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THE STRENGTH AND HARDNESS RELATIONSHIPS, AND CHARACTERISTIC PROPERTIES OF SINGLE HEAT-TREATED PLAIN-CARBON BOLTS

Thesis for the Degree of Met. E.
MICHIGAN STATE COLLEGE

Andrew N. Hoover

1939

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THESIS

INTRODUCTION

While working in the Heat Treat Department of the Olds Motor Works Division of General Motors at Lansing, Michigan, during the years 1934-1935, I first became interested in the subject of bolts. This interest grew in intensity later when I transferred to the Metallurgical Laboratory in October of 1935. The country at that time was emerging from a bad depression, which had necessitated many improvements in the manufacture of steel as well as in the processes of forming products from the steel. The development of the bolt manufacturing processes enabled the companies to furnish bolts which were superior to any heretofore made, without the use of the expensive alloys. In 1938 this enabled my company alone to use fifty different sizes and shapes of plain carbon bolts as they were furnished by the bolt manufacturers.

As the bolts, of the latest method of single heat treatment, have been on the market for only a short time, little or no data is available on their strength and hardness characteristics. So we in the laboratory are metallurgically interested in the bolts as they are used, and run routine checks on all bolts used, in the vital parts of the automobile. There seems to be a very wide disagreement between the strength of the bolt actually pulled in a tensile test and the strength as it could be approximated from a Brinell hardness test on the head. This apparent discrepancy challenged attention and a serious attempt has been made for the past fifteen months to analyze this, so as to reconcile the two sets of results, and to determine the best and most reliable routine test for plain carbon bolts. This thesis is the summation of the work done, the results observed, and the conclusions reached.

HISTORY

The ordinary bolts, as one casually buys them in the nearest "dime store", have a very interesting historical record, as have many other articles we use today. There is no definite record of the first use of a bolt as this piece of machinery is used today, and it is generally conceded that bolts as such have been used for untold thousands of years. Prior to 1300 B. C., only six iron articles are definitely proven to have existed. Two of these were of meteoric iron. By 1000 B. C., iron was being made regularly and used for various instruments of war and for crude tools. There are various records of the advancement of the iron refining processes through the ages, among which are a cast chain used in a bridge in Japan, built 70 A. D. Casting processes continued to develop slowly throughout the European countries, mainly through the pressure for the production of war materials, and iron utensils became common. In 1643 A. D., the first iron works, in what is now the United States, were established in Lynn, Massachusetts. Less than one hundred years ago, the first machine-made bolt was turned out in this country. Previous to this time, nothing but strictly hand-forged bolts had been used anywhere.

History shows that about the year 1550, the first screw threads were cut with an implement somewhat resembling our present day file. This method was greatly improved by having the shank of the bolt revolve and holding a thin, notched blade against it, thereby cutting the threads. About 1830 Thomas Oliver, of Staffordshire, England, developed a crude bolt-forging machine which has always been known to the industry as the "English Oliver", and occupies a conspicuous place in the history of bolt and nut making. His was strictly a hot forging process, the bellows being pumped by a boy hired for that purpose. The boy used up his spare time on the bellows by helping to operate the forging machine.

The American pioneer was Micah Rugg, a country blacksmith. Mr. Rugg lived in the small village of Marion, Southington Township, Connecticut. His contribution consisted of a heading machine coupled with a machine for trimming the forged head. The patents on these machines were received from the United States Patent office by Mr. Rugg in 1842. Micah Rugg took into partnership one Martin Barnes, to form the firm of Rugg & Barnes. In the year 1843 the first bolts and nuts manufactured for trade in America, were turned out by this firm. As an improvement over the system as used by the "English Oliver", this firm used a Treadmill propelled by a strong bull to furnish its power for the bellows blowing to maintain the heat necessary for the forging operation. With this power, six men were employed to produce on the average of five hundred bolts per day. (As time went on, other firms were formed, and many years later a considerable percentage of the bolt manufacturers could trace their lineage directly to the Southington Valley in Connecticut).

The most common bolt of the period was the 5/16 x 3 carriage bolt which sold for $33 per 1000 bolts.(1)

Directly following this period, there came a deluge of inventions. Improved quality and workmanship were coupled with the new and ingenuous continuous headers, roll threaders, automatic screw machines, automatic tappers and threaders, and other improvements over a long period of years -- until in 1921 many plants in the United States were producing over 1,000,000 bolts with nuts in one day's production. The same size bolts which formerly sold for $33 per 1000 now sold for $7.50 per 1000 (based on $42 steel).(2)

Previous to the time of the Civil War, practically all of the bolts made were from square stock. The neck of the bolt was left intact, the head was forged, and the shank was rounded and threaded to the required length. William J. Clark, about 1860, brought to the public use a method of forging bolts from round stock.

Up to this time apparently no effort had been made to standardize any heat treating practises. Very few bolts were heat treated and the local blacksmith did the work if heat treating was used. The use of alloys came in very slightly about this time, especially in the tool steels.

In 1862 Siemens invented the open hearth furnace; and with the start of the manufacturing of the soft open hearth

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(1) As to the wages paid, about this time it was recorded that the average workman received One Dollar for twelve hours work.

(2) At this time the average workman got for his days labor, from $6 to $8 for ten hours work.

steel, came the development of the process for cold heading of the smaller sizes of bolts. 1857 saw the firm of Russell, Burdsall & Ward begin the manufacturing of carriage bolts entirely by the cold forging process. They also introduced at this time the common stove bolts with shaved and slotted heads.

Development of inventions was rapid after the Civil War. In the following years the manufacturer was taxed to the limit to supply for the designing engineer the intricate shapes and sizes which he desired. And the World War did much to complicate the problem of the manufacturer. In 1921 the Upson Works of the Bourne Fuller Co. had 30,000 different dies for forging, trimming, and threading, none of which were duplicates or were considered entirely obsolete.

Until the year 1900 practically all of the larger sizes of bolts were made from wrought iron bars. During the period 1900 - 1922, there was a gradual change from wrought iron stock to the newer open hearth steel. By 1922 practically all bolts, regardless of size, were made from steel rather than iron.

The automobile industry greatly accelerated the purchases of bolts for widespread manufacturing use and let to a much greater demand upon the firms producing them. Thread-rolling machines came more and more into use to replace the much slower and more costly turning lathes. Previous to 1915 there were 240 thread rolling machines in use in the United States plants. In 1925 there were in use 880 machines, or an increase of 365%.

During this same period the thread cutting machines increased from 2085 in 1915 to 2432 in 1925, or an increase of only 16.6%. This shows the great trend to the more speedy and cheaper processes.

The development of alloy steel for general use had much to do with the heat treated, high-strength, bolts we see in use today. These bolts were generally adopted by the automobile manufacturers because of their lightness of weight, for the strength produced, resistance to severe shock, their resistance to corrosion, their resistance to fatigue, and their susceptibility to heat treatment. At the present time practically all alloy bolts are heat treated.

There are in the neighborhood of 550 bolts in every automobile. Oldsmobile sent 185,000 cars or more off the end of the assembly line in one season. It will readily be seen that ample material has been available for this study and that such conclusions as have been reached are founded on many tests.

Present Methods of Manufacture

The modern method of cold heading practise was accelerated by the demand for smoother shanks, more accurately maintained, and free from scale, all secured by the methods to be described in the following pages. This fact seems to be rather well known; The greater the fineness of grain a structure possesses, the greater is the capacity for deformation of the metal. With the recent practise of controlling the grain size of steel sold, no risk is being taken by the bolt manufacturer as to whether the metal will cold work or not. The stock used by the bolt maker is standard hot-rolled bar, easily obtained to close specifications: Chemical analysis, size, grain size, and freedom from surface defects.

The wire as it is received passes through three distinct stages before it is formed into bolts. First, the wire is pickled in a solution of sulphuric acid to remove the hot-rolling scale. Secondly, it is washed in water, then dipped in a hot solution of slaked lime. Thirdly, the wire is drawn through cold-drawing dies to the desired size for further forming into bolts. These drawing dies are greased with various substances; notably, aluminum stearate, soluble oil, and grease. These dies reduce the diameter of the wire from 15% to 30%, depending on the size of bolt to be made.

There are two main methods of manufacture in use at the present time, namely: Single extrusion double blow headed, and double extrusion, single blow headed.

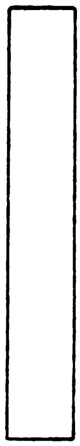
In the Kaufman Single Extrusion process, illustrated by the attached print, wire of the nominal diameter (instead of the pitch diameter) is pushed into the solid heading die and the "tulip" is formed, or coning as it is sometimes called. The head is upset in the usual manner and at the same time the shank is reduced to the pitch diameter for the thread section. By using wire of the nominal size instead of the pitch size, a considerably larger volume of stock may be upset; or for a given head size, less plastic flow of the metal is produced. Experience has shown that the unsupported end, to be upset in double blow heading, should not exceed in length three and one half wire diameters.

The double blow header is built so that the two dies which form the head are set in the same block and the block automatically shifts from one die to the other to make the forming a continuous process. With the later improvements and further developments of the single extrusion process, the double stroke header seems to have reached its limit as regards the amount of stock upset. This, however, may be changed with the possibility of a more plastic stock.

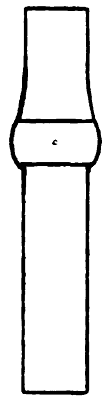
This method of bolt making was a great improvement over the hot forging and thread turning methods of the past. From plain carbon stock, with a single heat treatment, bolts could be made much cleaner, more free from die marks, and visibly stronger.

SINGLE EXTRUDED DOUBLE BLOW HEADED BOLT

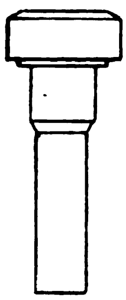
Steps in the Manufacture



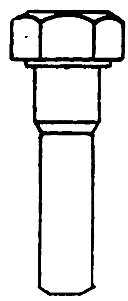
WIRE



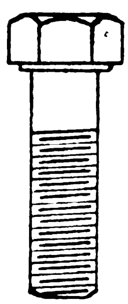
FIRST HEAD BLOW
(Tulipíng)



SECOND HEAD BLOW
AND SHANK EXTRUSION



TRIMMING THE HEAD



FINISHED BOLT

COARSE ETCH ON

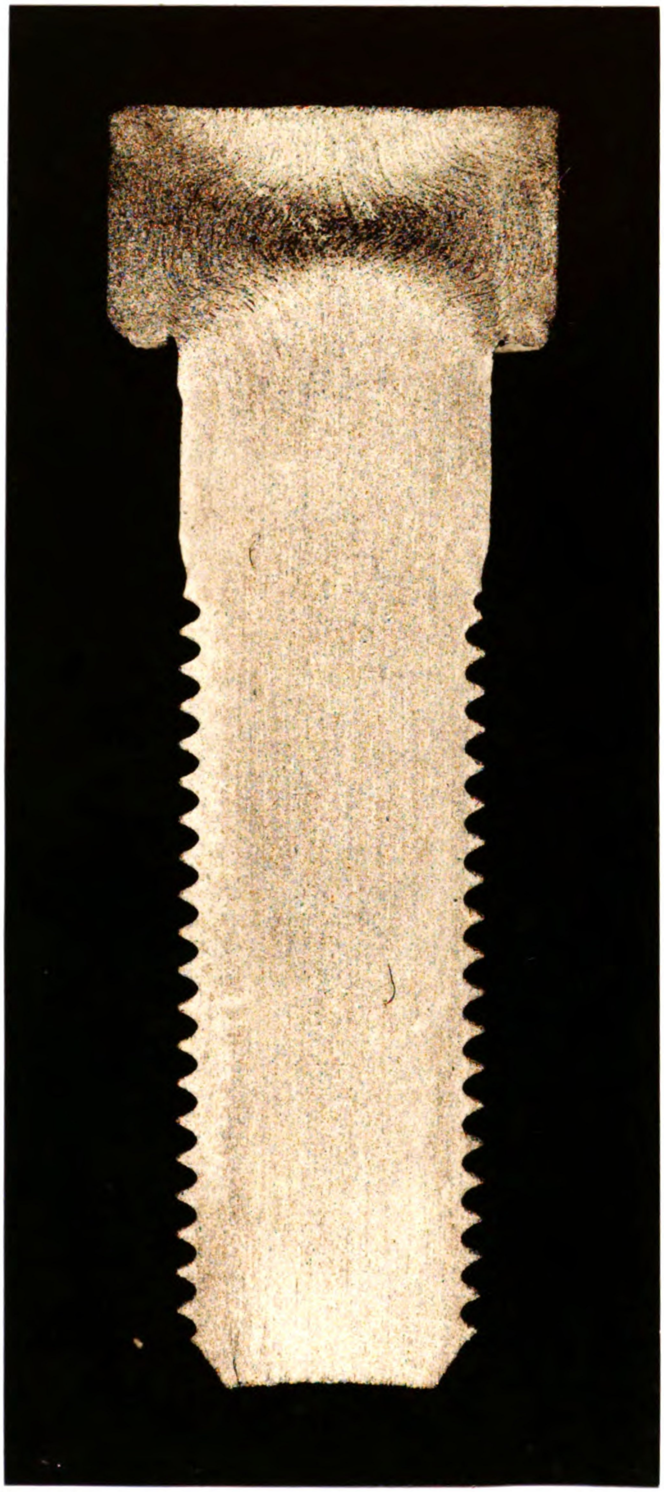
DOUBLE BLOW HEADED,

SINGLE EXTRUDED,

BOLT.

Showing
Work Lines.

X 3.86

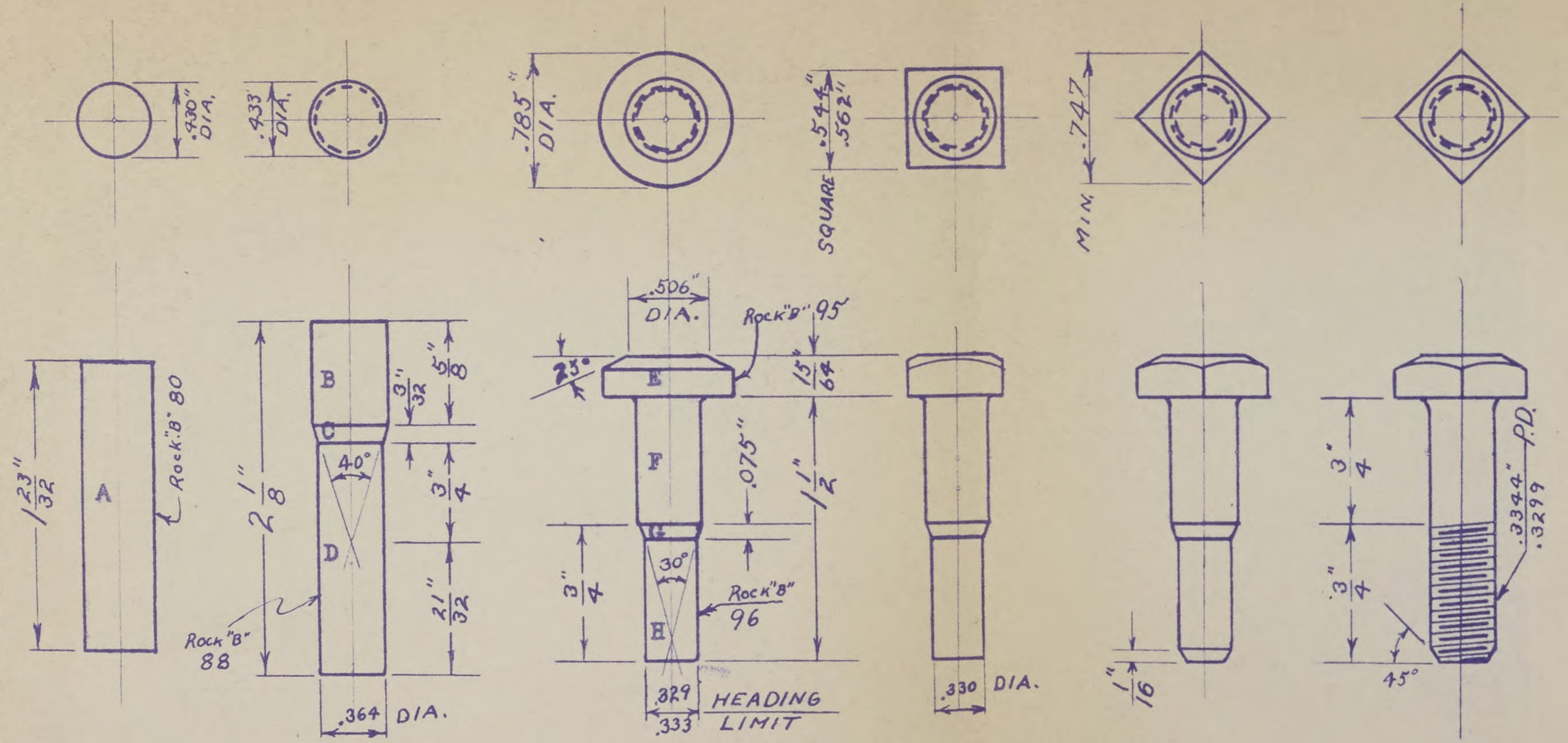


In the Double Extrusion Single Blow Headed process (DEX bolts) more recent developments have brought out the type of a machine known commercially as the Boltmaker. This is a multi-die, single stroke type of machine. It has a wider die space than the ordinary header and a series of dies arranged in a horizontal plane in the bed of the machine, each die being opposed by a heading tool in the slide. Each die is provided with a suitable kick-out pin. The machine is equipped with a transfer mechanism which grips each blank as it is ejected from the die and shifts it to the next die. In this manner a blank is started, a blank is finished, and intermediate blanks are formed in a new die-hammer combination at each stroke. As a result of the development of this machine we had the patenting, by Kaufman and others, of a process known as the "Double Extrusion" method of bolt making.

