The Arrangement of the Micro-crystals in Compressed Single-crystal Plates of Aluminium, Part IV

By

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(Received November 14, 1931)

Abstract

When rectangular single-crystal plates of aluminium were thoroughly compressed, the manner of the fibrous arrangements of the micro-crystals which were produced by the compression was seen to be divisible into four different types, the axis of the fibrous arrangement being always parallel to the direction of flow of the metal. These four different types occurred according to the initial crystallographic orientation of the specimen, depending mainly on the direction of the longer side of the specimen in reference to the crystallographic axes. In the present investigation, the relation between the initial crystallographic orientation of the specimen and the type of the fibrous arrangement of the micro-crystals produced by thorough compression, was examined closely.

In the previous investigations[1], it was made clear that, when a rectangular single-crystal plate of aluminium was compressed to a thickness of less than about 10% of the initial thickness, the micro-crystals in the specimen took the arrangement of an imcomplete fibre whose fibrous axis was always parallel to the direction of flow of the metal on compression, and that the manner of the fibrous arrangement might be divided into four different types, depending on the initial crystallographic orientation of the crystal mainly with respect to the direction of the longer side of the specimen. We named these four different types of fibrous arrangement (1), (2), (3) and (4), and they are illustrated in Table I. For example, it is shown in type (1) that most of the micro-crystals in a specimen are so arranged by thorough compression that their [111] and [110] axes and their (211) plane are nearly parallel to the direction of flow of the metal, to the direction

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[1] These Memoirs, **12**, 261 (1929);- **13**, 299(1930);- **14**, 97 (1931)

Table I

Type	Direction of flow of the metal (or fibrous axis)	Direction of the longer side	Plane parallel to the flat surface
(1)	[111]	[110]	(211)
(2)	[211]	[111]	(110)
(3)	[100]	[110]	(110)
(4)	[110]	[100]	(110)

of the longer side and to the flat surface of the specimen respectively. Mutatis mutandis, the same description applies to the other types given in Table I. It was also found that, of these four types, the first two occurred more frequently than the last two; and this fact was explained, at least to some extent, by the possible number of the crystallographic axes present in the cubic crystal of aluminium.

The object of the present investigation is to examine more closely, in continuation of the former investigations, the relation between the initial crystallographic orientation of the specimen and the fibrous arrangement of the micro-crystals produced by thorough compression. The results obtained with 51 specimens, which were compressed to a thickness of about 10% of the initial thickness, are described below. The length of the shorter and the longer side of these rectangular specimens was about 3 mms. and 5 mms. respectively; and the part of the specimen enlarged in breadth by compression was etched carefully off by some dilute acid at each step of the compression, so that the specimen had the same breadth as before. As shown by the third column of Table I, the crystallographic axis which becomes nearly parallel to the longer side of the specimen as a result of compression is any one of the [111], [110] or [100] axes which has initially a slight inclination to the longer side of the specimen. Of such three axes of the initial single crystal of aluminium plate, if the one which becomes nearly parallel to the longer side of the specimen as a result of compression is known, the kind of the fibrous arrangement of the micro-crystals produced by the compression will immediately be known by the aid of the crystallographic globe[1]. Thus special attention was paid in the present investigation to the initial orientation of that crystal axis which became nearly parallel to the direction of the longer side owing to compression.

In Fig. 1 the initial directions of the longer sides of 51 specimens,

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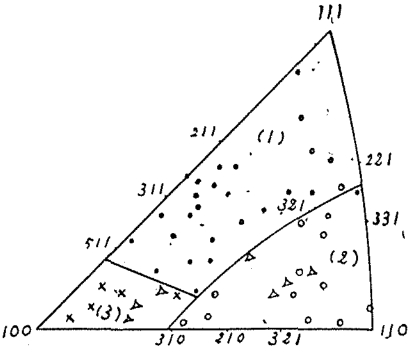
[1] Japanese J. Phys., **4**, 133 (1927).

