Tensile Strength and Fracture of Rolled Strips of Molybdenum

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Abstract

The tensile strength of rolled strips of molybdenum, especially in reference to the direction of rolling, was tested by an ordinary tensile testing machine, and their fractures were examined by means of micro-photographs and X-rays.

The tensile strength is seen to differ according to the inclination of the direction of tension to that of the rolling. When the strip is cut thin along the direction of rolling, and the tension is applied in the lengthwise direction of the strip—that is, in the direction parallel to that of rolling—the tensile strength is seen to be greater by about 20% than when the inclination of the direction of tension to that of rolling is 45° and 90°.

Many strips are broken by applying the tension in various directions; and it is inferred, from the direction of the line of fracture, that the break occurs at the atomic planes (211) and (110) of the cubic crystal of molybdenum.

Introduction

In 1923 G. I. Taylor and C. F. Elam[1] studied the distortion of an aluminium crystal during a tensile test. In 1925 they[2] examined the plastic extension and fracture of an Al crystal. Recently tensile tests have been applied to alloy crystals of various metals by C. F. Elam.[3] C. H. Mathewson[4] investigated the plastic deformation of coarse-grained zinc, and he described also the phenomena obtained by stretching single crystals of Zn, with special reference to the direction of rolling in the parent strip and the direction of the slip band. According to Mathewson the manner of the

1 Taylor and Elam; Proc. Roy. Soc., **102**, 643 (1923)
2 Taylor and Elam; Proc. Roy. Soc., **108**, 28 (1925)
3 C. F. Elam; Proc. Roy. Soc., **109**, 143 (1925)
" **115**, 133 (1927)
" **116**, 694 (1927)
4 C. H. Mathewson; The A. Institute of M.M.E., No. 1623, (1927)

breaking caused by tension is different according as the tension is applied in the direction parallel to that of rolling or perpendicular to that direction. This point was examined by preparing specimens cut thin along the direction of rolling and along the direction perpendicular to it. In the former case two (or more) sets of twin bands occurred, and in the later case two different types of failures were found. The first type was due to a simple cleavage of the basal plane, and the second type was due to one set of parallel twin bands thickly covering the surface of the specimen.

In the present experiment the tensile strength of rolled strips of molybdenum, especially in reference to the direction of rolling, which was carried out at room temperature, and the manner of their fractures were examined.

Experimental Method and Results

A. *The specimen*

The specimen now examined was a rolled molybdenum plate which was 0.009 cms. in thickness, 8 cms. in width and 35 cms. in length. It was carefully rolled always in the same direction by the ordinary rolling process. The width of the strips examined was 0.55 cms, and their length varied from 7 to 13 cms. These strips were obtained from the rolled plate above stated by so cutting it in different directions that the lengthwise directions of the strips, that is the direction of the tension to be applied afterwards, made various angles with the direction of rolling; the values of the angles given to various strips represent these angles.

B. *Tensile strength*

The tensile strength of these strips was measured by the usual testing method with an ordinary tensile testing machine. The tensile strengths, in k.g. per mm^2, obtained for various strips are tabulated in Table I, where the values for the strips 0°, 22.5°, 45°, 67.5° & 90° are given in the 2nd, 3rd, 4th, 5th and 6th columns respectively. The mean value for each group of the strips is given at the bottom of each column respectively.

From Table I it can easily be seen that the tensile strength of the rolled strip of molybdenum differs with the direction of the rolling. In the direction parallel to that of rolling it is maximum, and it is minimum in the directions making respectively angles of 45° and 90° with the direction of rolling.

C. *Fracture of the broken strip*

After the tensile strength was measured, photographs of the fractures of the tested specimens were taken from two different directions. First the

Table I

Tensile Strength of Molybdenum Strip in k.g. per mm²

No. of Specimen	Strip 0°	Strip 22.5°	Strip 45°	Strip 67.5°	Strip 90°
1	109.5	106.5	88.8	105.1	80.8
2	114.5	98.8	96.2	91.6	84.6
3	118.8	101.0	93.5	95.1	95.6
4	99.5	102.2	97.6	100.2	95.8
5	108.8	109.9	91.5	100.3	99.2
6	120.0	77.5	97.5	96.0	95.5
7	114.2	105.2	98.8	101.1	93.0
8	120.0	108.2		91.4	97.1
9	113.1			100.4	93.5
10	118.8			97.1	
11	110.2			103.8	
12	118.9			82.3	
Mean Value	113.9	101.2	94.8	97.0	92.8

side view of the edge of the fracture was photographed, and then its end-on view was taken. The magnification of the former was about 13 and that of the latter was about 60.

