The Recrystallization of Aluminium, Part I

By

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(Received December 21, 1929)

Abstract

Crystals produced by recrystallization in slightly deformed single crystals of aluminium show a tendency to have a certain definite orientation with reference to that of the mother crystal, though the scattering of their orientations is considerable. Of the crystals thus obtained, several types with twin-like orientation are observed. The effect of the direction of the stress applied to the mother crystal before annealing and the mode of the destruction of the crystal caused by such stress exercise a small influence upon the orientation of the new crystals.

The problem, whether or not the orientation of the crystals obtained by recrystallization in a slightly deformed single crystal of metal has any particular relation to that of the mother single crystal, has an important connection with the study of the nature of the nuclei of recrystallization and of the mechanism of recrystallization. Previously the writer[1] made an examination of the orientation of the single crystals of aluminium formed by recrystallization in slightly extended wires and plates which were composed of single crystals respectively. In that case the axes of the test-pieces in reference to the crystallographic axes of the crystals were found to be rather at random in both cases, irrespective of the degree of extension and the orientation of the initial crystal. Later Burgers and Basart[2] made a similar examination with aluminium single crystals by giving an extension of 10—15% to them, and found that, though the orientations of the new crystals were scattered considerably, they favoured on an average the orientation of the mother

1 These Memoirs, **11**, 229 (1928)

2 Zeit. f. Phys., **51**, 545 (1928)

crystal. Moreover, they noticed that the direction of the tension applied had also some effect upon the orientation of the crystals formed by recrystallization.

This result seems to contradict that of the writers mentioned before, and in the present research the crystallographic orientations of the mother crystal and of the crystals produced by recrystallization, in reference to the certain axes of the test-pieces, are examined more closely. The size of the cross-section of the test-pieces employed was 2.5×0.09 cm^2, and the length varied from 5 to 8 cms for a single crystal. These mother crystals were produced in commercial aluminium plate of 0.09 cm in thickness by the usual stress-annealing method. The determination of the orientation of the crystallographic axes of the crystals and the examination of their mutual positions by means of X-rays were very much facilitated by the use of the crystallographic globe devised by Prof. U. Yoshida[1]. After the crystallographic orientation of the mother crystals had been determined, they were subjected to an extension of about 10% and the effect of the extension upon them was also examined by means of X-rays. Then they were annealed at about 600°C for five hours to recrystallize. The crystallographic orientation of the crystals thus produced by recrystallization was next determined as before. The crystals formed near the two ends of the

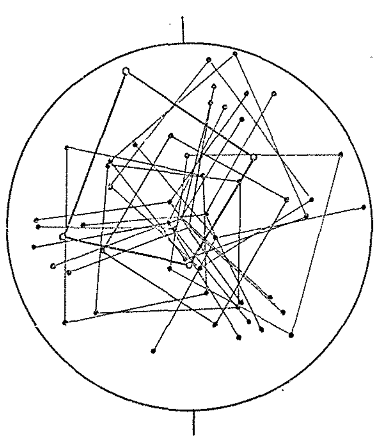

Fig. 1

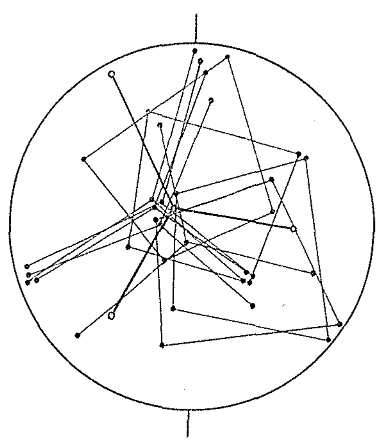

Fig. 2

specimens were omitted from examination, for they might have been

1. U. Yoshida, Jap. J. Phys., **4**, 133 (1927); S. Takeyama, These Memoirs, **12**, 257 (1929)

subjected to the effect of the pressure of the extension apparatus.

