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Report No. 344/21
Watertown Arsenal.

January 31, 1934.

Preliminary Survey of the Properties of Inconel, K Monel, S Monel and Monel

Contents

Purpose

This investigation is a preliminary survey of the properties of modified Monel Metal, known as "S" and "K" and of Inconel, to determine their suitability for Ordnance.

Conclusions

Of the alloys investigated "K" Monel shows sufficient promising properties that the Ordnance Department could consider it as a possible better substitute for monel metal parts, especially piston rods. The advantages are (a) equal if not better corrosion resistance than monel, though the material will have to be stress relieved after all machine work is done. (b) The properties of the alloy are subject to change by heat treatment. (c) Suitable physical properties. The disadvantages may be centered around the machinability of this material but the very small sample which was available at this Arsenal was in the hardened condition which is now known to be the worst possible condition for machining. Transverse ductility is also another feature which should be further investigated.

"S" Monel has no suitable properties for consideration as an ordnance material unless as valve parts in unstressed parts that must resist scoring and corrosion.

Inconel has poor corrosion resistance upon prolonged exposure to any corroding medium tested as compared to Monel, and for that reason its utilization for parts that are to be exposed for long periods of time to mild corroding agents must be carefully considered. Initial corrosion rates are very low.

Table 1.

Chemical Composition of Nickel Alloys

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	Monel Metal Type K	Monel Metal Type S	Inconel
C	.12	.15	.05
Mn	Nil	.30	.78
Si	.18	4.10	.10
S.	.005	.016	.008
Fe	.15	3.57	6.45
Al	4.17	.29	-
Cr	-	-	10.52
Copper	28.25	34.75	.05
Nickel	67.13	56.83	82.04
Mg	Nil	-	-

by A. Sloan,
Chemist.

High Silicon Monel Castings

In order to get a marked increase in hardness through silicon additions to Monel Metal, at least 3% must be added. However, such alloys cannot be worked: considerable difficulty is encountered in the rolling mills with 1-1/2% Si.

The addition of Si up to 1-1/4% in rolled products has been tried in order to increase machinability, which is claimed as being improved, but too much difficulty is encountered in the mills. Sulfur additions are now being used to produce machining quality rods of Monel.

High Silicon Monel Castings, because of their extreme hardness as compared to regular Monel, are being used by valve makers because of the resistance to corrosion and erosion. Burner orifices for waste petroleum products containing acids and gritty matter, is another typical example of use.

Ordinarily it is not necessary to heat treat the castings for they can be machined with ordinary high speed steel tools, but Carboloy tools give better ease of cutting.

The nominal composition of Grade "S" Monel Metal is:

Cu	32-33%
Si	3 3/4% approx.
Fe	2%
Ni	Balance

The known physical properties of such castings are:-

Density 8.75-8.80

0.317-0.318 pounds per cu. in.

Melting point 2400°F 1320°C

Specific Heat 0.127 c.g.s. units

Coefficients of linear expansion are:-

70-212°F	25-100°C	6.8×10^{-6} per°F	12.5×10^{-6} per°C
-600°F	-300	8.2	14.6
-1000°F	-525	8.7	15.7

Casting Practice

Pouring temperature 2750-2850°F 1525-1565°C

Shrinkage 1/4" per foot

Add Si just before pouring

Machining

Grade S is harder but not as tough as regular monel. Slower cutting speeds and lighter feeds should be used while machining. In the soft condition machining is easier.

The shops at W. A. reported the following:-

Sawing	Material tough - saw cut fair
Lathe	Rough turning - poor
	Finish turning - good at fine feed and slow speed
Threading	Fair at slow speed. Tool point rounded after 3 chips of 0.005".
Shaper	Tools would not cut after first few cuts
Filing	Difficult.

These observations were made while machining the tensile test specimens.

Galling

When tested in steam and air, "S" Monel does not seize on itself) itself if hardened) in
stainless iron) in air stainless iron) steam at
Monel) cast iron) 750°F
Cast Iron)at 750°F

Heat Treatment

Softening - BHN 180-200
Heat in S free atmosphere to 900°C (1652°F) hold 1-2 hours, and quench in water.
Rehardening - BHN - 340 approximate.
Heat in S free atmosphere to 600°C (1112°F) hold for 3 hours and slowly cool.

