The Arrangement of the Micro-crystals in Bent Wires of Tungsten and Molybdenum

By

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Abstract

The arrangement of the micro-crystals in a bent wire of tungsten, which was initially composed of a large single crystal, was studied by means of X-rays. The orientations of the micro-crystals produced by the destruction of the crystal at the time of bending are seen to be so scattered, to some extent around the initial orientation, that the orientations vary continuously from one part of the bent wire to the other, by keeping the initial crystallographic direction parallel to the axis of bending unaltered. In the case of the bent wire of molybdenum, which is not annealed after the drawing process, the common axis of the initial fibrous arrangement of the micro-crystals in the drawn wire is seen to have curved almost along the axis of the wire without destroying the initial fibrous arrangement.

Introduction

The effect of various regular cold workings upon the crystal arrangement in metals has been studied by many investigators, and it has been ascertained that the micro-crystals produced by the destruction of one initial crystal take a certain definite regular arrangement peculiar to the kind of working and of the metal. In 1925 C. H. Bosanquet [1] examined the effect of the bending of a rock salt crystal. Recently K. Tanaka [2] studied, from the distortion of the Laue-spots, the effect of the bending of aluminium plates and wires, each composed initially of a large single crystal. According to him the orientations of the micro-crystals, produced by the destruction of the single crystal at the time of bending, are so scattered around the initial orientation,

1 C. B. Bosanquet: Proc. Phys. Soc. of London, **38**, 88 (1925)
2 K. Tanaka: These Memoirs, **11**, 199 (1928)

that the micro-crystals revolve to some extent around the axis of bending, and that finally their arrangement tends to be fibrous owing to the process of bending.

In the present experiment the writer examined, by means of X-rays, the arrangement of the micro-crystals in a bent wire of tungsten, which was initially composed of a single crystal, and that in the unannealed drawn bent wire of molybdenum.

The Experimental Method

Single crystal wires of tungsten obtained by recrystallization to a form so coarse-grained that one single crystal of about several cms. in length occupied the whole section of the wire, and unannealed drawn wires of molybdenum were examined. In each case the orientation of the crystals in the initial undeformed wire was first determined by taking the Laue-photograph. Then the wire was bent by being pressed against the surface of a circular cylinder, called a mandrel, so as to give it the same radius of curvature as that of the mandrel. Next they were bent more and more in succession by using smaller mandrels. The diameters of the tungsten and the molybdenum wires were 0.07 and 0.08 mm. respectively, and those of the smallest mandrels were respectively 1.1 and 1.0 mms. in the case of the tungsten and the molybdenum wires. At each stage of bending two Laue-photographs were taken by letting the X-rays strike the specimen in the direction of the radius of curvature of the wire and in that of the axis of bending respectively, and by setting the photographic plates perpendicularly to the beam of incident X-rays. These Laue-photographs were taken by using parallel or convergent X-rays, as the case might be, which started from the focus on the Mo-target of a Coolidge tube. The arrangement of the crystals in the specimen was thus determined with these photographs.

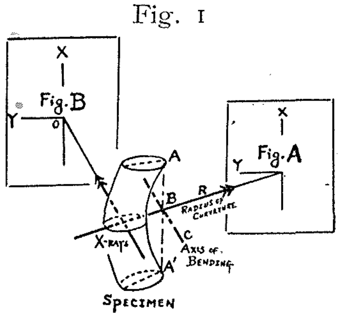
The potential applied to the tube was about 40 K. V. s, the current passed through 10 m. A. s and the duration of the exposure of each photograph varied from 5 to 70 hours according to the specimen. Some of the Laue-photographs thus taken are shown in Plates I & II.