In the double extrusion process the wire used for the manufacturing is processed the same as that for the single extrusion method inasmuch as it is pickled, washed, and drawn. The wire used for the making of a given size of bolt is usually about one sixteenth of an inch larger in diameter than the shank of the finished bolt. The shank portion is first pushed into an extrusion die and reduced to the nominal diameter. The portion remaining not extruded usually is not longer than two and one half wire diameters. In the next heading station this shank part is again extruded in part or to the length required to be

DEX BOLT

STEPS IN THE MANUFACTURE



I II III IV V VI

Station

Station I:
The Wire Blank, from which the bolt is made, is larger in diameter than the Bolt Shank.

Station II:
The first Extrusion operation extrudes the Shank portion leaving only a short partof the larger diameter, which becomes slightly swelled during the operation.

Station III:
While this Unextruded portion is Headed in one blow without detrimental Fracture of the Grain Structure, a part of the shank is Re-Extruded for the thread portion.

Station IV:
The Head of the Bolt Blank is Trimmed to desired size and shape. The head cannot be knocked off the finished bolt even though Unannealed.

Station V:
The Bolt Blank is Pointed to Facilitate assembly.

Station VI:
The Product will be finished after the thread is Rolled, holding the closest tolerances and having a perfect Form.

Volumetric Analysis of the Operations

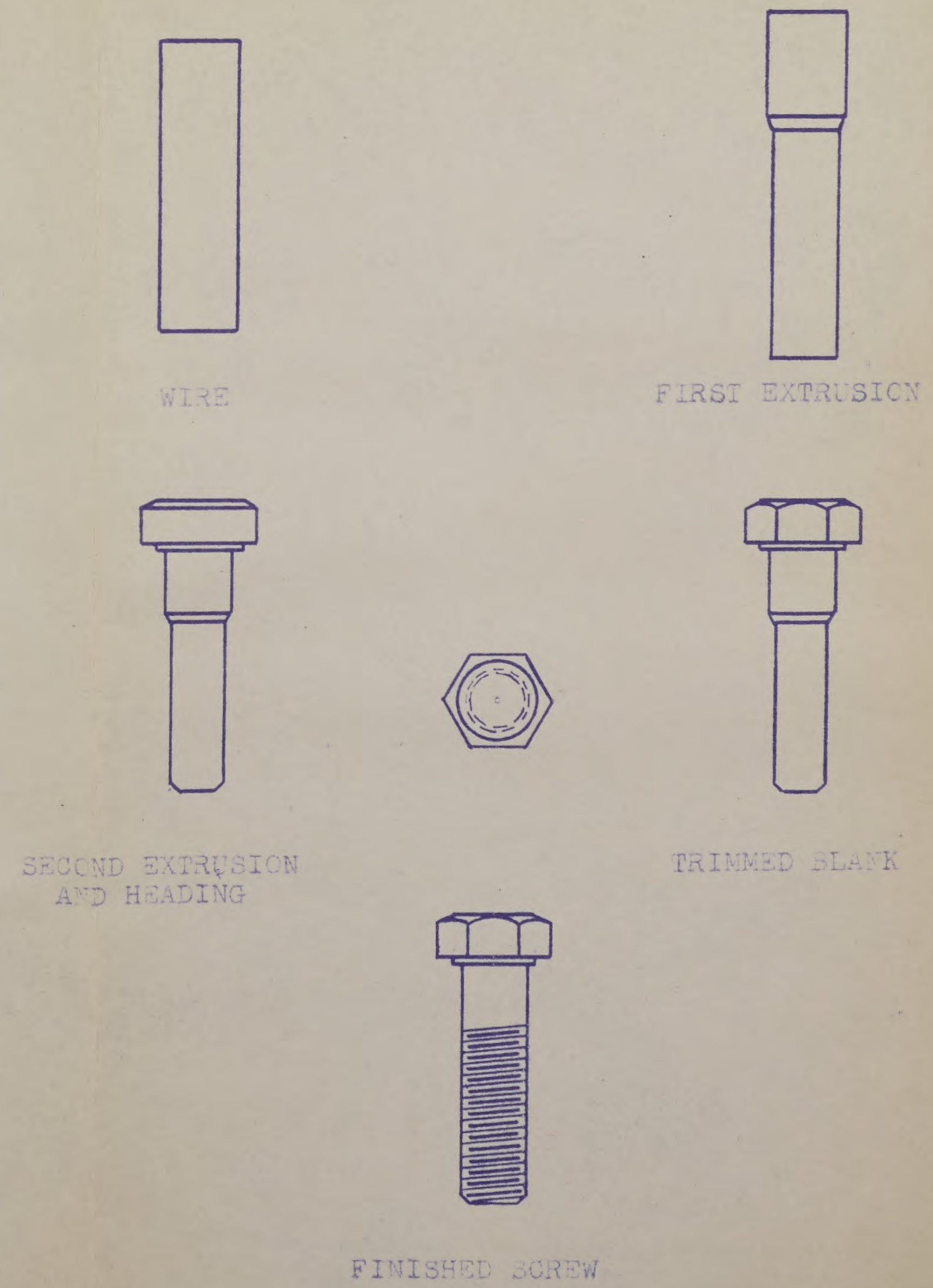
Volume of	A	.2496 Cu. In.
Volume of	B	.0920
" "	C	.0116
" "	D	.1463
Total		.2499 Cu. In.

Volume of	E	.1036 Cu. In.
" "	F	.0807
" "	G	.0072
" "	H	.0578
Total		.2493 Cu. In.

DOUBLE EXTRUDED CAP SCREW

HEX HEAD

Steps in the Manufacture



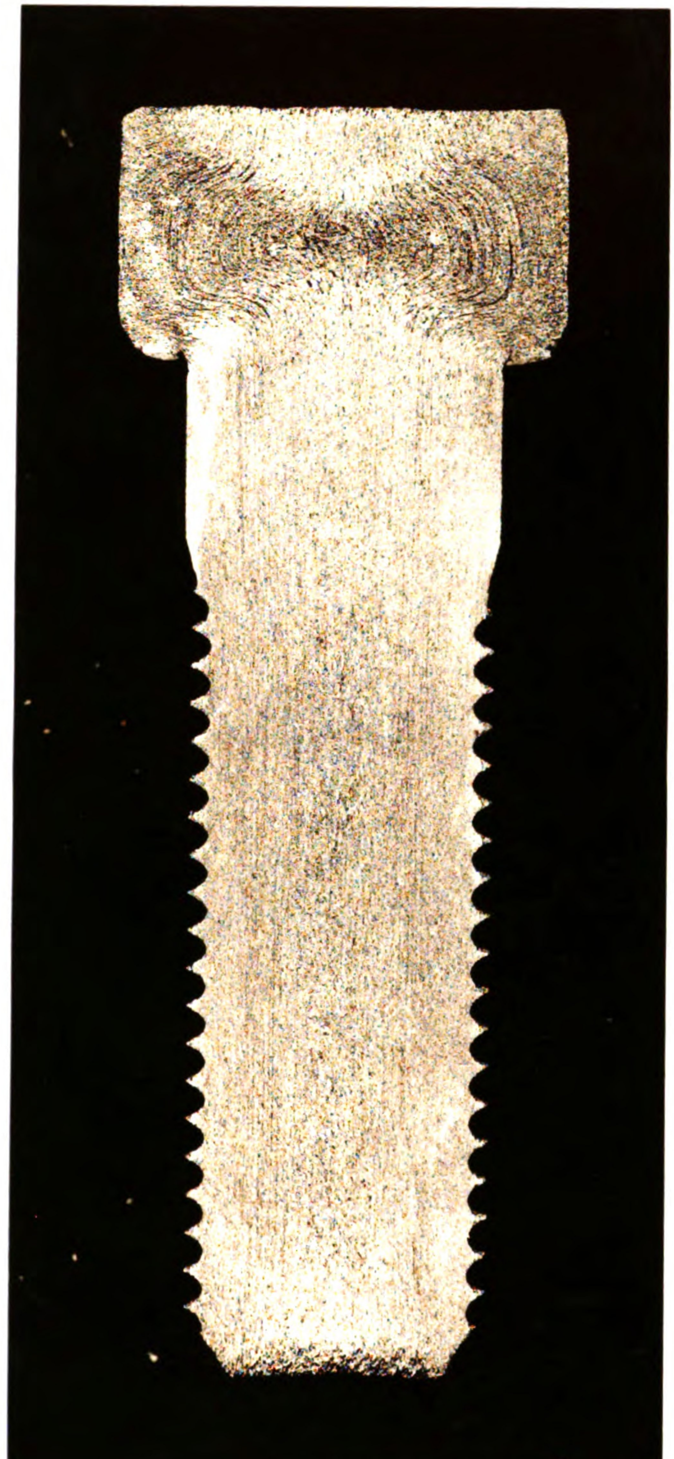
threaded. The diameter is that pitch diameter of the desired thread. The head is upset from the larger end in a single blow and consequently experiences a minimum of cold-working. These steps, together with the dimensional analysis are found on the attached page.

One print shows the process for a square headed bolt, the other for a common hex head bolt.

COARSE ETCH ON
SINGLE BLOW
HEADED, DOUBLE
EXTRUDED BOLT.

Showing
Work Lines.

X 3.86



TESTS

Bolt size--- 3/8-24 x 1 3/8"

Manufactured by Single Extrusion, Double Blow Heading process, all bolts had rolled threads.

Chemical Analysis--

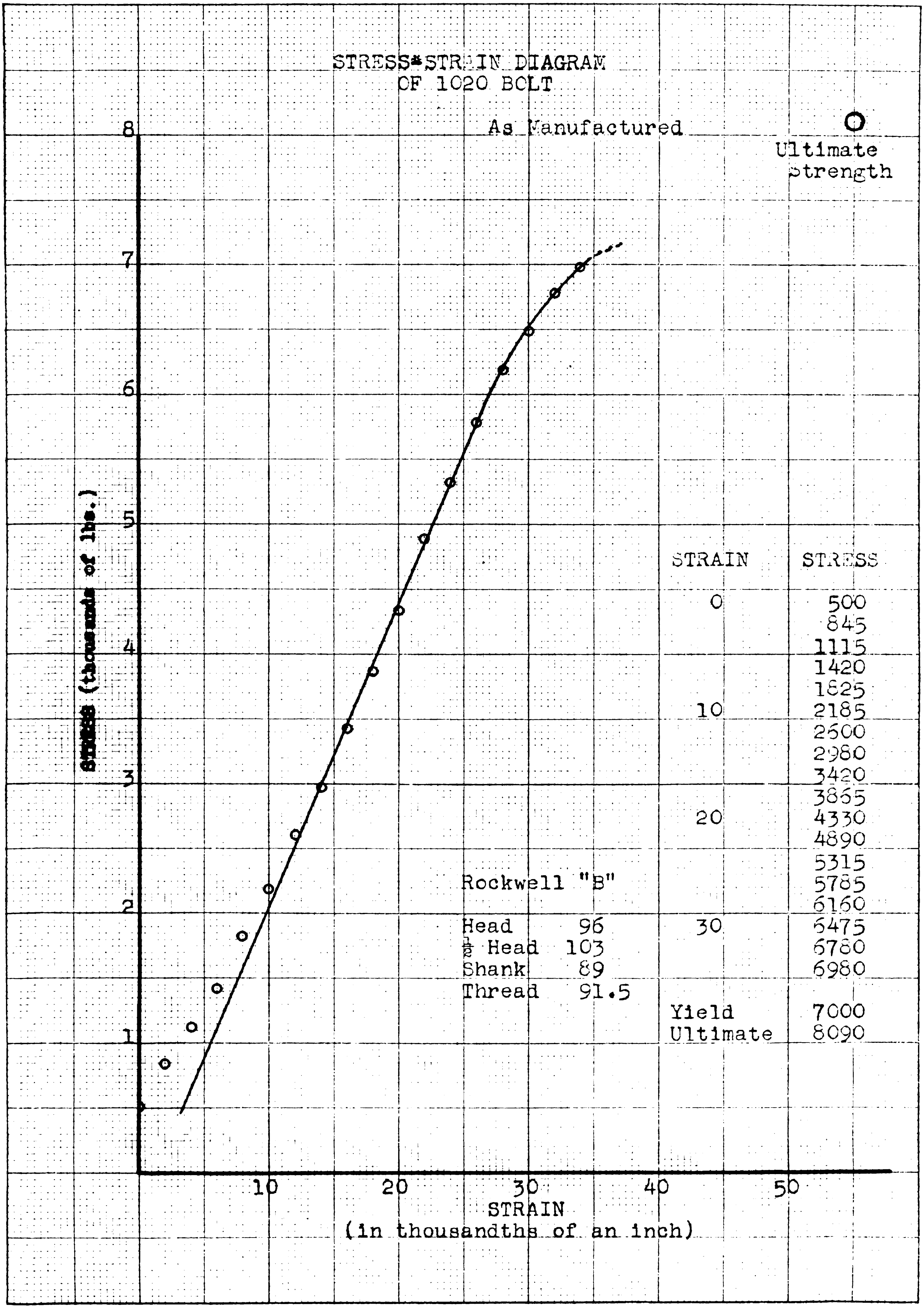
Carbon---	.20%
Manganese--	.53%

Grain Size (McQuaid-Ehn)-- 4-5

Tensile Test-- Pulled at the rate of .12 in. per Min. Pulled on a 30,000 lb. Machine.

Heat treated-- A resistance type of electric furnace was used.
Heat treated at the indicated temperatures, for 45 Min. (total time in the furnace).

Hardness-- This was taken on all transverse sections as specified,.

