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REPORT NO. 320/10

Partial Report Covering
Physical Property Characteristics of
Copper-Chromium Combinations in Mo-Gun Steels

INDEXED

By

H. C. Mann
Sr. Materials Engineer

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Report No. 320/10
Watertown Arsenal

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Partial Report Covering Physical Property Characteristics of Copper-Chromium Combinations in Mo-Gun Steels

(10) H. C. Mann

Object

To determine physical property characteristics of carbon-molybdenum gun steels containing various copper-chromium combinations.

Conclusions

Of the compositions tested, the maximum strength and hardness values without appreciable loss in ductility were obtained from the 1.06% copper .66% chromium combination. While it would appear that a ratio of copper to chromium of approximately 1.6 produces the best properties, such a conclusion can only be tentative since this investigation did not include copper-chromium combinations where one element was held constant and the other varied.

Material

The material used for this investigation was in the form of 1" rounds, forged from 60-pound ingots which were initially cast for the purpose of establishing

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370900 LB

spectrographic standards. Transformation points to insure proper quenching temperatures were obtained with the Leitz Universal Dilatometer. The amount of material available from each composition was only sufficient to provide two tensile test specimens from each tempering temperature. The results obtained are listed in the following tables and physical property charts.

Discussion

From the fact that this investigation covered only arbitrarily selected copper-chromium combinations in which neither of these elements was held constant while the other varied over a given range, any conclusions from the results obtained can be considered only as applying to the particular copper-chromium combinations listed. Thus, while the test values indicate that the combination of 1.06% copper, .66% chromium yields the highest strength with no appreciable loss in ductility, such evidence cannot be considered conclusive without additional data as to the effect produced by varying either one of these elements.

In view of the desirable strength and ductility properties imparted by the addition of copper and chromium to carbon-molybdenum steel, the scope of this study should be extended to cover more completely the copper-chromium combinations.

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Availability Codes
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Chemical Composition

No.	Heat	C	Mn	Si	Mo	Va	Cu	Cr	
1	2337	.205	.89	.430	.485	.115	.055	.09	Residual
2	2343	.235	.47	.420	.43	.105	.30	1.16	
3	2344	.210	.72	.400	.46	.115	.615	1.13	
4	2345	.215	.74	.330	.46	.10	.905	.85	
5	2346	.230	.75	.390	.52	.105	1.06	.66	
6	2348	.215	.68	.440	.45	.11	1.34	.53	
7	2349	.225	.69	.465	.485	.09	1.59	.26	

Transformation Points - Degrees F

No.	Heat	Ac_1	Ac_3	Ar_3	Ar_1
1	2337	1369	1596	1457	860
2	2343	1445	1562	1448	1257
3	2344	1421	1553	1402	795
4	2345	1405	1549	1389	824
5	2346	1405	1544	1373	923
6	2348	1394	1544	1393	(770 (455
7	2349	1371	1528	1389	(842 (431

Physical Properties

No. 1 - Heat 2337 - Quenched from 1670°F - Drawn as noted.

Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	82,500	117,500	18.6	65.0		
	83,000	117,500	18.6	68.0		
Ave.	82,750	117,500	18.6	66.5	235	21
900°F	85,000	113,500	20.0	67.0		
	86,000	115,000	19.3	67.7		
Ave.	85,500	114,250	19.7	67.4	230	20
1000°F	90,000	116,500	21.4	67.7		
	90,500	117,000	20.0	64.4		
Ave.	90,250	116,750	20.7	66.0	235	21
1100°F	100,500	121,500	21.4	65.4		
	97,000	119,500	20.7	66.0		
Ave.	98,750	120,500	21.1	65.7	240	22
1200°F	94,000	112,500	22.1	69.5		
	96,500	114,500	21.4	65.7		
Ave.	95,250	113,500	21.8	67.6	223	19
1300°F	86,500	102,000	23.6	71.4		
	84,000	103,500	23.6	70.5		
Ave.	85,250	102,750	23.6	71.0	197	14

No. 2 - Heat 2343 - Quenched from 1625°F - Drawn as noted.

Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	112,500	153,000	15.0	57.8		
	115,500	153,500	15.0	57.4		
Ave.	114,000	153,250	15.0	57.6	313	34
900°F	122,000	154,000	17.1	59.2		
	120,500	154,500	15.7	57.0		
Ave.	121,250	154,250	16.4	58.1	313	34
1000°F	121,500	152,500	17.9	59.2		
	123,500	153,500	16.4	58.1		
Ave.	122,500	153,000	17.2	58.7	313	34
1100°F	129,000	154,500	17.1	59.2		
	124,000	151,000	17.9	62.3		
Ave.	126,500	152,750	17.5	60.8	305	33
1200°F	110,500	126,000	20.0	67.0		
	113,500	130,500	19.3	63.7		
Ave.	112,000	128,250	19.7	65.4	260	26
1300°F	91,000	107,000	24.3	71.7		
	89,000	105,000	24.3	69.8		
Ave.	90,000	106,000	24.3	70.8	212	17

No. 3 - Heat 2344 - Quenched from 1625°F - Drawn as noted.

Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	137,500	172,000	15.0	56.3		
	134,500	169,000	14.3	57.0		
Ave.	136,000	170,500	14.8	56.7	352	38
900°F	143,000	169,500	15.0	54.1		
	137,500	167,000	16.4	56.3		
Ave.	140,250	168,250	15.7	55.2	342	37
1000°F	137,000	165,000	17.1	59.2		
	139,000	165,000	17.1	59.6		
Ave.	138,000	165,000	17.1	59.4	342	37
1100°F	142,000	164,000	18.0	59.6		
	141,500	163,000	18.6	59.2		
Ave.	141,750	163,500	18.3	59.4	332	36
1200°F	114,500	132,500	20.0	66.1		
	122,500	135,500	20.0	65.1		
Ave.	118,500	134,000	20.0	65.6	270	28
1300°F	98,000	110,000	24.3	68.6		
	101,000	111,000	24.3	69.3		
Ave.	99,500	110,500	24.3	68.9	217	18

No. 4 - Heat 2345 - Quenched from 1625°F - Drawn as noted.

Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	122,000	157,000	15.0	55.9		
	129,500	164,000	13.6	54.4		
Ave.	125,750	160,500	14.3	55.1	322	35
900°F	133,000	160,000	14.3	54.8		
	146,500	169,000	12.9	53.3		
Ave.	139,750	164,500	13.6	54.0	342	37
1000°F	125,000	151,500	15.7	57.0		
	135,500	161,500	17.1	57.0		
Ave.	130,250	156,500	16.4	57.0	322	35
1100°F	138,500	160,000	17.1	58.5		
	133,500	155,000	17.1	58.1		
Ave.	136,000	157,500	17.1	58.3	322	35
1200°F	119,000	134,000	18.6	61.7		
	118,000	131,000	20.0	65.4		
Ave.	118,500	132,500	19.3	63.6	265	27
1300°F	94,500	109,500	23.6	68.0		
	98,000	108,000	22.9	68.0		
Ave.	96,250	108,750	23.2	68.0	207	16

No. 5 - Heat 2346 - Quenched from 1625°F - Drawn as noted.

Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	154,000	182,500	14.3	52.9		
	151,500	182,000	13.6	50.2		
Ave.	152,750	182,250	14.0	51.4	372	40
900°F	157,000	179,000	15.7	55.9		
	158,500	181,000	15.7	53.7		
Ave.	157,750	180,000	15.7	54.8	372	40
1000°F	156,500	177,500	17.1	55.9		
	156,500	178,500	16.4	55.6		
Ave.	156,500	178,000	16.8	55.8	372	40
1100°F	151,500	171,500	17.1	58.9		
	153,000	171,000	17.1	57.4		
Ave.	152,250	171,250	17.1	58.1	352	38
1200°F	127,500	139,000	18.6	63.4		
	128,000	138,500	18.6	62.3		
Ave.	127,750	138,750	18.6	62.9	283	30
1300°F	106,000	116,500	22.9	67.3		
	97,000	113,000	22.9	69.8		
Ave.	101,500	114,750	22.9	68.6	230	20

No. 6 - Heat 2348 - Quenched from 1625°F - Drawn as noted.

Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	129,000	164,500	14.3	54.4		
	134,000	168,000	15.7	54.4		
Ave.	131,750	166,250	15.0	54.4	342	37
900°F	141,500	168,500	15.7	53.7		
	144,000	171,000	16.4	54.4		
Ave.	142,750	169,750	16.1	54.1	352	38
1000°F	137,000	163,000	17.1	57.8		
	135,500	163,500	17.1	56.7		
Ave.	136,250	163,250	17.1	57.3	332	36
1100°F	140,000	162,000	16.4	57.4		
	140,000	163,500	17.1	57.4		
Ave.	140,000	162,750	16.8	57.4	332	36
1200°F	124,500	138,000	20.0	62.0		
	124,000	137,000	19.3	61.3		
Ave.	124,250	137,500	19.7	61.7	283	30
1300°F	100,000	113,000	22.9	66.7		
	103,000	116,000	22.9	67.7		
Ave.	101,500	114,500	22.9	67.2	230	20

