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EFFECT OF ROLLING TEMPERATURE ON THE PREFERRED
ORIENTATION IN ROLLED URANIUM RODS

by

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Final Report - Metallurgy Program 4.1.9

Part of this material has appeared in the following reports:

ANL-4923	P 81	Sept. 30, 1952
ANL-4966	P 32	Dec. 31, 1952
ANL-5234	P 44	Dec. 31, 1952

March 1957

Operated by The University of Chicago
under
Contract W-31-109-eng-38

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EFFECT OF ROLLING TEMPERATURE ON THE PREFERRED ORIENTATION IN ROLLED URANIUM RODS

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ABSTRACT

A study has been made of the radial symmetry of the texture produced by two different types of roll passes. A plot of the radial distribution of the (002) poles indicated an asymmetric pattern with the oval, edge-oval pass sequence and a rather uniform distribution of these poles with the hand round roll passes.

A preferred orientation study has also been made of a number of uranium rods rolled at 300°, 400°, 500°, 600° and 640°C whose physical and mechanical properties have been determined. All rods were given a 75% final reduction with either hand round or oval pass roll designs. The orientation study was carried out using the reflection technique with the X-ray diffractometer. The pole charts obtained from these rods indicated that the rods rolled at the lower temperatures showed approximate (010) and (120) components with the (010) predominating. There was a gradual decrease of the (010) component with increasing rolling temperature and a corresponding increase of the (120) component. At the higher temperatures the (120) component shifted to an approximate (110) with a minor (010) component. A study of the texture in these same rods after annealing in the high alpha range showed that the rods rolled at 600° and 640°C showed very little change. There appeared to be little difference in orientation results between the hand round rolled and the oval rolled rods except for the rather high degree of radial asymmetry produced by the oval, edge-oval roll pass sequence.

INTRODUCTION

A previous study⁽¹⁾ indicated that an oval-round pass sequence of the rolls had considerable effect on the radial symmetry of the texture. Therefore, it was of interest to investigate the effect of rolling with the oval-edge-oval pass sequence in which the radial distribution of the applied stress is even more nonuniform, and then to compare the results obtained with hand round type of rolls.

In addition to the determination of the radial symmetry of the texture it was of interest to determine the type of preferred orientation developed in uranium rods rolled with different types of rolls and at various temperatures. This was especially true since previous reports^(2,3) had indicated that there was considerable change in texture by changing the final rolling temperature from 300°C to 600°C.

A number of physical and mechanical properties have been reported⁽⁴⁾ for uranium rods rolled at 300°C, 400°C, 500°C, 600°C and 640°C which

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provided a set of samples for such a study. Since these rods were given a final reduction of 75%, the prior fabrication history should have little or no effect on the final texture. This conclusion is based on a previous report⁽³⁾ which had indicated that a 70% final reduction at a given temperature produced the same preferred orientation regardless of the previous history. Therefore, this set of rods should afford an opportunity to study the change in texture as a function of final rolling temperature in the range of 300°C to 640°C.

PART A - RADIAL SYMMETRY OF ROD TEXTURE

Material Studied

The rolled uranium rods used for the study of radial asymmetry were fabricated from castings made from melted uranium scrap which was bottom poured into MgO-washed, 3" square graphite molds.

The two billets used for the oval, edge-oval sequence of final passes were rough rolled from 3" square to $1\frac{1}{2}$ " diameter at 600°C in open square and hand round passes at a rolling speed of approximately 150 ft/min. Before rolling, the billets were preheated 30 minutes in a Li_2CO_3 - K_2CO_3 bath, and, during rolling, the bars were soaked 5 minutes after every third pass.

Two rods were finish rolled at approximately 300°C with the oval, edge-oval pass rolls at approximately 75 ft/min. Both rods were preheated 20 minutes in oil at 300°C and were soaked 3 minutes after every pass. The positions of the major and minor axes found in the cross sections of these rods were determined by the flat oval passes which occurred just before the final guide round passes. The relative location of these axes in the bar was retained by stopping the bar just before completely going through the final rounding pass rolls. The sequence of passes used in rolling is shown in Tables I and II.