Some of the photographs thus taken are reproduced in Figs. in Plates I and II, where Figs. 1, 2, 3, 4, and 5 of Plate I are the side view of the edges of the strips 0°, 22.5°, 45°, 67.5° and 90° respectively. Figs. 6 & 7 of Plate I and Figs. 1, 2 & 3 of Plate II are the end-on view of the strips 0°, 22.5°, 45°, 67.5° & 90° respectively.

The angle ψ between the edge of the fracture and the direction of the tension applied, that is length-wise direction of the specimen, was measured for every specimen by the micro-photographs. The angle ε between the two sides forming the wedge of the fracture was also observed by the micro-photographs taken in the end-on direction of the wedge. These results are tabulated in Table II, where the No. of the specimen, which corresponds to that in Table I, is given in the 1st column, and the angle ψ for the strips 0°, 22.5°, 45°, 67.5° and 90° is given in the 2nd, 4th, 6th, 8th and 10th columns respectively. The values of the angle ε are given in the 3rd, 5th, 7th, 9th and 11th columns respectively. In the case of the fracture which is composed of several broken lines as shown schematically in Fig. 1, the angle ψ for each of these broken lines, such as a, b & c are tabulated; and when the value of ψ was greater than $\frac{\pi}{2}$ its supplement is given with negative sign, as shown in Fig. 1. The mean value for each group of the strips is given at the bottom of each column.

Fig. 1

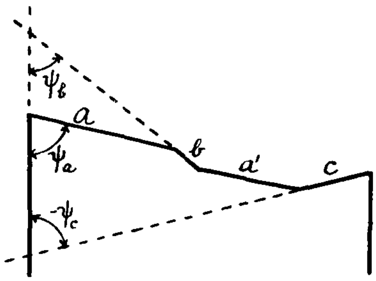


Table II

The Values of ψ and ε, in Degrees

No. of Specimen	Strip 0°		Strip 22.5°		Strip 45°		Strip 67.5°		Strip 90°	
	ψ	ε	ψ	ε	ψ	ε	ψ	ε	ψ	ε
1	68°, 45°	51°	57°	55°	60°	50°	68°	45°	90°	45°
2	66°,-85°	50°	59°	60°	58°	55°	68°	60°	90°	50°
3	70°,-74°	30°	58°	60°	58°	55°	69°	45°	90°	50°
4	78°,-50°	50°	58°	50°	47°	55°	70°	45°	90°	45°
5	70°, 47°	60°	50°	60°	55°	50°	69°	55°	90°	45°
6	66°, 84°	52°	58°	50°	60°	51°	71°	50°	90°	42°
7	66°,-85°	50°	67°	50°	70°	55°	66°	55°	90°	50°
8	70,°47°,-85°	30°	69°	55°			68°	45°	90°	50°
9	77°,-73°	50°					71°	45°	90°	47°
10	66°,-72°	50°					54°	45°	90°	50°
11							68°	50°		
Average	70,° 45,° and 75°	50°	58°	55°	60°	55°	68°	48°	90°	47°

From the photographs shown in Plates I and II, it can be seen that the edges of the fractures are nearly straight lines; and it was confirmed, from photographs taken of many specimens, that the angle ϕ was nearly the same for different specimens belonging to the same kind of the strips. But, strictly speaking, the edge is not exactly straight, and it is composed rather of several broken lines. This tendency seems to be a little more marked in the cases of the strips 0°, 22.5° and 67.5° than in the others.

Lastly it was detected, from the enlarged photographs of the fractures, that the break down of the strips 0°, 22.5° and 45° was preceded by the slips of the crystals. This point was confirmed by projecting a parallel light on the slipped edge, and by detecting the presence of a great number of small metallic parallel planes there. In the cases of the strips 67.5° and 90°, especially in the latter, any trace of the slip of the crystal could scarcely be detected.