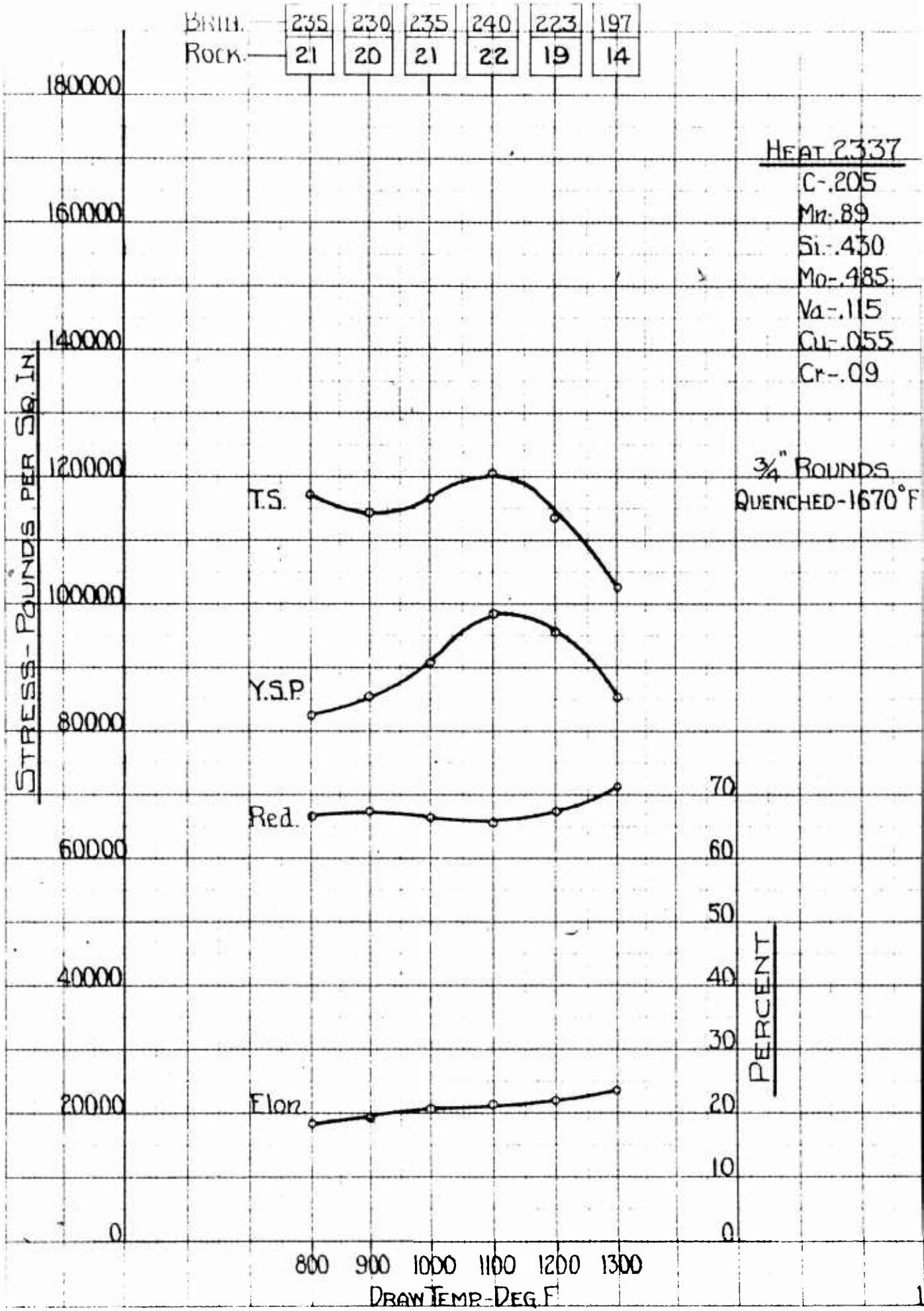
No. 7 - Heat 2349 - Quenched from 1600°F - Drawn as noted.

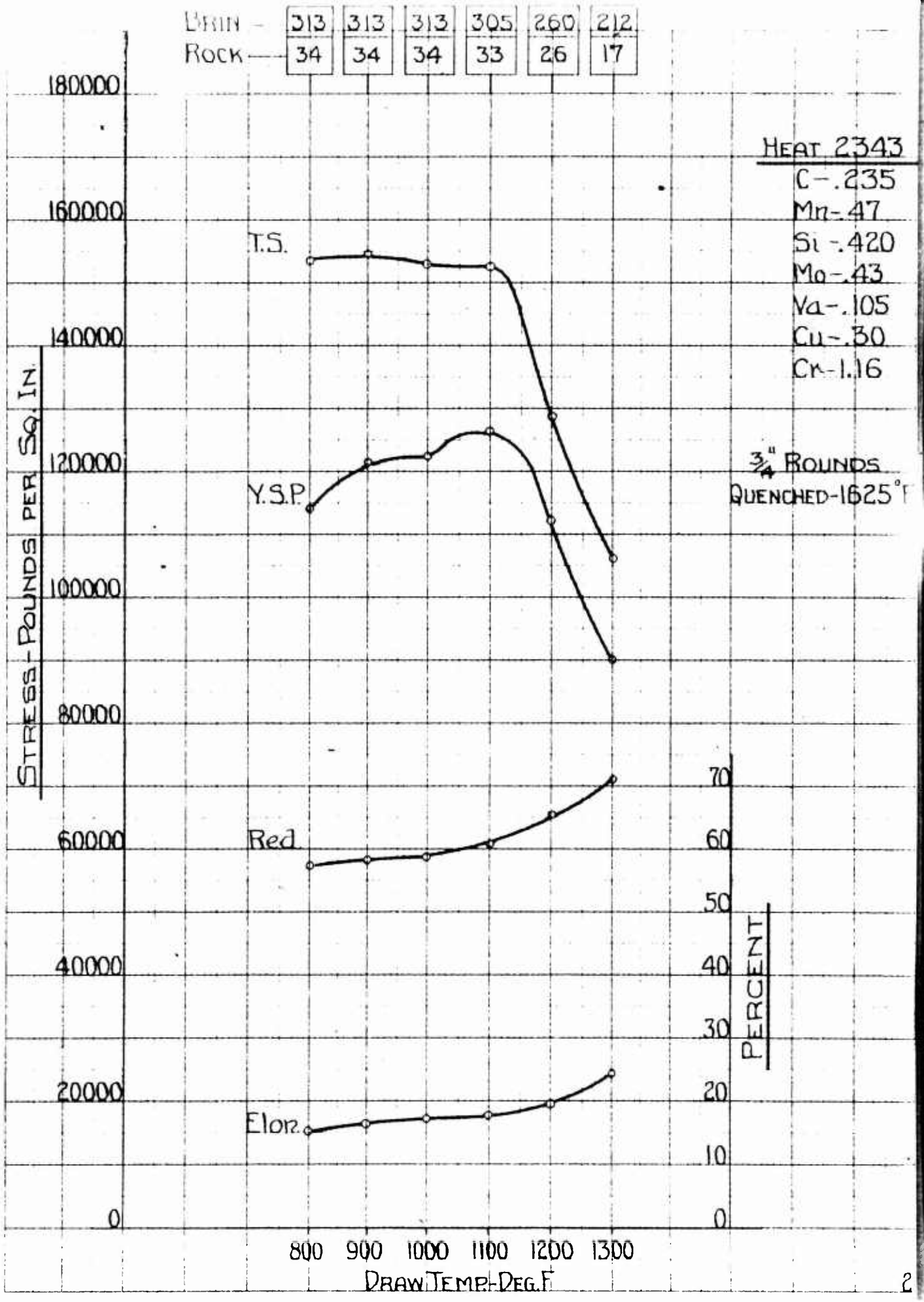
Draw Temp.	Y.S.P.	T. S.	Elon.	Red.	Hardness Brinell	Hardness Rockwell "C"
800°F	147,000	175,500	14.3	51.0		
	147,500	174,000	13.6	52.5		
Ave.	147,250	174,750	14.0	51.8	363	39
900°F	151,000	174,500	14.3	51.0		
	148,500	173,000	15.0	52.5		
Ave.	149,750	173,750	14.7	51.8	363	39
1000°F	140,500	164,000	16.4	55.2		
	140,500	161,500	15.7	53.7		
Ave.	140,500	162,750	16.1	54.5	332	36
1100°F	142,000	163,000	17.1	55.9		
	138,000	160,000	17.1	56.3		
Ave.	140,000	161,500	17.1	56.1	332	36
1200°F	127,500	137,000	18.6	61.7		
	131,000	140,000	19.3	60.3		
Ave.	129,250	138,500	19.0	61.0	283	30
1300°F	97,000	112,000	22.9	67.0		
	98,000	112,500	22.9	67.7		
Ave.	97,500	112,250	22.9	67.4	223	19