Fig. 1

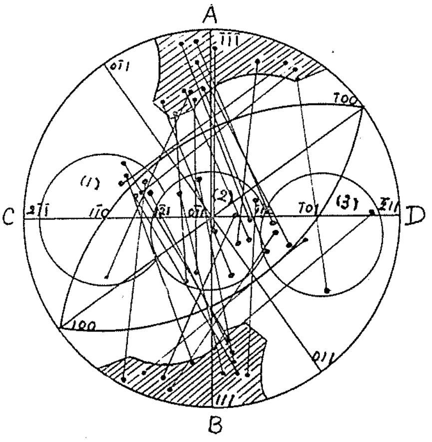


with reference to the crystallographic axes, are shown in stereographic projection. Of these, the ones which correspond to the specimens in which the fibrous arrangement became that in type (2) on thorough compression, are shown by the dots. The ones which correspond to the specimens, in which the fibrous arrangement became that in type (1) on thorough compression are shown by the small circles. Similarly, the small triangles and the crosses correspond respectively to the specimens in which the fibrous arrangements arrived at as a result of compression were types (3) and (4).

In Fig. 1 the writer divided roughly the domain bounded by the margin into three parts: that is, parts (1), (2) and (3). Part (1) contains almost nothing but dots, part (2) contains almost nothing but small circles and some small triangles, and part (3) contains crosses and small triangles. By such division, the dots, the small circles and the crosses are segregated respectively into different parts. But the small triangles are scattered in parts (2) and (3). So far as the present experiment is concerned, a specimen in which the direction of the longer side is in part (1) was observed to belong always to type (2), irrespective of the crystallographic orientation of the normal to the flat surface of the specimen. But in the case of the specimens in which the direction of the longer side is in part (2) or (3), different types of fibrous arrangement were observed, as is shown in Fig. 1, and this fact seems to be made clearer by considering the orientation of the normal to the flat surface with reference to the crystallographic axes. Thus we shall consider the orientation of the micro-crystals in the compressed specimens with reference to the direction of the normal to the flat surface and to that of the longer side of the specimen.

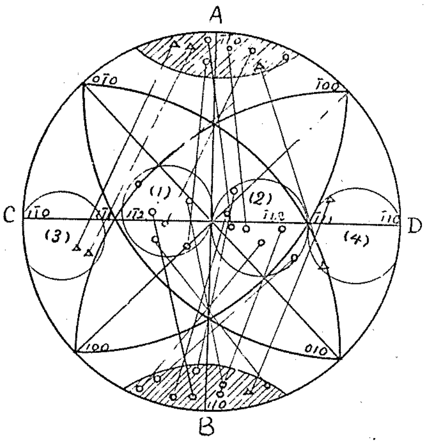
First we shall deal with the specimens which correspond to the dots in part (1) in Fig. 1. A and B in Fig. 2 are the direction of the [111] axis which becomes nearly parallel to the longer side of the specimen as a result of thorough compression; the upper and the lower shaded parts in Fig. 2 correspond to part (1) in Fig. 1 and the dots in these shaded parts also correspond to the dots in part (1)

Fig. 2



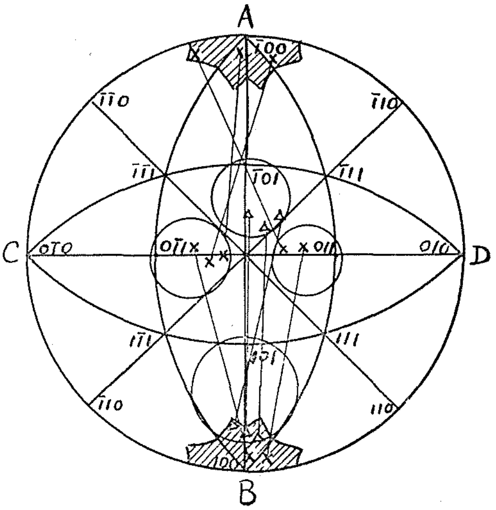
in Fig. 1. The dots which are scattered in the neighbourhood of the line CD represent the directions of the normal to the flat surface of those specimens which correspond to the dots in the shaded parts. Where two dots are connected by a straight line, it indicates that they belong to the same specimen. Thus the angle subtended between such two dots is a right angle. The writer divided the dots in the neighbourhood of CD into three groups, namely (1), (2) and (3). On thorough compression, the dots in the upper and lower shaded parts approached respectively A and B, and simultaneously the dots belonging to groups (1), (2) and (3) approached respectively the $[1\bar{1}0]$, $[0\bar{1}1]$ and $[\bar{1}01]$ axes. In other words, in each case, the dodecahedral face became nearly parallel to the flat surface. Therefore, the $[211]$ axis which is perpendicular to the $[111]$ axis, that becomes nearly parallel to the longer side, and which is also perpendicular to the $[110]$ axis that is nearly perpendicular to the flat surface, became nearly parallel to the flow of the metal as a result of compression. For instance, when the $[1\bar{1}0]$ axis on CD becomes nearly perpendicular to the flat surface, the $[\bar{1}\bar{1}2]$ axis on CD becomes nearly parallel to the flow of the metal owing to compression. The fibrous arrangement type (2) was obtained in such a manner.