Table I

PASS SEQUENCE FOR $3/4$ " DIAMETER ROD

Rod No.	Pass	Type of Pass	Reduction %
4D-654	A ₁	Flat oval	13
	A ₂	Flat oval	25
	B	Edge oval	16
	C	Flat oval	25
	D	Edge oval	16
	F	Flat oval	10
	J	Guide round	24

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Table II

PASS SEQUENCE FOR 1" DIAMETER ROD

Rod No.	Pass	Type of Pass	Reduction %
4D-621B	A ₁	Flat oval	13
	A ₂	Flat oval	25
	B	Edge oval	16
	E	Flat oval	13
	H	Guide round	14

The hand round rod used for the radial symmetry study was rough rolled in the open square and hand round passes at approximately 300°C with intermediate 600°C anneals. The resulting 1.2-inch diameter rod was then given a final reduction of 59% at 300°C with hand round passes. A section of this rod, which was approximately 3/4" in diameter, was then used for the symmetry study.

Instrument and Method of Study

In order to determine the effect of roll pass design, the symmetry of the texture with respect to the rod axis was made by measuring the intensity of the beam diffracted by the (002) planes around the circumference of the rod. In this method, which was described previously,⁽¹⁾ a short length of the rod is held on the diffractometer in such a way that the cylindrical surface of the specimen touches the focussing circle of the diffractometer and the rod axis is perpendicular to the plane of this circle. The intensity in counts per second is then obtained for the (002) reflection by setting at the proper Bragg angle and rotating the specimen manually at 10° intervals, around 360° of the specimen. This intensity data is then plotted as a function of the circumference around the rod.

Experimental Results

The radial symmetry of the (002) reflection for the 3/4" diameter and 1" diameter rods, which were rolled with the oval, edge-oval pass design rolls, was determined at the surface and at successive layers below the surface. Figure 1 shows the intensity around the circumference of the 1" diameter bar after removing 0.001 - 0.002" by electropolishing. The plot of this intensity forms a "cloverleaf" pattern with the areas of highest intensity approximately 45° to the major and minor axes.

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Approximately $1/8$ " was then removed from the diameter of the same specimen, by machining with light cuts followed by an electropolish in order to remove the cold worked layer from this machining. Intensity data were then obtained for a plot similar to that shown in Fig. 1. This same procedure was repeated several times in order to determine the extent of this "cloverleaf" effect. The results shown in Fig. 1 after the third and fifth machining and electropolishing, respectively, indicate that this lack of radial symmetry apparently extends through the entire diameter of the bar. The low intensity, shown in Fig. 1, from the rod after the initial electropolish may be due to a rougher surface condition. Results similar to those shown above for the 1" diameter rods were also obtained for the $3/4$ " diameter rods.

In contrast to the type of (002) symmetry observed above, the hand round roll pass design produced higher degrees of radial symmetry of the (002) reflection. For example, Fig. 2 shows the (002) intensity around the circumference of a $3/4$ " diameter rod which had been given a 59% final reduction with hand round pass rolls. It can be noted that the intensity distribution is rather uniform. The intensity as plotted in Fig. 2 is somewhat lower than that shown in Fig. 1, which is probably due primarily to the smaller X-ray tube slit used for the hand round rolled rods.

This difference in radial symmetry between the two types of roll pass designs can be accounted for quite easily if consideration is given to the (002) pole figure obtained from rolled uranium sheets.⁽⁵⁾ For the rolled sheet it was found that the (002) pole figure showed maxima approximately 30° - 35° from the center of the pole figure towards the transverse direction. Hence, it would appear that many of (002) planes, in the case of rolled rods, might assume an orientation at an angle to the applied force and parallel to the rolling direction. Therefore, with hand round rolls, since the pressure in rolling is rather uniform around the circumference of the rod, it might be expected that the (002) planes would take a rather uniform distribution around this circumference. However, in the case of rods rolled with the oval, edge-oval rolls, since the applied force is always along two axes 90° to each other during all the passes, it would be expected that the (002) concentration would show four maxima around the rod 90° to each other and displaced from the major and minor axes.