Tensile Properties	Cast	"S" Monel	
	To be expected	Found at W.A.	*1
Yield point psi	35,000-45,000		
Proportional limit psi		Longitudinal	114,000-116,000
		Transverse	114,000-124,000
Tensile Strength psi	100,000-120,000	Longitudinal	114,400-117,200
		Transverse	135,200-134,400
Elongation %	2-5	Longitudinal	2
		Transverse	2-3
Reduction of Area %	5	Longitudinal	0
		Transverse	0
Hardiness BHN	275-350	321	
Impact Izod ft. lbs.	5-15	4.0-4.2	
Tensile Charpy - ft. lbs.		Longitudinal	4.0-4.1
		Coarse granular structure	

* Centrifugal casting 3 11/16" O.D. x 2 1/2 I.D. x 2 7/8" long. 0.252" dia. tensile specimen used.

1 Macro etched: the structure near the bore was dense but toward the outside it was not as homogeneous and considerable defects were present.

"K" Monel

The use of this alloy is still rather limited due to its newness. It is available in rods, wire and strip and the physical properties can be changed by heat treatment.

The nominal composition of K Monel is:-

Cu	23-28%
Al	3-5%
Ni	62-67%
Other metals	under 5%

Machining of K Monel

As long as the tensile strength is not over 100,000 psi, the machining of this alloy is described as being similar to Monel; for tensile strength between 100,000 and 140,000 psi tool wear is considerable; above 140,000 psi tensile strength machining is admitted as being difficult by the manufacturing company.

The shops at Watertown Arsenal reported the following:

Sawing	Tough material
Lathe	Good if not too coarse feed is used.
Threading	Fair. Point of tool rounded very easily.

Milling	Good with side cutter
Filing	Good with fine file
	Fair with coarse file
Grinding	Fair on slow work.

These observations were made while machining test specimens from material in the hardened condition whose BHN was 311.

Heat Treatment

Softening BHN - 140

Heat to the temperature range 1400-1600°F, 760-870°C, preferably 1500°F, 815°C, hold till piece is heated throughout, and quench in water or oil.

Hardening BHN - 325

Heat to the temperature range 1000-1200° F., 540-650° C., preferably 1100° F., 593° C., and slowly cool or air cool. Time at temperature varies from two hours if material is originally hot rolled, to 6-12 hours if material is soft.

Material which has been hardened may be heated to any temperature below 1200° F. without affecting the properties, but if heated above 1200° F., the properties will be decreased; slowly cooling from the temperature which is above 1200° F. will give a harder alloy than quenching.

Forging temperature is 2150-1800° F., 1175-980° C.; forging should not be continued below 1700° F.

Heating should be carried out in an S-free, neutral or slightly reducing atmosphere. If slowly cooled after forging the material will be medium hard; if quenched the material will be soft. Quenching at temperatures above 1500°-1550°F. is not recommended since it will result in increased time of heating to restore the full hard properties.

Tensile Properties K Monel

	To Be Expected			Found *,1	
Property	Soft	Hard	Hot Rolled	At W. A.	
Proportional Limit psi	25,000	100,000	40,000 - 60,000	Long.	92,000 - 104,000
				Trans.	103,000 - 117,000
Yield Strength psi (0.5% El.)	35,000	120,000	60,000 - 85,000	Long.	140,000 - 141,000
				Trans.	137,000 - 140,000
Tensile Strength psi	90,000	160,000	90,000 - 120,000	Long.	163,400 - 165,000
				Trans.	159,300 - 162,600
Elongation %	50.	20.	25-35	Long.	15.6-18.8
				Trans.	12.4-13.0
Reduction of Area %	60.	35.	35-50	Long.	28.4-30.9
				Trans.	18.7
Hardness BHN	140.	325.	175-200		311
Impact Tensile Charpy ft. lbs.				Long.	31.4-32.6
Impact Izod ft. lbs.	100-120	70-90	30-50		

(Endurance (strip) hard K Monel 36,000 psi
Monel Metal 34,000 psi)

* Bar 1-1/8" x 6" - results indicate bar tested in hardened condition, but originally believed hot rolled.
1 Transverse specimens .125" Dia. - 0.50".
Longitudinal specimens .125" dia. - 0.5" and .252" dia. - 1.0" results checked.

