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Rept. No. 344/22

19 Sept. 34

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Report No. 344/22
Watertown Arsenal

Sept. 19, 1934

K Monel Metal - Its Tensile Properties and Heat Treatment

Object

It is the purpose of this report to record all data obtained in the study of K Monel incident to its use in Navy Mounts.

Reference

W. A. Report #344/21

Correspondence file O.O.472.6/869, W. A. 472.6/271, 11/20/33, "5"/25 Cal. A.A. Gun Mounts - Recommendations".

Conclusions

K Monel metal is a corrosion resistant non-ferrous alloy with properties suitable for ordnance purposes. In the soft condition K Monel has properties slightly higher than Monel metal. The advantage lies in the fact that K Monel can be hardened by heat treatment.

Soft K Monel with a hardness around 140/150 BHN_{3000} can have its hardness raised to 300/320 by furnace cooling from 1100°F (593°C) after being kept at temperature for upwards of 6 hours. Variations of temperature and time at temperature affect the hardness. Hardness due to heat treatment is additive to hardness due to cold working, so that hardnesses as high as 400 BHN_{3000} are obtainable.

Material whose hardness must be slightly lowered can be softened in one step by air cooling from temperatures between 1100° and 1550°F (593° 842°C), the particular temperature being chosen according to the hardness desired. As the rate change of hardness with temperature is high, and as the cooling rate also has an appreciable effect, careful control is necessary.

If machined at slow speeds little difficulty is encountered when the hardness is less than 310. Hobbing requires extremely slow speeds, and large angles of rake and clearance.

Essential data for making up specifications are given.

Introduction

In the study of corrosion resisting material suitable for the uses of the Ordnance Department, a preliminary survey of a nickel-copper alloy containing Al showed it to have interesting properties. The alloy was K Monel Metal marketed by the International Nickel Company, and developed principally by Merica & Mudge.

The only reference to K Monel in the literature is that by Paul D. Merica* in which he refers to the unpublished work of Mudge. Copper-nickel alloys containing more than 5% or either Cu or Ni, and from 1 to 10% Al age harden. The identity of the hardening constituent is not certain, but it appears to be a solid solution of NiAl and Cu_3Al in varying proportions. Alloys containing 40-80% Ni give no microscopic evidence of any precipitation after age hardening. These alloys cannot be overaged: maximum hardness is obtained at 1000°F; at higher temperatures the hardness is decreased, due to resolution of hardening particles in the solvent. The limit of solubility of Al in Cu-Ni alloy appears to be 2.% from room temperature up to ca. 1150°F, 5% at ca. 1750°F and 10% at ca. 2350°F. The hardening compounds tend to be precipitated at the grain boundaries and consequently the hot working properties are impaired. The ductility of these alloys approach low values if tested at temperatures between 1200 and 1400°F.
U. S. Patents #1755554, 5,6,7, (1930) have been issued to Dr. W. A. Mudge, covering the heat treatment of this alloy. U. S. Patent #1572744 was issued to P. D. Merica.

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*"The Age-Hardening of Metals" Trans. A. I. M. E. Vol. 99, 1932, pages 13-54, especially pages 34-35 and 47.

K Monel metal is Monel metal with Al and Ti additions. Its physical properties may be changed by heat treatment. The major constituents are Ni 62-67%; Cu 23-28%; Al 2-5%; other metals under 5%. Average analyses of heats are shown in Table I. This metal is available in form of rods up to 6" dia., 16 ft. long, and tubes 5" dia., 1/2" wall, 16 ft. long. The tubes would be manufactured by forging, boring, and heat treating.

Table I

Average Analyses of 7 Heats of K Monel.

Data supplied by International Nickel Co. (W.A.470.1/3296)

Element	Per Cent		
	Ave.	Mx.	Mn.
Ni	66.1	67.2	65.2
Cu	28.3	29.4	27.2
Al	3.58	4.15	3.40
Fe	1.43	1.77	1.19
Mn	0.05	0.09	Trace
Si	0.21	0.24	0.15
S	0.005	0.005	0.005
C	0.15	0.12	0.17

Simultaneous with our study, the Navy Department required the use of K Monel in gun mounts being manufactured at this Arsenal.

Communication with the International Nickel Company and engineering studies revealed the desirability of heat treating K Monel at this Arsenal. An opportunity was therefore, given to study the characteristics of this alloy.

Material

The International Nickel Company supplied this Arsenal with two test bars, 48" x 2" dia., from the same heat, one rolled and quenched, the other hot rolled and heat treated. The material used for navy mounts was obtained on P. O. 7561. The analyses are given on Table II

Table II

Chemical Analyses of K Monel Used at Watertown Arsenal

Element	Test Bar K Heat #666 Invoice INCO-H 12586	Buffer 112"x 1-3/4"d 3 analyses range	Piston 108" x 3½" d #809	Piston 108" x 3½" d #810
	Per Cent			
Ni	64.86	66.29-66.19	64.76	64.24
Cu	30.55	29.15-29.25	28.80	29.90
Al (+Ti)	3.61	3.05- 3.05	3.42	3.31
Fe	0.64	0.99- 0.99	1.47	1.47
Si	0.10	0.28- 0.28	0.24	0.21
Mn	0.24	0.12- 0.10	1.16	1.07
C		0.14- 0.14	0.18	0.14
Ti	0.03			

The tensile properties of the two test bars are given in Table III.

Table III

Tensile Properties and Hardness of K Monel Metal from Heat #666

	Hard "HK"		Soft "K"	
	Long.	Trans.	Long.	Trans.
Dia. of test bar, inches	0.357 T.S.	0.125	0.357 T.S.	0.125
P.L. p.s.i.	81,000	92,500	42,000	39,000
Y.S. (0 5% set) p.s.i		106,000	.....	46,100
T.S. p.s.i.	149,500	151,600	93,800	98,400
Elong. %	21.4	23.	47.5	48.
Red. of area	37.6	26.	66.7	52.
Hardness, Brinell BHN $_{3000}$		321 286		157-149
Rockwell $_{150}$R c		31-1/2 29		14-9
Tensile charpy Ft. Lbs.	53.3	44.1	81.1	56.4

True stess data were also obtained for these metals and are given on figures 1 and 2. On figure 3 is shown the effect of placing a test specimen of hot rolled K Monel in liquid oxygen but allowing to come to room temperature before pulling.

The drop in strain occurring at 45,000 p.s.i. stress was eliminated. For purposes of comparison data for Monel metal (P.O.3110) is given on figure 4. This metal was cold worked and therefore has a higher proportional limit than soft K Monel, but the true breaking stress is lower than for K Monel. In general the properties of Monel metal are slightly lower than K Monel in the equivalent condition.

The areas under the true stress curves are listed on Table IV. There are also given the energies absorbed when bars of the same size were broken by impact at a velocity of approximately 32 ft./sec.

Table IV

Energy of Rupture

	Area under true stress curve ft.lbs.	Energy absorbed upon impact ft. lbs.
Monel Metal	534	442
K Monel-Hot rolled	769	555
" " " " treated in liquid air	732	
" " Heat treated	516	459

There is a difference between the energy of rupture at zero rate (area under true stress curve) and energy of rupture of rate of impact of 32 ft./sec. (impact test). The difference for soft K Monel is greater than for hard

K Monel indicative that the energy of rupture of the latter decreases with increased speed of rupture at a lower rate and that at rates of impact higher than 32 ft./sec. hard K Monel will absorb more energy at rupture than soft K Monel.