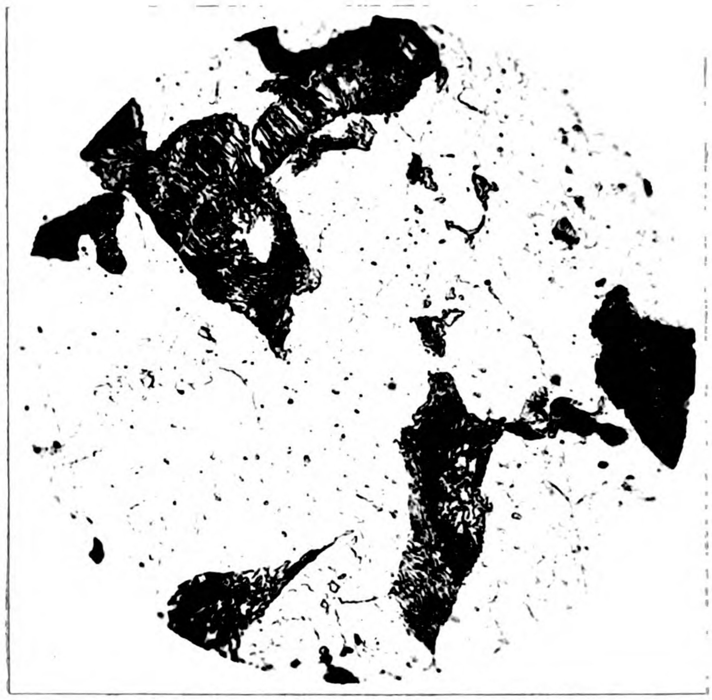


STRESS-STRAIN DIAGRAM
OF 1020 BOLT
As Manufactured
Ultimate Strength
STRESS (thousands of lbs.)
8
7
6
5
4
3
2
1
STRAIN
(in thousandths of an inch)
10
20
30
40
50
STRAIN STRESS
0 500
845
1115
1420
1825
10 2185
2600
2980
3420
3865
20 4330
4890
5315
5785
6160
30 6475
6780
6980
Yield 7000
Ultimate 8090
Rockwell "B"
Head 96
½ Head 103
Shank 89
Thread 91.5

1020 BOLT: HEAD SECTION
Untempered

Cross
Sectional
Grain

X 750



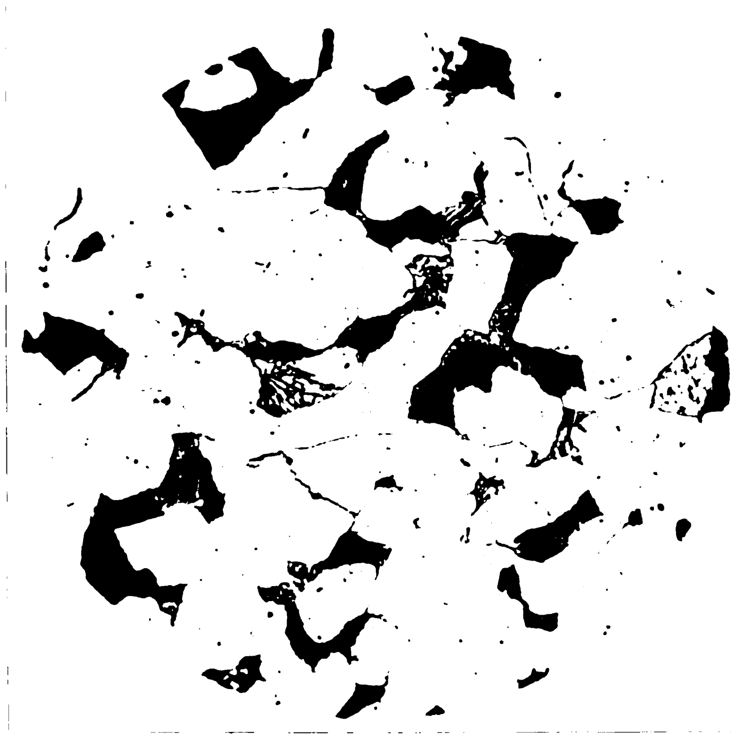
Longitudinal
Grain

X 750

1020 BOLT: SHANK SECTION
Untempered

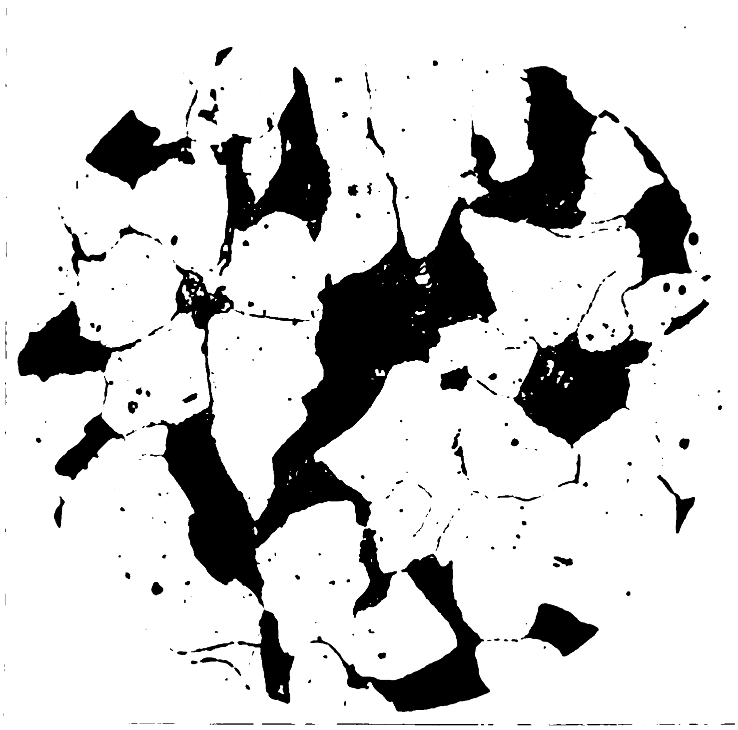
Cross Sectional Grain

X 750



Longitudinal Grain

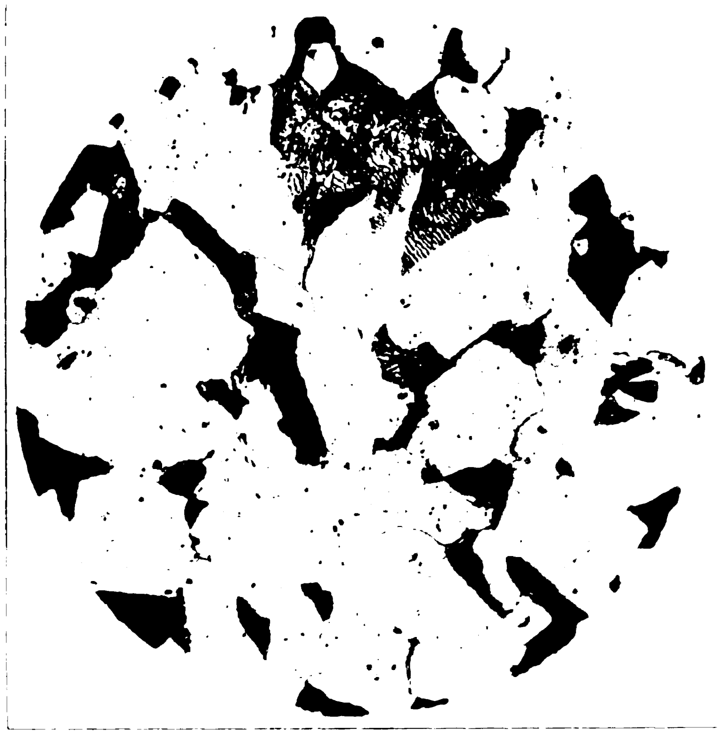
X 750



1020 BOLT: THREAD SECTION
Untempered

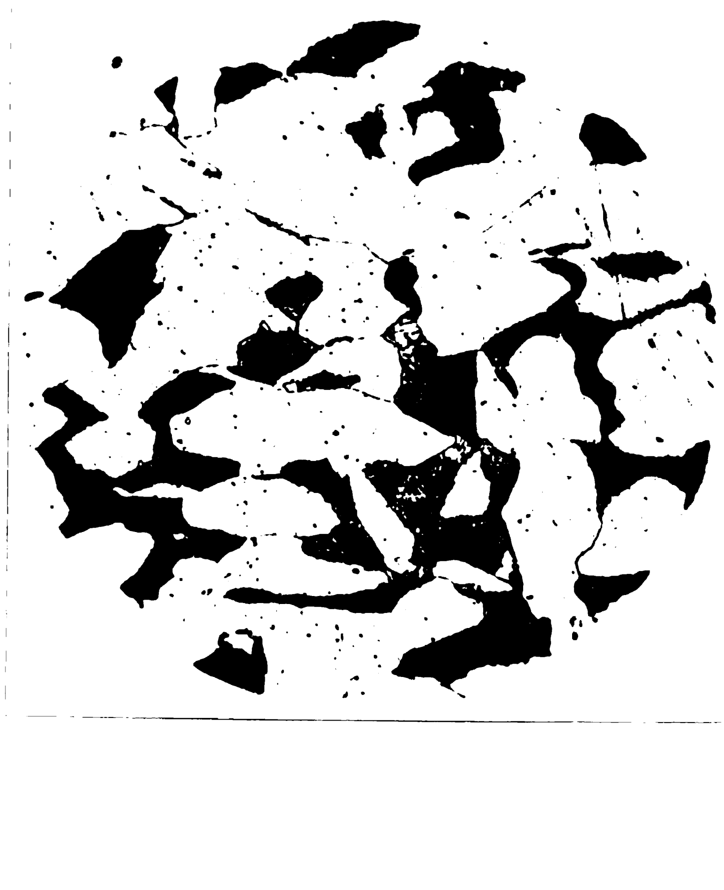
Cross
Sectional
Grain

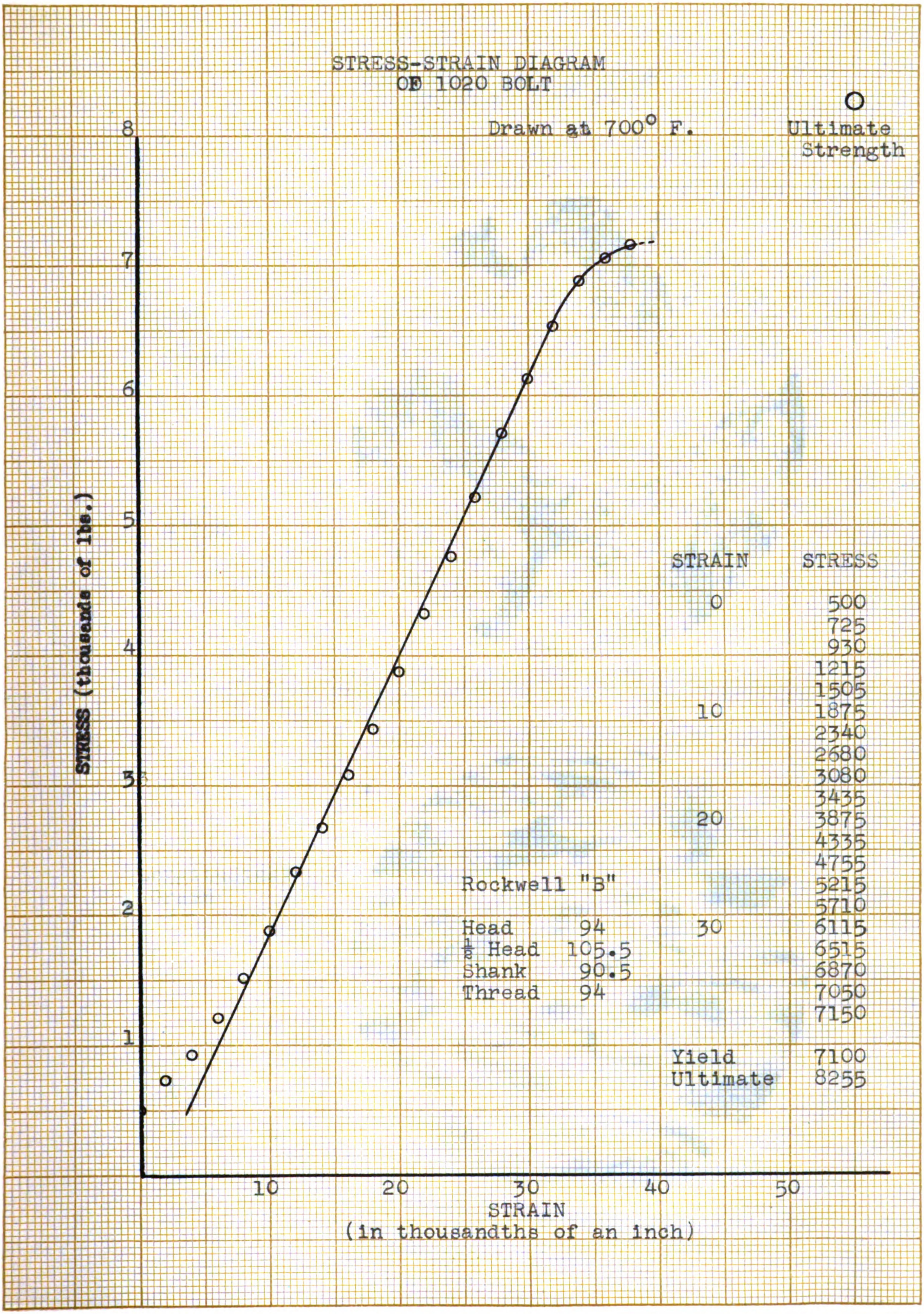
X 750



Longitudinal
Grain

X 750





STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 700° F.
Ultimate Strength
STRESS (thousands of lbs.)
8
7
6
5
4
3
2
1
STRAIN
(in thousandths of an inch)
10
20
30
40
50
STRAIN STRESS
0 500
725
930
1215
1505
10 1875
2340
2680
3080
3435
20 3875
4335
4755
5215
5710
30 6115
6515
6870
7050
7150
Yield 7100
Ultimate 8255
Rockwell "B"
Head 94
½ Head 105.5
Shank 90.5
Thread 94

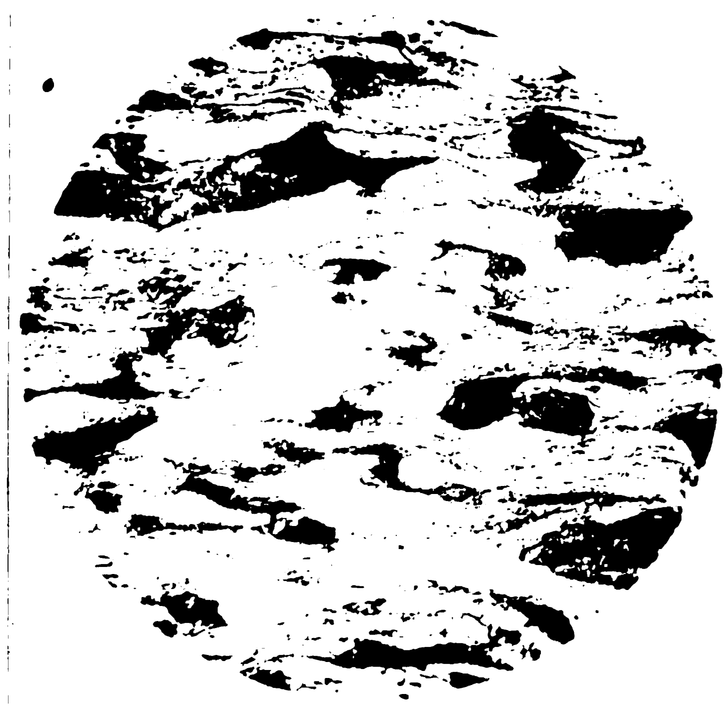
1020 BOLT: HEAD SECTION
Drawn at 700° F.