Discusson of the Results

A. Single Crystal Wire of Tungsten

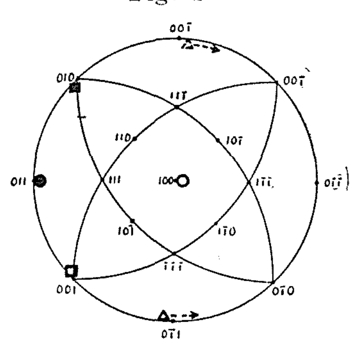
Many single crystal wires of tungsten, which were bent in the manner stated above, were examined by taking the Laue-photographs; and here a typical one is discussed whose Laue-photographs are reproduced in Figs. 1, 2 and 3 in Plate I. Fig. 1 in Plate I is the Laue-photograph taken with the initial undeformed single crystal wire by letting the X-rays strike the specimen in the direction perpendicular to the axis of wire. Figs. 2 and 3 in Plate I are taken with the bent specimen by letting the X-rays strike the specimen in two different directions as shown in Fig. 1, where Figs. A and B correspond to Figs. 2 & 3 in Plate I respectively. In Fig. 1 ABA′ is a chord of the bent specimen, BC the axis of bending, BR the radius of curvature and the directions represented by two arrows indicate those of the incident X-rays respectively. Fig. 1 in Plate I was taken with convergent X-rays and Figs. 2 and 3 in Plate I were taken with a narrow beam of parallel X-rays.

Fig. 1



Now in Fig. 1 in Plate I we can see that the pattern consists of Laue-spots and spectral lines as was reported before [1]. Thus the writer obtained the indices of the atomic planes by which the spectral lines and the Laue-spots are caused in the same way as in the former case. Next the orientation of the single crystal in the wire was determined by treating the Laue-spots with the crystallographic globe devised by Prof. U. Yoshida [2], with which all determinations of the crystallographic orientations in this experiment were also carried out.

Fig. 2



The orientation of the crystal thus determined is shown in Fig. 2 by stereographic projection, where 100, 110, 211, etc. represent respectively the direction of the normals to the atomic planes (100), (110), (211), etc., and the points marked △ and ∴, the direction of the axis of wire, and the point marked ○ that of the

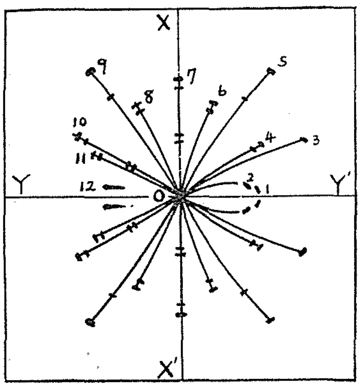
1 T. Fujiwara: These Memoirs, **11**, 283 (1928)

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

axis of bending around which the wire was bent afterwards in the direction represented by dotted arrows respectively.

In Fig. 2 in Plate I we can see that the pattern consists of many radiating bands distributed symmetrically about the horizontal line; The distribution of these radiating bands are sketched in Fig. 3 where the line YOY′ is the symmetrical line which is parallel to the axis of bending.

Fig. 3



From this photograph it can easily be seen that by the process of bending the single crystal was broken up into micro-crystals which are so arranged in a fibrous manner, that the axis of the fibre is in the direction parallel to the line YOY′, that is the axis of bending.

From the distribution of the bands in this photograph the indices of the atomic planes by whose reflections the bands are caused, and the arrangement of the micro-crystals, and consequently the axis of the fibrous arrangement and the radius of curvature were determined by means of the crystallographic globe. The axis of fibrous arrangement thus determined is in the direction nearly the same as that of the axis of bending, and the direction of the radius of curvature, which is perpendicular to the axis of bending, is in the direction represented by the point marked ● in Fig. 2, in which the result obtained from Fig. 1 in Plate I is represented as stated before. The maximum angle of revolution of the micro-crystals around the axis of the fibre, which is parallel to the axis of bending was found, from the length of the radiating bands, to be about 40° equally on both sides of the initial orientation.

In Fig. 3 in Plate I which was obtained by letting the X-rays strike the bent specimen in the direction parallel to the axis of bending, we can see that the pattern consists of several curved spectral lines distributed on several concentric circles with their common centre nearly at the central spot impressed by the direct beam of X-rays. This is, of course, caused by the scattering of the orientation of the micro-crystals, with in some angle around the axis of revolution which is the axis of bending. The axis of such revolution of the micro-crystals was determined by the following considerations :—The whole assemblage of the end-points of spectral lines must be two sets of the short spectral lines due to the micro-crystals at two different orientations. These two different orientations are two extreme ones, and the central portions between the two extremities of every spectral line are caused bv the micro-crystals at the central orientations between the two extreme ones.