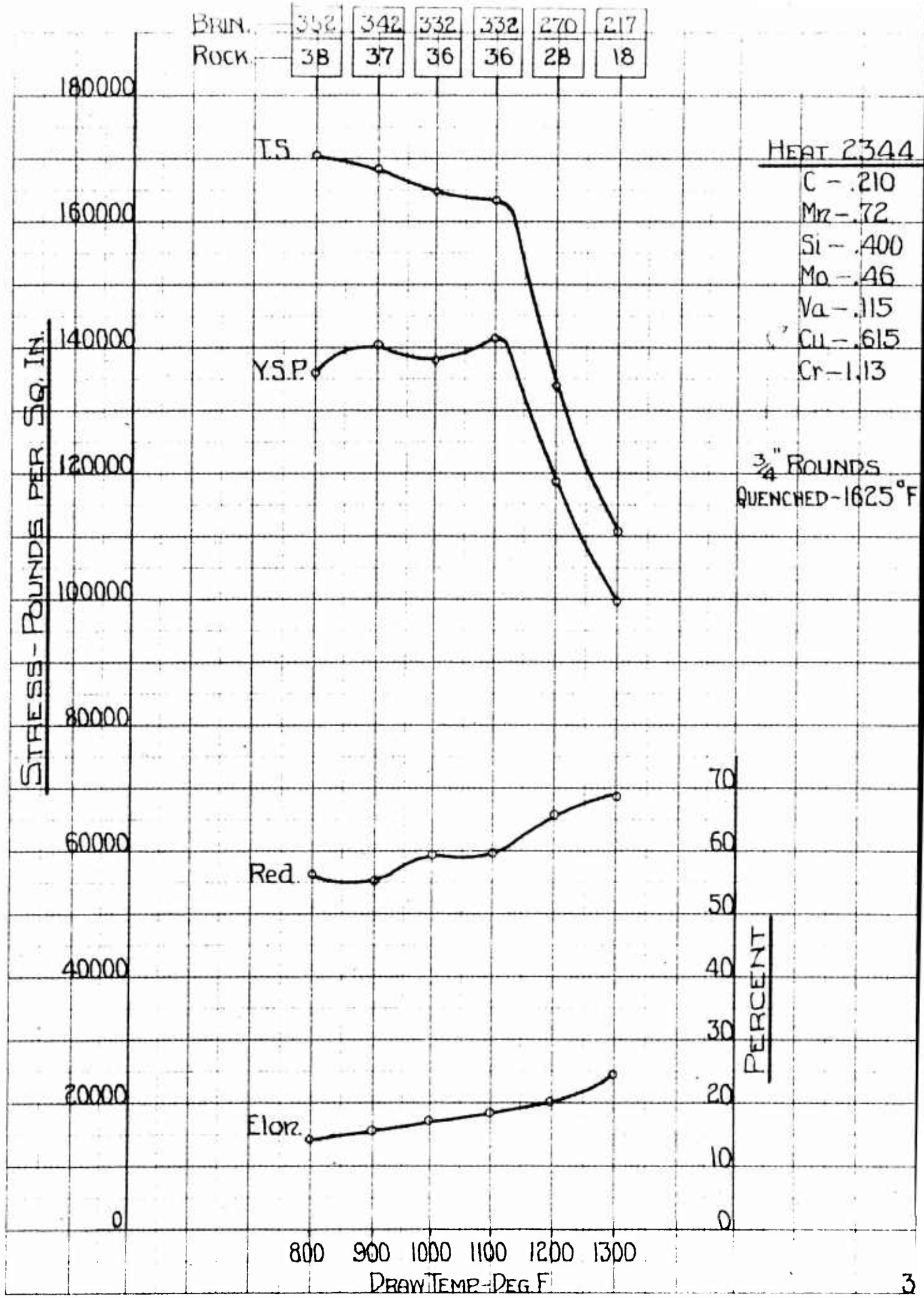
Respectfully submitted,

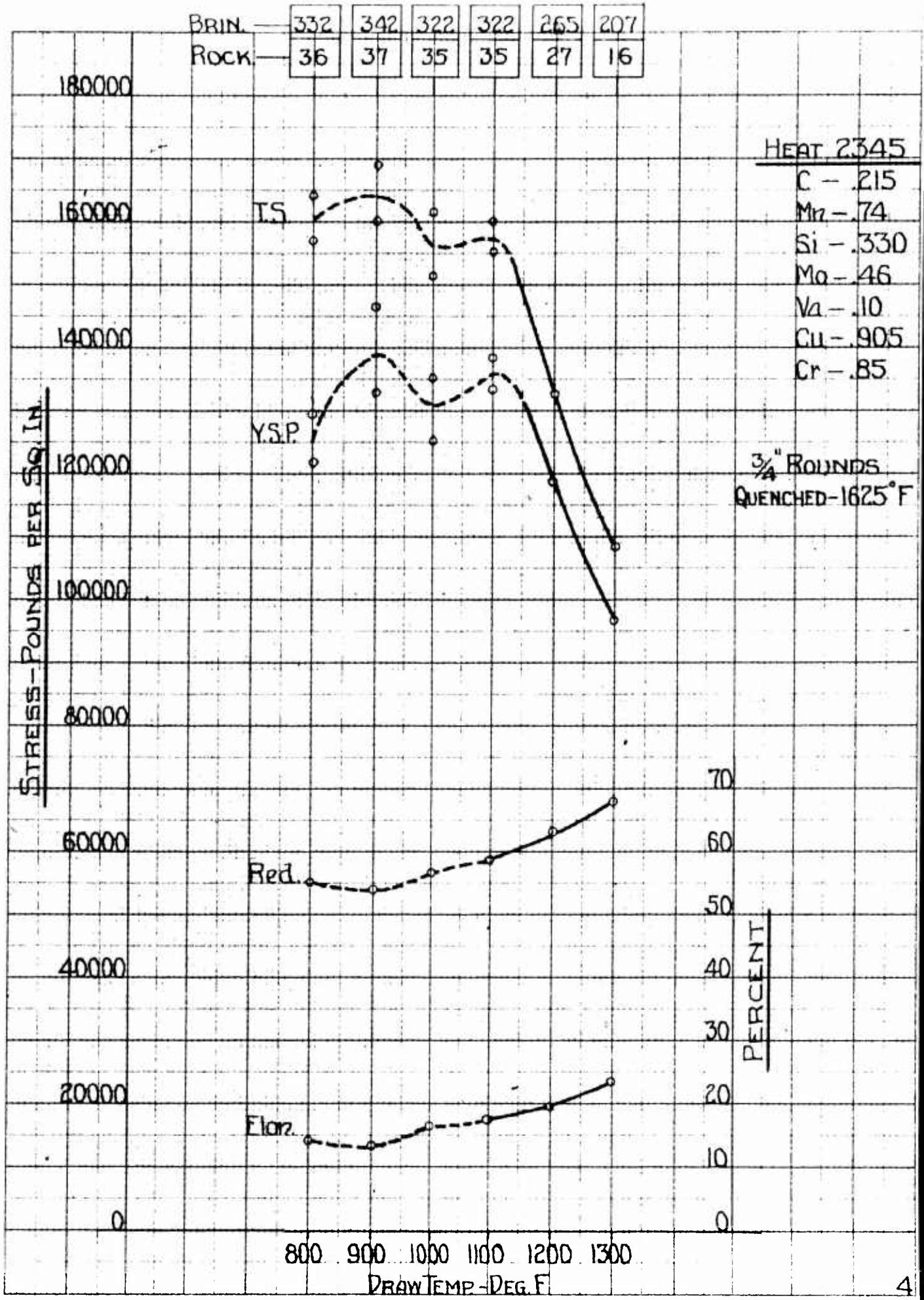
H C Mann

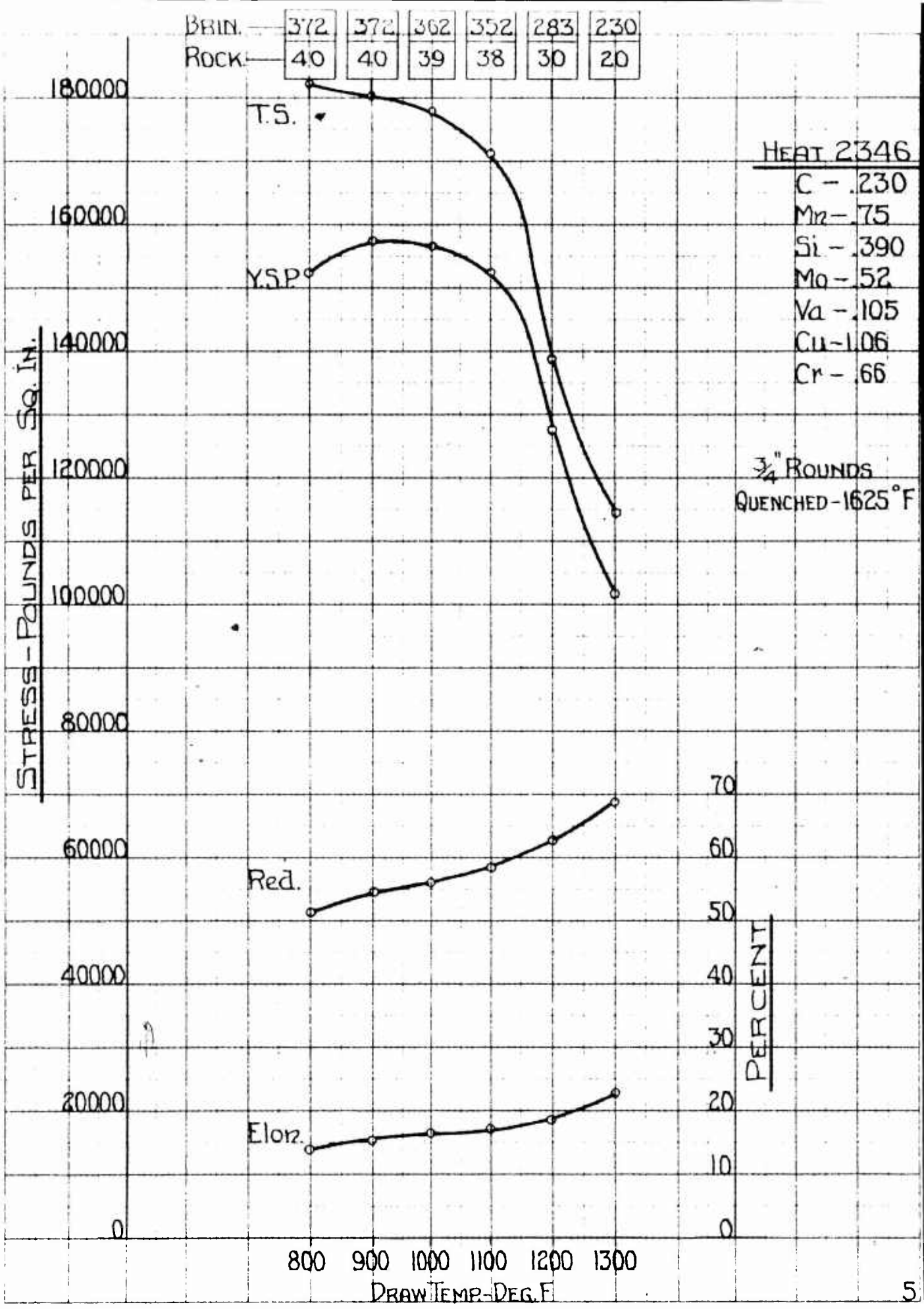
H. C. Mann,
Sr. Materials Engineer.