Upon testing with armor piercing cal. 30 bullets of 1000 ft./sec. velocity, 3/16" plates of hard K Monel were punctured to a lesser degree than soft K Monel indicative that the former absorbed more energy than the latter. The soft plate was deformed appreciably by the impact of the bullet. Both plates showed a petalling effect, coarser cracks being present on the soft plate.

Effect of Heat Treatment

Discs of hard K Monel 1/2 inch thick were heated to various temperatures and water quenched. These discs were numbered "HK1"to "HK5" respectively. Some of these discs were rehardened and were renumbered with an "r".

Cylinders of soft K Monel, 2" long were heated to various temperatures and cooled at various rates. These cylinders were numbered "K10" to "K14", furnace cooled, "KA", air cooled, and "KO" water quenched. The cylinders were split in half and properties determined either in the lonitudinal or transverse direction. Hardnesses were absorbed on machined surfaces. The results obtained are listed on Table V & VI and are graphically shown in figure 5.

Table V

The Effect Of Heat Treatment upon the Hardness of K Monel

Heat # 666-2" dia.

Specimen No.	°C	Heat Treatment Hrs at temp.	Cooling+ Medium	Hardness BHN_{3000} Ctr. ++	BHN_{3000} 50% R +++	150^{R} C Ctr. ++	150^{R} C 50% R +++	Length of spec. in.
HK		Commercial		302	286	29.	30.	48
HK1	410	2	W	311	305	30	30	1/2
HK2	510	2	W	321	305	32	31-1/2	1/2
HK3	610	2	W	269	260	26	25	1/2
HK4	660	2	W	217	207	20	18-1/2	1/2
HK5	710	2	W	156	152	10	10	1/2
HK^1	825	1	W		150		5-1/2	2
K^3	825		W		148		10-1/2	1-1/2
K15	Commercial		W	156	157	11	11	48
KO	598	3	W	248	241	25-1/2	22-1/2	1
KA	598	3	A	269	269	24	25	2
K10	598	2-1/2	F	302	302	30	31-1/2	2
K11	598	5-1/2	F	311	305	29	29	2
K16r	598	5	F	315	305	32-1/2	32	2
K3r	598	5	F	310	301	32	30	2
HK5r	598	5	F	311	302	29	[illegible]-1/2	1/2
HK4r	598	5	F	302	280	26	25-1/2	1/2
HK3r	598	5	F	302	293	29	27-1/2	1/2
KAr	598	5	F	302	299	28-1/2	29	1/2
K12	598	7-1/2	F		293	32-1/2	30++++	2
K13	653	2-1/2	F	269	264	24-1/2	24	2
K14	653	5-1/2	F		247	23	22++++	2
K14	653	5-1/2	F			27		
K14	653	" + 120° C 4 hrs.				27-1/2		

++++ Split longitudinally, all others split transversely
+++ Ave. of 3 or more observations
++ 1 observation
+ W = water A= air F= furnace

Table VI

Hardness and Tensile Properties of K Monel Metal

Test bars taken at 50% radius
L-longitudinal T-Transverse

Specimen No.	Heat Treatment	Hardness BHN_{3000}	Hardness 150^{R}	T.S. 1000 p.s.i.	P. L. 1000 p.s.i.	Y.S. 0.2% set 1000 p.s.i.	Y.S. 0.5% p.s.i.	El. %	RA %	Test Spec.
$HK_{666}L$)	Commercial	286	30	149.5	81.0	-	-	22.4	37.6	.357L
$HK_{666}T$)	Bar 666			151.6	92.5	-	106.0	23.	26.	.125T
$KA_{666}L$	598°C 3 hrs. Air cooled	269	25	138.2	86.2	93.5	97.2	27.0	26.8	0.125L
$K11_{666}T$	598°C 5-1/2 hrs. F.C.	305	29	152.8	96.[illegible]	109.6	114.6	21.8	35.8	0.125T
$K15_{666}L$)	Commercial	157	11	93.8	42.0	-	--	47.5	66.7	
$K15_{666}T$)	Bar 666			98.4	39.0	--	46.1	48.	52	
Production Work - W. A.										
1 Buffers 1-3/4" d.	Commercial Soft	187		101.0	35.	--	68.	32.0	66.6	0.252L
2 "	1100°F 7 hrs. F. C. 1st	296	31.5 (29.±3)	151.0	88.	--	115	25.0	47.0	0.357L
3 " 813-1	" 2nd	280	24.7	142.5	91.5	99.5	102.0	28.6	54.4	0.357L
4 " -2	" "	302	30.3	149.5	93.5	117.5	114.0	29.7	49.0	"
5 " -3	" "	305	27.5	150.5	96.0	113.5	117.5	25.0	49.4	"
1 Pistons 3-1/2" d.	Commercial Soft	149	7.0	96.0	28.5	--	44.5	51.	57.0	0.252T
2	1100°F. 5-1/2 hrs. F.C.	340	36.5	168.0	90.0	--	--	17.9	26.0	0.357T
3 "	1100°F. 5-1/2 hrs. F.C. 1210°F 2 hrs. A. C.	299	28.5	147.0	78.0	106.6	--	21.4	29.4	0.357T
4 "	1100°F 5-1/2 hrs. F. C. 1190°F 2 hrs. A. C.	317	30.0	157.0	100.0	116.0	118.7	22.1	28.4	0.357T

Table V con't

Hardness and Tensile Properties of K Monel Metal

Test bars taken at 50% Radium
L=Longitudinal T=Transverse

Specimen No.	Heat Treatment	Hardness BHN 3000	Hardness R_c 150	T. S. 1000 p.s.i.	P.L 1000 p.s.i.	Y.S. 0.2% set 1000 p.s.i.	Y.S. 0.5% set 1000 p.s.i.	El. %	RA %	Test Spec.
Information from International Nickel Co.										
K787		340	33	166.5	110.0	-	127.4	13.8	18.3	(0.505L)
798		302	29	158.5	86.0	-	110	27.	35.4	"
796		344	33	168.0	110.5	-	128.0	12.0	11.5	"

Discussion of Effects of Heat Treatment

Quenching from temperatures as high as 510°C (950°F) was found to have a very slight hardening effect, but quenching from temperatures above 610°C caused a marked softening of hard K Monel. When plotted the observed hardness values fall on one of two straight lines as shown on figure 5, and these two lines intersect at about 570°C, (1058°F). This is 23°C lower than the maximum temperature as given by the International Nickel Company for heating followed by quenching without affecting the tensile properties. The rate of change of BHN_{3000} with temperatures in the range 570°C to 710°C, (1022°F-1310°F) is high being 1.1 BHN/°C.

Soft K Monel whose BHN_{3000} was 157 had its hardness raised to 305 by being furnace cooled from 598°C (1110°F) after being kept at temperature for 5 1/2 hours. A faster rate of cooling as air cooling gave a softer temper; a higher temperature also gave a softer temper. Variations in rates of furnace cooling between 60° C/hr. and 33° C/hr. gave little difference in hardness obtained.

K Monel that was only partially softened could be rehardened satisfactorily upon reheat treatment.

The heat treatment of the pistons and of the rammer buffers was carried on at this Arsenal with the help of Dr. W. A. Mudge of the International Nickel Company.

On table II are listed the analyses of stock used for navy mounts. On table VI, under production work at W.A. are given the observed physical properties of these bars before and after heat treatment.