Cross Sectional Grain

X 750

Longitudinal Grain

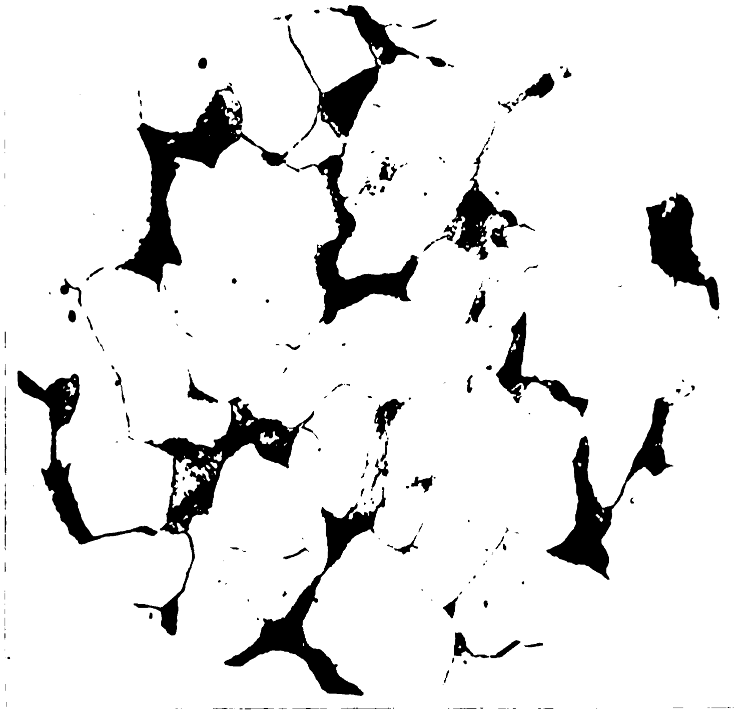
X 750



1020 BOLT: SHANK SECTION
Drawn at 700° F.

Cross
Sectional
Grain

X 750



Longitudinal
Grain

X 750

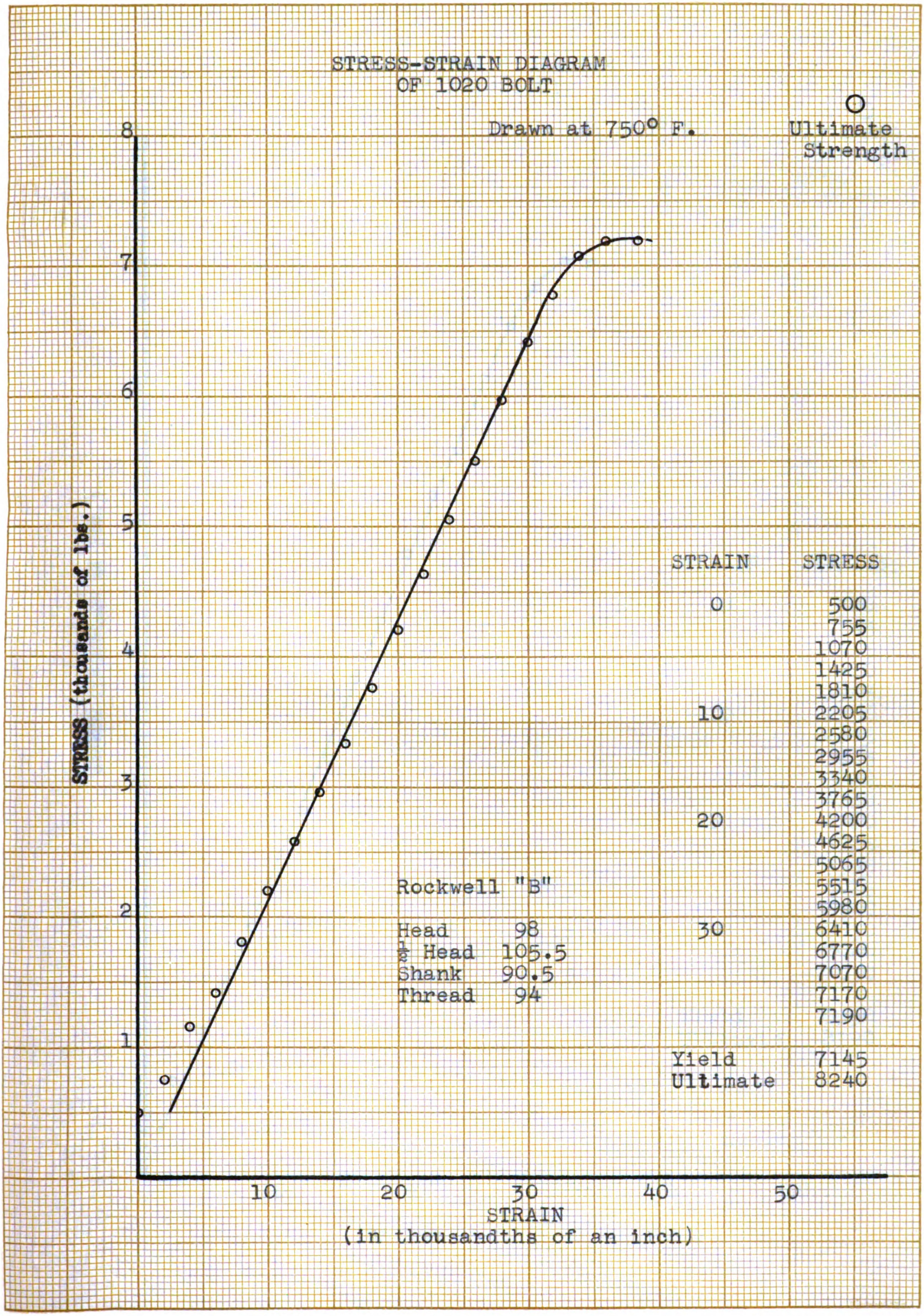
1020 BOLT: THREAD SECTION
Drawn at 700° F.

Cross
Sectional
Grain

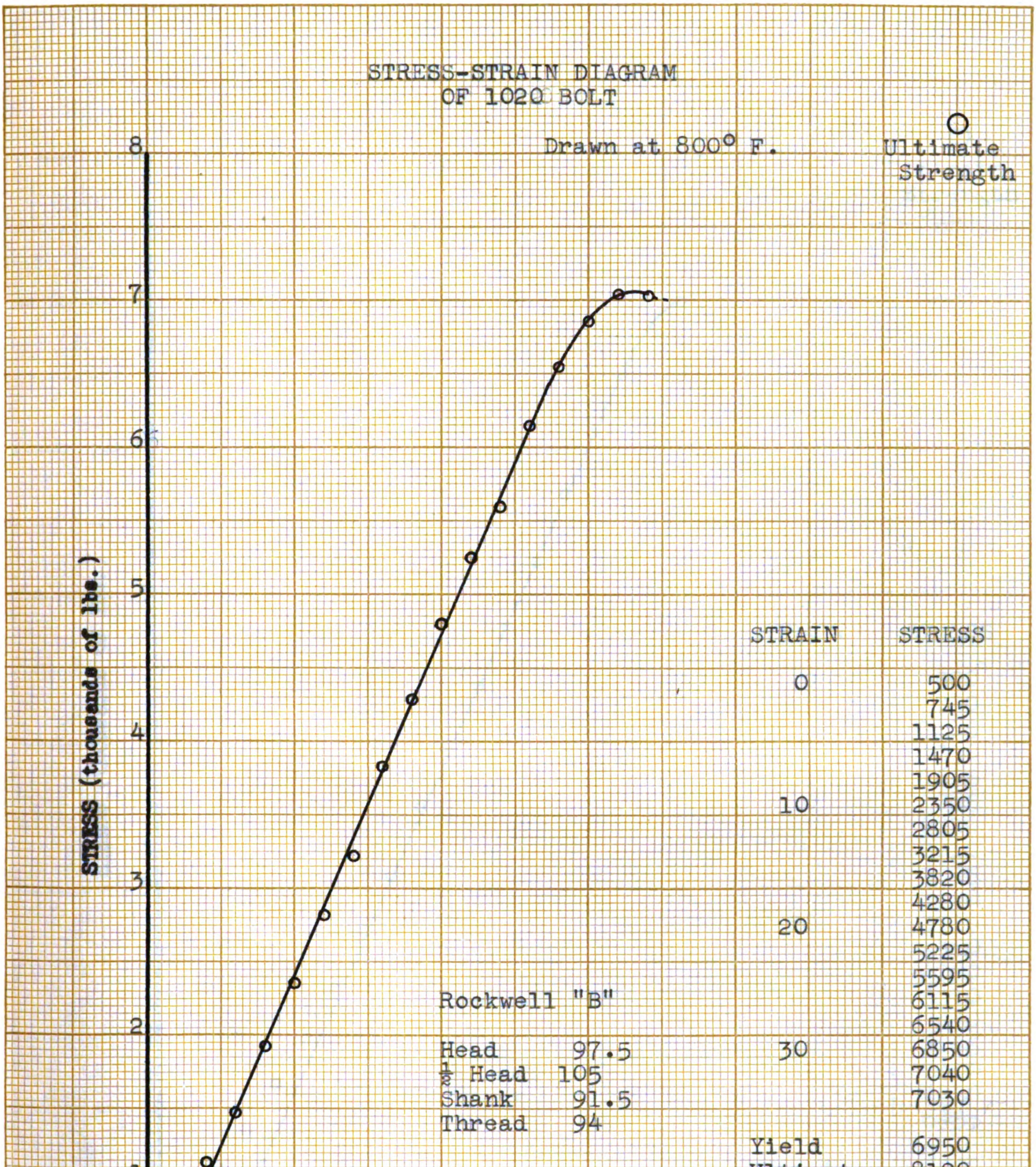
X 750

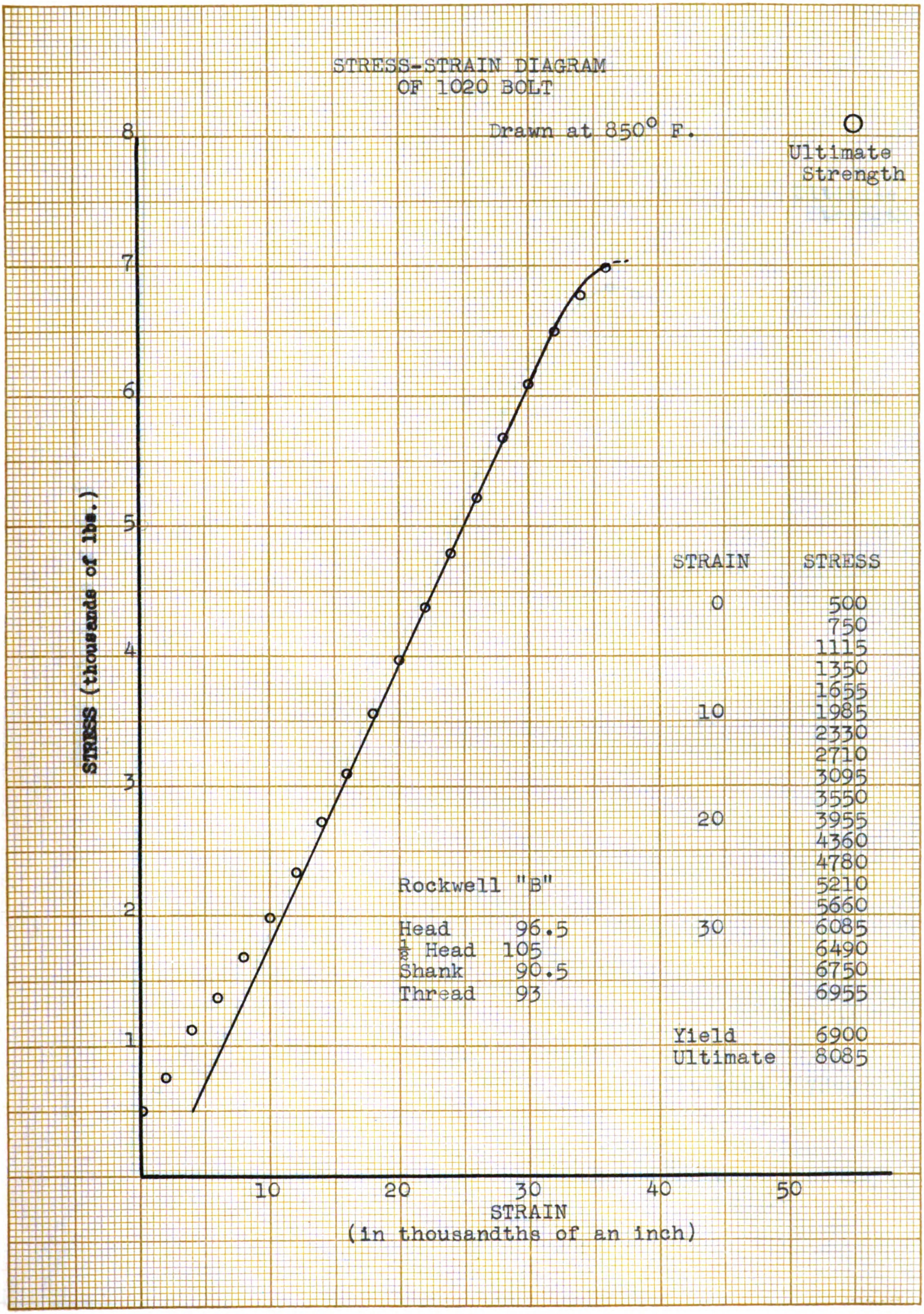
Longitudinal
Grain

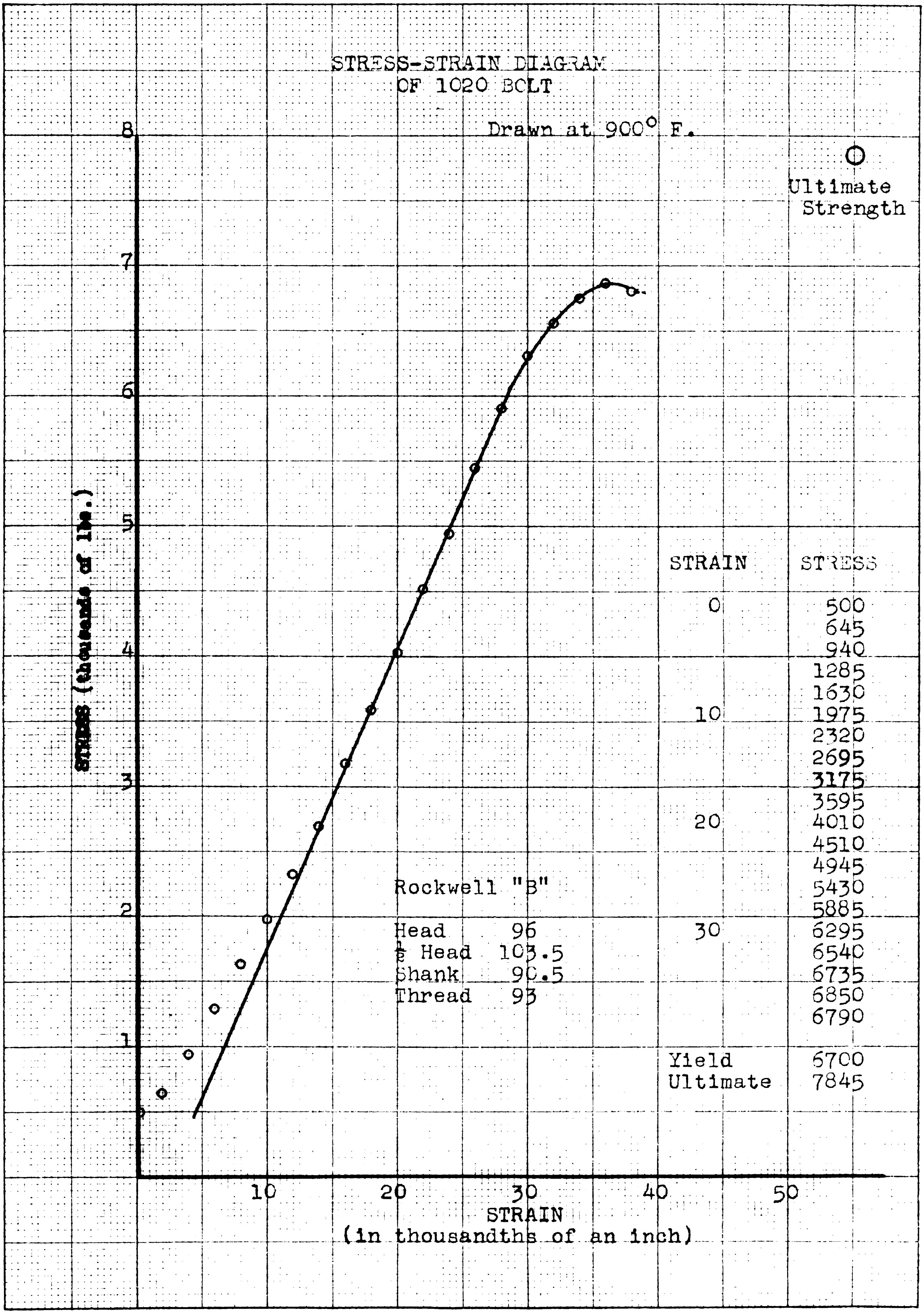
X 750

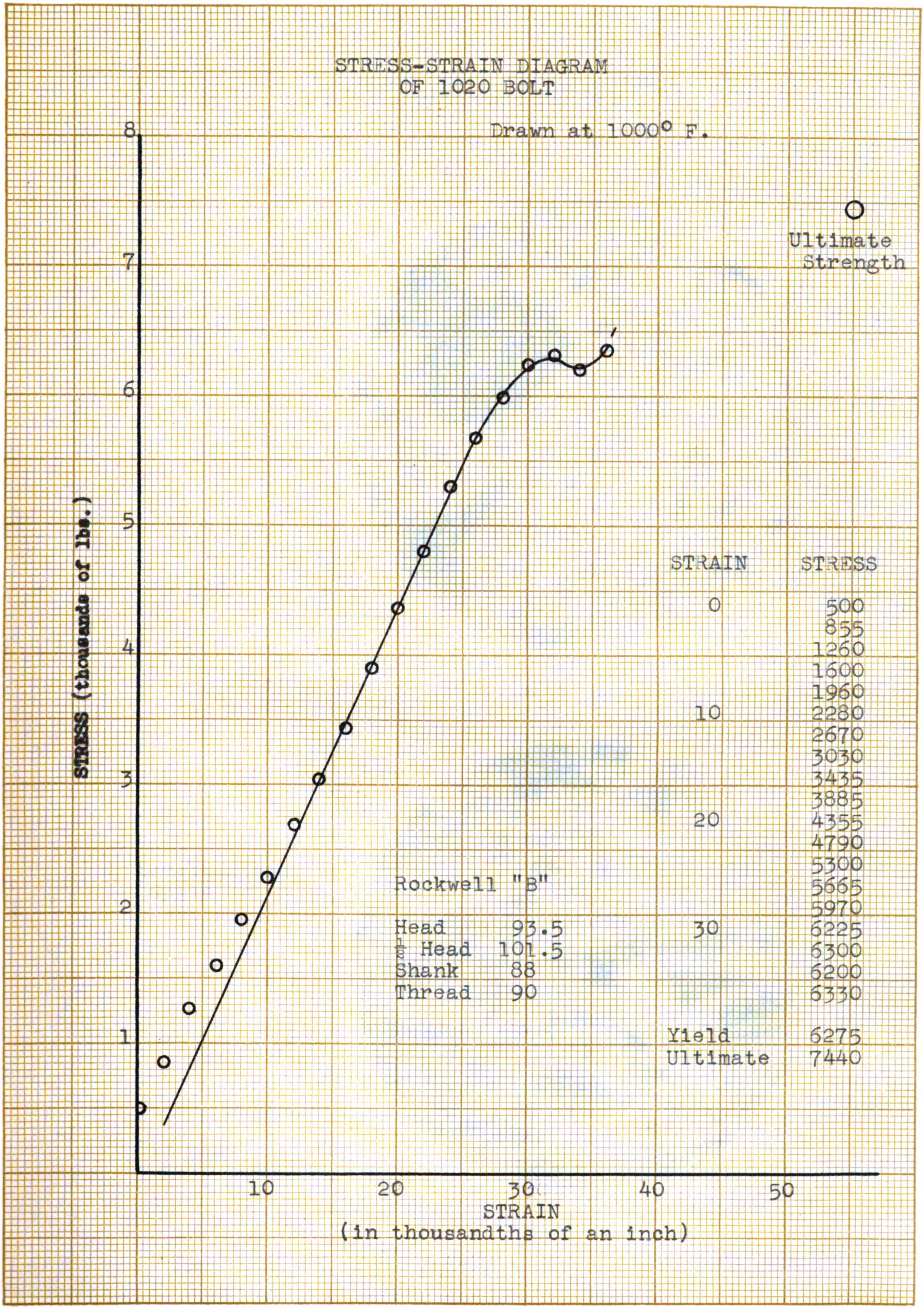


STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 750° F.
Ultimate
Strength
STRESS (thousands of lbs.)
1
2
3
4
5
6
7
8
10
20
30
40
50
STRAIN
(in thousandths of an inch)
Rockwell "B"
Head 98
½ Head 105.5
Shank 90.5
Thread 94
STRAIN STRESS
0 500
755
1070
1425
1810
10 2205
2580
2955
3340
3765
20 4200
4625
5065
5515
5980
30 6410
6770
7070
7170
7190
Yield 7145
Ultimate 8240


STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 800° F.
Ultimate
Strength
STRESS (thousands of lbs.)
1
2
3
4
5
6
7
8
STRAIN
(in thousandths of an inch)
10
20
30
40
50
STRAIN STRESS
0 500
745
1125
1470
1905
10 2350
2805
3215
3820
4280
20 4780
5225
5595
6115
6540
30 6850
7040
7030
Yield 6950
Ultimate 8190
Rockwell "B"
Head 97.5
½ Head 105
Shank 91.5
Thread 94


STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 850° F.
Ultimate Strength
STRESS (thousands of lbs.)
1
2
3
4
5
6
7
8
STRAIN
(in thousandths of an inch)
10
20
30
40
50
Rockwell "B"
Head 96.5
⅛ Head 105
Shank 90.5
Thread 93
STRAIN STRESS
0 500
750
1115
1350
1655
10 1985
2330
2710
3095
3550
20 3955
4360
4780
5210
5660
30 6085
6490
6750
6955
Yield 6900
Ultimate 8085

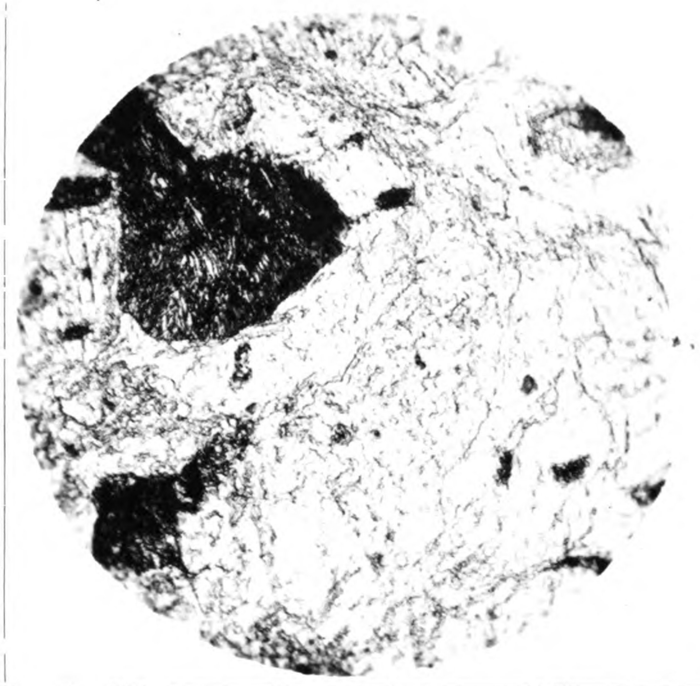

STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 900° F.
Ultimate Strength
STRESS (thousands of lbs.)
8
7
6
5
4
3
2
1
10
20
30
40
50
STRAIN
(in thousandths of an inch)
STRAIN STRESS
0 500
645
940
1285
1630
10 1975
2320
2695
3175
3595
20 4010
4510
4945
5430
5885
30 6295
6540
6735
6850
6790
Yield 6700
Ultimate 7845
Rockwell "B"
Head 96
½ Head 103.5
Shank 90.5
Thread 93


STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 1000° F.
Ultimate
Strength
STRESS (thousands of lbs.)
8
7
6
5
4
3
2
1
10
20
30
40
50
STRAIN
(in thousandths of an inch)
Rockwell "B"
Head 93.5
½ Head 101.5
Shank 88
Thread 90
STRAIN STRESS
0 500
855
1260
1600
1960
10 2280
2670
3030
3435
3885
20 4355
4790
5300
5665
5970
30 6225
6300
6200
6330
Yield 6275
Ultimate 7440

1020 BOLT: HEAD SECTION
Drawn at 1000° F.

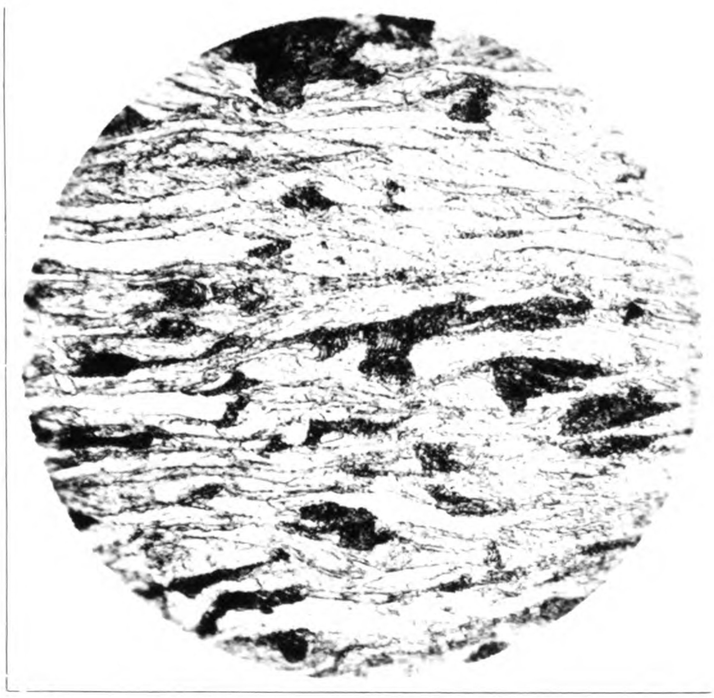
Cross
Sectional
Grain

X 750



Longitudinal
Grain

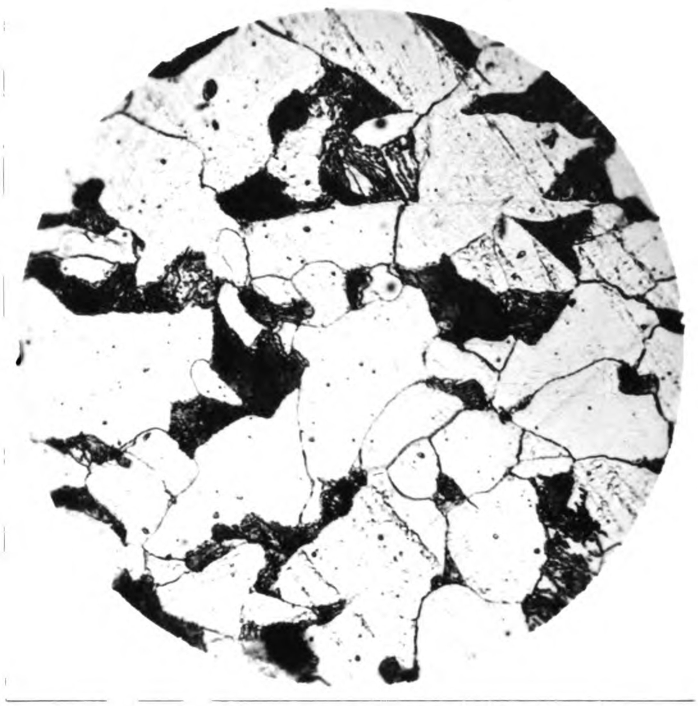
X 750



1020 BOLT: SHANK SECTION
Drawn at 1000° F.

Cross
Sectional
Grain

X 750



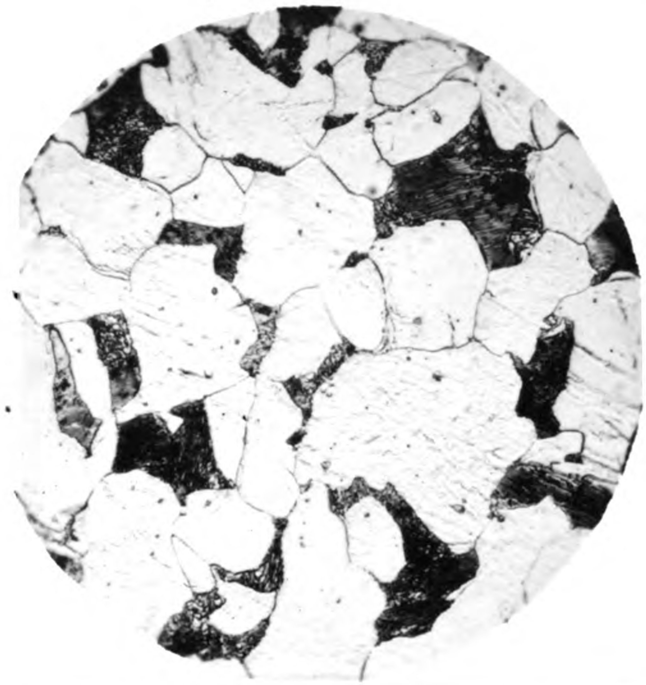
Longitudinal
Grain

X 750

1020 BOLT: THREAD SECTION
Drawn at 1000° F.

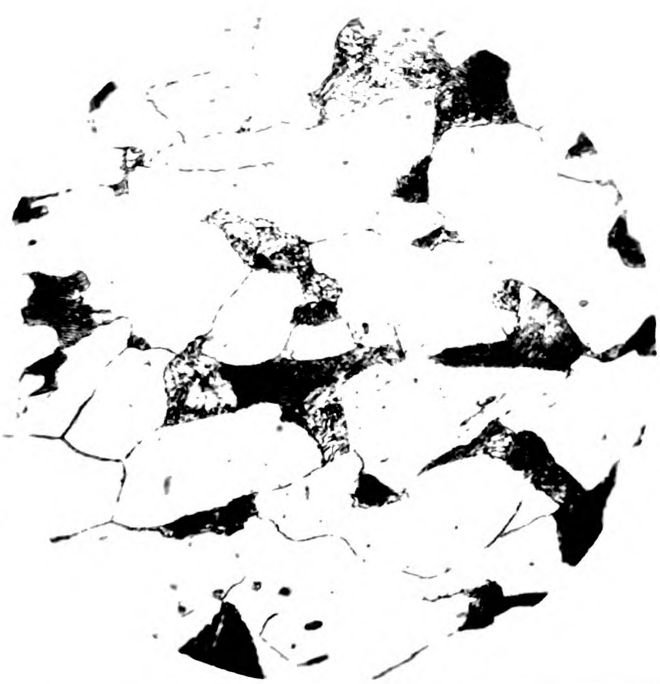
Cross
Sectional
Grain

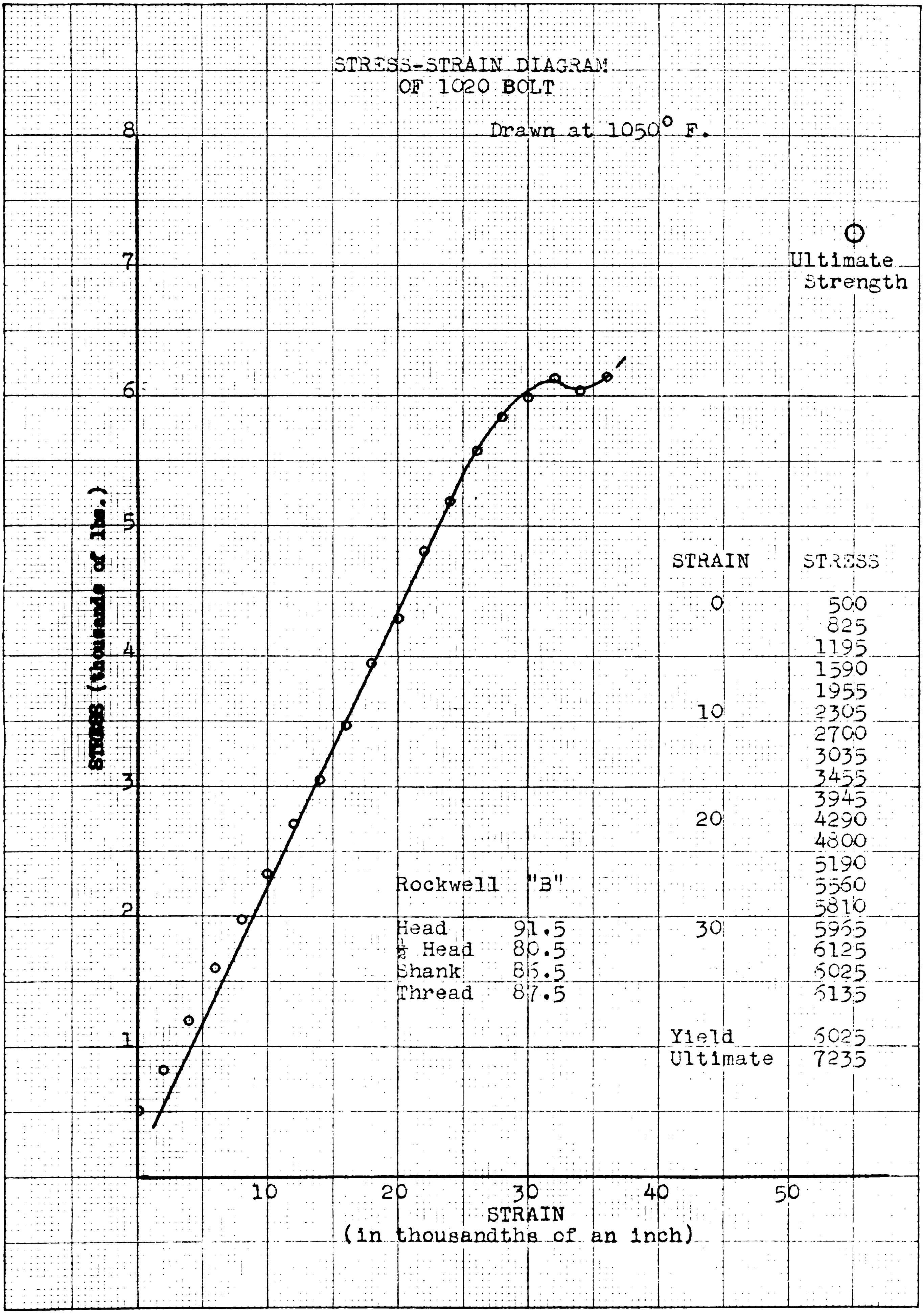
X 750



Longitudinal
Grain

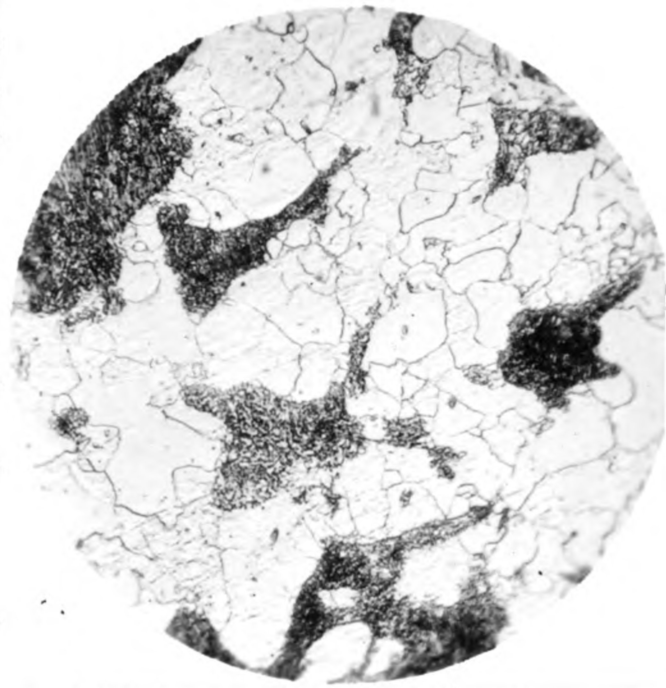
X 750




STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 1050° F.
Ultimate
Strength
STRESS (thousands of lbs.)
STRAIN
(in thousandths of an inch)
8
7
6
5
4
3
2
1
10
20
30
40
50
STRAIN
STRESS
0
10
20
30
500
825
1195
1590
1955
2305
2700
3035
3455
3945
4290
4800
5190
5560
5810
5965
6125
6025
6135
Yield 6025
Ultimate 7235
Rockwell "B"
Head 91.5
½ Head 80.5
Shank 85.5
Thread 87.5