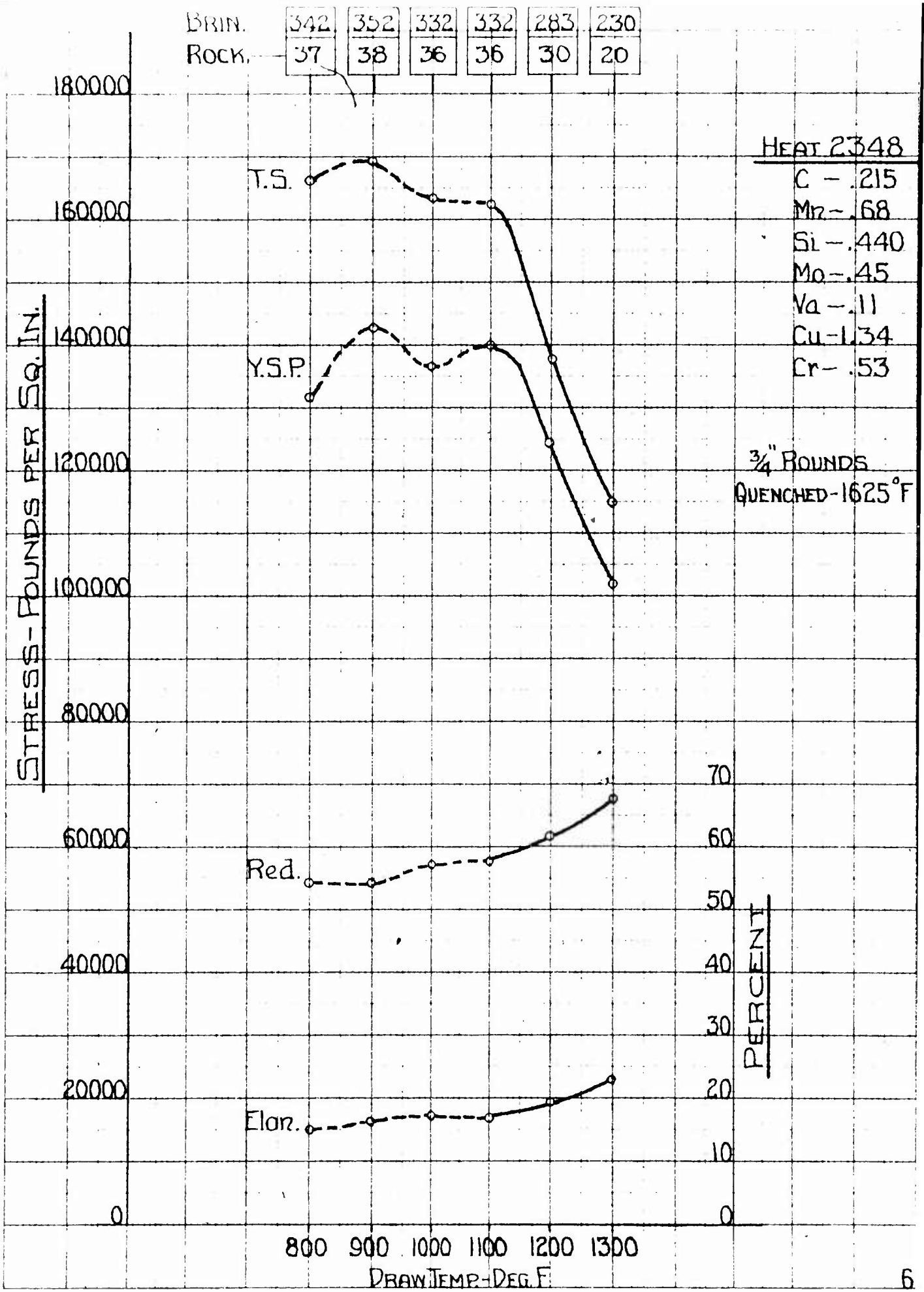

Brin. 235 230 235 240 223 197
Rock. 21 20 21 22 19 14
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Stress-Pounds per Sq. In.
T.S.
Y.S.P.
Red.
Elon.
70
60
50
40
30
20
10
0
Percent
800 900 1000 1100 1200 1300
Draw Temp-Deg. F
Heat 2337
C-.205
Mn-.89
Si-.430
Mo-.485
Va-.115
Cu-.055
Cr-.09
3/4" Rounds
Quenched-1670°F

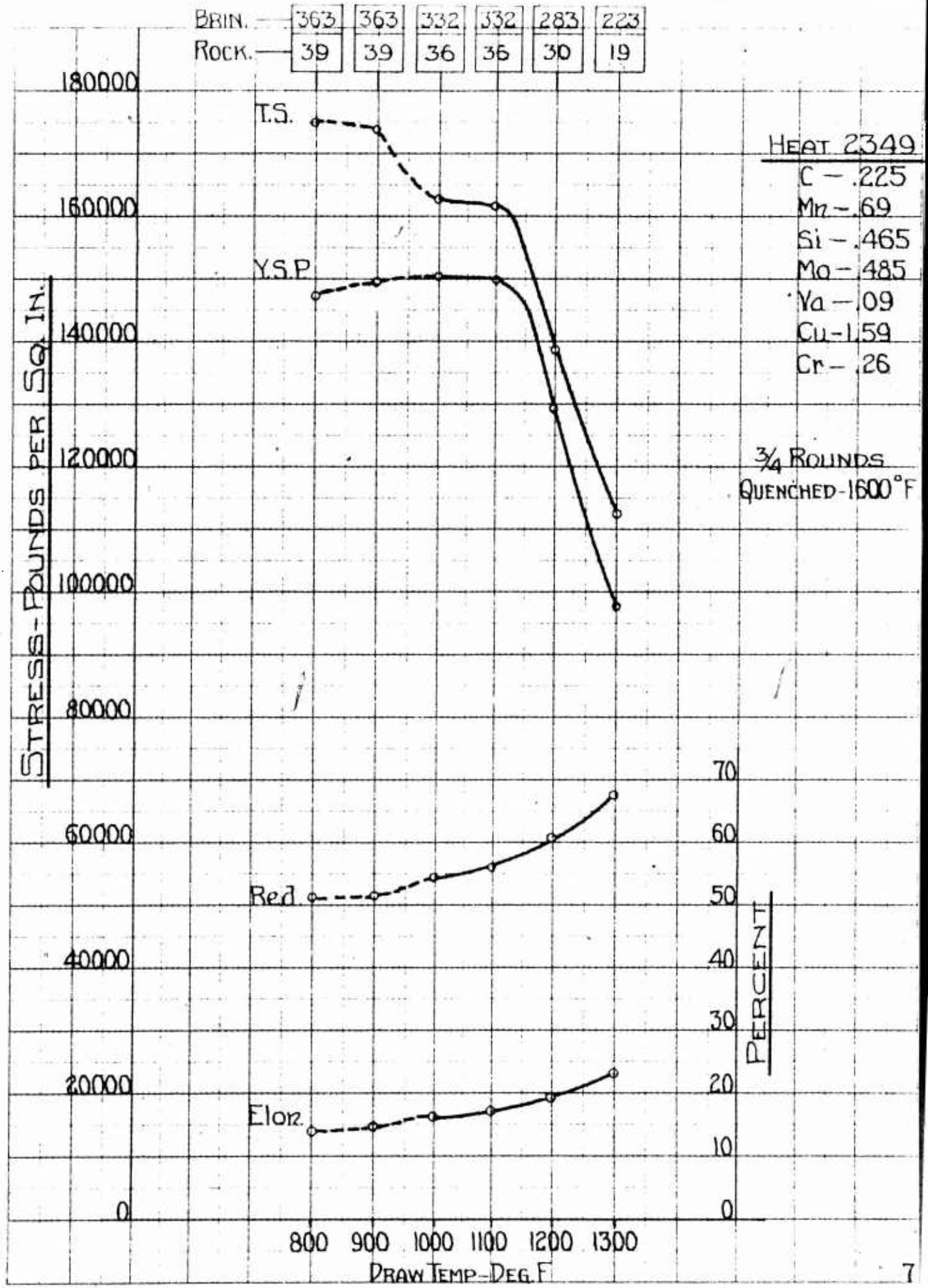

Brin 313 313 313 305 260 212
Rock 34 34 34 33 26 17
Heat 2343
C-.235
Mn-.47
Si-.420
Mo-.43
Va-.105
Cu-.30
Cr-1.16
3/4" Rounds
Quenched-1625°F
T.S.
Y.S.P.
Red.
Elon.
Stress-Pounds per Sq. In.
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
70
60
50
40
30
20
10
0
Percent
800 900 1000 1100 1200 1300
Draw Temp.-Deg.F

