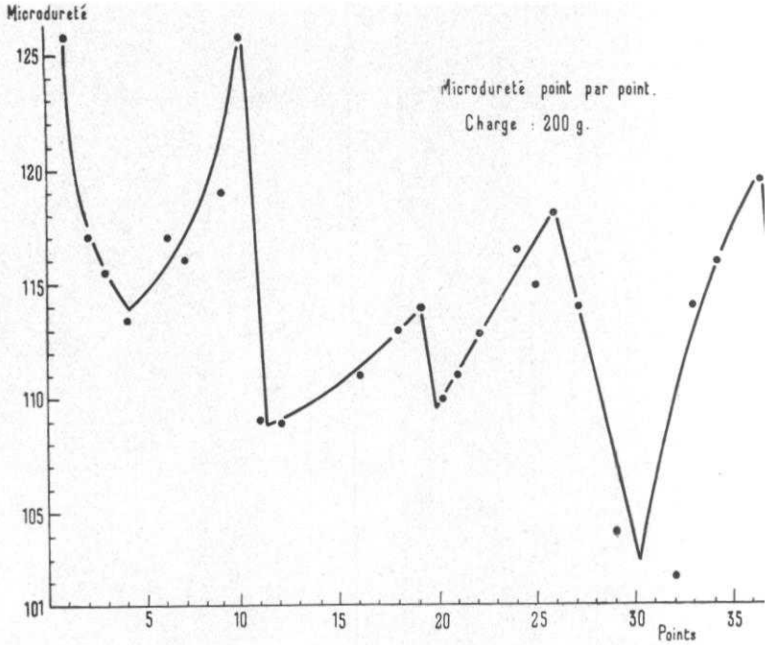

Fig. 12.

Point by point curve of the specimen which gave the photograph shown in Fig. 11.

2. *In certain cases, monocrystals deformed by tension present zones resistant to slip :* In the initial monocrystal, the regions which will slip in the course of subsequent tension can be detected by X-rays[3].

After a certain elongation we thus observe the development of the expected slip bands. In the double-film chamber photographs this is represented by two wide and bright lines. (Fig. 11). If the micro-hardness curve is traced point by point, we get a curve representing the fluctuations of intensity of the sliding band, detected on the film (Fig. 12).

It is invariably found that micro-hardness in the region of a slip band is lower than that of an undeformed zone. The following example will help in fixing ideas : The diagonals of the impressions are 31–30·4–32 microns in a slip band. They are only 27·9–28·5–26·3 microns in the adjacent undeformed zone.

After an elongation which is double the preceding one, the slip bands widen but do not increase in number. Micro-hardness values do not vary.

From one end to the other end of the specimen we therefore find alternatively, zones liable and resistant to slip.

From the fact that the regions which are liable to slip can be detected before any deformation we can deduce that they are constituted by finer and more disoriented crystallites[1] than those of the matrix, which is consistent with the presence of a larger number of Frank-Read sources and even of dislocations.

Similarly, from the fact that certain zones are resistant to slip it can be deduced that they are poor in Frank-Read sources.

IV. Influence of dimensions of the monocrystalline specimen on the evolution of slip bands during tension

The ideal rotation of the system[5,6] produced by a pure slip cannot take place when the extremities of the specimen are clamped in grips. A "S"-shaped deformation[5] is then produced and this disorients the central portion of the specimen without bending it. This process introduces kink bands or deformation bands at the extremities. Thus, after a great elongation of the specimen, the dot seen in Fig. 13 is transformed into that visible in Fig. 14. Using the double film chamber it is possible to specify that the hazy vertical bands are from the extremities of the specimen. The central portion of dots from the centre of specimen, is itself not very clear, which indicates that in general, kink and deformation bands of the extremities of the specimen have deeply disturbed the crystal.

To avoid such deep penetration of the disturbance of the extremities of the specimen, we have used longer specimens of single crystals. Other phenomena then appear. We[1] had already observed a sinusoidal deformation around the axis of the specimen ; we had explained this by the appearance, after deformation of sub-boundaries constituted by helicoidal dislocation network. The symmetry of the deformation is caused by the evenness of helicoidal dislocations formed during deformation.

By the use of these long single crystal specimens, it is possible to have an almost pure slip phenomenon in the central portion of the specimen. Distinct slip

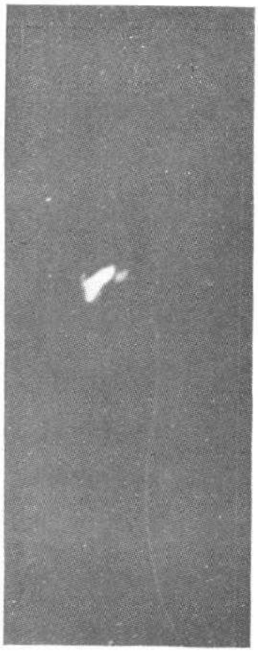

Fig. 13. ×1
Photograph of the initial state. Double film chamber method. Distance X-ray source-specimen : 23·5 cm. Distance Specimen-film : 10·8 cm.

Fig. 14. ×1
X-ray photograph of the specimen which gave Fig. 13 after 22·4% elongation in the Chevehard micro-machine.
Distance source-specimen 23·5 cm.
Distance specimen-film (dot at the bottom) 5·9 cm.
Distance specimen-film (dot at the top) 10 cm.

bands are then observed, giving sharp lines on the diffraction spots (Fig. 15). Fig. 15 (long monocrystal). can be compared to Figs. 11 and 14 (short monocrystal). This will show the importance of the effect of dimensions of the specimen on the orientation of slip bands.