Inconel

Inconel is a recent development for the dairy industry, and should be used for all equipment handling sweet milk in which, after pasteurizing, it is cooled down from the holding temperature to 65° F. Because of its newness, the general corrosion resistance of Inconel is not known. Tests indicate that it resists alkalis and brines similarly as does nickel, which is very resistant. It is certainlyy resistant to chlorine sterlizing solutions. Recent reports indicate extreme corrosion resistance and tarnish resistance to the atmosphere.

The nominal composition of Inconel is:

Cr.	12 - 14%
Fe.	6%
Ni.	Remainder

The known physical properties are:

Density	8.53 to 8.57
Melting Point	2460-2550° F., 1348-1398° C.
Coefficient of Linear Expansion	$8.x10^{-6}$ per °F., $1.4x10^{-6}$ per °C.

Fabrication

Inconel is hardenable by cold-working only. The metal is ductile and can be bent and shaped without difficulty. Soft- and hard-soldering, and brazing and welding are easy.

Tensile Properties

Inconel

	To be Expected			*
	Annealed Sheet	Cold Worked Sheet Thickness Reduced 86%	Regular Sheet	Found at W.A.
Yield Point psi	28,300	151,200	45,000	
Proportional limit psi				Longitudinal 124,000 Transverse 98,000
Tensile Strength psi	83,200	166,300	90,000	Longitudinal 150,000-152,000 Transverse 145,500-147,800
Elongation %	51.	1.5	40	Longitudinal 14. - 9. Transverse 9.8 - 9.
Reduction in Area %				Longitudinal 27.2 - 37.6 Transverse 36.0 - 41.6
Hardness Rockwell B	67	107	75-85	
BHN				156-245

* Tube 2 3/8 x 1 7/8 x 6" Test Spec. 0.125" dia. .5" gage length.

Machining

The following was reported by the shops at W. A.:-

Lathe	very good with small cuts
Milling	very slow, hard on cutters
"	saw cuts fair, dulls saw quickly
Threading	fair

Monel Metal is well known, and is covered by U. S. Army Specification No. 57-168A, so that its physical properties and uses will not be discussed.

Relative Corrosion Resistance of Monel, K Monel, S Monel and Inconel

The number of samples of these materials were rather limited so that the following observations are only indicative of what may be expected.

Samples were polished on 80 grit emery cloth and exposed at room temperature to 5.9% C.P. sulfuric acid (Sp. G. 1.035) by being dipped once every 15 minutes in 250 cc of solution for 300 cycles. The results were calculated over into relative corrosion considering the corrosion rate of Monel Metal during the first exposure as 100 and are tabulated on Table II. The corrosion rate of monel tended to increase with time to a maximum; so did S Monel, but this alloy formed a black scum on its surface.

The corrosion rate of K Monel tended to increase with time at a fast rate. The alloy sludges also. At any place where stresses were left from the machining operations, very

TABLE II

Comparative Corrosion Rate of Modified Monel Metals and Inconel in 6% Sulfuric Acid (Sp. G. 1.035 = 5.9% H_2SO_4)

. Rating (Monel Metal = 100 at 1st Exposure)

	Exposure*			
Metal	1st	2nd	3rd	
Monel	100	135	153	Metal corroded most at those places with maximum thickness liquid film, i. e., lowest O_2 concentration.
S Monel	229	282	341	Sludges. Surface macroetched.
K Monel	120	300	665	Sludges. Cracks opened up around drill hole and mark of grind wheel.
Inconel	22	85	276	Tendency of localized micro pitting. (Brinell hardness of ring not uniform).