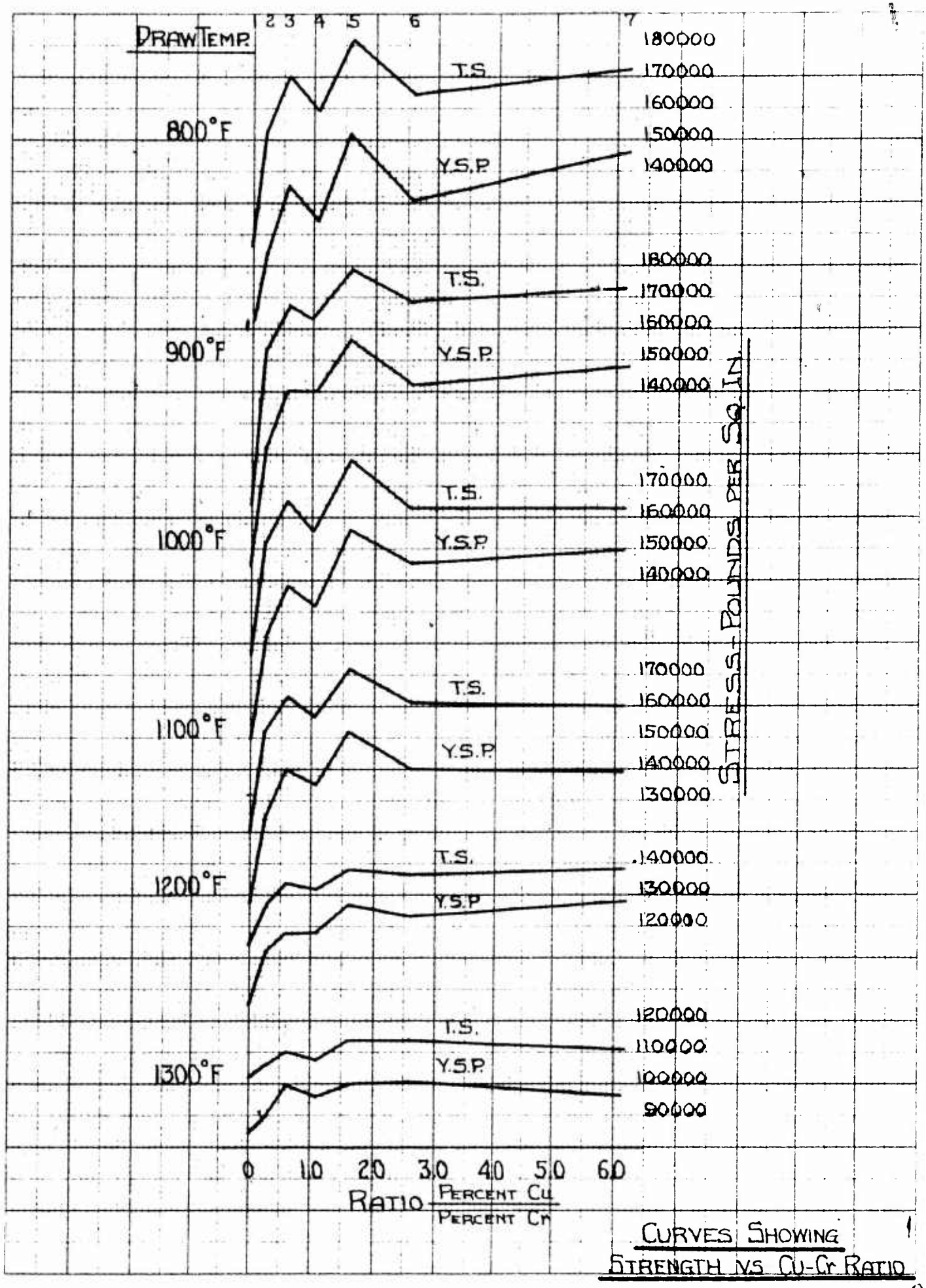

BRIN. 352 342 332 332 270 217
ROCK. 38 37 36 36 28 18
T.S
Y.S.P.
Red.
Elon.
HEAT 2344
C - .210
Mn - .72
Si - .400
Mo - .46
Va - .115
Cu - .615
Cr - 1.13
3/4" ROUNDS
QUENCHED - 1625°F
STRESS - POUNDS PER SQ. IN.
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
70
60
50
40
30
20
10
0
PERCENT
800 900 1000 1100 1200 1300
DRAW TEMP - DEG. F


BRIN. 332 342 322 322 265 207
ROCK. 36 37 35 35 27 16
HEAT 2345
C – .215
Mn – .74
Si – .330
Mo – .46
Va – .10
Cu – .905
Cr – .85
¾" ROUNDS
QUENCHED – 1625°F
T.S.
Y.S.P.
Red.
Elon.
STRESS – POUNDS PER SQ. IN.
PERCENT
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
70
60
50
40
30
20
10
0
800 900 1000 1100 1200 1300
DRAW TEMP – DEG. F


BRIN. 372 372 362 352 283 230
ROCK 40 40 39 38 30 20
T.S.
Y.S.P.
Red.
Elon.
HEAT 2346
C - .230
Mn - .75
Si - .390
Mo - .52
Va - .105
Cu - 1.06
Cr - .66
¾" ROUNDS
QUENCHED - 1625°F
STRESS - POUNDS PER SQ. IN.
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
70
60
50
40
30
20
10
0
PERCENT
800 900 1000 1100 1200 1300
DRAW TEMP. - DEG. F


BRIN. 342 352 332 332 283 230
ROCK. 37 38 36 36 30 20
HEAT 2348
C - .215
Mn - .68
Si - .440
Mo - .45
Va - .11
Cu - 1.34
Cr - .53
3/4" ROUNDS
QUENCHED - 1625°F
T.S.
Y.S.P.
Red.
Elon.
STRESS - POUNDS PER SQ. IN.
PERCENT
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
70
60
50
40
30
20
10
0
800 900 1000 1100 1200 1300
DRAW TEMP - DEG. F


BRIN. 363 363 332 332 283 223
ROCK. 39 39 36 36 30 19
T.S.
Y.S.P.
Red.
Elon.
HEAT 2349
C – .225
Mn – .69
Si – .465
Mo – .485
Va – .09
Cu – 1.59
Cr – .26
¾ ROUNDS
QUENCHED – 1600°F
STRESS – POUNDS PER SQ. IN.
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
70
60
50
40
30
20
10
0
PERCENT
800 900 1000 1100 1200 1300
DRAW TEMP – DEG. F



CURVES SHOWING
STRENGTH VS CU-Cr RATIO

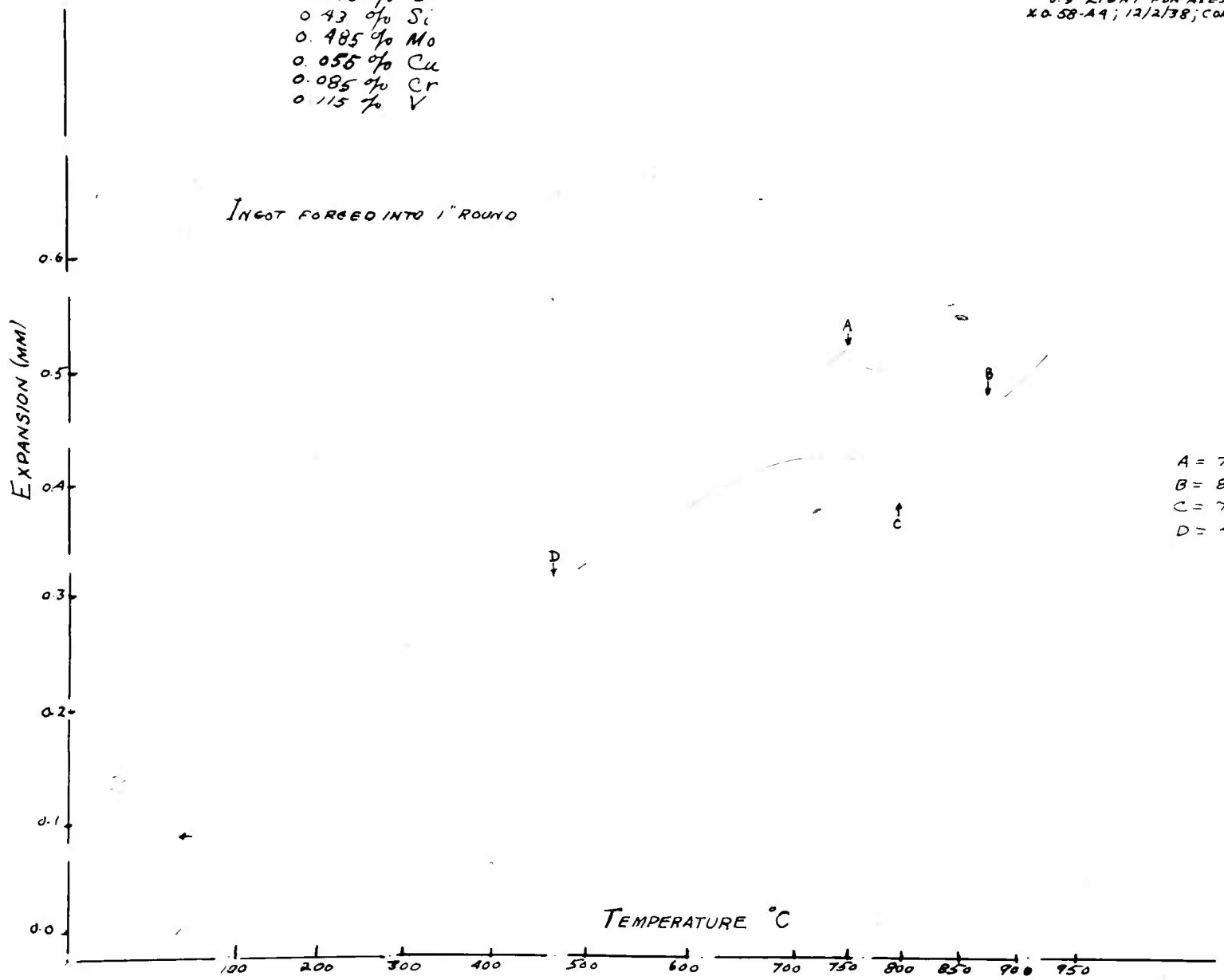
Dilatometer Run #122

Chronin vs B-1
Max. temp. 900°C; Room temp. 22°C
Length of spec. before: 1.9715" after: [illegible]
Heating rate = 3°/min; Cooling rate = 3°/min.
Contraction at A = 3.2 x 10⁻⁴ units/U.L.
" " B = 6.0 " " "
Expansion " C = 7.1 " " "
Coef. of Exp. (20°-700°) = 14.5 x 10⁻⁶
0.3 light for axes, .05 for curve
X 0.58-A9; 12/2/38; Comm. Film X1; M.B.G.