Fig. 3



Next we shall deal with the specimens which correspond to the small circles and the small triangles in part (2) in Fig. 1. In Fig. 3, A and B are the direction of the $[110]$ axis which becomes nearly parallel to the longer side of the specimen as a result of thorough compression. The upper and the lower shaded parts correspond to part (2) in Fig. 1. The small circles and small triangles in the shaded parts also correspond respectively to the small circles and the small triangles in part (2) in Fig. 1, and show respectively the initial directions of the longer side of these specimens. The small circles and small triangles scattered in the neighbourhood of the line CD represent the direction of the normal to the flat surface of the specimens which correspond to the small circles and the small triangles in the shaded parts respectively. Where the same two marks are connected by a straight line, it shows that they belong to the same specimen. Let us divide the marks in the neighbourhood of CD into four groups, namely (1), (2), (3) and (4). Groups (1) and (2) contain only small circles and groups (3) and (4) contain only small triangles. On thorough compression, the marks in the upper and lower shaded parts approached A and B respectively and the small circles of the groups (1) and (2) approached the [$1\bar{1}2$] and [$\bar{1}12$] axes on CD respectively. In other words, in both cases the trapezohedral face became nearly parallel to the flat surface of the specimen. Consequently the [$\bar{1}11$] and [$1\bar{1}1$] axes on CD which are perpendicular to the [$1\bar{1}2$] and [$\bar{1}12$] axes on CD respectively became nearly parallel to the flow of the metal as a result of compression. Thus in the cases of groups (1) and (2), the

Fig. 4



fibrous arrangement of type (1) was obtained. In the cases of groups (3) and (4), the small triangles approached to the $[1\bar{1}0]$ and $[\bar{1}10]$ axes respectively, that is, the dodecahedral face became nearly parallel to the flat surface of the specimen. Therefore the $[001]$ axis on CD became nearly parallel to the flow of the metal as a result of compression. Thus in the cases of groups (3) and (4), the fibrous arrangement of type (3) was obtained.

In Fig. 4, the shaded parts correspond to part (3) in Fig. 1 and the crosses and the small triangles in these parts also correspond to the crosses and the small triangles in part (3) in Fig. 1, and show respectively the directions of the longer side of the specimens. The crosses and the small triangles in the neighbourhood of CD show respectively the directions of the normals to the flat surface of the specimens which correspond to the crosses and the small triangles in the shaded parts. Where the same two marks are connected by a straight line, it indicates that they refer to the same specimen. On thorough compression, the crosses in the upper and lower parts approached A and B respectively. Of the five crosses very near the line CD, the two on the right side of AB approached the $[011]$ axis on CD, and the directions of the flow of the metal approached the $[0\bar{1}1]$ axis on CD which is perpendicular to the $[011]$ axis. The three crosses on the left side of AB approached the $[0\bar{1}1]$ axis on CD, and the directions of the flow of the metal approached the $[011]$ axis on CD. Thus in the case of the specimens which correspond to the crosses, the fibrous arrangement of type (4) was obtained. On the other hand, the three small triangles in the lower shaded part approached the $[101]$ axis on AB and the three small triangles which are far above the line CD and the crosses, approached the $[\bar{1}01]$ axis on AB. Therefore the $[010]$ axis, which is perpendicular to the $[101]$ and $[\bar{1}01]$ axes, became parallel to the flow of the metal as a result of compression. The fibrous arrangement type (3) was obtained in such a manner.

The total number of the dots represented in Fig. 1 is 26, which is much larger than that of any of the other marks. The area occupied by part (1) is also much larger than that of any of the other parts. These facts show clearly that the micro-crystals in a thoroughly compressed specimen chiefly tend to take the fibrous arrangement type (2). It was found, in the previous investigation on compressed and rolled pollycrystalline specimens, that the fibrous arrangement of the micro-crystals was the same as type (2); and such fibrous arrangement was also found by S. Tanaka in the case of rolled single-crystal foils[1]. Moreover, with rolled foils of copper, silver, gold and platinum which belong to the face centred cubic lattice type, the fibrous arrangement of the micro-crystals was observed to be of type (2) by S. Tanaka[2] and Mark and Weissenberg[3].