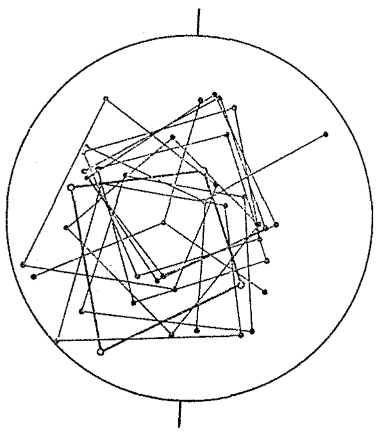

Fig. 3

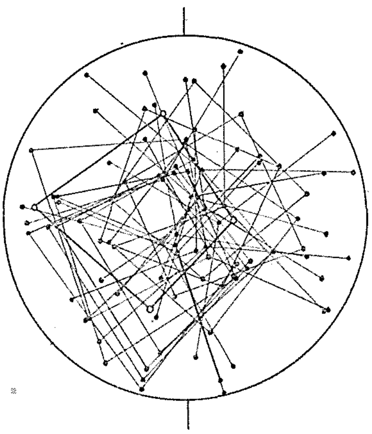

Fig. 4

Figs. 1, 2, 3 and 4 are four examples of the results. These figures are the stereographic projections of the crystallographic axes of the mother and the new crystals. The plane of projection and the pole correspond respectively to the plane of the plate and its surface normal, and the vertical direction represented by the straight line in these figures corresponds to the direction of the stress applied before annealing. In these figures four small circles and four dots connected by straight lines show the directions of the normals of the four octahedral planes respectively of the mother crystal and of the new crystals formed by the recrystallization.

Examining these figures, we can see that though the crystallographic orientation of the new crystals is scattered considerably, it cannot be regarded as entirely at random, and there are some crystals whose crystallographic orientations are similar. These circumstances are more clearly shown by the stereographic projections in Figs. 1′, 2′, 3′ and 4′. Four small circles in each of these figures show the directions of the normals to four octahedral faces of the mother crystal, and three dots which are connected by three straight lines represent the directions of the normals to three of the four octahedral faces of the crystals formed by recrystallization. These figures correspond respectively to Figs. 1, 2, 3 and 4, and they are simply a different mode of representation of the relative orientation of the crystallographic axes of the mother crystal and of the crystals produced by recrystallization, which are represented in Figs. 1, 2, 3 and 4.

Fig. 1′, which corresponds to Fig. 1, is drawn in the following way :— Of the four dots connected by straight lines in Fig. 1, the one which is

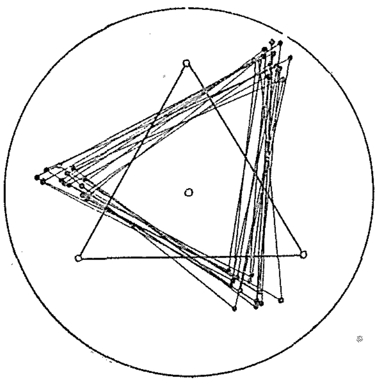

Fig 1′

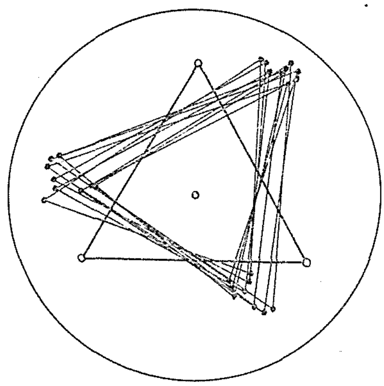

Fig. 2′

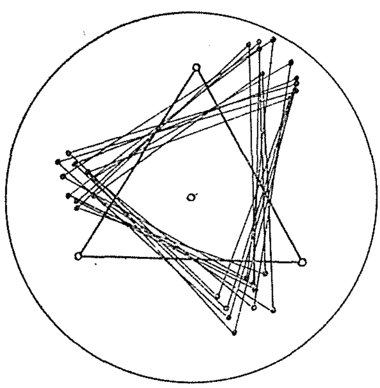

Fig. 3′

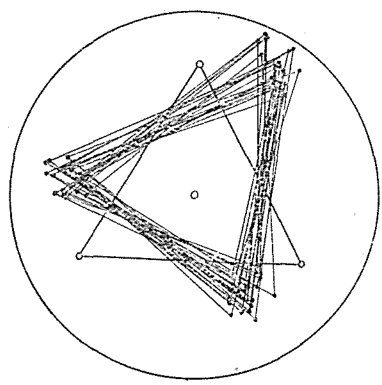

Fig 4′

nearest to any one of the four small circles in the same figure is omitted in Fig. 1′, and the orientation of the remaining three dots is represented by three dots connected by three straight lines in Fig. 1′ in reference to the directions of the normals to four octahedral faces of the mother crystal, the direction of one of four such normals, which is nearest to that of the omitted dots, being represented by the small circle at the centre of Fig. 1′. Figs. 2′, 3′ and 4′, which correspond respectively to Figs. 2, 3 and 4 are drawn entirely in the same way. In these figures, though the orientation of the crystallographic axes of the new crystals relative to those of the mother crystal is scattered to some extent, they clearly tend to be situated in some definite position relative to the mother crystal.