Fig. 6 and 7 give data made available to us by Dr. Mudge. The average physical properties are given in Figure 6 which shows the relation between Brinell Hardness and other physical properties. The yield point is defined as that stress which gives 0.5% set.

Agreement of individual determinations with these curves of average values will not be as close as if the data were for steels. Data on Table V show the wide variation in $_{150}$ R C numbers with respect to comparable Brinell numbers.

K Monel will be made commercially available in 4 tempers to be referred to as No. A, B, C, and D. These tempers are obtained (A) by quenching in water from between 14-1600°F, preferable 1500°F - soft - BHN 180. (B) reheating the soft material to 1000°F and furnace cooling, -BHN -230. (C) reheating the soft material to 1050°F and furnace cooling -BHN-280. (D) reheating the soft material to 1100°F and furnace cooling -BHN-330.

On Fig. 7 data useful for heat treating K Monel is given Curve 3 shows the relation between hardness and time at 1100°F, followed by furnace cooling. Little is to be gained by holding at temperatures longer than eight hours.

Holding for 7 hours would give a hardness slightly lower, around 300 BHN_{3000}.

The maximum hardness obtainable due to heat treatment of soft metal is 310/320 BHN, an increase of 170/180 units, but if the hardness of the soft material is raised by cold working then the hardness obtainable by heat treatment will be additive and superimposed. Thus cold worked K Monel with a hardness of ca. 230 BHN will have its hardness increased to ca. 400 BHN by heat treatment, an increase of 170 units. However, if this metal be exposed to high temperatures for long periods of time, the hardness due to cold work will be eliminated, so that the Brinell values will fall to 310/320, which is that value obtainable by heat treatment alone. For instance, at the hardening temperature 1100°F, the hardness obtained on a fully cold worked metal in 10 hours was about 400 BHN, but in two months it was only about 300 BHN.

Curve 1, fig. 7 shows the change in hardness of hardened K Monel when heated to the indicated temperatures and water quenched. The maximum temperatures from which the metal may be quenched without affecting physical properties is around 593°C (1100°F). This is some 23°C higher than estimated from limited data obtained at this Arsenal. The rate change in the temperature range 593-842 C is around 0.63 BHN/°C.

However, when the metal is cooled more slowly as by air cooling the rate of change is reduced to about 0.40 BHN/°C. Curve 2, figure 7 shows this difference and also shows that 200 BHN is the minimum hardness obtainable by air cooling from 842°C (1550°F). If quenched from higher temperatures, higher hardnesses are obtained due to increased solubility of the hardening agent and to the greater length of time during cooling for precipitation hardening to occur.

Curve 2 is useful for softening in one step K Monel that is too hard. However, allowances must be made for the changing rate of cooling in the air in mid-summer, and the air in mid-winter, especially at Watertown Arsenal where extremes are encountered in unheated buildings where heat treatment is carried on.

The material for the pistons used in the navy mounts when hardened, was too hard for machining. A pilot piece was softened by heating to 1200-1220°F, holding for sufficient length of time to heat through and air cooling. As the physicals obtained of the pilot piece were at the minimum desirable the rest of the material was softened by heating to 1180-1200°F. The desired physicals were then obtained.

Uniformity of Hardness

The uniformity of hardness of K Monel rods ware measured by systematically observing Rockwell values. The hardness of a 108" rod, 1-3/4" dia., was determined every 12", 3 readings, 90° apart, being taken at each place on the circumference. The average value was 28.8 $_{150}$R C with 31-1/2 maximum and 24 minimum being the limits of variation.

On figure 8 are plotted "iso-hardness" or lines of equal hardness of a test specimen 2" long x 2" dia. $_{150}$R C 19, 21, and 23 being indicated. Attempts to explain the discrepancy reported for specimen K14 lead to the belief that the metal actually has the differences reported. Methods of testing, of mounting even of heating due to mounting or grinding were varied, but without effect on the values recorded.

Metallography

K Monel was found to have a simple metallography structure indicative of the existence of a single phase only, even in the hardened condition. The hardening constituent was not observable. Upon etching, the grain boundaries were found to be very susceptible to the agent, over etching and pitting along the grain boundary occurring easily. Figure 9 and 10 are characteristic of the alloy.

Machinability

The shops reported the following regarding machining both tempers of bar 666:

1 - Both materials could be sawed, threaded, ground, drilled, coarse cut and finish cut.

2 - Hard K Monel had a much better finish after finish cutting than soft K Monel.

3 - Cutting edges tended to be dulled quickly, especially if speed of cutting was high.

4 - Best speeds of cutting were estimated as half those used for steels.

5 - Hard K Monel gave a long continuous curly chip slightly discolored, whereas the soft bar gave short fragmented irregular chips which tended to be badly discolored due to heat.

With hardnesses at the upper limit of acceptable material, machining became more difficult. The stock for pistons hardened too much when heat treated. With a Brinell of 340 the material was sawed with extreme difficulty. The hardness was lowered to 317 and the material was able to be sawed, rough cut, fine cut, threaded bored, drilled, but only at extremely slow speeds.

The rammer buffers with a hardness around 300 BHN_{3000} were machined with little trouble. The bars were extremely long and with small diameter. The principal difficulty was "spotting", but once properly centered was relatively easy.

Cutting speeds used for rough machining corresponded to 30 linear ft./min.

Hard K Monel could be lapped and polished more easily than cold rolled Monel metal as might be expected.

The only operation where persistent difficulty was experienced was hobbing, but with information supplied by Mr. G. A. Chadwick of the Navy Department, a worm wheel of K Monel was finally obtained. The hob was reground so that each tooth had a 10° rake, 22° clearance, 1/32" land, in front, though no rake, 3° clearance and a very slight land on the sides. Cutting at 21 r.p.m. corresponding to a linear speed of 14 ft./min. with a feed of 0.003" and using Houghton's Refrigerant Base Cutting Oil, the worm wheel was finally finished with a very good surface. The hardness of the metal was $_{150}R_C$=20. It is believed that one wheel can be rough cut and two finish cut for each sharpening of the hob, indicative that some 20 wheels can be machined per hob.

Before the wheel was actually cut to size, it had been hardened and softened in accordance with the following heat treatments:

	Treatment	Hardness $_{150}R_C$
1	As received	12
2	Hardened, 1100°F, 5½ hrs, F.C	28
3	Softened, 1300°F, 1½ " A.C.	4
4	Hardened. 1000°F 6 " F.C	20

In step 3 it was intended to soften the metal lightly using treatment suggested by curve 2, figure 7. The metal was found to be soft, indicating that data on figure 5 are more accurate. Machining was attempted in each temper, but it was not until the speed was uniform and around 14 ft./min. that the operation was accomplished. The use of S+Cl cutting oil would probably improve tool life. Such an oil would be Houghton's F Cutting Base Oil diluted 8:1.

The simple operation of drilling small holes in hardened K Monel shows the necessity of using tool steel drills rather than carbon steel. The latter were quickly dulled, and left excessive internal stresses in the metal. These stresses under active corrodants accelerate intergranular failure. Test bars uniformly cold worked did not fail by intergranular attach under similar conditions. This is indicative of the detrimental influence of unevenly distributed stresses in corrosion.

Specifications

Under date of August 13, 1934, the International Nickel Company informed the Arsenal that they are ready to approve the specification proposed by the Navy Department.

The essential data are:

Chemical Composition	
Ni	63% min.
Cu	25% min.
Al	5% max.
C	0.20% max.
Other metals	5% max.