PART B - PREFERRED ORIENTATION OF RODS

Material Studied

A set of uranium rods was fabricated with a 75% final reduction with hand round rolls at each of the following five final rolling temperatures: 300° , 400° , 500° , 600° and 640°C . Another set of rods was prepared under the same conditions except oval, edge-oval roll passes were used for the

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75% final reductions. A portion of each of the above two sets of rods was given an alpha anneal in order to completely recrystallize the material wherever possible. A more detailed description of these rods and their preparation is given in ANL-5296.⁽⁴⁾

Specimen Preparation

Three different sections from each of the rods described above were used in order to obtain sufficient pole intensity data by the Schulz reflection technique for the construction of pole charts. The three sections were cut from the rod so that the plane surfaces of the cross, 45° and longitudinal sections could be said to be formed by rotating a plane surface about an axis perpendicular to the rolling direction and passing through the center of the rod. This is shown in Fig. 3. The sections were cut in this way in order to minimize the effect of asymmetry which might be produced by roll pass design, especially by designs other than hand rounds. It was not possible to cut the sections from the oval, edge-rolled rods in a fixed relationship to the major and minor axes of the rolling ovals since all evidence for these axes disappeared with the final rounding pass.

After cutting each specimen carefully with a cut-off wheel to the correct angle, approximately 0.010" was removed from the plane surface by hand polishing on fine paper. Several thousandths of an inch were then removed by electropolishing in order to remove the last trace of cold work.

Instrument and Method for Studying Preferred Orientation

The data for the pole charts were obtained with an X-ray diffractometer using a Geiger Counter and the modified Schulz device previously described.⁽⁴⁾ Each specimen section, as described above, was mounted and aligned on a scanning table - the cross section on the rotating scanning table and the other two sections on the oscillating table.⁽⁶⁾ Intensity data were then obtained from each section from the (020), (110), (002), (200), (131), (111) and (021) reflections. The cross section of each rod was used to obtain intensity data from 0 to 30° from the rolling direction, a 45° section for the 15° to 65° positions, and a longitudinal section for the 60° to 90° positions. This scheme, as previously used,^(2,3) provided considerable overlap between sections.

The intensity data minus background were then plotted in the form of pole charts, shown in Figs. 4 through 31, in which the intensity is plotted vs. degrees from the rolling direction (ϕ). The intensity at each individual point is not shown in these pole charts due to the large amount of data in each figure. There was no difficulty encountered in drawing smooth curves through the plotted points for the 300°, 400° and 500°C rolled rods; however, considerable bumping of the data was observed with the 600° and 640°C rolled rods due to larger grain size. Therefore, the best curves were drawn for these latter rods as determined by visual inspection of the plotted points.

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It has been recognized for some time that the intensity data obtained for pole charts should be corrected as a function of the angle. Although a rigorous method of correcting has not been found, it has been suggested^(2,7) that pole charts be plotted in terms of $I \cdot \sin \phi$ vs ϕ . This $\sin \phi$ correction appears to be quite good for ϕ angles greater than approximately 20° ; however, for angles less than 20° it becomes inaccurate since the intensity goes to 0 for a ϕ angle of 0° . The pole charts shown in Figs. 4 through 31 are plotted in terms of uncorrected data, since it is still possible to obtain considerable information from these uncorrected curves. For example, it will be shown later that considerable information can be obtained in this present study from the intensity shown at the R.D. on the (020) and (110) pole charts. However, curves corrected for $\sin \phi$ are shown in Figs. 32 through 35 for the (200), since it is a particularly good pole chart for locating intensity maxima for rolled and recrystallized uranium rods, which will be discussed later.

The calculated locations of high intensity areas for certain texture components are indicated on all pole charts by the heavy arrows together with the texture component. It should be kept in mind that all high intensity areas observed on uncorrected curves would be shifted to higher ϕ angles if corrected by the $\sin \phi$ function.

The inability to cut the sections from the rods rolled with the oval, edge-oval pass sequence in reference to the major and minor axes may have had some effect on the relative intensities between the various sets of specimens. For example, one would expect to obtain considerable difference in intensity of the (002) reflection from a longitudinal section cut perpendicular to the major axis and one cut perpendicular to the minor axis, which was discussed under Part A of this report. This may account for some of the peculiar intensity relationships observed between sets of specimens especially in the high angle positions.