D. *X-ray examination of the fracture*

Next, the arrangement of the micro-crystals in some of the specimens was examined by means of the X-ray diffraction patterns which were taken at two different portions of the strip: one at the edge of the fracture, and the other at a portion about 2 mms. from the edge.

The method employed was just the same as in the case[1] of the rolled plates of tungsten and molybdenum. A Coolidge X-ray tube with molybdenum target was used, and the current passed through and the voltage applied were 10 milliamperes and about 40 K.V.s respectively. Generally the flat surface of the strip was set perpendicularly to the narrow beam of the X-rays. Some of the X-ray photographs thus taken are reproduced in Figs. 4, 5 and 6, Plate II.

Discussion of the Results

A. *Arrangements of the micro-crystals in the rolled molybdenum strip and at the fracture*

The arrangement of the micro-crystals in a rolled molybdenum strip has already been examined by the writer[2]. When the process of rolling advances always in the same direction, the micro-crystals are arranged in such a manner that one of the atomic planes (110), the diagonal plane, is arranged perpendicularly to the direction of rolling, and the atomic plane

1 T. Fujiwara; Mazda Kenkyu-Jiho **1**, No. 1, (1925)

2 *loc. cit.*

(100) which is perpendicular to the above mentioned diagonal plane is arranged nearly parallel to the surface of the strip. Strictly speaking, however, the orientation of the latter atomic plane is not exactly so for all the micro-crystals, but it takes the orientations rotated by various angles less than about ten degrees around the diagonal axis which is parallel to the direction of rolling.

Some of the photographs thus taken are shown in Plate II. Fig. 4 in Plate II is the diffraction pattern obtained with the original rolled strip. Figs. 5 and 6 in Plate II are those obtained at the edges of the fractures of the strips 0° and 90° respectively.

To make things clearer, the writer has sketched in Figs. 2 and 3, as the typical ones, the distribution of the radiating bands and the intense spots appearing in all the photographs taken. In these sketches the line OA represents the direction parallel to that of rolling on the photographic plate, the spots A′, B, C, D, E and F represent the intense spots, and the lines OA′, OB, OC, OD, OE and OF represent the radiating bands.

The sketch given in Fig. 2 represents the diffraction pattern obtained with the original rolled plate, and that given in Fig. 3 shows that obtained at the edges of the fractures of the strips 0°, 22.5° and 45°. By comparing the photographs, it was observed that the diffraction pattern obtained at the edges of the fracture with strips 67.5° and 90°, was nearly the same as that obtained with the original rolled plate; and that it was slightly modified with strips 0°, 22.5° and 45°, as shown in Fig. 3.

The only clear difference which we can recognize between Figs. 2 and

Fig. 2

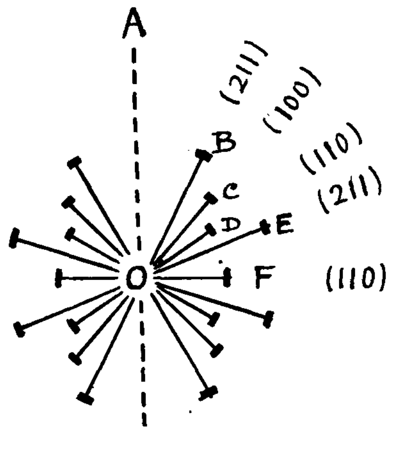
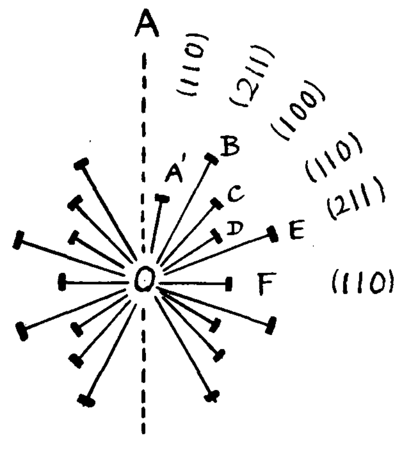
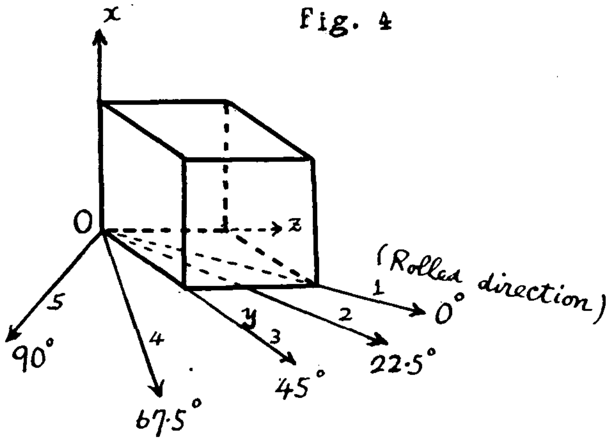