Chem. Analysis

0.205 % C
0.89 % Mn
0.009 % P
0.018 % S
0.43 % Si
0.485 % Mo
0.056 % Cu
0.085 % Cr
0.115 % V

Ingot forged into 1" round



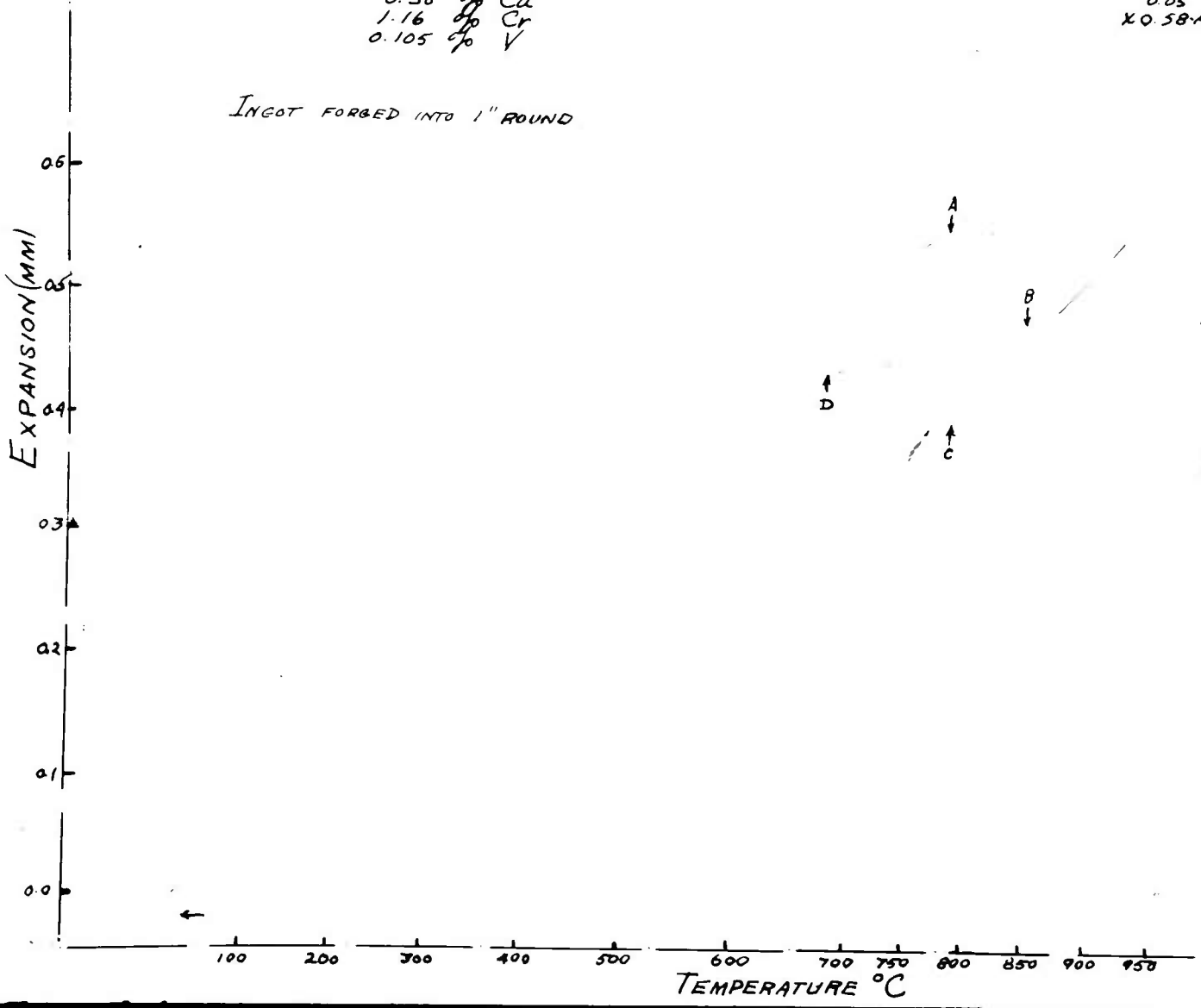
A = 743°C (1369°F)
B = 869°C (1596°F)
C = 792°C (1457°F)
D = 460°C (860°F)

DILATOMETER RUN #123
CHRONIN VS. B-2
MAX. TEMP. 900°C · ROOM TEMP. 22°C
LENGTH OF SPEC. BEFORE = 1.9710"
" " " AFTER = 1.9700"
HEATING RATE = 3.0°/MIN.
COOLING " = 3.0°/MIN.
CONTRACTION A TO B = 15.0 UNITS/U.L. $\times 10^{-4}$
EXPANSION AT C = 9.0 " " "
" " D = 0.5 " " "
COEF OF EXP. (20-700°) = 14.6×10^{-6}
0.3 LIGHT FOR AXES
0.05 " " CURVE
X 0.58-AA; COMM. FILM x1; 12/1/38 M.B.G.

CHEM. ANALYSIS

0.235 %	C
0.47 %	Mn
0.009 %	P
0.018 %	S
0.42 %	Si
0.43 %	Mo
0.30 %	Cu
1.16 %	Cr
0.105 %	V

INGOT FORGED INTO 1" ROUND

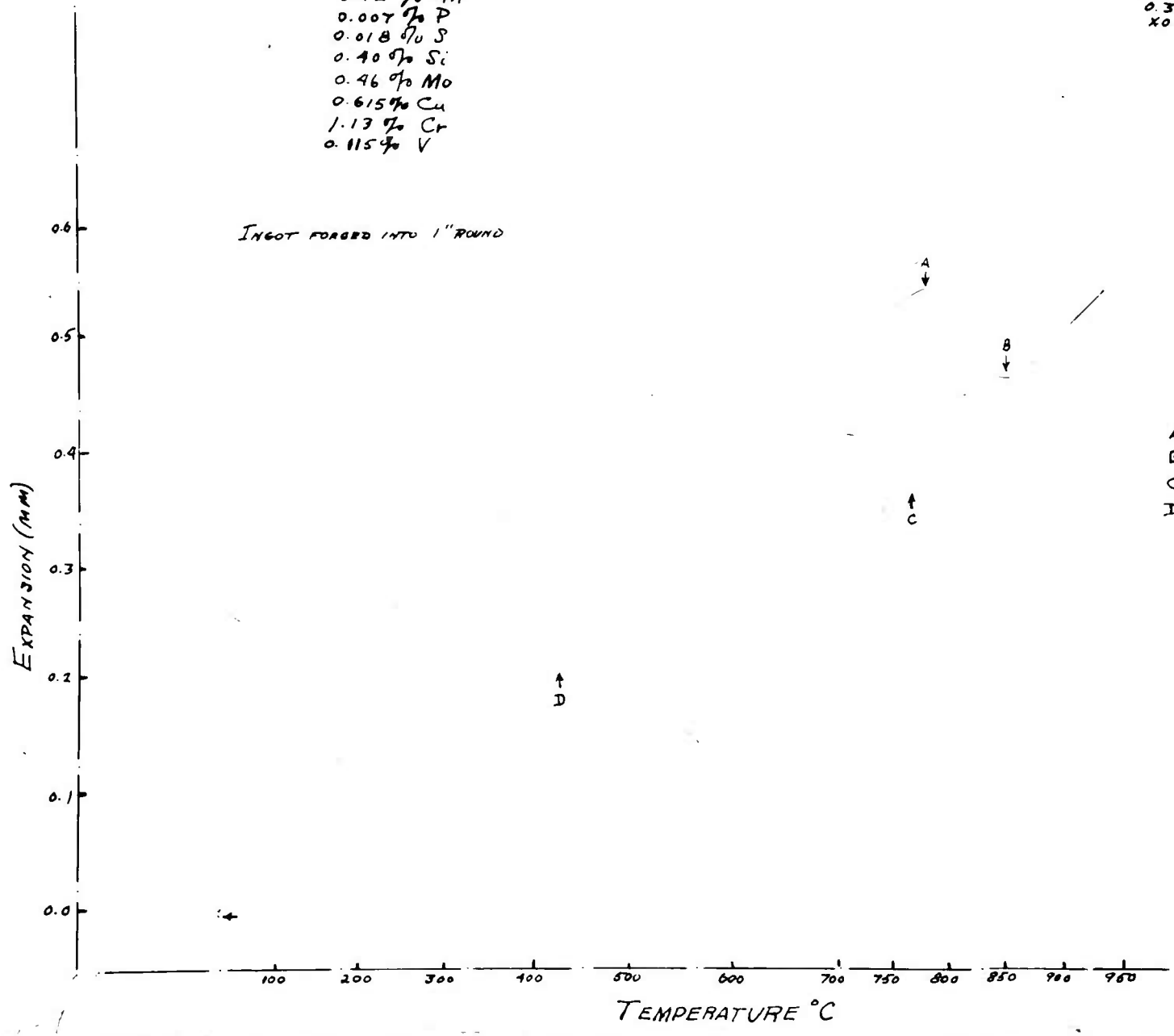


A = 784 °C (1445°F)
B = 849 °C (1562°F)
C = 788 °C (1448°F)
D = 682 °C (1259°F)

DILATOMETER RUN # 124
CHROMIN VS. B 3
MAX. TEMP. 900°C; ROOM TEMP. 28°C
LENGTH OF SPEC. BEFORE AND AFTER = L.995"
HEATING AND COOLING RATE = 3.6°/min
CONTRACTION A TO B = 5.7 UNITS/.1".
EXPANSION AT C = 9.8 " "
COEF. OF EXP. (20°-700°) = 14.8×10^{-6}
0.3 LIGHT FOR AXES; .05 FOR CURVE
XO 58A4 COMM. FILM X1 12/5/38 MBC