EXPERIMENTAL RESULTS - AS ROLLED RODS

(020) Pole Charts

The amount of intensity near the rolling direction, as shown in the (020) pole charts for the hand round rolled rods (Fig. 4), appears to be a function of temperature. The higher the rolling temperature the lower the intensity near the rolling direction, which would indicate a decrease of the approximate (010) component at the higher temperature. Similar results are shown in Fig. 5 for the rods rolled with the oval, edge-oval rolls, although the change of intensity with temperature is not as definite. There is also intensity indicated on these composite pole figures at angles greater than 30° . However, the locations of maximum intensity areas are not clear; therefore, evidence for other components, such as (120) and (110), will be discussed in connection with other pole charts.

(110) Pole Charts

The (110) pole charts for the hand round rolled rods (Fig. 6) show, in general, a steady increase in intensity near the rolling direction with temperature, except for the 500° C rolled rod, which has an unexplained high intensity near the rolling direction. There is also evidence in these pole charts that the intensity from a (120) component steadily decreases with increasing rolling temperature. This is shown by the intensity at a ϕ angle of approximately 80°. The pole charts shown in Fig. 7 for the oval, edge-oval rods indicate a similar trend to that shown in Fig. 6.

(021) Pole Charts

The maximum intensity areas on the (021) pole charts (Figs. 8 and 9) for the 300°, 400° and 500° C rolled rods appear somewhat displaced to the left of the expected positions for (010) and (120) components. However, if a $\sin \phi$ correction were applied, these maxima would coincide quite closely to the expected positions for these two components. Although the intensities obtained for the 600° and 640° C rolled rods indicate a rather wide distribution, as shown in Figs. 8 and 9, if a $\sin \phi$ correction were applied to these curves there would be considerable intensity near $\phi = 70^\circ$, which could be accounted for by a (110) component.

(111) Pole Charts

The plotted intensities shown on the (111) pole charts for both types of rods rolled at 300°, 400° and 500° C, indicate two high intensity areas, one at a ϕ angle of approximately 30° and the other near the region 60°-70° (Figs. 10 and 11). The peak at the lower ϕ angle shows increased intensity with increasing temperature, which can be explained by an increase of the (110) component with the higher rolling temperatures. The peak at the higher ϕ angle appears to shift to a slightly lower angle with increased rolling temperature, which could be due to a decrease in relative amounts of (010) and (120) components and an increase of the (110). This is evident on the hand round rolled rods, but is not as clearly shown on the oval, edge-oval rods.

The rods rolled at 600° and 640° C show even higher intensities in the 20°-30° areas than the rods rolled at lower temperatures which can be accounted for by an increase in the (110) component with these higher rolling temperatures. Since a (110) component should have a maximum at a ϕ angle of 57°, in addition to 27°, there is a general spreading out of the intensity on these pole charts without showing a resolved peak.

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(131) Pole Charts

The (131) pole charts, as shown in Figs. 12 and 13, do not indicate a great deal concerning the texture components present in these rods. This is due primarily to the peculiar bunching together on this pole chart of the expected high intensity locations for the low and high temperature texture components. However, the intensity shown on these pole charts can be quite adequately accounted for by the three previously mentioned texture components; the (010), (120) and (110). It should be kept in mind that the maximum intensity which appears at the rolling direction for some of these rods does not indicate necessarily the presence of a (131) component, since there has been no correction, such as a $\sin \phi$ correction, applied to the (131) intensity as shown on these charts.

(002) Pole Charts

Figures 14 and 15, which are (002) pole charts for these rolled rods, show maximum intensity in a region 80° - 90° from the rolling direction. In some cases the maximum intensity appears at 90° , whereas other pole charts show this maximum displaced towards a slightly lower angle. This shifting of intensity may be accounted for in terms of previously observed⁽³⁾ inverse pole figures for rolled uranium rods. In these inverse pole figures the maximum intensity was sometimes found near the (041) rather than the (010). Since the (041) is approximately 80° from the (001), a maximum might be expected at 80° on a (002) pole chart for such a rod.