Fig. 3



3, is that a new-radiating band OA′ due to the atomic plane (110) is added in Fig. 3 to the radiating bands shown in Fig. 2, in the direction making the angle of 10^0 to OA. This fact indicates that the micro-crystals at the edges of the fractures of strips 0°, 22.5° and 45° are so rearranged, by the fracture, that the atomic plane (110), which was previously perpendicular to the direction of rolling, now deviates from the former orientation by various angles less than about 10^0. This is consistent with the occurrence of the preliminary slip of the crystals, at the fracture of strips 0°, 22.5° and 45°, previous to the rupture of the strips.

Fig. 4



B. Fracture of the broken strips

As was stated before, the micro-crystals in a rolled strip of molybdenum are arranged nearly in the same orientation. Thus if we assume that the orientation of all of them is exactly the ideal one described before, then the direction of the tension applied to various kinds of the strips, in reference to the crystallographic axes, will be such as is represented in Fig.4. It is already known that the slip occurs along the atomic plane (110) or (211)[1] in the case of the tungsten crystal. Thus it seems not unnatural to suppose that the fracture, in our case, is caused by the slip along the atomic plane (110) or along the atomic plane (211). The orientation of the fracture plane will now be compared with that of the atomic plane (110) or (211), assuming that the direction of the tension applied is such as represented in Fig.4. From the values of ψ given in Table II, which is the angle between the edge of the fracture and the direction of the tension applied, the writer

1 Goucher; phil. Mag., **48**, 800 (1924)

calculated the values of the angle between the edge of the fracture and the diagonal line passing through the origin O of the square in the yz-plane in Fig. 4. This angle is represented by φ, and its values for various kinds of specimens are given in the third column of Table III. The values of ψ and ε in Table II are also included in the same table.

If the fracture of the specimen is caused by the slip along the atomic planes (110) and (211) as is assumed above, then the edge of the fracture must be the intersection of any one of these atomic planes with the rolled surface of the strip, that is the yz-plane in Fig. 4. The values of the angle between this intersection and the rolled direction, given in Table III, were calculated by picking out those which are very close to the values of φ for various kinds of strips; the indices of the atomic planes which are responsible respectively for each of these values of φ' are given in the 5th column of the same table. The agreement between the values of φ and φ' must be considered to be entirely satisfactory in this sort of experiment. Thus if our consideration be correct, that the fractures are caused by the slip along the atomic planes having the indices given in the fifth column of Table III, then the angles ε' between these atomic planes and the atomic plane (100), which is parallel to the rolled surface of the specimen, must be equal respectively to the values of ε given in the 4th column of Table III. In the 7th column of the same table, the calculated values of ε' for various atomic planes having the indices given in the 5th column are tabulated.

The atomic planes having the indices given in the 8th column are therefore selected so that the values of ε' are concordant respectively with

Table III

Kind of strip	ψ in degrees	φ in degrees	ε in degrees	Indices of the atomic plane	φ' in degrees	ε' in degrees	Indices of the atomic plane by which the fracture is caused
Strip 0°	70° 45° -75°	70° 45° -75°	50° 40° 50°	(121) (110) or (101) (112)	72° 45° -72°	53° 37° 53°	(121), (112), and (110) or (101)
Strip 22.5°	58°	35.5°	55°	(110)	45°	54°	(110)
Strip 45°	60°	15°	55°	(121)	18.5°	53°	(121)
Strip 67.5°	68°	0°	48°	(211) (011)	0° 0°	37° 90°	(211)
Strip 90°	90°	0°	47°	(211) (011)	0° 0°	40° 90°	(211)

those of ε, which must be regarded rather as rough estimations. Considering thus, it seems to be convincingly probable that the fracture of the specimens is caused by the slip along the atomic planes tabulated in the 8th column of Table III.