* Repeated immersion (4 times per hour for 300 immersions)

marked intergranular corrosion occurred, revealing the necessity to stress-relieve this material. What influences these stresses had on the increase in corrosion rate with time is not known, but is believed to be appreciable. The results reported are therefore to be considered abnormal.

The corrosion rate of Inconel slowly increased with time from 1/5x to 2x that of Monel.

Upon free exposure to the atmosphere all of the very small samples were tarnished in the following order, the first being considered the best. (The Monel Metal Specimen was lost though after the first week it was similar to K Monel.)

Inconel, K Monel and S Monel.

Stainless alloys of the 18/8 class and stainless iron were not tarnished as much after two years free exposure to the atmosphere.

The observed increase in weight due to 1-months free exposure to the atmosphere places the alloys in the same order as that observed on first exposure to 6% sulfuric acid, viz. Inconel: K Monel: S Monel.

Upon exposure to spray from 4% synthetic sea salt, no specimens showed any change during the first 100 hours, but changes occurred during the next 100 hours exposure. After a total of 200 hours exposure K Monel appeared the best in the series with a few points of attack on narrow edge of disc. Regular monel was next best with a few isolated

areas of attack revealed by green stains. S Monel was stained considerably with green specks and some white streaks. Inconel was very badly stained with localized areas colored brown. Evidently at these areas, sufficient metal was corroded and the iron separated as rust. This behaviour is similar to that reported for Inconel in sulfuric acid where the original corrosion resistance was high but rapidly decreased.

On Table III and Fig. 1 are given the results of the determination of the effect of chips of these metals on neutral 50:50 glycerine solutions when continuously aerated at 65°C. The metal that had the least effect was K Monel.

To facilitate intercomparisons of tensile properties of these four metals as observed at this Arsenal, Table IV was compiled. Stress strains diagrams for each metal are also given in Figs. 2-5.

Respectfully submitted,

P. R. Kosting.

TABLE III

The Effect of Modified Monel Metals and Inconel on Glycer

DAYS ELAPSED	MONEL METAL			S MONEL			
			ACIDITY			ACIDITY	
	N*	gNaOH/l	N*	N*	gNaOH/l	N*	
0	$5x10^{-4}$	.02		$5x10^{-4}$	.02		$5x10^{-4}$
6	5 "	.02	sol. yellowish	5 "	.02	sol. brown	12 "
14	12 "	.048	sol. greenish sludged	15 "	.060	brown sludge	14 "
20	20 "	.030		34 "	.14	sol. cloudy brown	17 "
28	37 "	.15	pH 4 3/4	32 "	.13	pH 4 1/2	20 "
36	37 "	.15		99 "	.4		22 "
43	69 "	.23	sol. brown pH 4 1/4	310 "	1.2	heavy sludge pH 4 1/4	25 "
Metal lost mg.		330			707		
Chips		bright			dark green brown Cu pot'd		
Sol. color		Cloudy brown			Cloudy brown		Cle
Breakdown		(38 dys.)			33 dys.		(> 4

* Normality

** Glycerine Water 50:50 (vol.) solution, aerated at 65°C.

TABLE III

The Effect of Modified Monel Metals and Inconel on Glycerine Solutions**

	S MONEL		K MONEL			INCONEL	
	ACIDITY						
	N*	gNaOH/l	N*	gNaOH/l		N*	gNaOH/l
	$5x10^{-4}$	.02	$5x10^{-4}$	.02		$5x10^{-4}$	.02
ish	5 "	.02 sol. brown	12 "	.048	sol. colorless	5 "	.02 sol brown
ish	15 "	.060 brown sludge	14 "	.056	sol. yellowish	12 "	.048 "
	34 "	.14 sol. cloudy brown	17 "	.068	"	21 "	.084 "
	32 "	.13 pH 4 1/2	20 "	.080	v. sl. sludge pH 4	22 "	.088 sol. green sludged pH
	99 "	.4	22 "	.088		55 "	.22
	310 "	1.2 heavy sludge pH 4 1/4	25 "	.10	pH 4 1/4	268 "	1.1 pH 4 1/4
	707		60			540	
	dark green brown Cu ppt'd		bright			bronze colored	
	Cloudy brown		Clear green			Sl. cloudy green	
	33 dys.		(>40 dys.)			34 dy.	

aerated at 65°C.