The extremely low intensity near the 90° position for the 600° and 640° C oval, edge-oval rolled rods may be due to the nonsymmetry produced by the pass rolls as discussed in Part A of this report.

(200) Pole Charts

Two types of (200) pole charts are shown for these rolled rods. In Figs. 16 and 18 the uncorrected intensity is plotted as a function of ϕ and in Figs. 17 and 19 $I \cdot \sin \phi$ is plotted vs ϕ . All four composite plots show, in general, a decrease of intensity near the 90° position with temperature, which may be explained by a decrease of the (010) component with increasing rolling temperature. The maximum which appears in the vicinity of 45° - 50° in all of the curves for the 300° rolled rods shifts to a lower ϕ angle with increasing temperature. This may be accounted for by a steady decrease of the (120) and a gradual increase of a (110) component. The curves shown in Figs. 17 and 19 show the effect of applying the $\sin \phi$ correction to the intensity. It should be noted that this correction overcorrects the intensity near the rolling direction.

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EXPERIMENTAL RESULTS - ANNEALED RODS

(020) Pole Charts

The (020) pole charts (Fig. 20) for the 300°, 400° and 500° C hand round rolled and annealed rods show a maximum near a ϕ of 20° which may be accounted for by a (140) component. In addition, there is considerable intensity near the rolling direction which may be due to some (010) component remaining in the annealed oval, edge-oval rods rolled at these same temperatures, as shown in Fig. 21. The curves obtained for the 600° and 640° C rolled and annealed rods (Figs. 20 and 21) are practically the same as those obtained for similarly rolled rods without annealing (Figs. 4 and 5).

(110) Pole Charts

A comparison of Fig. 6 and Fig. 22 indicates that, after annealing the 300°, 400° and 500° C round rolled rods, there is a considerable shift in the location of the maximum intensity on the (110) pole charts. This shift may be accounted for by the appearance of an approximately (140) component which develops by recrystallization during annealing. Similar observations were also noted with the oval, edge-oval rods (Figs. 7 and 23); however, there is still considerable intensity near the rolling direction after annealing (Fig. 23), which may indicate partial recrystallization.

The curves as shown in Figs. 22 and 23 for the 600° and 640° C annealed rods do not indicate any significant change from those obtained for the as-rolled rods (Figs. 6 and 7).

(021) Pole Charts

It can be noted from Figs. 24 and 25 that the expected locations for high intensity areas due to (010) and (140) components, indicated by arrows, are too close together to be resolved. Therefore the high intensity areas near 30°-40°, which appear in these two figures of composite pole charts for the 300°, 400° and 500° C rolled and annealed rods, could be accounted for by the presence of either the (010) or the (140) components or both.

Although there was considerable irregularity of the intensity data as obtained for the 600° C and 640° C rods due to large grain size, there is fairly good evidence that there is high intensity near 68° with considerable spread in this area. This high intensity area could be explained by a (110) component. There appears to be rather high intensity at the rolling direction for all of the rolled and annealed oval, edge-oval rods (Fig. 25) which might be due to the presence of considerable unrecrystallized material.

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(111) Pole Charts

The high intensity areas near ϕ angles of 45° and 90° which appear on the (111) pole charts for the three lowest temperature rolled and annealed rods (Figs. 26 and 27) may be accounted for by a (140) component. The considerable intensity spread between these two locations may be due to an (010) component.

The (111) pole charts (Fig. 26) for the annealed rods rolled at 600° and 640° C are quite similar to those obtained for the as-rolled rods (Fig. 10). The intensity observed may be explained by the presence of approximate (110) and (010) components. The results obtained from the annealed 600° and 640° C oval, edge-oval rolled rods are similar except there seems to be considerable intensity near the rolling direction (Fig. 27).

(131) Pole Charts

There is considerable intensity observed near the rolling direction on the (131) pole charts for the three lowest temperature rolled rods (Figs. 28 and 29). This may be due to the presence of an approximate (140) component since the angular distance between the (131) and (140) is only 19.5° . However, it is difficult to determine the exact texture component from the (131) pole chart only, since the highest intensity which appears near the rolling direction must be corrected in some manner similar to the $\sin \phi$ correction.