C. Theoretical consideration

When an external force is applied to a crystal and its value reaches a certain amount, the crystal is crushed into microcrystals and they tend to arrange themselves in a certain regular manner.

Now we consider the case of a single crystal which is subjected to a tension. If θ represents the angle between the direction of the tension applied and the normal to a possible slip-plane, η the angle between the projection of the direction of the tension on the slip-plane and a possible direction of the slip in the slip-plane, T the magnitude of the tension applied to the specimen, and A the area of the cross-section of the specimen in the direction perpendicular to that of the tension, then the component τ of the tension along the direction of the slip per unit area of the slip plane will be given by

$$\tau = \left(\frac{T}{A}\right)\cos\theta\sin\theta\cos\eta.$$

As was stated before, the micro-crystals in a rolled strip of molybdenum are arranged nearly in the same orientation, so that it may be regarded as being composed of a single crystal. Thus the writer assumed that the strip is composed of one block of a single crystal, and that the tension is applied to this single crystal in the directions shown in Fig. 4.

According to Goucher's study the slip occurs, in the case of tungsten, in the direction of [111] in the atomic plane (211). In the present case we have observed that the fracture is caused by the slip along some of the atomic planes (211) or (110). Next as to the direction of the slip in the slip planes (211) or (110), the writer examined the direction [111] and various other prominent crystallographic directions, but could not obtain any satisfactory result with any one of these axes. Consequently he disregarded entirely the slip direction, and assumed that the slip occurs with equal ease in all directions in the same slip plane. Thus he calculated the values of $\cos\theta\sin\theta$ for all the atomic planes (211) and (110), and they are given in the tables from IV to VIII. From these tables, the atomic planes which have comparatively large values of $\cos\theta\sin\theta$ are selected, and they are tabulated in Table IX.

Generally the atomic planes which have larger values of $\cos\theta\sin\theta$ are less resistant against the extentional force; consequently if any extentional force be applied to the strip, the atomic planes which are tabulated in Table IX will slip easier than the others, and the strip will be broken along these atomic planes.

In Table IX, the kind of strips is given in the 1st column, comparatively large values of $\cos\theta \sin\theta$ in the 2nd column, and the indices of the atomic planes, to which those values of $\cos\theta \sin\theta$ are due respectively, are given in the 3rd column. The atomic planes whose indices are given in the 4th

Table IV, Strip 0°

Indices of the atomic plane	θ in degrees	$\cos\theta \sin\theta$
$(11\bar{2})$	-73.2°	-0.279
$(1\bar{2}1)$	-73.2°	-0.279
$(\bar{2}11)$	-54.5°	-0.473
$(12\bar{1})$	73.2°	0.279
$(1\bar{1}2)$	73.2°	0.279
(211)	54.5°	0.473
$(\bar{1}21)$	-30°	-0.433
(112)	30°	0.433
$(2\bar{1}1)$	90°	0
(121)	30°	0.433
$(\bar{1}12)$	-30°	-0.433
$(21\bar{1})$	90°	0
(011)	0°	0
$(01\bar{1})$	90°	0
(101)	60°	0.433
$(10\bar{1})$	-60°	-0.433
(110)	60°	0.433
$(1\bar{1}0)$	-60°	-0.433