Physical Properties

Table VII which is a copy of table I of proposed Navy Ordnance specifications gives the limitations in the physical properties.

It would be desirable for the Ordnance Department to use the same specifications, yet there are certain objections. These objections are not serious since the metal is a patented composition and obtainable only from the International Nickel Company, but it is not believed that the best interests of the Army are served.

Objections

There is no minimum value for the aluminum content. According to Merica's published work* the solubility limit of Al in Monel is ca. 2.5%, yet Dr. Mudge intimated that hardening can be done with Al at 2%. It would therefore,

*Trans. A. I. M. E. Vol. 99, 1932, p 35

be reasonable to set the lower limit for Al at 2% and maximum limit at 5%.

On table VII the heading in the 1st column should be "temper" rather than "grade". In notes, "grade" should be replaced by temper.

The International Nickel Company indicates that probably no change need be made in the minimum values for yield strength if it is defined as the stress causing 0.2% set. Actually the yield strength at 0.2% set is as much as 3700 p.s.i. lower than at 0.5% set. Typical stress strain curves are shown in figure 11.

In all probability temper C will be used extensively if this metal is used at all. Machinability decreases markedly as hardness increases above 300. Hardnesses as high as 317 have been handled in production work. If the material supplied is always at the lower side of the range no difficulty in production work will be experienced. It would be beneficial to limit hardness to 310 mx for this temper

Discussion & Summary

The characteristics of K Monel Metal have been studied. It was found that the hardness could be raised from about 140/150 to about 300/320 by furnace cooling from 1100°F (593°C) after being kept at temperature for upwards of six hours. The effect of varying time at temperature, temperature of heating and rates of cooling have been studied. Hardness due to heat treatment is additive to hardness due to cold work. Methods of slightly lowering extreme hardnesses have been studied.

K Monel metal is machinable if the hardness is less than 310 BHN_{3000}. Hobbing offered considerable difficulty but was finally accomplished by cutting at 14 ft./min., using 10° rake, 22° clearance, 1/32" land. Of course, the machinability is nowhere like that of steel, or even straight monel. Sharp tools and very slow speeds are necessary. Tools of carbon steel do not stand up; high speed tool steels are necessary.

Metallographic study reveals that the grain boundaries are easily over etched, pitting being evident. The hardening constituent is not observable under the microscope. Indications are that something occurs at the grain boundaries for the alloy tends to be brittle if tested at temperatures in the precipitating range, and if internal strains are induced as by machining hard metal with dull tools, intergranular cracking occurs when the metal is subject to active corroding agents.

The present day theories of precipitation hardening or age hardening are not believed to be sufficient to explain completely the hardening of K Monel. For instance, why the necessity of furnace cooling upon heat treatment of the quenched or softened metal. This should be an excellent thesis problem for the Ordnance school.

Respectfully submitted,

P. R. Kosting
Chemical Engineer

TABLE VII

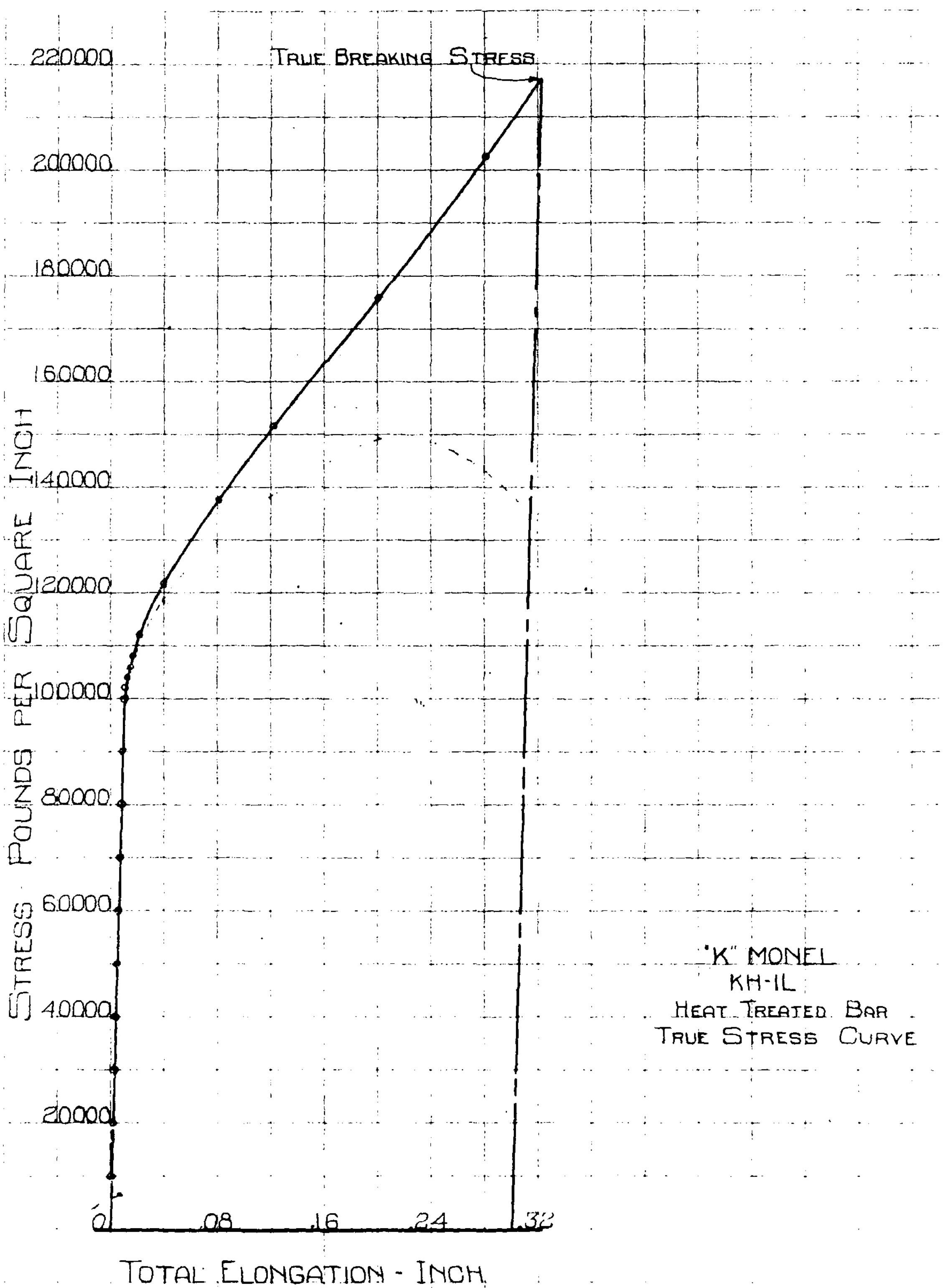
Grade	Tensile strength lb. per sq in.	Proportional limit lbs per sq in.	Yield Strength at 0.5 per cent. Elong. lbs. per sq. in	Elongation per cent.	Reduction of area per cent.	Brinell Hardness Range
A	120000 max.	60000 max	80000 max.	40 min.	50 min	softer than 225
B	120000 min. 140000 max.	60000 min. 80000 max.	80000 min. 100000 max.	30 min.	35 min.	225 - 275
C	140000 min. 160000 max.	80000 min. 100000 max.	100000 min. 120000 max.	20 min.	25 min.	275 - 325
D	160000 min	100000 min.	120000 min.	15 min.	20 min.	harder than 325

NOTES: Grade A is the softest grade obtained by a softening heat treatment. It will be specified where greatest softness is necessary for fabricating operations. Parts made from Grade A will in most cases be hardened by heat treatment after fabrication. The values of tensile strength, proportional limit and yield strength are maxima for this grade.