The (131) pole charts for the 600° and 640° C annealed round rolled rods show considerable intensity in the vicinity of 35° which can be ascribed to a (110) component with some (010). There is also considerable intensity present near the 90° position, which can be due to a (110) component. The variations shown on the (131) for the same type of rods rolled with the oval, edge-oval rolls (Fig. 29) are probably not significant since considerable fluctuation of intensity due to grain size was observed.

(002) Pole Charts

The (002) pole charts (Figs. 30 and 31) for both types of annealed rods appear to be practically the same as those observed previously for these rods in the as-rolled condition (Figs. 14 and 15). This similarity of pole charts is not surprising since all of the texture components ascribed to the rolled or annealed rods require a high intensity area at or near the 90° position on the (002) pole charts.

(200) Pole Charts

Again, as in the case of the as-rolled rods, two different types of plotted (200) pole charts are included. The curves shown in Figs. 32 and 34 were obtained by plotting I vs ϕ , whereas Figs. 33 and 35 show the

curves obtained from the same data by plotting $I \cdot \sin \phi$ vs ϕ . It seems quite evident from these four figures that the texture of the rods originally rolled at 300°, 400° and 500° C and then annealed consists primarily of approximately (140) and (010) texture components.

The texture of rods rolled at 600° and 640° C and then annealed seems to be practically the same as that observed for these rods in the as-rolled condition (Figs. 16 through 19). This similarity of pole charts is not surprising since the two highest rolling temperatures were apparently sufficiently high so that there was no recrystallization as a result of the anneal.

DISCUSSION AND CONCLUSION

The data obtained for the rods rolled at the three lowest temperatures, namely 300°, 400° and 500° C, resulted in smooth curves when plotted as pole charts. However, the data from the rods rolled at the highest temperatures, 600° and 640° C resulted in considerable bumping on the pole chart curves. This latter condition might be expected from the considerably larger grain size produced at these higher rolling temperatures.

The types of textures observed in these rods, both in the as-rolled and in the annealed conditions, also seemed to divide these rods into two categories based on the temperature of rolling as indicated above. The as-rolled texture observed in the group of lower temperature rolled rods can be quite adequately described as consisting of an approximately (010) component together with another component near a (120). The rods rolled at the two higher temperatures seem to show an approximate (110) component together with some (010). The rods rolled at the highest rolling temperature, namely, 640° C, also showed some indication of a spread of the (110) component towards and perhaps including the (100).

Although there is some indication of a rather gradual change in texture as a function of rolling temperature, there appears to be a rather sharp break between the two groups as described above. These observations can be quite clearly seen from the (200) pole charts shown in Figs. 16 through 19.

The preferred orientation determination made on these rods after annealing also indicated that there were two major types of textures after the alpha anneal. The texture found in the rods rolled at the three lowest temperatures could be described as an (010) component with an approximate (140) component (Figs. 32 through 35). This is the typical recrystallization texture reported previously^(2,3) for uranium rods. The texture found in the 600° and 640° C rolled rods after annealing appears to be practically the same as observed in the as-rolled conditions. This lack of change of texture is not surprising since the metallography and other physical properties studies made on these rods did not indicate much change in the 600° and 640° C rods after annealing.

From previous studies⁽³⁾ of the preferred orientation in uranium rods and also from this present investigation it has been found that considerable information concerning the texture can be obtained from the (002) and (200) pole charts only. In studies made of rods which have been given a fairly high reduction, the (002) pole chart indicates that the texture component is usually about 90° from the (001) and can therefore be thought of as corresponding to a pole on the periphery of an (001) standard projection for uranium. The (200) pole chart then becomes an ideal "vantage point" for determining the texture component in terms of poles along the periphery of the (001) projection. These two pole charts also have the advantage that a correction of the intensity, such as the $\sin \phi$ correction, has little or no effect on the (002) pole chart and a minimum effect on the (200). In the (200) pole charts, especially for rods rolled at the lower temperatures, most of the intensity is usually away from the rolling direction and the application of the $\sin \phi$ correction to these curves only shifts the location of the maximum intensities slightly.