Table V, Strip 22.5°

Indices of the atomic plane	θ in degrees	$\cos\theta \sin\theta$
$(11\bar{2})$	-86°	-0.070
$(1\bar{2}1)$	-53°	-0.481
$(\bar{2}11)$	-57°	-0.457
$(12\bar{1})$	53°	0.481
$(1\bar{1}2)$	- 86°	-0.070
(211)	57°	0.457
$(\bar{1}21)$	-23.5°	-0.366
(112)	46.5°	0.500
$(2\bar{1}1)$	-77°	-0.219
(121)	23.5°	0.366
$(\bar{1}12)$	-46.5°	-0.500
$(21\bar{1})$	77°	0.219
(011)	24°	0.372
$(01\bar{1})$	66°	0.372
(101)	73°	0.280
$(10\bar{1})$	-73°	-0.280
(110)	48°	0.497
$(1\bar{1}0)$	-48°	-0.497

Table VI, Strip 45°

Indices of the atomic plane	θ in degrees	cosθ sinθ
$(11\bar{2})$	66°	0.372
$(1\bar{2}1)$	-35°	-0.470
$(\bar{2}11)$	-66°	-0.372
$(12\bar{1})$	35°	0.470
$(1\bar{1}2)$	-66°	-0.372
(211)	66°	0.372
$(\bar{1}21)$	-35°	-0.470
(112)	66°	0.372
$(2\bar{1}1)$	-66°	-0.372
(121)	35°	0.470
$(\bar{1}12)$	-66°	-0.372
$(21\bar{1})$	66°	0.372
(011)	45°	0.500
$(01\bar{1})$	45°	0.500
(101)	90°	0
$(10\bar{1})$	90°	0
(110)	45°	0.500
$(1\bar{1}0)$	-45°	-0.500

Table VII, Strip 67.5°

Indices of the atomic plane	θ in degrees	cosθ sinθ
$(11\bar{2})$	46.5°	0.500
$(1\bar{2}1)$	-23.5°	-0.366
$(\bar{2}11)$	-77	-0.219
$(12\bar{1})$	23.5°	0.366
$(1\bar{1}2)$	-46.5°	-0.500
(211)	77°	0.219
$(\bar{1}21)$	-53°	-0.481
(112)	86°	0.070
$(2\bar{1}1)$	-57°	-0.457
(121)	53°	0.481
$(\bar{1}12)$	86°	0.070
$(21\bar{1})$	57°	0.457
(011)	66°	0.372
$(01\bar{1})$	24°	0.372
(101)	73°	0.280
$(10\bar{1})$	73°	0.280
(110)	48°	0.497
$(1\bar{1}0)$	-48°	-0.497

Table VIII, Strip 90°

Indices of the atomic plane	θ in degrees	cosθ sinθ
$(11\bar{2})$	30°	0.433
$(1\bar{2}1)$	−30°	−0.433
$(\bar{2}11)$	90°	0
$(12\bar{1})$	30°	0.433
$(1\bar{1}2)$	−30°	−0.433
(211)	90°	0
$(\bar{1}21)$	−73.2°	−0.279
(112)	−73.2°	−0.279
$(2\bar{1}1)$	−54.5°	−0.473
(121)	73.2°	0.279
$(\bar{1}12)$	73.2°	0.279
$(21\bar{1})$	54.5°	0.473
(011)	90°	0
$(01\bar{1})$	0°	0
(101)	−60°	−0.433
$(10\bar{1})$	60°	0.433
(110)	60°	0.433
$(1\bar{1}0)$	−60°	−0.433

column, are those obtained by the observation of the fractures, and which are already given in Table III. If the atomic planes under consideration have the same absolute value of $\cos\theta \sin\theta$ in Tables IV,V,VI,VII and VIII, the plane which has a positive sign is tabulated in Table IX.

Table IX

Kind of strip	The value of cosθ sinθ	Indices of the atomic plane	Indices of the atomic plane obtained by micro-photos.
Strip 0°	0.473 0.433 0.433	(211) (121) & (112) (110) & (101)	(121) and (110)
Strip 22.5°	0.500 0.481 0.457 0.497	(112) $(12\bar{1})$ (211) (110)	(110)
Strip 45°	0.470 0.500	$(12\bar{1})$ (110) & (011)	$(12\bar{1})$
Strip 67.5°	0.500 0.481 0.457 0.497	$(11\bar{2})$ (121) $(21\bar{1})$ (110)	$(21\bar{1})$
Strip 90°	0.473 0.433 0.433	$(21\bar{1})$ $(11\bar{2})$ & $(12\bar{1})$ (101) & (110)	(211)