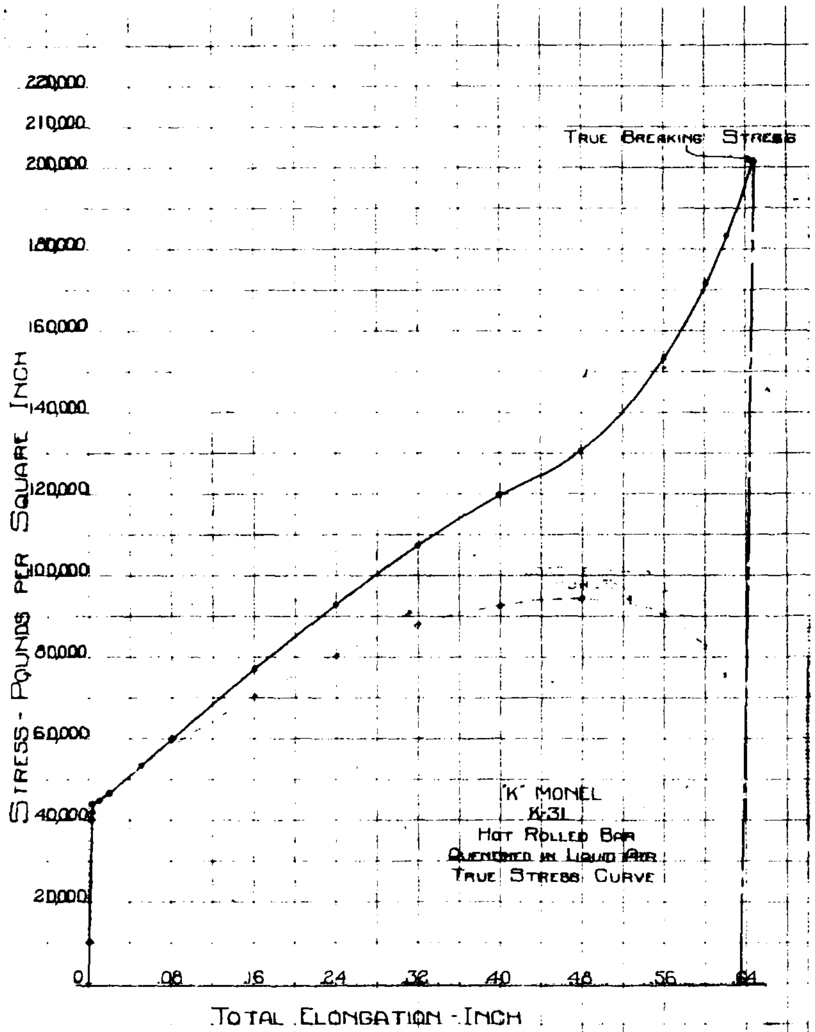
Grades B and C are intermediate. The minimum values of strength and ductility are to be considered the specification in each case and the producer should aim at the minimum strength values for the grade. The upper limits are set forth only as the boundary of the next higher grade. Grade C is the strongest grade that can be machined to advantage. Grade C will be specified in cases where parts are to be machined and used without further heat treatment.

Grade D is the fully heat treated alloy in hardest and strongest condition. Grade D can be machined only with difficulty. Grade D should be specified for parts where highest hardness and strength are desirable and where low ductility is not detrimental. Grade D can be used for parts purchased finished or that can be finished by grinding.

The Brinell hardness range values are not to be a basis for rejection under this specification. They are given as an indication of the probable hardness corresponding to the four grades.

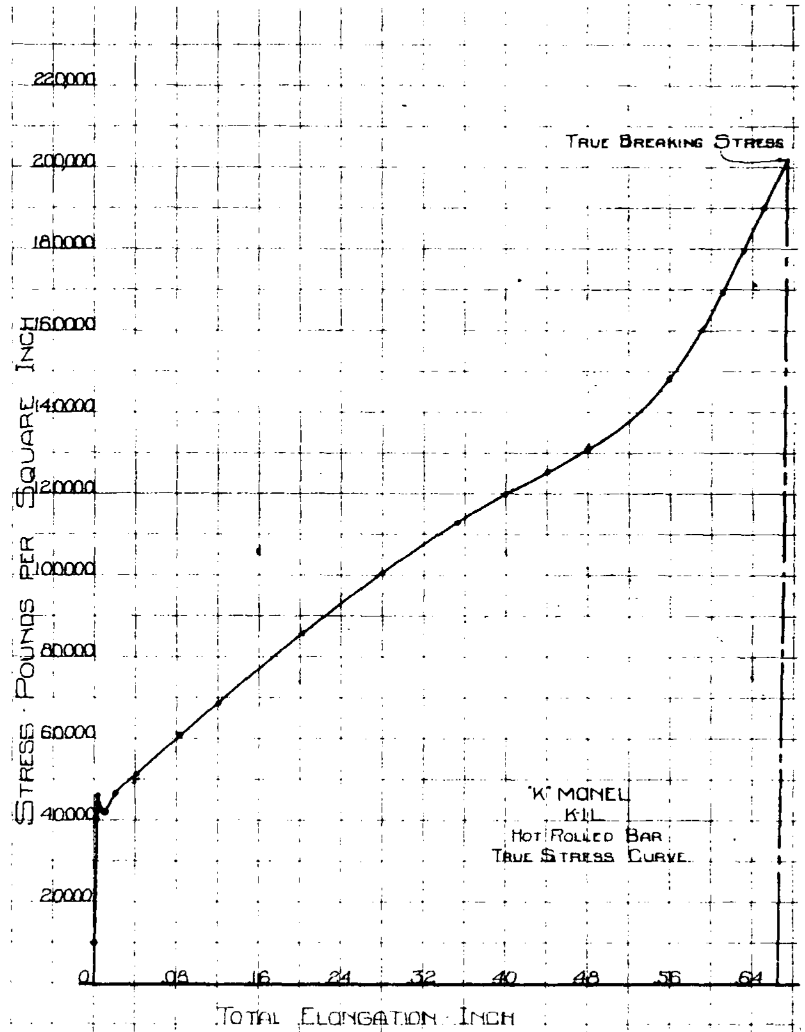


True Breaking Stress
220000
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
.08
.16
.24
.32
Stress Pounds per Square Inch
Total Elongation - Inch
"K" MONEL
KH-IL
Heat Treated Bar
True Stress Curve