V. Influence of the state of perfection of monocrystal on the aspect of slip bands formed in the course of subsequent tension

In the previous part of the paper we have observed that the lines of Figs. 15 were much more distinct than those of Figs. 11 and 14. This sharpness is only due to the greater length of the specimen.

Another feature was also noted on this specimen : For a comparatively small elongation the lines are considerably closer together. We have observed this state of affairs each time we used specimens having a good initial state of perfection.

Thus, the initial monocrystal shown in Fig. 16 has been extensively annealed : 100 days, at a temperature near the melting point. The different sub-blocks are very uniform, very sharply separated and perfect.

After an elongation of 3% this monocrystal gave the diagram shown in Fig. 15.

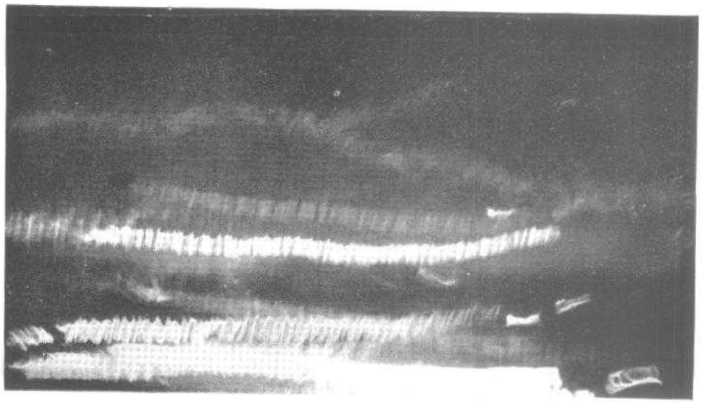

Fig. 15. ×1
Photograph of a long single crystal specimen elongated by 3%.
Distance source-specimen : 2·9 cm.
Distance specimen-film : 2·6 cm.

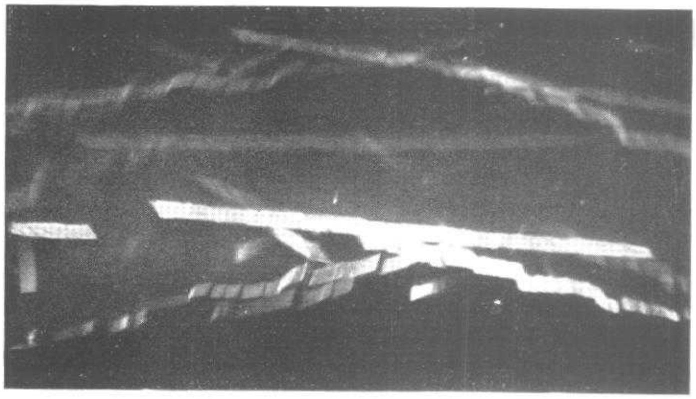

Fig. 16. ×1
Initial single crystal (conditions same as those for Fig. 15).

From this last observation we have deduced that vacancies or foreign atoms or even Frank-Read sources are still present in the large sub-blocks of the monocrystals which were not sufficiently annealed. They then hinder the displacement of edge dislocations during tension and bring about the development of screw dislocations by preventing certain portions of the plane to slip. In this case we, therefore, observe heterogeneous groupings of slip bands and more of serrations. On the contrary when the annealing has swept out all obstacles, leaving only uniform distributed Frank-Read sources, the slip bands are closer together and produce less disturbance in the stretched monocrystal.

Conclusions

Microscopic and X-ray investigations on long specimens and on Chevenard tensile specimens of 99·983%

purity Aluminium, consisting of a few large crystals, have given the following results:

When a crystal is harder than an adjacent one, its hardness decreases towards the boundary.

When a crystal is oriented such that its micro-hardness is greater than that of the adjacent crystal, it can start in this latter and in the neighbourhood of the boundary, a second slip system.

In certain cases, monocrystals deformed by tension show zones resistant to slip. Such zones are harder than those rich in slip bands. It is assumed that they have less Frank-Read dislocations sources.

Kink bands and deformation bands which develop near the grips of the tensile machine deeply disturb the crystal, and in particular, the whole of a specimen of insufficient length.

The slip bands are more compact and more uniformly distributed after elongation as the initial single crystal is more perfect. This seems to show that edge dislocations can move more freely. This results in a decrease in the number of screw dislocations which group themselves to form the serrations which we have referred to in a recent publication.

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DISCUSSIONS

Mr. M. B. Shankar, Hindustan Aircraft Ltd., Bangalore: Let me compliment the authors on the very interesting paper. It delves into a very important field. The mechanism of deformation of aluminium in relation to its crystal structure is by slip along the cleavage planes. The consequential reorientation of crystals sets in "tensions" or "potentials" in the material which ultimately brings about failure. Extrapolated, the subject is of particular significance to the aircraft industry wherein complex or compound stresses are effective and the basic material is not pure aluminium. It may be interesting to extend the field of study to embrace aluminium alloys subjected to compound stresses. May I enquire from the authors if such studies have also been engaging their attention? They may wish to kindly elucidate.

Dr. H. J. Latiere (Author): Systematic study of deformation bands in general, has been made on iron (Pfeil), brass (Mathewson, Philips), copper (Johnson), cupro-nickel (Adcock), nickel, silver (Elam), Cu-Ni-Mn alloy (Rosenhain), zinc (Jillson), cadmium. It is probable that they are formed in all cubic metals and therefore in aluminium alloyed with certain other elements; however, I do not know of any study made in this connection, in spite of the great industrial importance of this phenomenon.