The number of the small circles and the small triangles in Fig. 1 is 13 and 7 respectively, and the area occupied by part (2) is somewhat large. These facts show that the micro-crystals in a thoroughly compressed specimen have also a somewhat great tendency to take the fibrous arrangement type (1). The same type of fibrous arrangement was also observed by S. Tanaka[4] and Wever[5] in the case of rolled single-crystal foils of aluminium.

The number of the crosses is only 5 in Fig. 1, and the area occupied by part (3) is also very small. These facts indicate that the micro-crystals in a thoroughly compressed specimen have the least tendency to take the fibrous arrangement type (4).

Thus we are now able to determine, at least to some extent, the boundary of the initial crystallographic orientation of a specimen which corresponds to one or other of the four different types of fibrous arrangement described above. Thus if the initial crystallographic orientation of a specimen is known, we can now predict more strictly the kind of the fibrous arrangement of the micro-crystals in a specimen produced by compression.

Finally, when the crystallographic axis which approaches the longer side as a result of compression deviates much initially from being parallel to the latter, the mean orientation of the micro-crystals arranged fibrously as a result of thorough compression also deviates much from the ideal orientation shown in Table I. Thus, when the crystallographic orientation is in the neighbourhood of the boundary, the greater part of the micro-crystals in the specimen seem to take on an orientation intermediate between the different types which correspond to the two parts lying on the two sides of the boundary. In those cases, the writer took three Laue-photographs, by sending the X-ray beam from three different directions: normally to the flat surface, parallel to the flat surface and also to the longer side, and

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[1] These Memoirs, **10**, 303 (1927)

[2] „ **8**, 319 (1925)

[3] Zeit. f. Physik, **14**, 328 (1923)
„ **28**, 69 (1924)

[4] These Memoirs, **10**, 303 (1927)

[5] Zeit. f. Physik, **28**, 69 (1924)

parallel to the flat surface and also to the direction of flow of the metal on compression. From these photographs he was able with some difficulty to classify such indistinct fibrous arrangements. Figs. 5 and 6, which correspond to type (1) and (2) respectively, are seen to illustrate the facts stated above. In these figures, the dots, the small triangles and the crosses show respectively the direction of the longer side, of the flow of the metal and the normal to the flat surface of the specimen at its initial orientation. The numbering of three different marks with the same figure shows that they belong to the same specimen. The ends of the arrows show the positions of the mean crystallographic orientations of the micro-crystals which were scattered at the last compression. Fig. 5 shows that the dots, the small triangles and the crosses approach the [110], [111] and [211] axes respectively as the process of compression is continued, and also shows that the greater the deviation of the initial crystallographic orientation from the ideal orientation, the greater is that of the micro-crystals at the last compression from the ideal orientation. In Fig. 6, the dots, the small triangles and the crosses approach the [111], [211] and [110] axes respectively and we can see the same things in this case as are mentioned in connection with Fig. 5.

Fig. 5

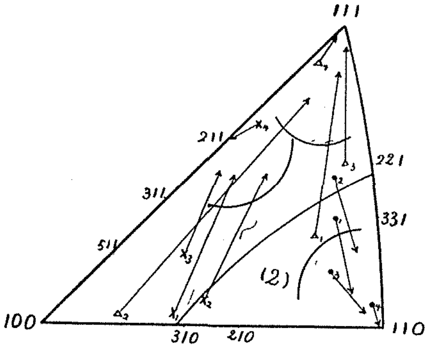
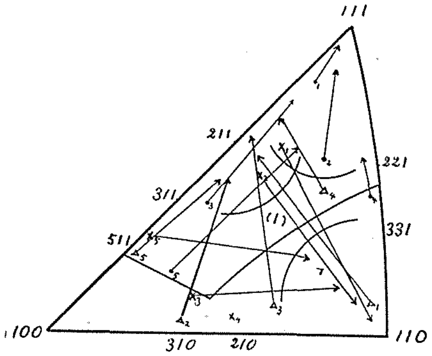


Fig. 6



In conclusion, the writer wishes to express his sincere thanks to Professor U. Yoshida for his kind guidance and suggestions during this research.