The new crystals thus produced by recrystallization in a deformed single crystal have very straight boundaries, and they have a different appearance from that of the crystals formed by recrystallization in polycrystalline aluminium. In this respect the conditions of the annealing for recrystallization seem to have some effect upon the size of the grains and the crystal boundaries. When the strained single crystal was heated uniformly and rapidly by putting it in a furnace which was already heated up to 600°C, the grains produced by annealing were of rather even size, and their boundaries were very straight. But when it was heated gradually from one end to the other, the grains produced were of very uneven size, and their boundaries were not so straight as before. The orientation of the new crystals, however, seems not to be appreciably affected by such difference in the annealing conditions, so far as the writer has examined.

Among the crystals formed by annealing in a deformed single crystal of aluminium, Elam[1] has found some annealing twins of the type having the rotation of 60° about a [111] axis and in a {111} plane. To ascertain the existence of such twins the writer has also examined the mutual orientation of every two neighbouring crystals and the results of such examination are summarized in Table I. In many pairs of neighbouring crystals the writer could detect many twin-like orientations as shown in the table. The indices 100, 110 etc. given in the first column are the common axes, the angles given in the second column are the amount of rotation of the two component crystals about the common axes, and the numbers in brackets represent the number of such twins observed. Of these many types of twins, though some of them may be regarded as the results of some accidental coincidence, those which are of frequent occurrence may be regarded as true crystallographic twins. As most of such twin crystals were not separated by straight boundaries, the

Table I

100	33° 45°
110	55°(2) 90°
111	40° 60°(5)
211	12°(4) 19° 27°(2) 48°(5) 52°(2) 75° 82° 90°(3) 112° 148° 167°(4) 170°
311	14°(2) 25° 42° 58° 83°(5) 90°(2) 102° 110° 132°(3 140° 158° 163°(3)

1 Roy. Soc. Proc. A, **121**, 237 (1928)

planes of composition of these twins were not determined. But, as was observed by Elam, a few of the twins belonging to the type of the rotation of 60° about the [111] axis have very straight common boundaries, which agree with the traces of the twin planes. Some examples of the twins shown in Table I are illustrated in Fig. 5 by the stereographic projection: where the direction of the common crystallographic twin axis is taken as the pole and is represented by ◉, and the directions of the normals to the octahedral planes of the two component crystals are indicated by the small circles and the dots respectively. The angle written at the centre of each of these figures is the angle of rotation of one of the component crystals to the other around the common twin axis.

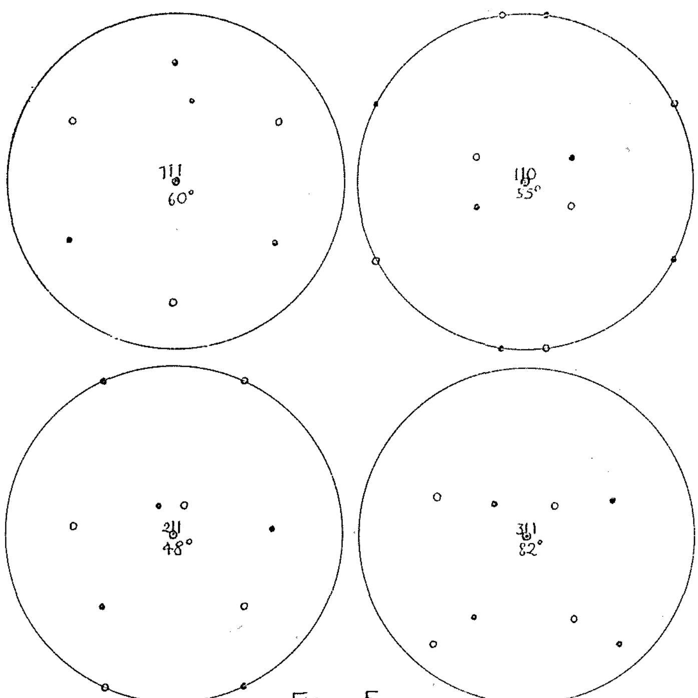

Fig. 5

For the examination of such twin-like orientations with the aid of the Laue-photographs taken with each one of the component crystals, the use of the crystallographic globe was very convenient, and the crystallographic relation between the two crystals was easily found with it. By applying two hemispherical caps of celluloid provided with the same crystallographic marks simultaneously on the same crystallographic globe having two sets of marks corresponding to two component crystals, the common crystallographic axis of the component crystals can be found easily, and the amount of the relative rotation of two component crystals about this common axis can be read at once by the use of hemispherical cap having the same spherical scale as that of the globe.