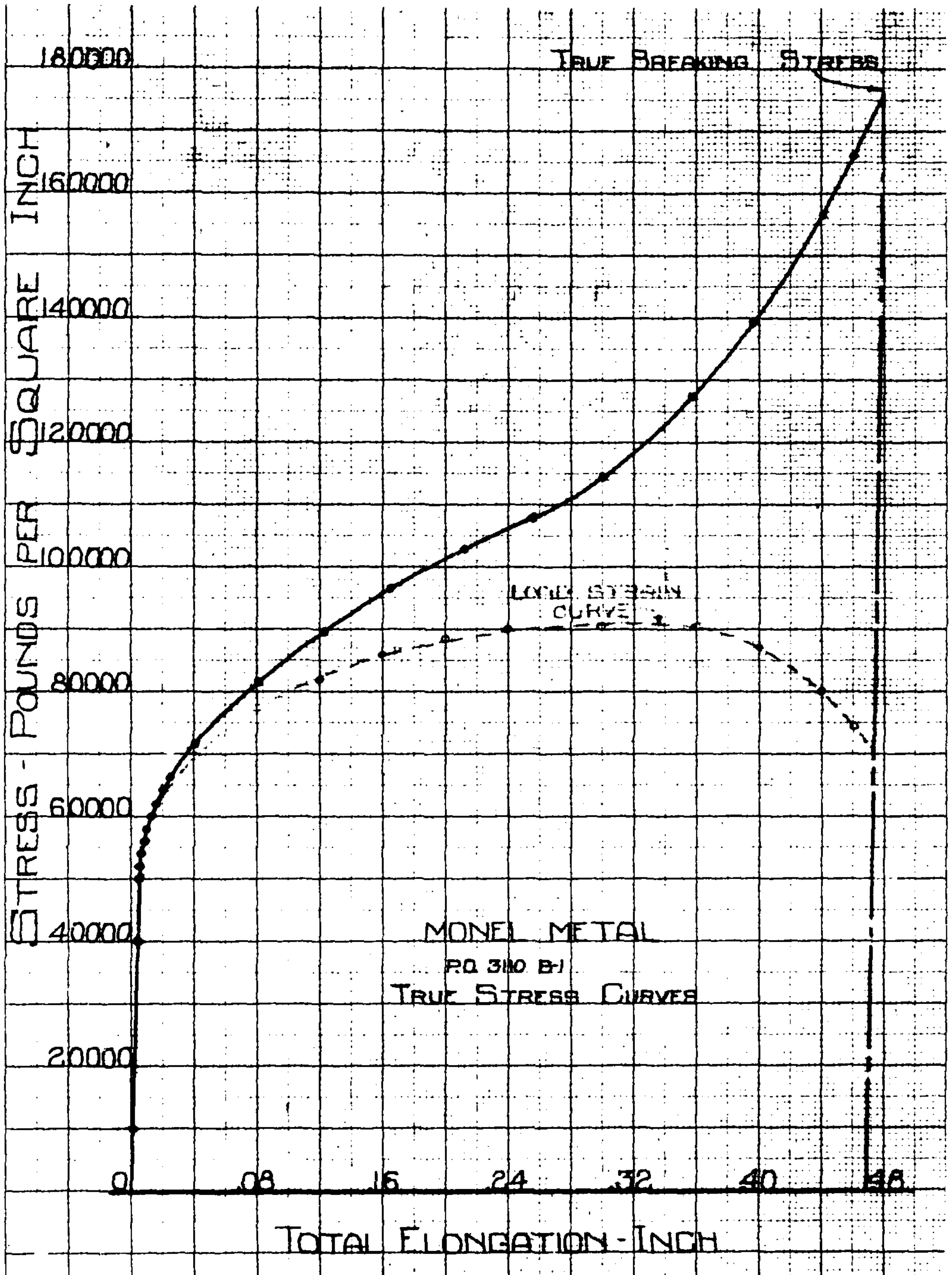
True Breaking Stress
220,000
210,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
.08
.16
.24
.32
.40
.48
.56
.64
Stress - Pounds per Square Inch
'K' Monel
K-31
Hot Rolled Bar
Quenched in Liquid Air
True Stress Curve
Total Elongation - Inch

Fig. 8



True Breaking Stress
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
.08
.16
.24
.32
.40
.48
.56
.64
Stress - Pounds per Square Inch
'K' Monel
K-1L
Hot Rolled Bar
True Stress Curve
Total Elongation - Inch

Fig. 9



Stress - Pounds per Square Inch
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
.08
.16
.24
.32
.40
.48
Total Elongation - Inch
True Breaking Stress
Local Strain Curve
Monel Metal
True Stress Curves