From Table IX, we can see that, though the atomic plane which has the largest value of cos θ sin θ among the atomic planes belonging to every kind of strip is not always the fracture plane observed by the micro-photographs, but the fracture planes observed by the micro-photographs have always comparatively large values of cos θ sin θ. Thus we may conclude that the fracture occurred along the atomic planes given in the last column of Table IX because they have comparatively large values of cos θ sin θ. A small discrepancy between the observation and the calculation, as seen in Table IX, must of course be allowed for in this sort of experiment, because the scattering of the orientation of the micro-crystals, and the other factors such as the simultaneous slippings along two atomic planes etc. are entirely ignored in the above calculation.

D. Tensile strength of the strip

As was stated in the preceding paragraph, the extentional force which will be needed to break the crystal is inversely proportional to cos θ sin θ, that is the tensile strength of the strip will depend upon the reciprocal of the value of cos θ sin θ.

Now from the results shown in Table IX the writer calculated the ratio of the value of cos θ sin θ of strip 22.5° to that of strip 0°, and also the ratios of the values of strips 67.5° and 90° to that of strip 45°. The ratios thus obtained are expressed in percentage in the 6th column in Table X, where the kind of strip is given in the 1st column, the indices of the atomic plane along which the slip is occurred in the 2nd column, the value of cos θ sin θ in the 3rd, and its reciprocal in the 4th column respectively. The tensile strength shown in Table I is reproduced in the 5th column, and the ratio of the values of the tensile strength corresponding to the ratio of cos θ sin θ is given in the 7th column of the same table. In the case of strips 45°, 67.5° and 90° the slip-plane is (211), while in the case of strips 0° and 22.5° it is different. This is the reason why the ratios of the tensile strengths and of the values of cosθ sinθ are taken separately in two cases.

It can be clearly seen that the ratios of the values of cosθ sinθ, agree well with those of the tensile strength, thus we can say reversely that the variation in the tensile strength of the rolled strips of molybdenum with reference to the direction of rolling is due to the arrangement of the micro-crystals in the rolled strip. Moreover the fine agreement between the calculation and the observation supports also reversely the considerations assumed in the preceding paragraphs.

Table X

Kind of specimen	Indices of the atomic plane	$\cos\theta \sin\theta$	$\frac{1}{\cos\theta \sin\theta}$	T. S.	Ratio in %	
					$1/(\cos\theta \sin\theta)$	T. S.
0°	(121) or (110)	0.433	2.31	113.9	100	100
22.5°	(110)	0.497	2.01	101.2	87.4	89
45°	(121)	0.470	2.13	94.8	100	100
67.5°	(211)	0.457	2.19	97.0	103	102
90°	(211)	0.473	2.11	92.8	99.1	98.0