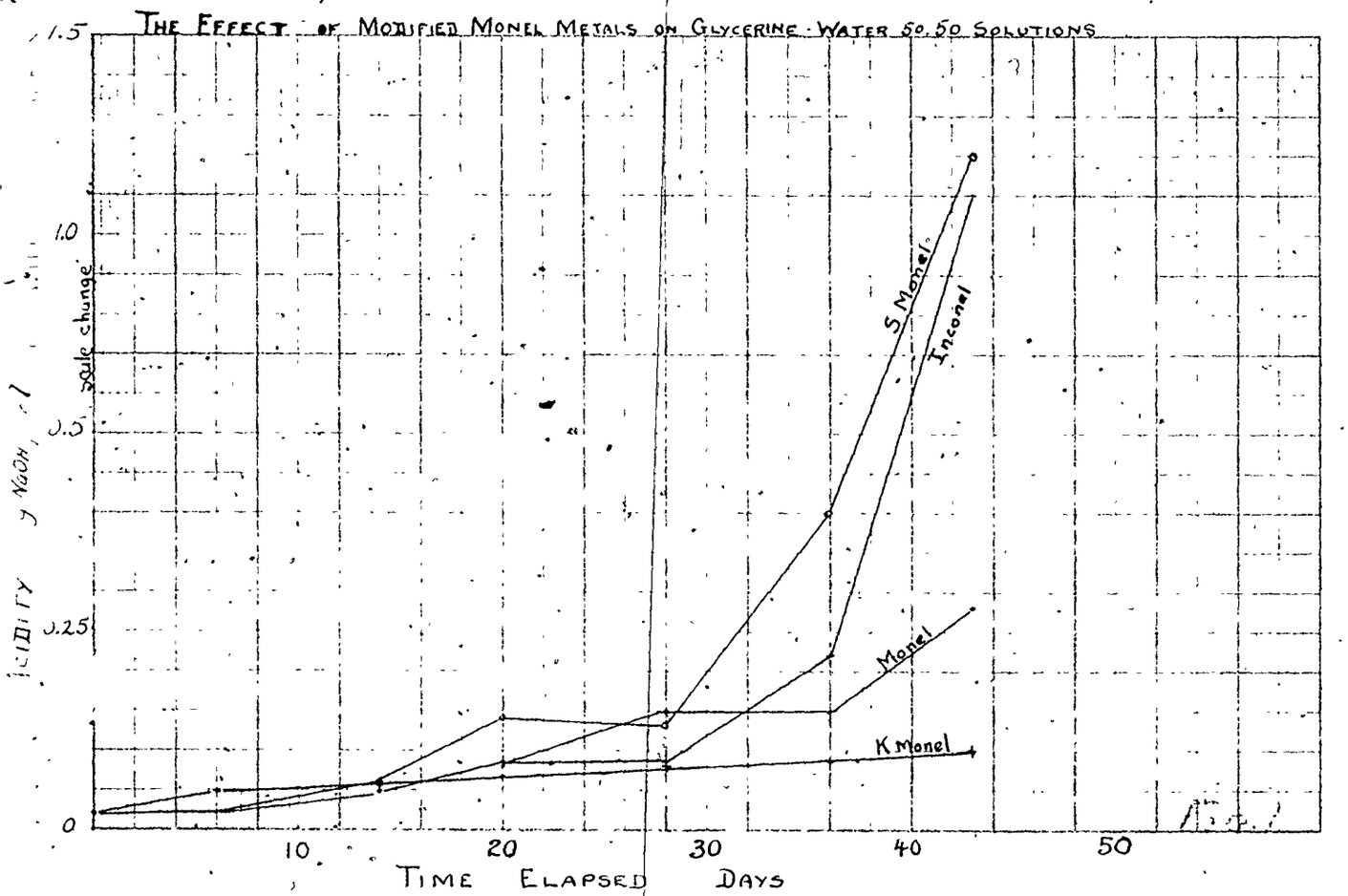
2