FIG 4

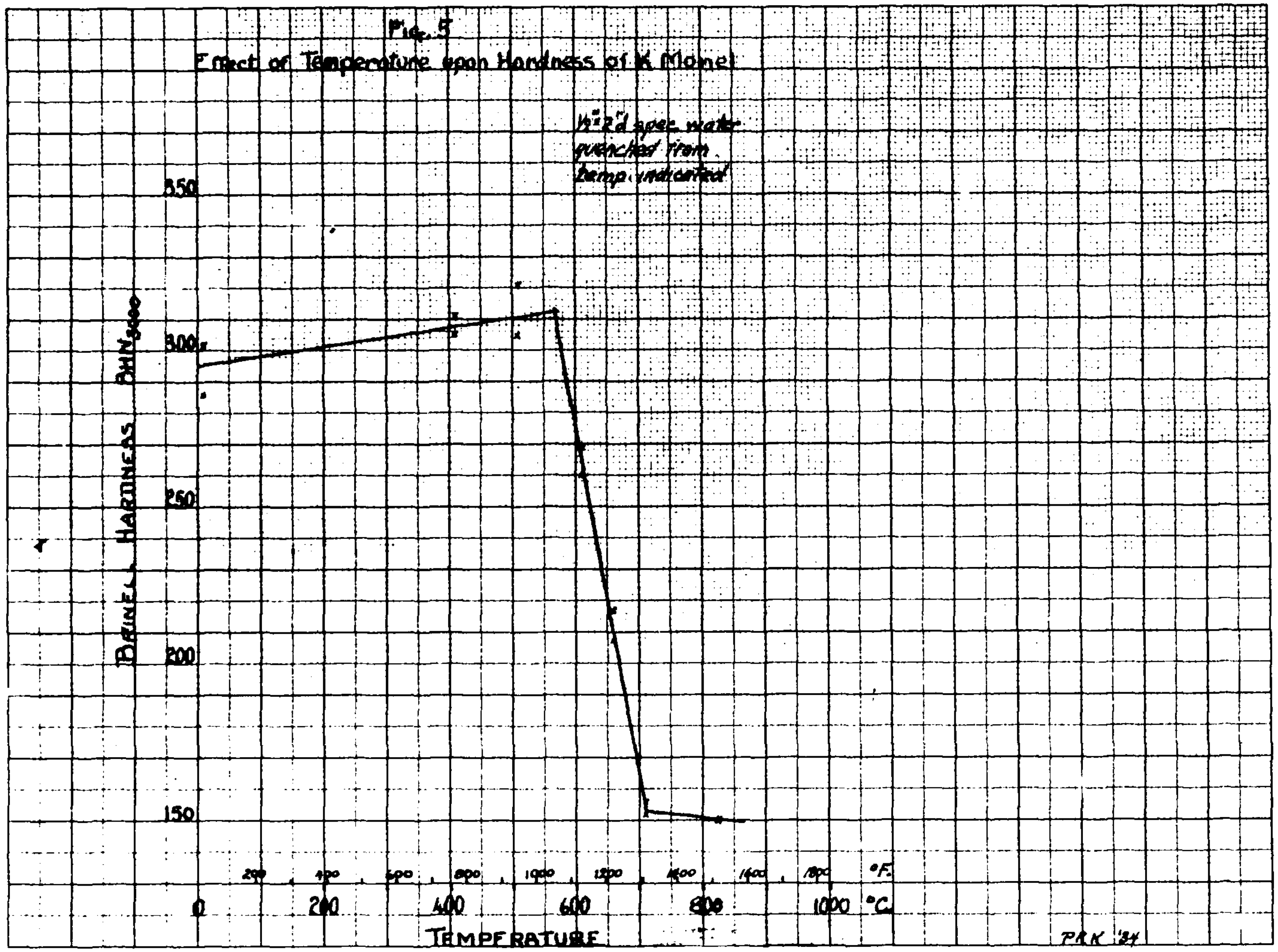
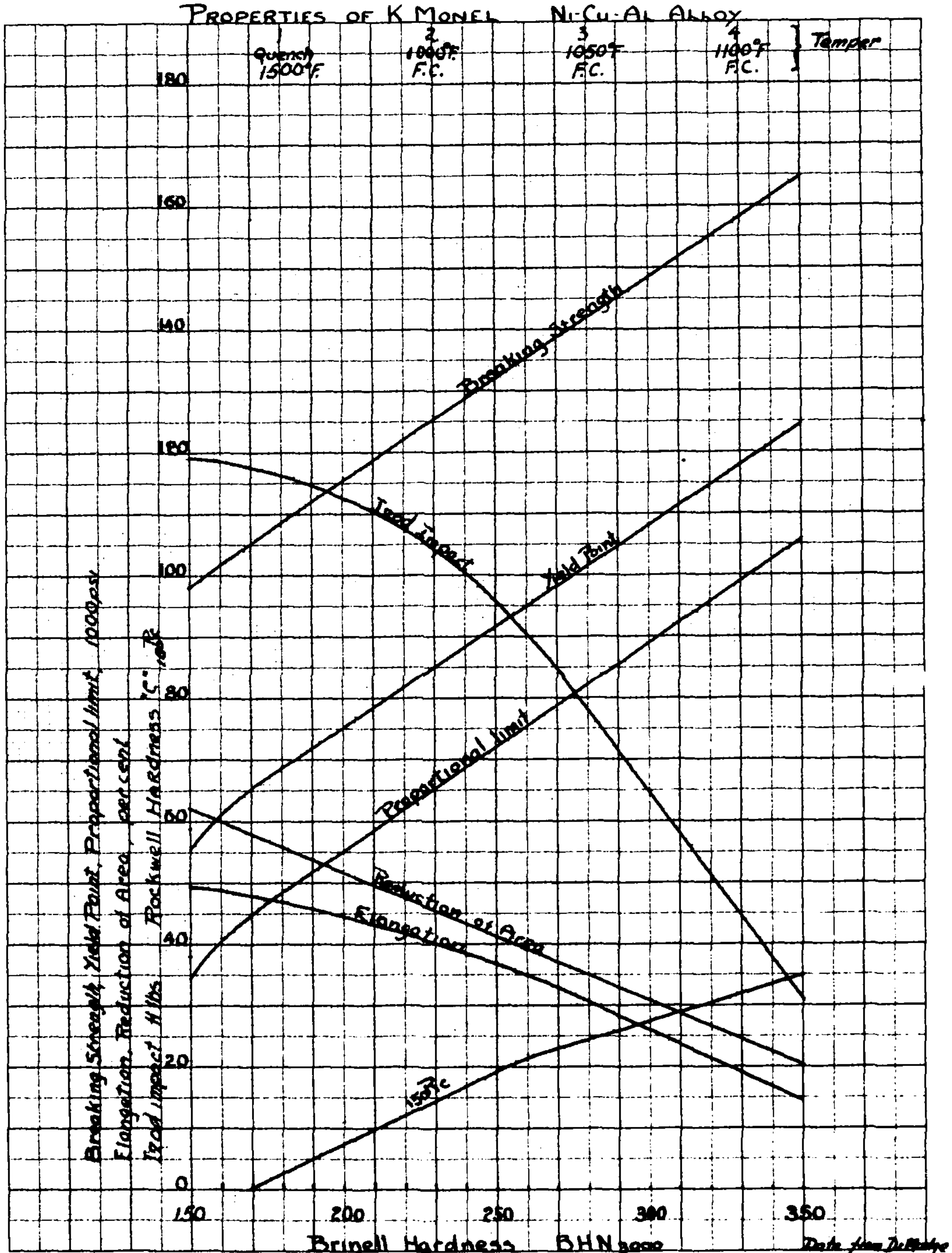


Fig. 5
Effect of Temperature upon Hardness of K Monel
½"×2"d spec. water quenched from temp. indicated
BRINELL HARDNESS BHN3000
350
300
250
200
150
200
400
600
800
1000
1200
1400
1600
1800
°F.
0
200
400
600
800
1000
°C.
TEMPERATURE
PRK '34



Properties of K Monel Ni-Cu-Al Alloy
1 Quench 1500°F
2 1000°F F.C.
3 1050°F F.C.
4 1100°F F.C.
Temper
Breaking Strength
Yield Impact
Yield Point
Proportional limit
Reduction of Area
Elongation
150 Rc
Breaking Strength, Yield Point, Proportional limit, 1000 psi
Elongation, Reduction of Area, percent
Izod impact ft lbs Rockwell Hardness "C"
180
160
140
120
100
80
60
40
20
0
150
200
250
300
350
Brinell Hardness BHN 3000
P.R.K. '84