In many of the pole charts for the rods rolled with the oval, edge-oval rolls the results were not as self consistent as those obtained for the rods rolled with the hand round rolls. This may be the result of the non-radial symmetry produced by the oval rolls as explained previously.

In general, it may be said that the preferred orientation found in the rods studied in the present investigation was not particularly different from that found previously, however, this study did show the change of texture as a function of rolling temperature and the peculiar asymmetry produced by the oval, edge-oval roll pass design.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. R. M. Mayfield for making available sufficient rod material for carrying out this investigation and to Mr. R. E. Macherey under whose supervision the rods were originally rolled. Thanks are also due to Dr. F. G. Foote and Dr. S. S. Sidhu for their advice and encouragement during this investigation.

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Fig. 1 Radial Intensity of the (002) Reflection from a 1" Round Uranium Rod Rolled in an Oval, Edge-Oval Pass Sequence (Cu K_{α} radiation, using 0.2° Geiger tube slit and 1° X-ray tube slit).

Fig. 2 Radial Intensity of the (002) Reflection from a $3/4$ " Round Uranium Rod Rolled with Hand Round Pass Rolls. ($\text{Cu K}\alpha$ radiation, using 0.2° Geiger tube slit and 0.4° X-ray tube slit).

Fig. 3 Diagram of Method Used for Cutting Samples from Rods for Orientation Study

Fig. 4 (020) Pole Charts for As Rolled Rods Using Hand Round Rolls

Fig. 5 (020) Pole Charts for As Rolled Rods Using Oval, Edge-Oval Rolls

Fig. 6 (110) Pole Charts for As Rolled Rods Using Hand Round Rolls

Fig. 7 (110) Pole Charts for As Rolled Rod Using Oval, Edge-Oval Rolls

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Fig. 8 (021) Pole Charts for As Rolled Rod Using Hand Round Rolls

Fig. 9 (021) Pole Charts for As Rolled Rods Using Oval, Edge-Oval Rolls

Fig. 10 (111) Pole Charts for As Rolled Rods Using Hand Round Rolls

Fig. 11 (111) Pole Charts for As Rolled Rods Using Oval, Edge-Oval Rolls

Fig. 12 (131) Pole Charts for As Rolled Rods Using Hand Round Rolls

Fig. 13 (131) Pole Charts for As Rolled Rods Using Oval, Edge-Oval Rolls

Fig. 16 (200) Pole Charts for As Rolled Rods Using Round Rolls

Fig. 17 (200) Pole Charts for As Rolled Rods Using Round Rolls

Fig. 18 (200) Pole Charts for As Rolled Rods Using Oval, Edge-Oval Rolls

Fig. 19 (200) Charts for As Rolled Rods Using Oval, Edge-Oval Rolls

Fig. 20 (020) Pole Charts for Annealed Rods Using Hand Round Rolls

Fig. 21 (020) Pole Charts for Annealed Rods Using Oval, Edge-Oval Rolls

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Fig. 22 (110) Pole Charts for Annealed Rods Using Hand Round Rolls

Fig. 23 (110) Pole Charts for Annealed Rods Using Oval, Edge-Oval Rolls

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Fig. 24 (021) Pole Charts for Annealed Rods Using Hand Round Rolls

Fig. 25 (021) Pole Charts for Annealed Rods Using Oval, Edge-Oval Rolls

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Fig. 28 (131) Pole Charts for Annealed Rods Using Hand Round Rolls

Fig. 29 (131) Pole Charts for Annealed Rods Using Oval, Edge-Oval Rolls

Fig. 32 (200) Pole Charts for Annealed Rods Using Hand Round Rolls

Fig. 33 (200) Pole Charts for Annealed Rods Using Hand Round Rolls

Fig. 34 (200) Pole Charts for Annealed Rods Using Oval, Edge-Oval Rolls

Fig. 35 (200) Chart for Annealed Rods Using Oval, Edge-Oval Rolls