By this convenient use of the crystallographic globe several interesting relations between several crystals which were in contact with each other were observed. Two examplee of such relations are shown in Figs. a and b in Fig. 6. The dots in these figures represent, in

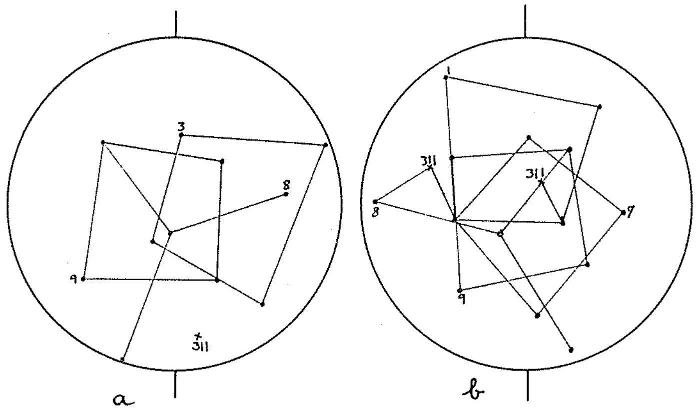

Fig. 6

stereographic projection, the directions of the normals to the {111} faces of the crystals. Three crystals shown in Fig. a have a common [311] axis represented by a cross in the figure, and the crystals 8 and 9 have a common [111] axis and the relative rotation around this axis is 60°. Four crystals shown in Fig. b belong two sets of the twins found by Elam, the sets of the crystals 1—7 and 8—9 forming two different such twins. Moreover, every set of the 7—8 and 1—9 has respectively a common [311] axis, · In addition to these, the writer could find many cases which were similar to the two examples stated above, though the relative orientation of the crystals was not the same for different cases.

Next, the writer examined the effect of the stress applied to the mother crystal upon the destruction of the mother crystals and upon the orientation of the new crystals. To see the effect of such stress upon the destruction of the mother crystal, the test-pieces subjected to the extension were examined by means of the general X-rays from a tungsten anti-cathode before annealing for recrystallization. By treating the elongated Laue-spots due to the crystal thus deformed with the crystallographic globe, in the same way as was described in the case of the bent aluminium crystal[1], the axis around which the micro-crystals produced by the destruction of the mother crystal rotated was easily determined. The distribution of the orientation of the micro-crystals caused by the extension was such that they were always revolved within some angle around a certain crystallographic axis of the mother crystal. The axis of such revolution was found to be different for different orientations of the initial crystal, and the angle within which the micro-crystals were revolved was also found to be different for different crystals and varied from 7° to 12° for the crystals examined with an extension of about ten per cent of the original length. Some examples showing the relation between the initial orientation of the crystal and the axis of revolution of the micro-crystals are given in Fig. 7 by stereographic projection. In this figure four dots and a small circle connected by straight lines are the projection of the normals of the four octahedral planes and the axis of the scattering of the micro-crystals respectively, and the vertical direction corresponds to the direction of the extension applied to the specimen. As seen in the figure the axes around which the micro-crystals revolved are nearly in the position perpendicular to the stress applied. Though these axes do not coincide exactly with any simple crystallographic axis of the mother crystal, they are nearly in the position perpendicular to one of the normals of the octahedral planes, that is, a direction between the [110] and the [211] axes; and some of them coincided with the [110] axis, or with the [211] axis, and the others took the directions between those two axes.

Direction of the Extension

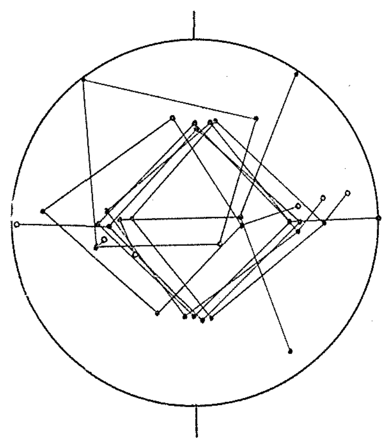

Fig. 7

The relation between the scattered orientation of the micro-crystals

1 These Memoirs, **11**, 199 (1928)

and the orientation of the crystals produced by recrystallization from them was also examined by plotting the direction of the axis of the scattering of the micro-crystals and the direction of the crystallographic axes of the new crystal in the same stereographic projection. But so far, no appreciable influence of the orientation of the micro-crystals upon the orientation of the new crystals formed by recrystallization has been detected.

Next, to see the effect of the direction of the stress applied to the specimen before annealing upon the orientation of the new crystals, an examination similar to that carried out in the previous research[1] was repeated for every crystal. The result of such examination, however, only confirmed the previous result, and no appreciable influence of the stress was detected.

In conclusion, the writer wishes to express his sincere thanks to Prof. U. Yoshida for his kind guidance in the research.

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1 loc. cit.