FIG. 6

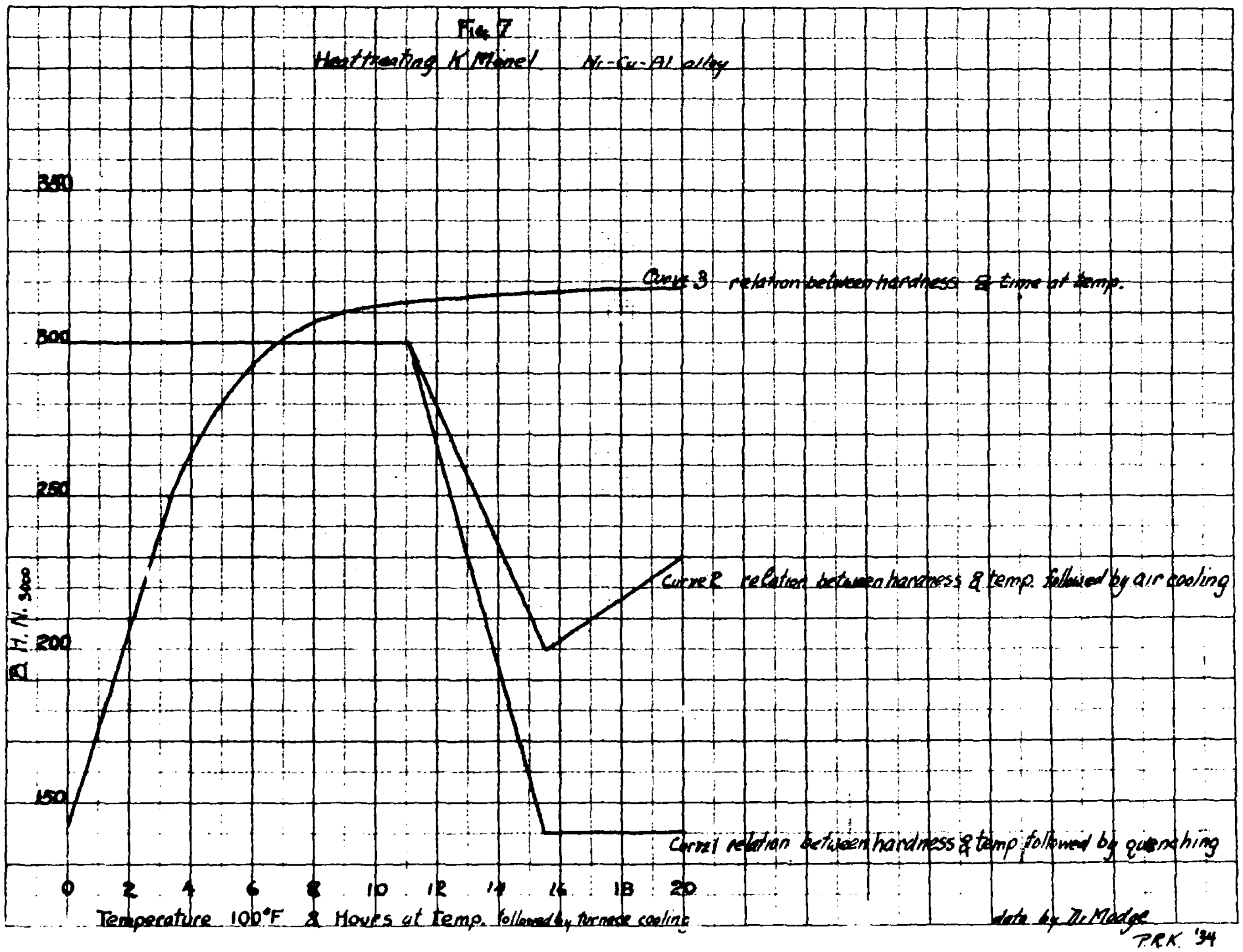


Fig. 7
Heattreating K Monel Ni-Cu-Al alloy
350
300
250
200
150
B. H. N. 3000
Curve 3 relation between hardness & time at temp.
Curve 2 relation between hardness & temp. followed by air cooling
Curve 1 relation between hardness & temp followed by quenching
0 2 4 6 8 10 12 14 16 18 20
Temperature 100°F & Hours at Temp. followed by furnace cooling
data by Dr. Madge
P.R.K. '34

STRESS-STRAIN CURVES - K MONEL

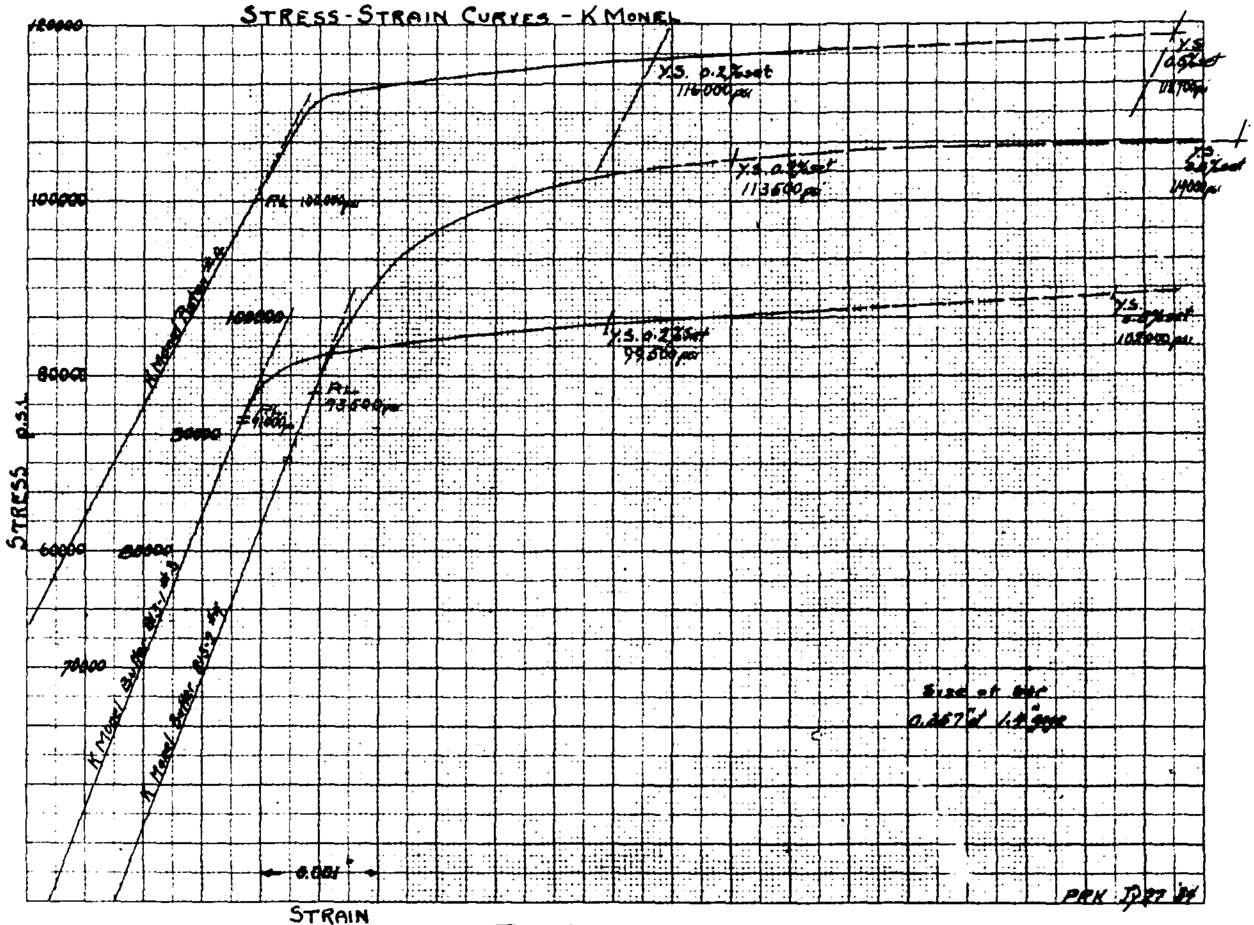


FIG 11

HARDNESS SURVEY K MONEL 2" dia x 2" 1200°F 5½ hrs F.C.

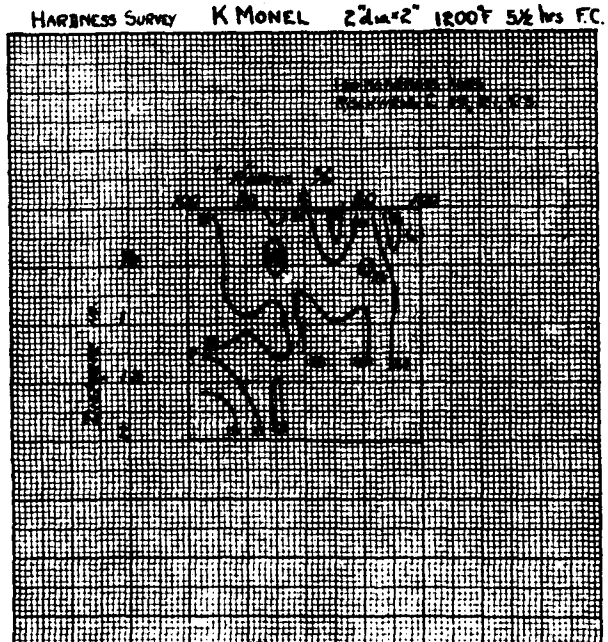


Fig. 8

FIG.9 WA # MM78 X500

SOFT K MONEL BAR .666 ETCH ACH+HNO_3
NO SECONDARY CONSTITUENT VISABLE

FIG.10 WA # MM77 X1000

HARD K MONEL BAR .666 ETCH ACH+HNO_3
SEPARATION OF A SECOND CONSTITUENT
AT GRAIN BOUNDARY IS VISABLE. THIS IS
REPORTED AS BEING A MG. COMPOUND