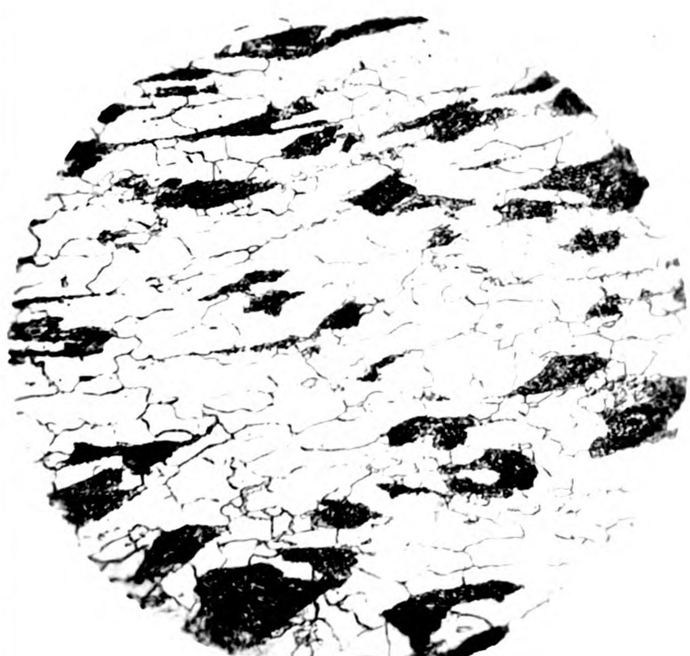
1020 BOLT: HEAD SECTION
Drawn at 1050° F.

Cross
Sectional
Grain



X 750

Longitudinal
Grain

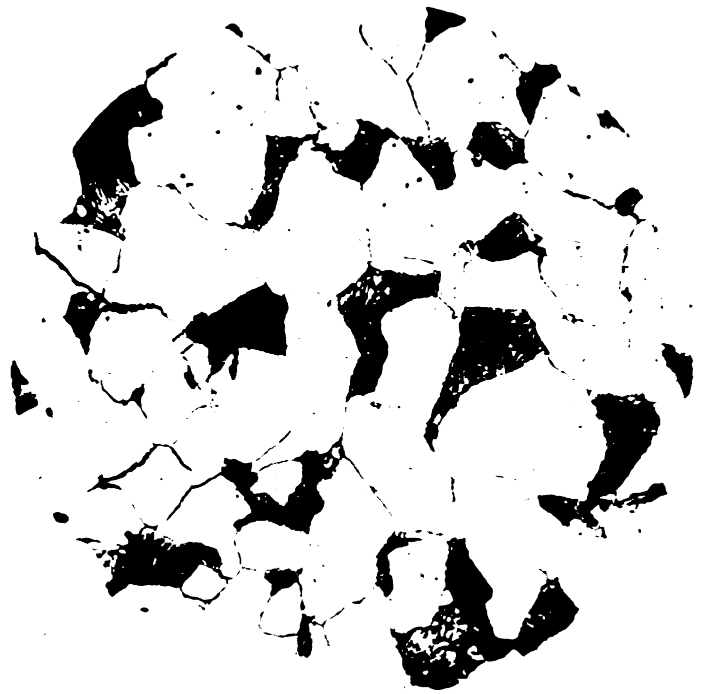


X 750

1020 BOLT: SHANK SECTION
Drawn at 1050° F.

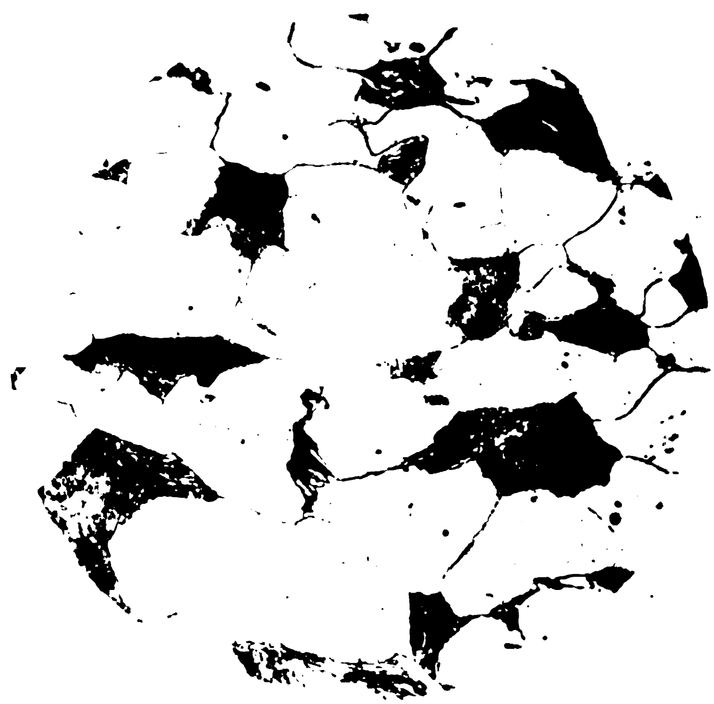
Cross Sectional Grain

X 750



Longitudinal Grain

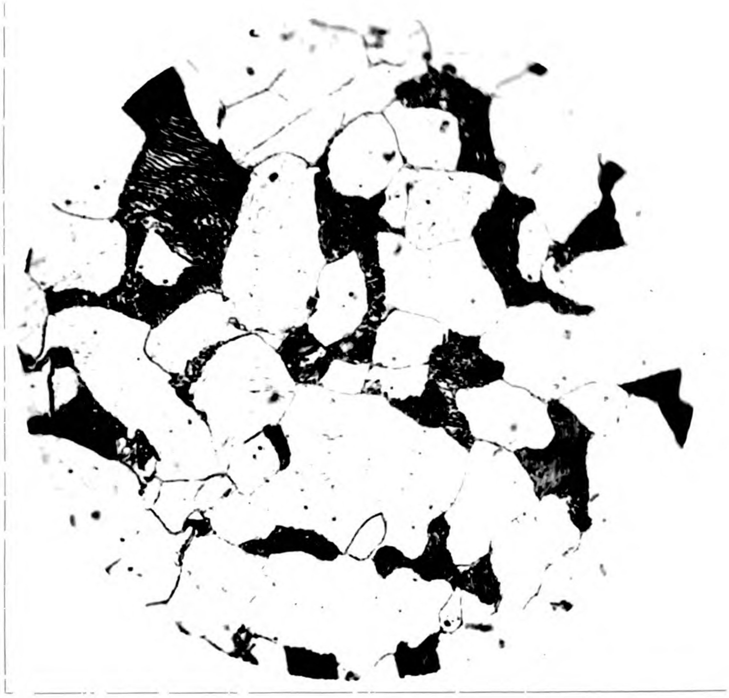
X 750



1020 BOLT: THREAD SECTION
Drawn at 1050° F.

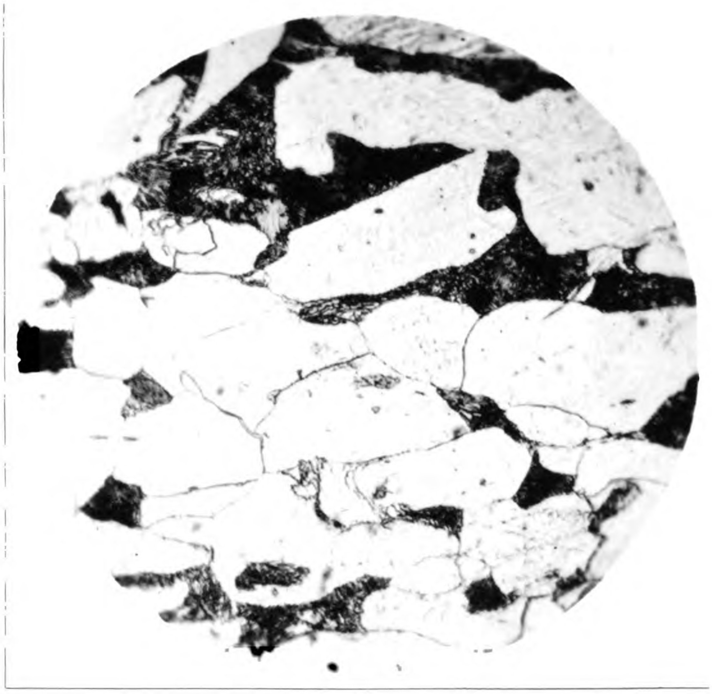
Cross
Sectional
Grain

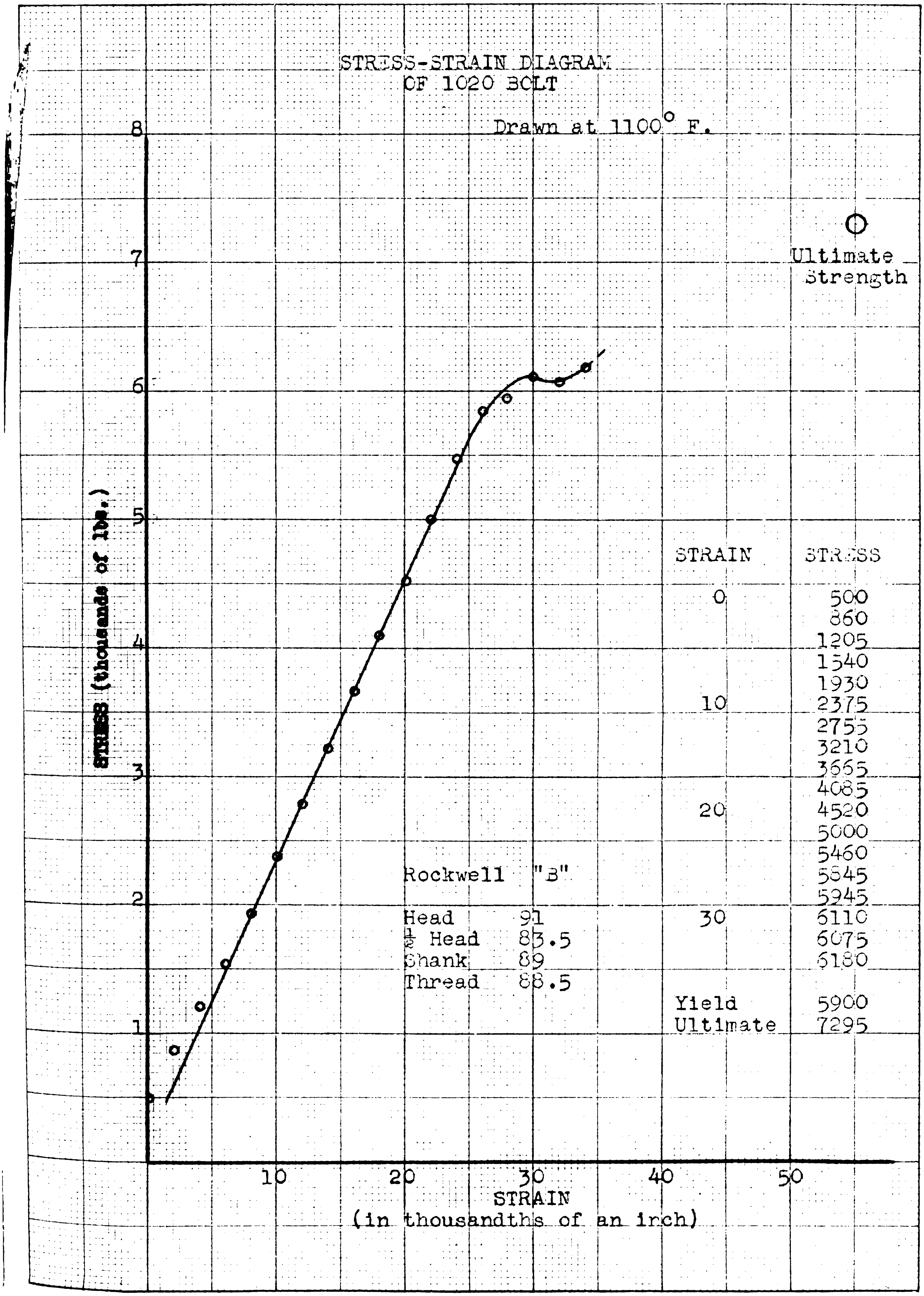
X 750



Longitudinal
Grain

X 750

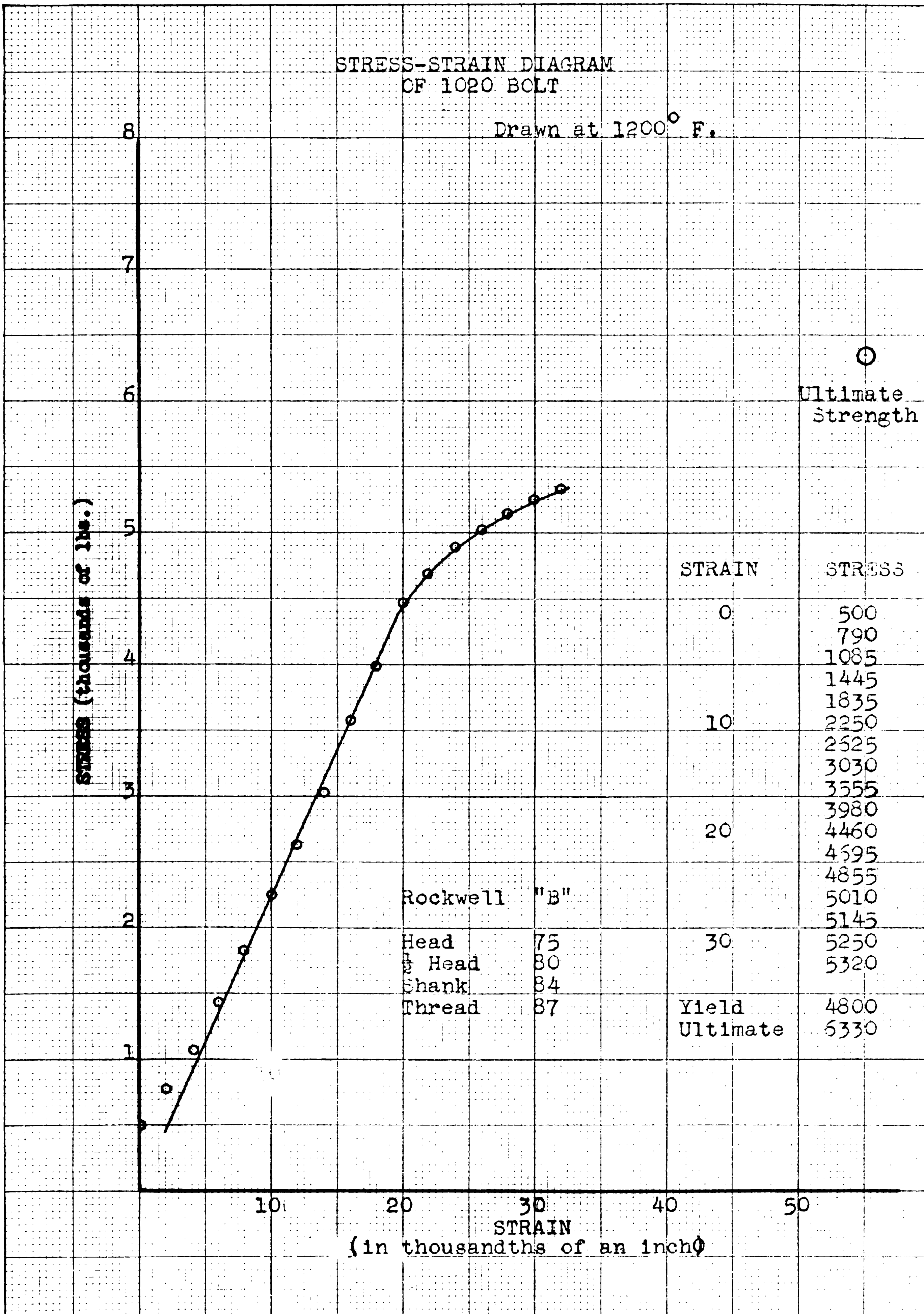




STRAIN	STRESS
0	500
	860
	1205
	1540
	1930
10	2375
	2755
	3210
	3665
	4085
20	4520
	5000
	5460
	5845
	5945
30	6110
	6075
	6180
Yield	5900
Ultimate	7295