CHEM. ANALYSIS
0.21 % C
0.72 % Mn
0.007 % P
0.018 % S
0.40 % Si
0.46 % Mo
0.615 % Cu
1.13 % Cr
0.115 % V

INGOT FORGED INTO 1" ROUND

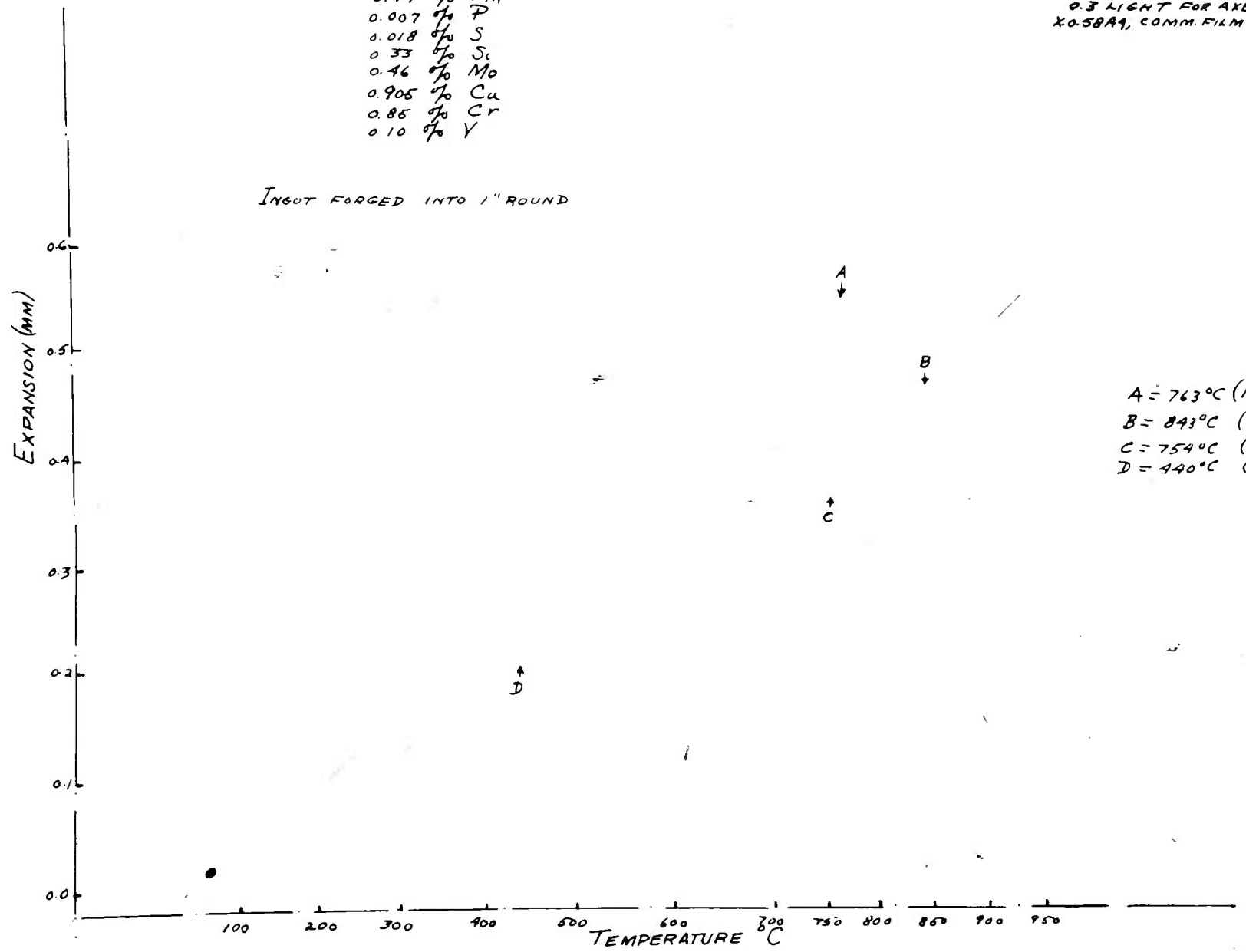


A = 772 °C (1421 °F)
B = 845 °C (1553 °F)
C = 761 °C (1402 °F)
D = 424 °C (795 °F)

DILATOMETER RUN #125
CHRONIN V3. B-4
MAX. TEMP. 900°C; ROOM TEMP. 28°C
HEATING AND COOLING RATE 3.9°/MIN.
CONTRACTION A TO B = 15.3 UNITS/U.L. $\times 10^{-4}$
EXPANSION AT C = 8.3 "
" " D = 1.0 "
COEF. OF EXP. (20-700°) = 14.8×10^{-6}
0.3 LIGHT FOR AXES, .05 CURVE
X0.58A9, COMM. FILM X1; 12/5/38 MBG

CHEM. ANALYSIS
0.215 % C
0.74 % Mn
0.007 % P
0.018 % S
0.33 % Si
0.46 % Mo
0.905 % Cu
0.85 % Cr
0.10 % V

INGOT FORGED INTO 1" ROUND



A = 763°C (1405°F)
B = 843°C (1549°F)
C = 754°C (1389°F)
D = 440°C (824°F)

DILATOMETER RUN #126

CHROMIN V3 B-5

MAX. TEMP SETTING 900°C, ROOM TEMP. 25°C

HEATING AND COOLING RATE = 3°/min.

CONTRACTION A TO B = 12.9 X 10⁻⁴ U.N.L.

EXPANSION AT C = 6.0 " "

COEF. OF EXP. (20-700) = 14.7 X 10⁻⁶

LENGTH OF SPEC. BEFORE = 1.9700

" " AFTER = 1.9697

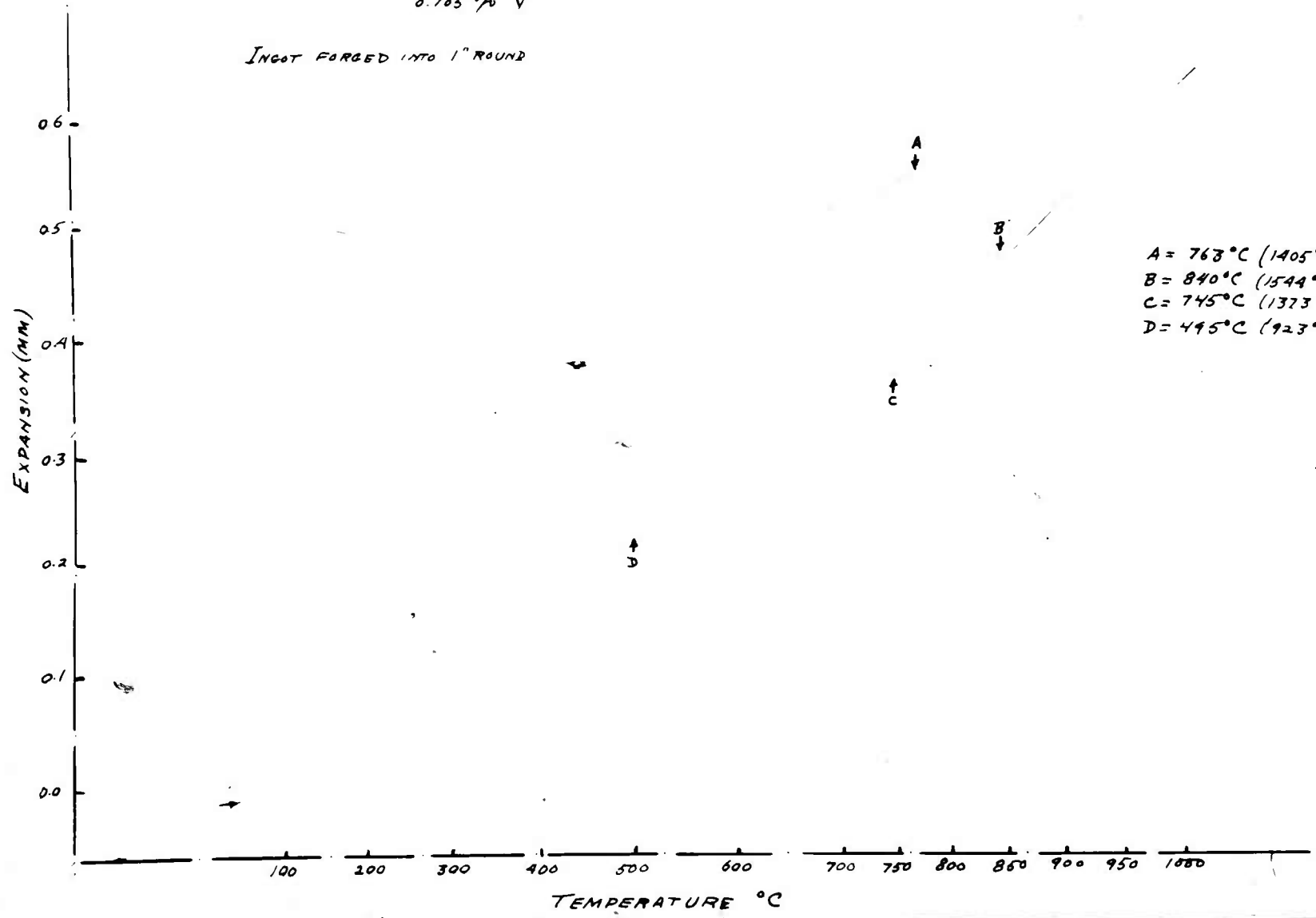
0.3 LIGHT FOR AXES; .05 FOR CURVE

X 0.58 A4; COPPA FILM #1; 12/4/78 MBG.