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

Fig. 1, Strip 0°

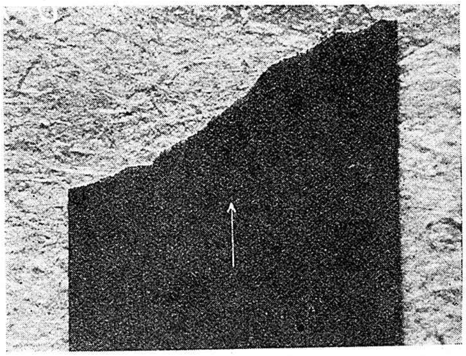


Fig. 2, Strip 22.5°

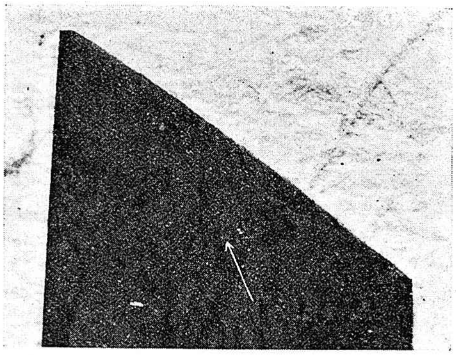


Fig. 3, Strip 45°

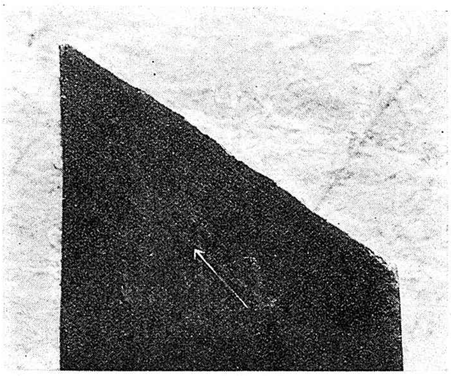


Fig. 4, Strip 67.5°

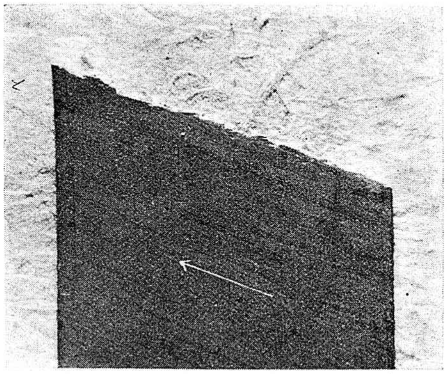


Fig. 5, Strip 90°

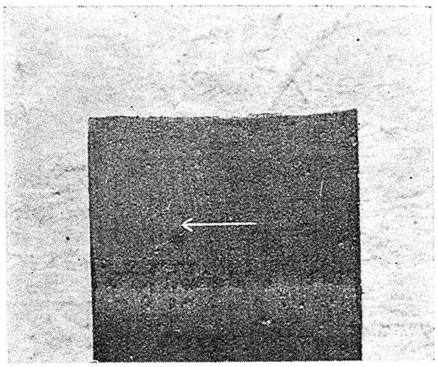


Fig. 6, Strip 0°

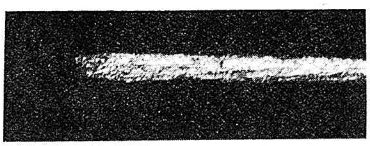


Fig. 7, Strip 22.5°

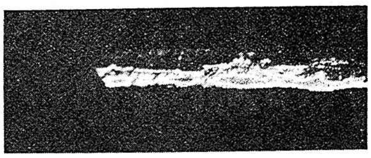


Plate II

Fig. 1, Strip 45°

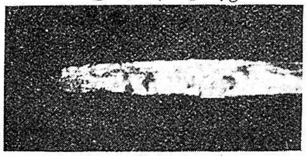


Fig. 2, Strip 67.5°

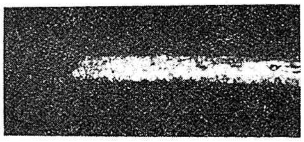
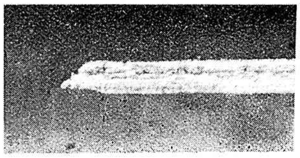


Fig. 3, Strip 90°



X-Ray Photographs of the Strip

Fig. 4,
Strip 0° (original)

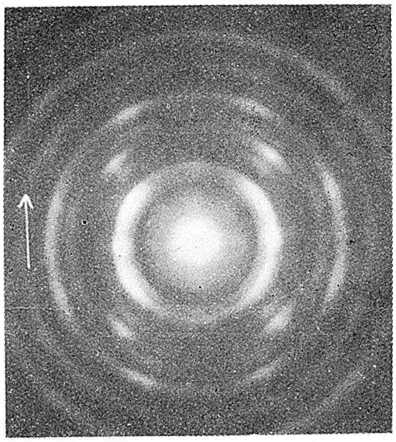


Fig. 5,
Strip 0° (tested)

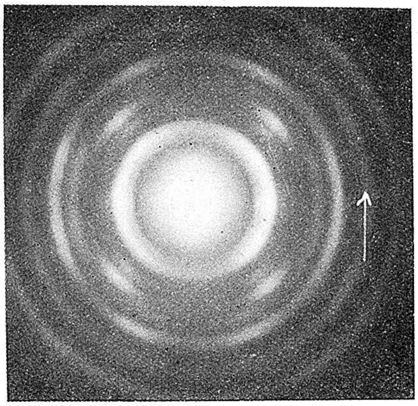


Fig. 6,
Strip 90° (tested)