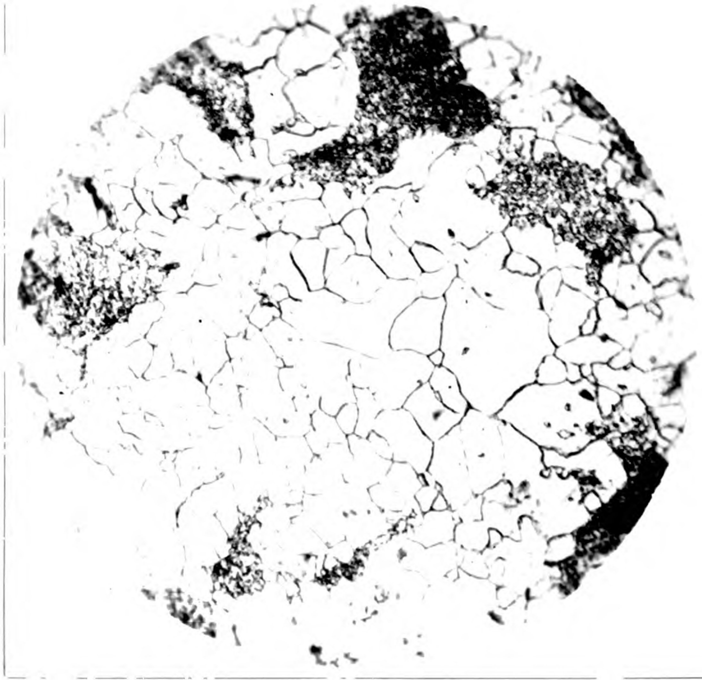
Rockwell "B"

Head	91
½ Head	83.5
Shank	89
Thread	88.5


STRESS-STRAIN DIAGRAM
OF 1020 BOLT
Drawn at 1200° F.
Ultimate Strength
STRESS (thousands of lbs.)
1
2
3
4
5
6
7
8
10
20
30
40
50
STRAIN
(in thousandths of an inch)
STRAIN STRESS
0 500
790
1085
1445
1835
10 2250
2625
3030
3555
3980
20 4460
4595
4855
5010
5145
30 5250
5320
Yield 4800
Ultimate 6330
Rockwell "B"
Head 75
½ Head 80
Shank 84
Thread 87

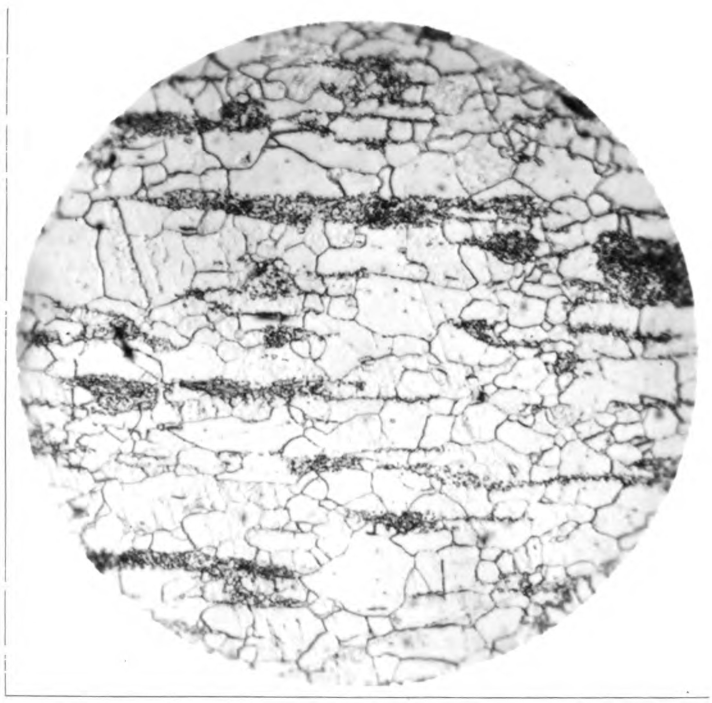
1020 BOLT: HEAD SECTION
Drawn at 1250° F.

Cross
Sectional
Grain



X 750

Longitudinal
Grain

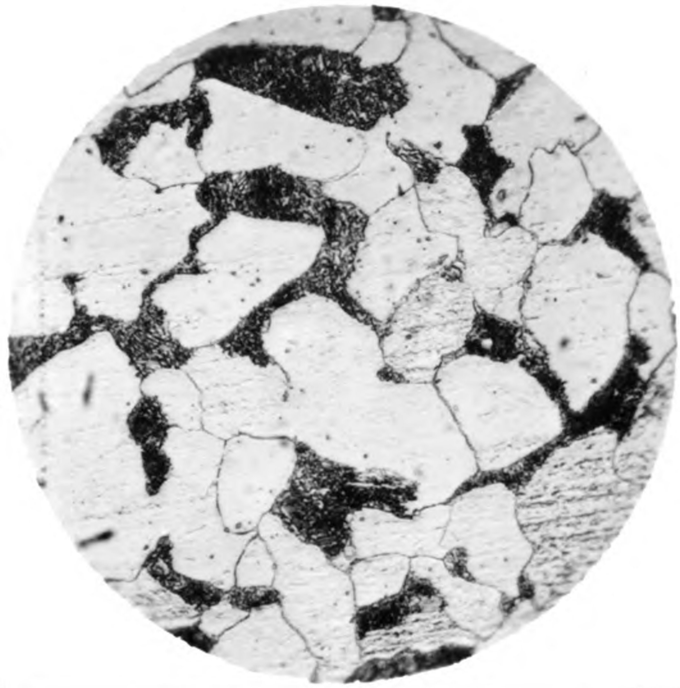


X 750

1020 BOLT: SHANK SECTION
Drawn at 1250° F.

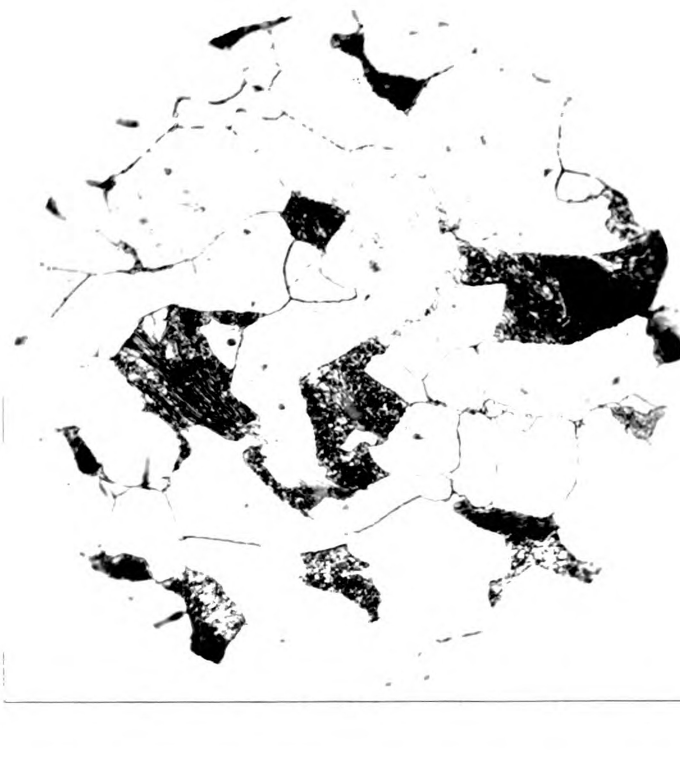
Cross Sectional Grain

X 750



Longitudinal Grain

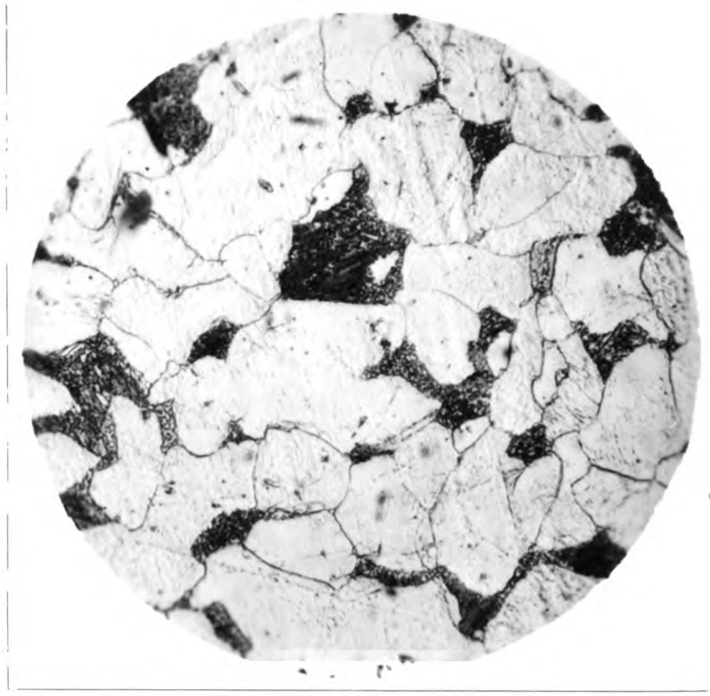
X 750



1020 BOLT: THREAD SECTION
Drawn at 1250° F.

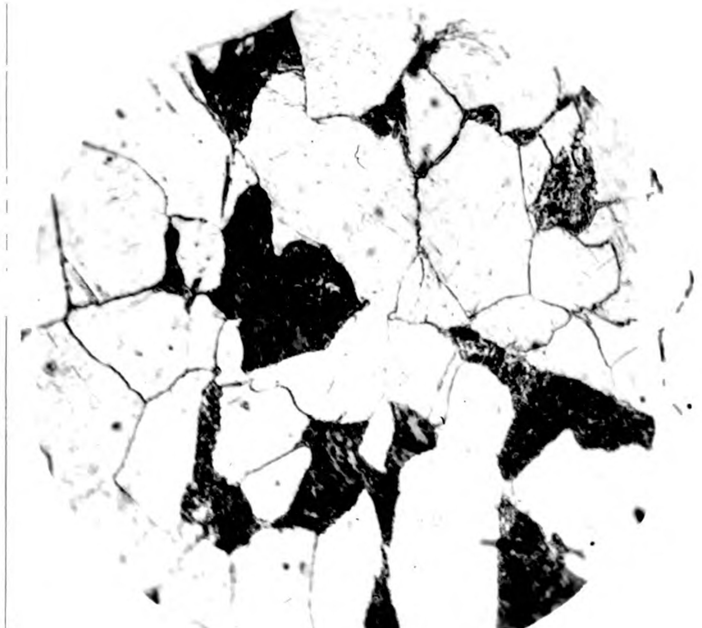
Cross Sectional Grain

X 750



Longitudinal Grain

X 750



SUMMATION CHART

1020 BOLTS

3/8 -24 x 1 3/8"

SINGLE EXTRUDED, DOUBLE BLOW HEADED

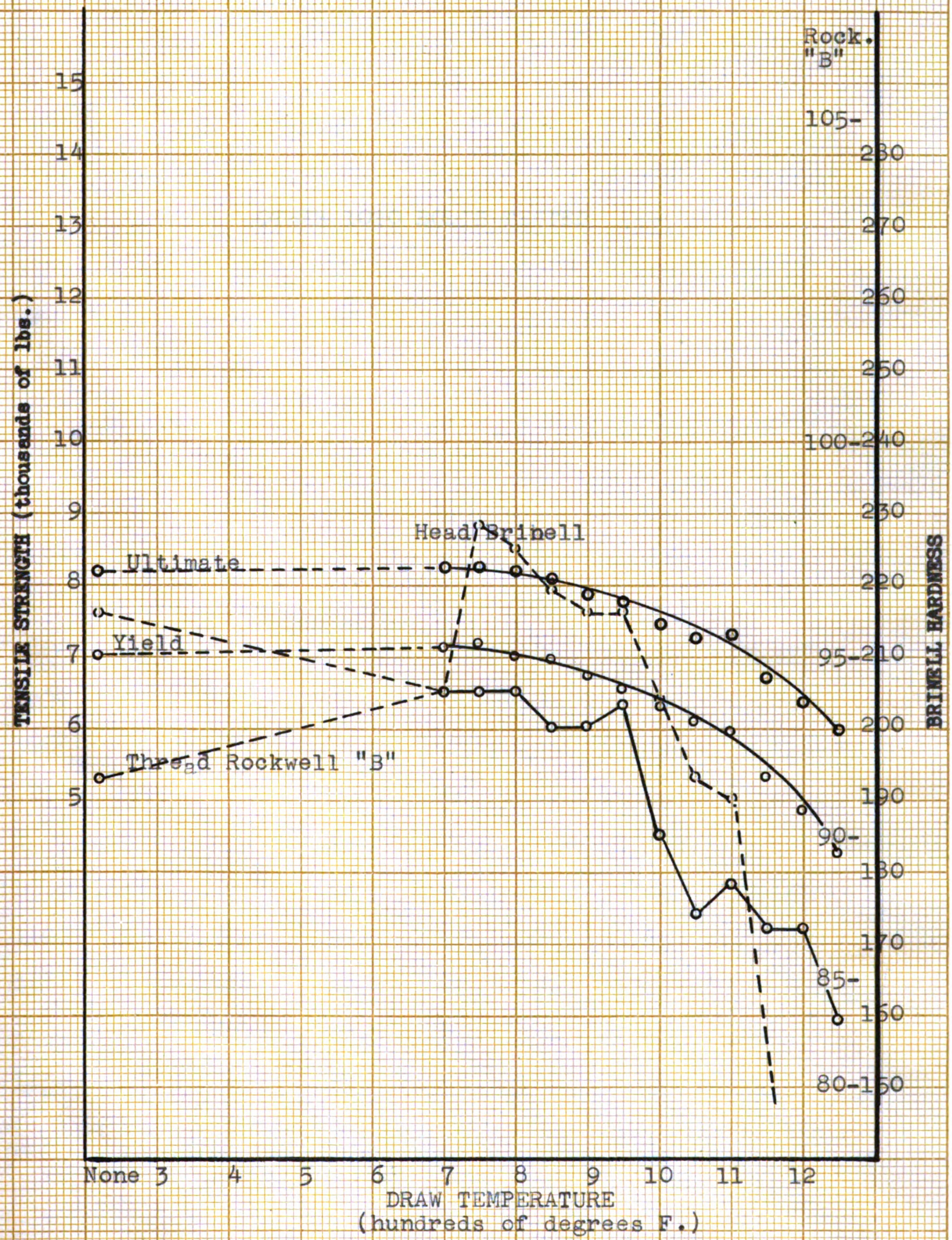
TEMP. of Draw °F.	HARDNESS Brinell Hd.	Rockwell "B" ½ Hd.	Rockwell "B" Shank	Rockwell "B" Thread	TENSILE STRENGTH Yield lbs.	TENSILE STRENGTH Ultimate lbs.
None	216	103**	89	91.5-193*	7000	8090
700	205	105.5	90.5	94 -205	7100	8255
750	228	105.5	90.5	94 -205	7145	8240
800	225	105	91.5	94 -205	6950	8190
850	219	105	90.5	93 -200	6900	8085
900	216	103.5	90.5	93 -200	6700	7845
950	216	104	90	93.5-203	6500	7735
1000	203	101.5	88	90 -185	6275	7440
1050	193	80.5	86.5	87.5-174	6025	7235
1100	190	83.5	89	88.5-178	5900	7295
1150	144	80	85.5	87 -172	5250	6680
1200	137	80	84	87 -172	4800	6330
1250	135	79	82.5	83 159	4200	5975

* This is the Brinell equivalent of the Rockwell "B" hardness.