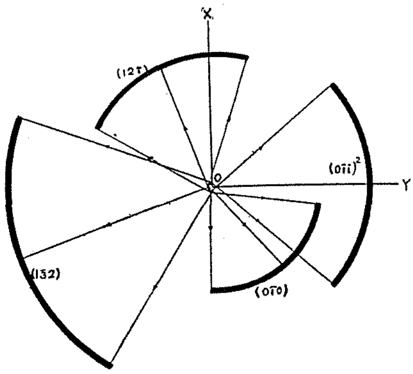
By means of the crystallographic globe, the central orientation and these two extreme ones, and consequently the axis of revolution and its angle, were determined and are represented in Fig. 2, in which the results obtained in the former two cases are represented together. The directions of the axis of bending and the radius of curvature of the central orientation thus obtained are the same respectively as those obtained from Fig. 2 in Plate I, and which are represented by the points marked ○ and ◉ in Fig. 2. The direction of the axis of bending of two extreme orientations coincides with that of the central one, and the directions of the radius of curvature of them are represented by the points marked □ and ■ respectively. Thus the micro-crystals take the orientations rotated, around the axis of bending, with the angle of about 40° on both sides from the central orientation, as was observed before.

Next the writer calculated the angle of bending of the portion of the specimen which was illuminated by the beam of X-rays, by estimating the diameter of the beam from that of the slit, and ascertained that the maximum angle of revolution of the micro-crystals was nearly the same as that of the bending of the illuminated portion of the specimen.

From the consideration stated above we can conclude that the arrangement of the micro-crystals varies continuously from one part of the specimen to the other; and that at every portion of the specimen the relative orientation of the micro-crystals to the axis of bending and to the radius of curvature at that portion is, for the majority of the micro-crystals, the same as that of the micro-crystals at the central orientation. The correctness of this consideration will be seen from the agreement of the photograph with the diagram calculated under the above consideration. Fig. 4, which corresponds to Fig. 3 in Plate I, is drawn by taking 80° as the angle of bending of the specimen at the portion illuminated by the beam of X-rays.

Nearly the same results were obtained with other single crystal wire of tungsten of different crystallographic orientations. The axis of revolution of the micro-crystals in a bent wire always coincided with the axis of bending, irrespectively of the crystallographic orientation of the initial single crystal; and in every case the angle of revolution of the micro-crystals was nearly the same as that of bending of the specimen. This angle of revolution of the micro-crystals becomes larger with a smaller radius of curvature of the bent wire, and at each stage of bending it showed a tendency to be slightly larger than that of the bending.

Fig. 4



Thus we may say that the orientation of the micro-crystals produced by the destruction of the single crystal at the time of bending is so scattered around that of the initial single crystal, that it varies continuously from one part of the specimen to the other, when the crystallographic direction parallel to the axis of bending is kept unaltered, and that, when the bent wire is considered as a whole, the micro-crystals tend to arrange themselves in a fibrous manner by taking the axis of bending as their common axis.

To see whether the same result as the above can be obtained in the case of coiling a single crystal wire of tungsten, the writer examined the coiled wire in the same way as in the former case, and the same result was obtained.

B. Unannealed Drawn Wire of Molybdenum

In this case the Laue-photographs were taken in the same way as before. Some of the photographs thus taken are reproduced in Fig. 4 in Plate I and Figs. 1 & 2 in Plate II, where Fig. 4 in Plate I is the Laue-photograph taken with undeformed initial wire and Figs. 1 & 2 in Plate II are those taken with the bent wire. Figs. 1 & 2 were respectively taken by sending the X-rays in the manner shown in Fig. 1, so that Fig. 1 in Plate II corresponds to Fig. A in Fig. 1, and Fig. 2 in Plate II corresponds to Fig. B in Fig. 1.

In Fig. 1 in Plate II, which is similar to Fig. 4 in Plate I, the band caused by the reflection from the atomic plane (110) is lengthened in the direction of the initial axis of the wire. Moreover the pattern reproduced in Fig. 2 in Plate II consists almost entirely of concentric rings around the axis of bending. These phenomena indicate that the scattering of the orientation of the micro-crystals follows the bending so well that the micro-crystals revolve themselves around the axis of bending without destroying their initial arrangements very much.

The maximum angle of such revolution of the micro-crystals around the axis of bending was determined from Figs. 1 & 2 in Plate II, and in both cases it was found to be about 80°, in fair agreement with the angle of bending of the portion of the specimen which was illuminated by the incident beam of X-rays.