CHEM. ANALYSIS

0.23 % C
0.75 % Mn
0.008 % P
0.018 % S
0.39 % Si
0.52 % Mo
1.06 % Cu
0.66 % Cr
0.105 % V

INGOT FORGED INTO 1" ROUND



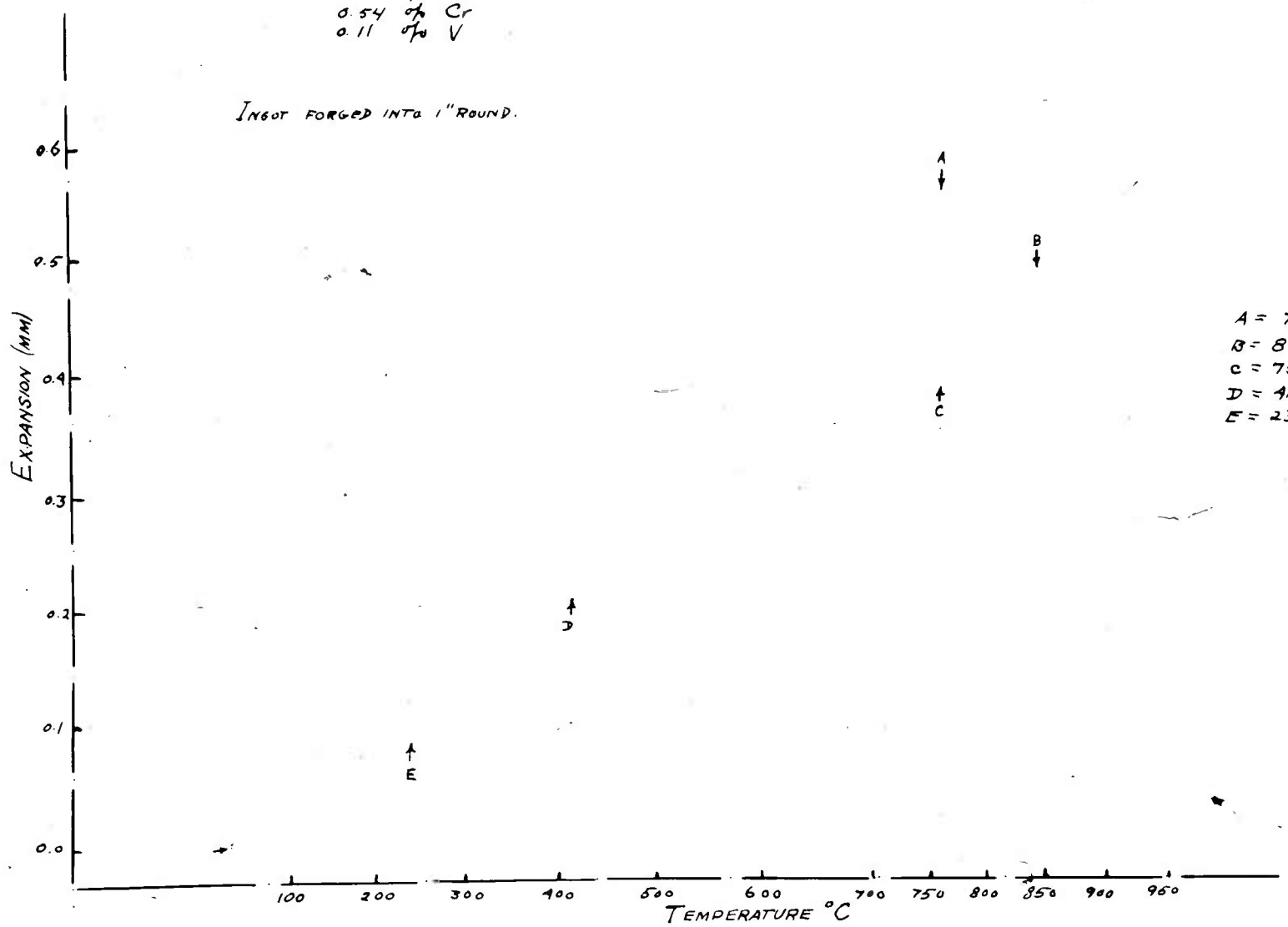
A = 768°C (1405°F)
B = 840°C (1544°F)
C = 745°C (1373°F)
D = 495°C (923°F)

DILATOMETER RUN #127
CHROMIN VS. B-C
MAX TEMP 900°C; ROOM TEMP 24°C
HEATING AND COOLING RATES = 3°/MIN.
EXPANSION AT C = 7.4 x 10⁻⁴ U/U..
CONTRACTION A TO B = 13.6 " "
COEF OF EXP (20-706°) = 15.2 x 10⁻⁶
0.3 LIGHT FOR AXES, 0.6 FOR CURVE
X 0.58 A Y; COMM. FILM X1; 12/9/38 M.B.G.
LENGTH OF SPEC. BEFORE = 1.9700", AFTER = 1.9691"

CHEM. ANALYSIS

0.25 %	C
0.68 %	Mn
0.007 %	P
.018 %	S
0.44 %	Si
0.45 %	Mo
1.34 %	Cu
0.54 %	Cr
0.11 %	V

INGOT FORGED INTO 1" ROUND.

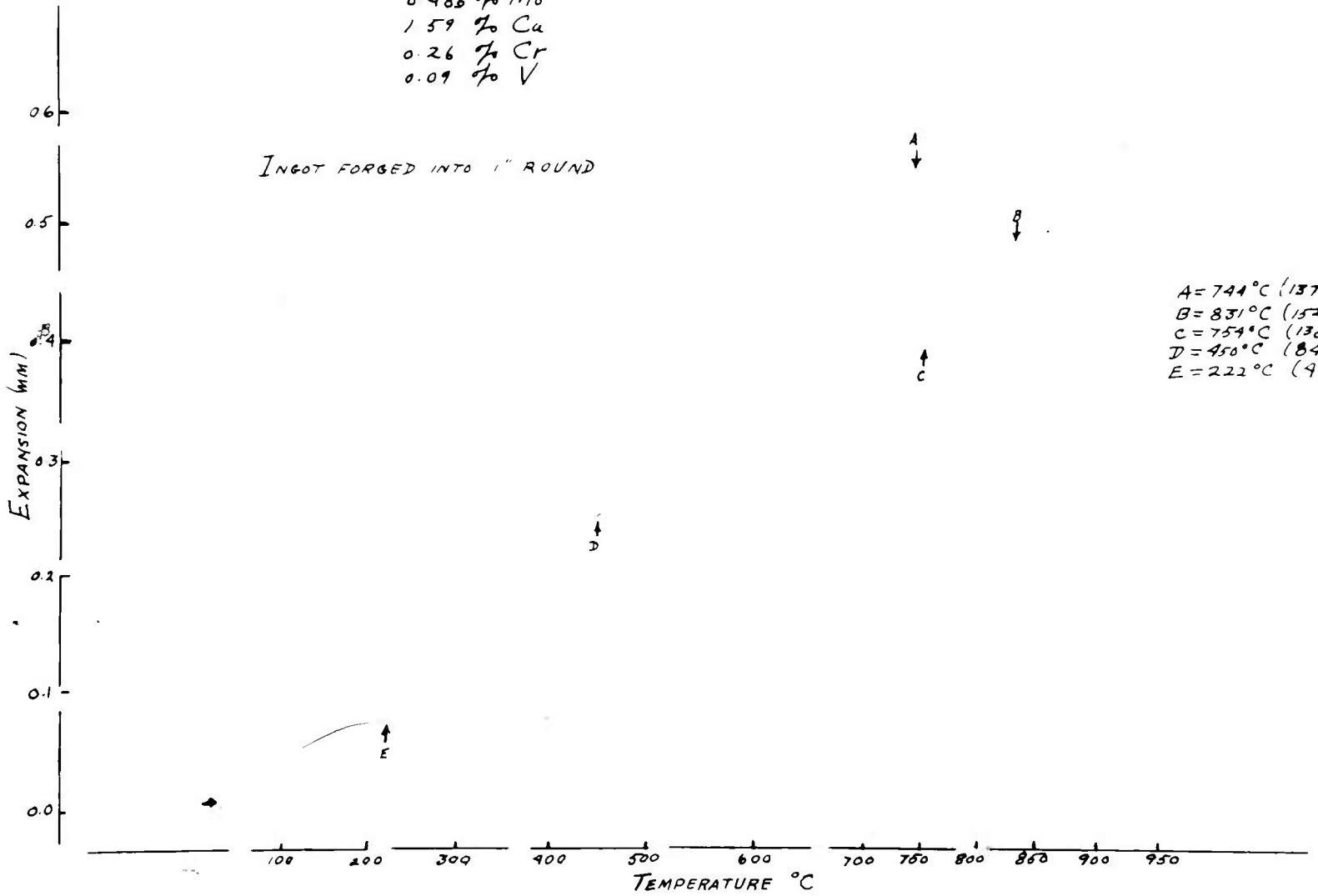


A = 757°C (1394°F)
B = 840°C (1544°F)
C = 756°C (1393°F)
D = 410°C (770°F)
E = 235°C (455°F)

DILATOMETER RUN #4/28
CHROMIN VS. B-7
MAX TEMP SETTING 900°C, ROOM TEMP. 24°C
HEATING AND COOLING RATES 3.3°/MIN.
CONTRACTION A TO B = 12.8 X10⁻⁴ U./U.L.
EXPANSION AT C = 8.0 X10⁻⁴ " "
COEF OF EXP (20-700) = 15.3 X10⁻⁶
LENGTH OF SPEC. BEFORE = 1.9705"
" " AFTER = 1.9705"
0.3 LIGHT FOR AXES, .05 FOR CURVE
X0.584Y, COMM. FILM X1; 12/12/38 M.B.G.

CHEM ANALYSIS
0.225 % C
0.69 % Mn
0.007 % P
0.018 % S
0.465 % Si
0.485 % Mo
1.59 % Cu
0.26 % Cr
0.09 % V

INGOT FORGED INTO 1" ROUND



A = 744°C (1371°F)
B = 831°C (1528°F)
C = 754°C (1389°F)
D = 450°C (842°F)
E = 222°C (431°F)