** This hardness is taken in the severely cold worked part of the bolt head by splitting the head in cross section.

SUMMATION CURVE
1020 BOLTS 3/8-24 x 1 3/8"

SINGLE EXTRUDED, DOUBLE BLOW HEADED



OTHER 1020 BOLTS TESTED

1020 Bolts

7/16- 20 x 1 3/8

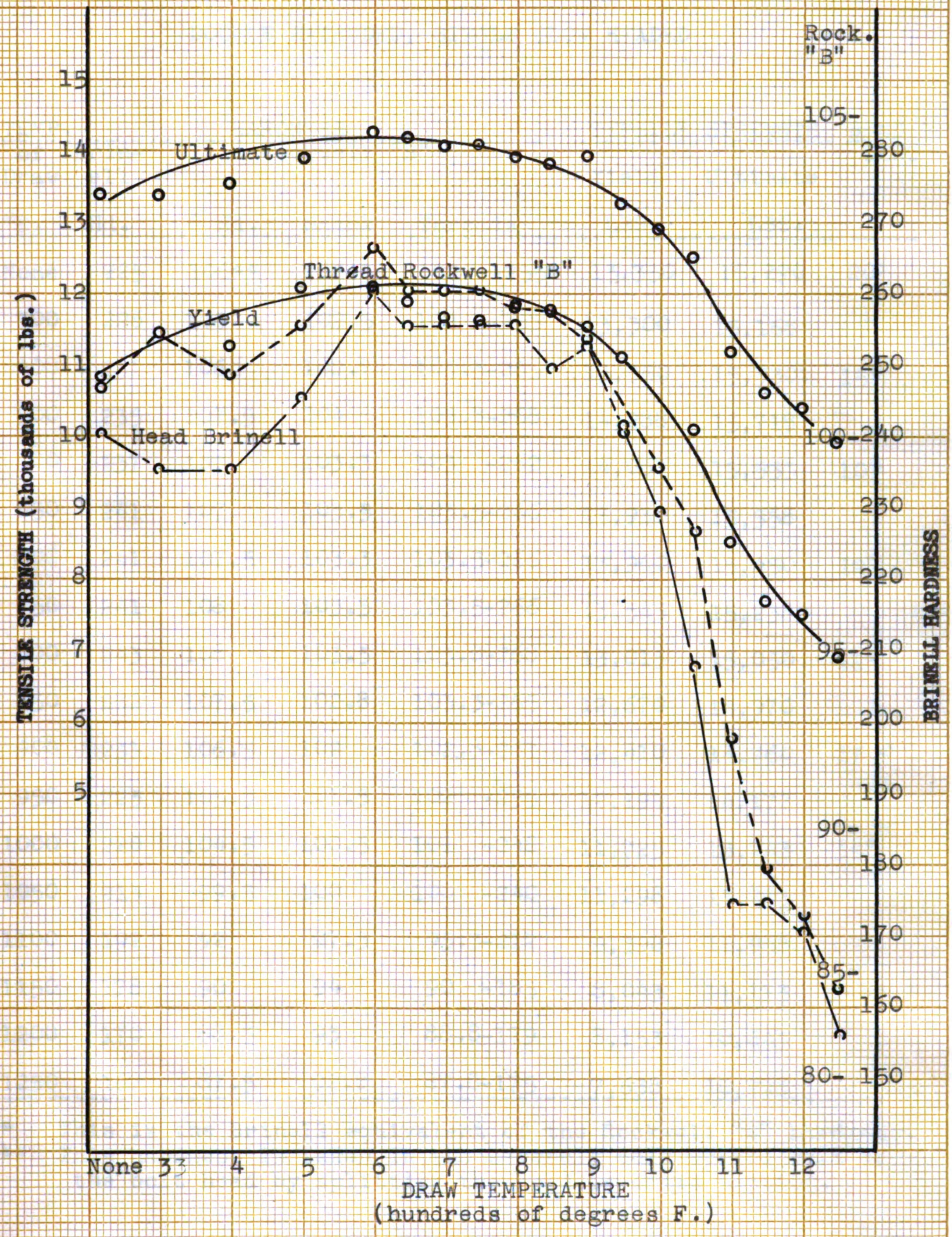
SINGLE EXTRUDED, DOUBLE BLOW HEADED

TEMP. of Draw °F.	HARDNESS Brinell Hd.	Rockwell "B" ½ Hd.	Rockwell "B" Shank	Rockwell "B" Threads		TENSILE STRENGTH Yield lbs.	TENSILE STRENGTH Ultimate lbs.
None	240	105.7**	100.5	101	-248*	10,642	13,367
300	235	-	101	102	-255	11,440	13,367
400	235	-	101	101	-248	11,225	13,505
500	245	-	101.5	102	-255	12,045	13,890
600	260	109.5	103	103.5	-266	12,047	14,257
650	255	109.3	102.8	102.7	-260	11,842	14,150
700	255	109.3	102.3	102.8	-260	11,638	14,018
750	255	109	102.3	102.7	-260	11,593	14,043
800	255	108.7	101.8	102.4	-258	11,795	13,873
850	249	106.3	101.7	102.3	-257	11,717	13,783
900	252	107	101.5	101.7	-253	11,492	13,888
950	241	106.3	100.2	100	-240	11,055	13,202
1000	229	103.3	99.2	99.2	-235	10,480	12,842
1050	207	95.5	98	97.6	-226	10,052	12,465
1100	174	90.7	94.5	92.3	-197	8,430	11,130
1150	174	91	94.7	88.7	-179	7,633	10,553
1200	170	88.5	93.5	87	-172	7,435	10,343
1250	156	-	92	84	-162	6,820	9,850

* This is the Brinell equivalent of the Rockwell "B" hardness.
** This hardness is taken in the severely cold worked part of the bolt head by splitting the head in cross section.

SUMMATION CURVE
1020 BOLTS
7/16-20 x 1 3/8"

SINGLE EXTRUDED, DOUBLE BLOW HEADED



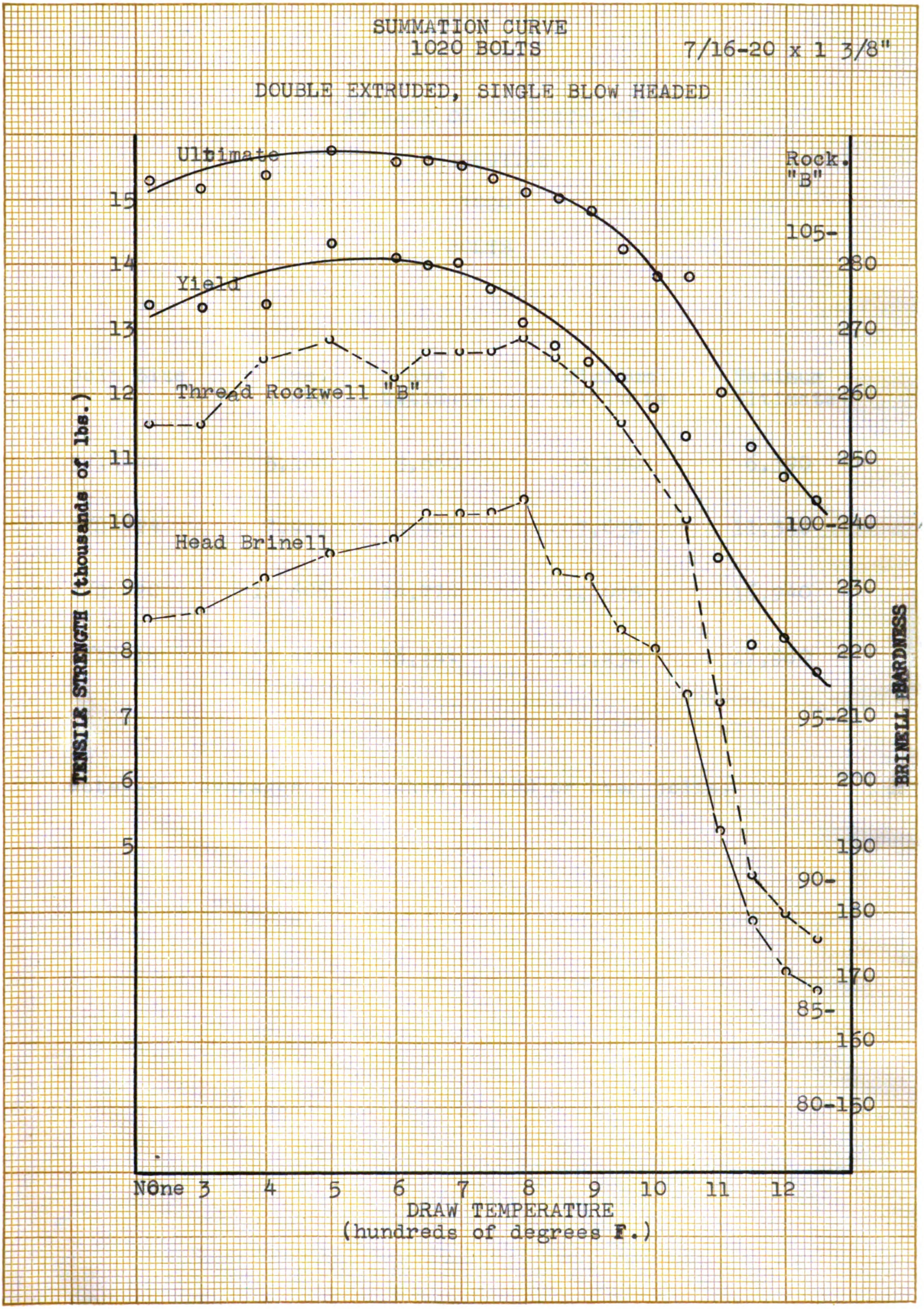
1020 BOLTS

7/16-20 x 1 3/8"

DOUBLE EXTRUDED, SINGLE BLOW HEADED

TEMP. of Draw °F.	HARDNESS Brinell Hd.	Rockwell "B" ½ Hd.	Shank	Threads	TENSILE STRENGTH Yield LBS.	Ultimate LBS.	BEND TEST
None	225	106**	102.5	102 -255*	13,350	15,290	20°
300	226	106	102.5	102 -255	13,300	15,168	
400	231	106.	102.7	103.3-265	13,350	15,330	15°
500	235	107.5	104	103.8-268	14,288	15,718	
600	237	107	103.3	103 -262	14,067	15,555	10°
650	241	107.	103.5	103.5-266	13,930	15,558	
700	241	107.5	103.3	103.5-266	13,960	15,450	12°
750	241	108	103.5	103.5-266	13,545	15,238	
800	243	108	103.5	103.8-268	13,015	15,050	12°
850	232	107.5	102.8	103.3-265	12,670	14,970	
900	231	106.5	102	102.8-261	12,410	14,760	17°
950	223	105.5	101.5	102 -255	12,195	14,177	
1000	220	104.5	100.5	101 -248	11,725	13,743	35°
1050	213	99.5	100	100 -240	11,298	13,743	
1100	192	92	97.5	95.3-212	9,398	11,958	
1150	178	90	94	90 -185	8,043	11,113	
1200	170	88.5	93	88.8-179	8,153	10,643	
1250	167	87.5	92.8	87.8-175	7,633	10,298	

* This is the Brinell equivalent of the Rockwell "B" hardness.
** This hardness is taken in the severely cold worked part of the bolt head by splitting the head in cross section.


SUMMATION CURVE
1020 BOLTS
7/16-20 x 1 3/8"
DOUBLE EXTRUDED, SINGLE BLOW HEADED
Ultimate
Yield
Thread Rockwell "B"
Head Brinell
Rock. "B"
TENSILE STRENGTH (thousands of lbs.)
BRINELL HARDNESS
DRAW TEMPERATURE
(hundreds of degrees F.)
None 3 4 5 6 7 8 9 10 11 12
15 14 13 12 11 10 9 8 7 6 5
105- 100- 95- 90- 85- 80-
280 270 260 250 240 230 220 210 200 190 180 170 160 150

AVERAGE OF STRENGTHS OF

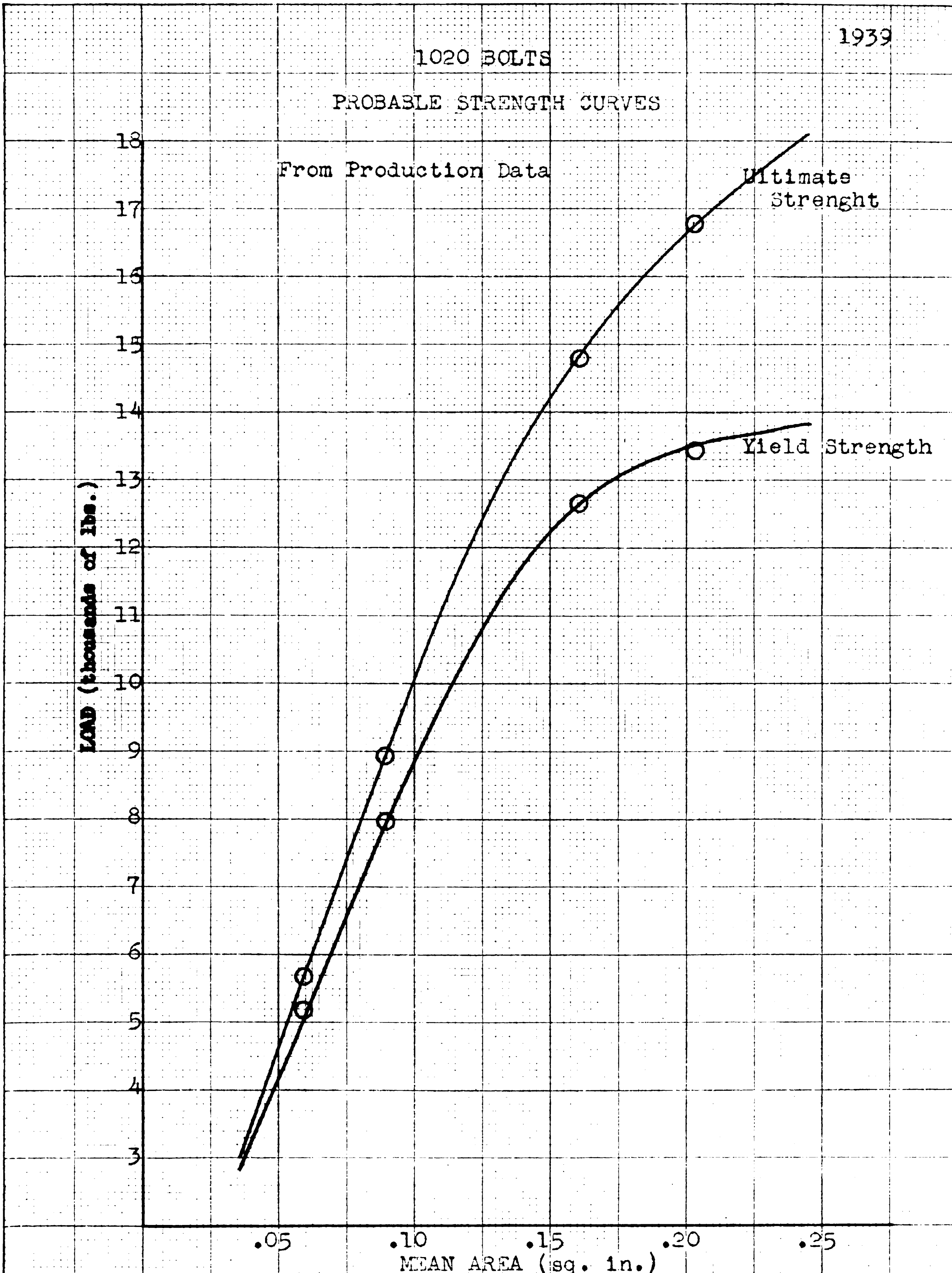
PRODUCTION

1020

BOLTS

Bolt Size	Ave. Yield	Ave Ultimate	Minimum Ultimate	Maximum Ultimate
5/16-24	5,168	5,660	5,120	6,390
3/8 -24	7,966	8,925	7,050	11,350
1/2 -20	12,606	14,770	12,025	16,940
9/16-18	13,410	16,741	15,230	17,980

Note--- Averages were taken on 100 or over bolts.



The Mean Area is figrued from the average of the pitch and minor diameters.

SUMMATION

1. In figuring the Tensile Strength of a bolt from the hardness, the Rockwell "B" is more accurate than the Brinell, especially in the smaller sizes of bolts, and if the Rockwell test is made on a transverse section of the threads.

2. A Rockwell "B" hardness in the threads of from 85 to 100 is practicable.

3. Recrystallization of the ferrite in the head is not necessary to insure good ductility, but a draw treatment of from 950 to 1000 degrees F. should be used. This will guard against any brittleness if mixed stock is used or segregation is encountered.

4. For strengths see Summation Charts and Curves.