In conclusion, the writer wishes to express his sincere thanks to Professor U. Yoshida, of Kyoto Imperial University for his invaluable suggestions.

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Plate I

axis of wire

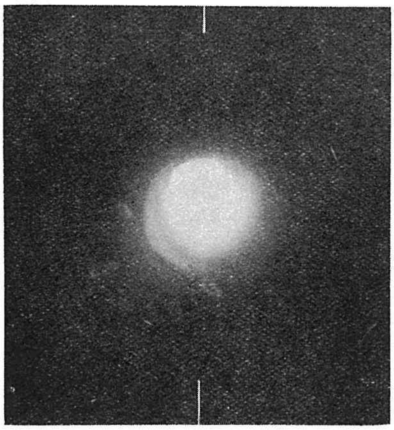
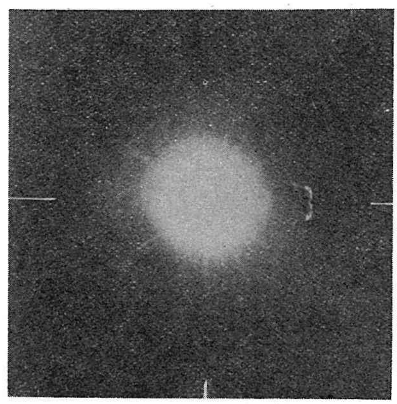


Fig. 1

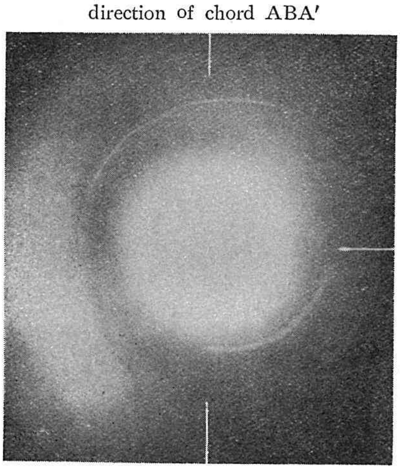
direction of chord ABA′



axis of bending

Fig. 2

direction of chord ABA′



direction of radius of curvature

Fig. 3

axis of wire

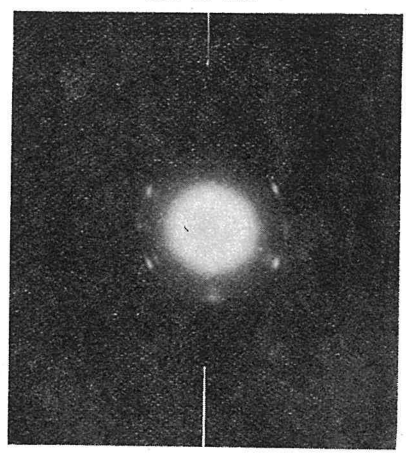
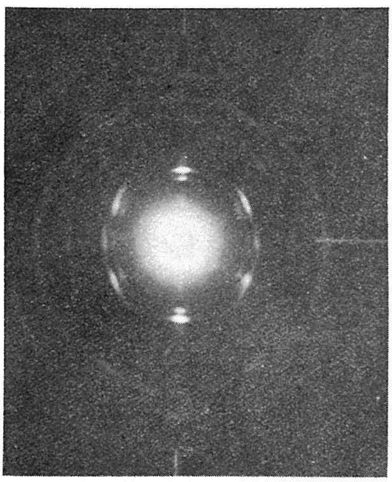


Fig. 4

Plate II

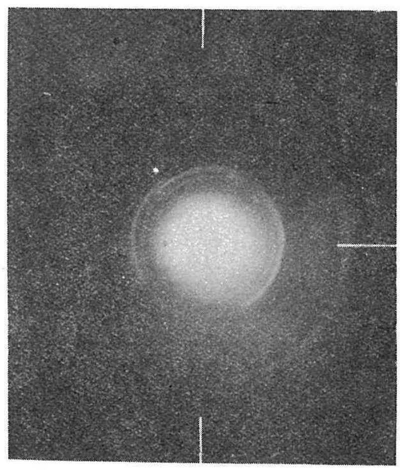
direction of chord ABA′



axis of bending

Fig. 1

direction of chord ABA′



direction of radius of curvature

Fig. 2