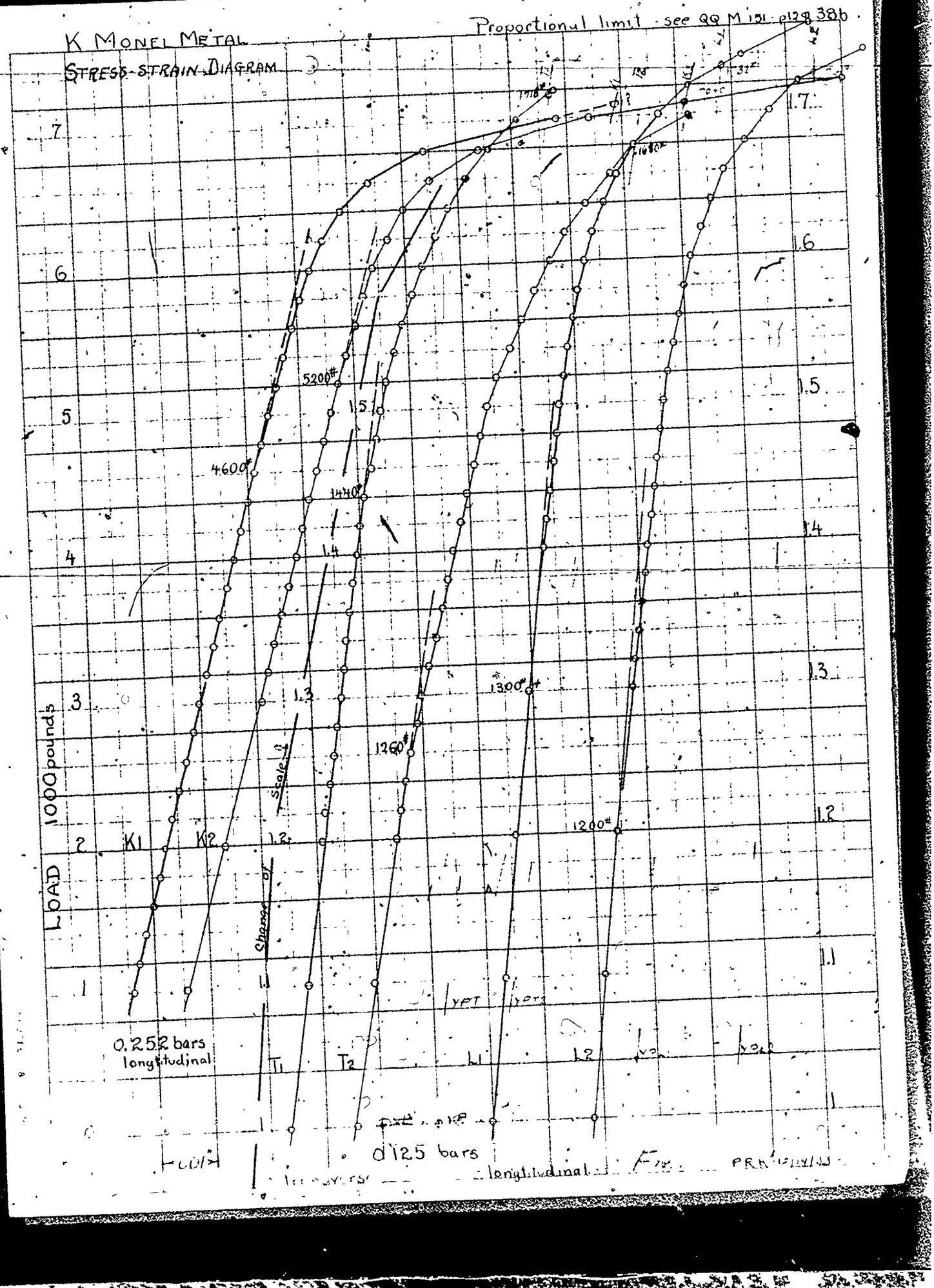
TABLE IV

SUMMARY

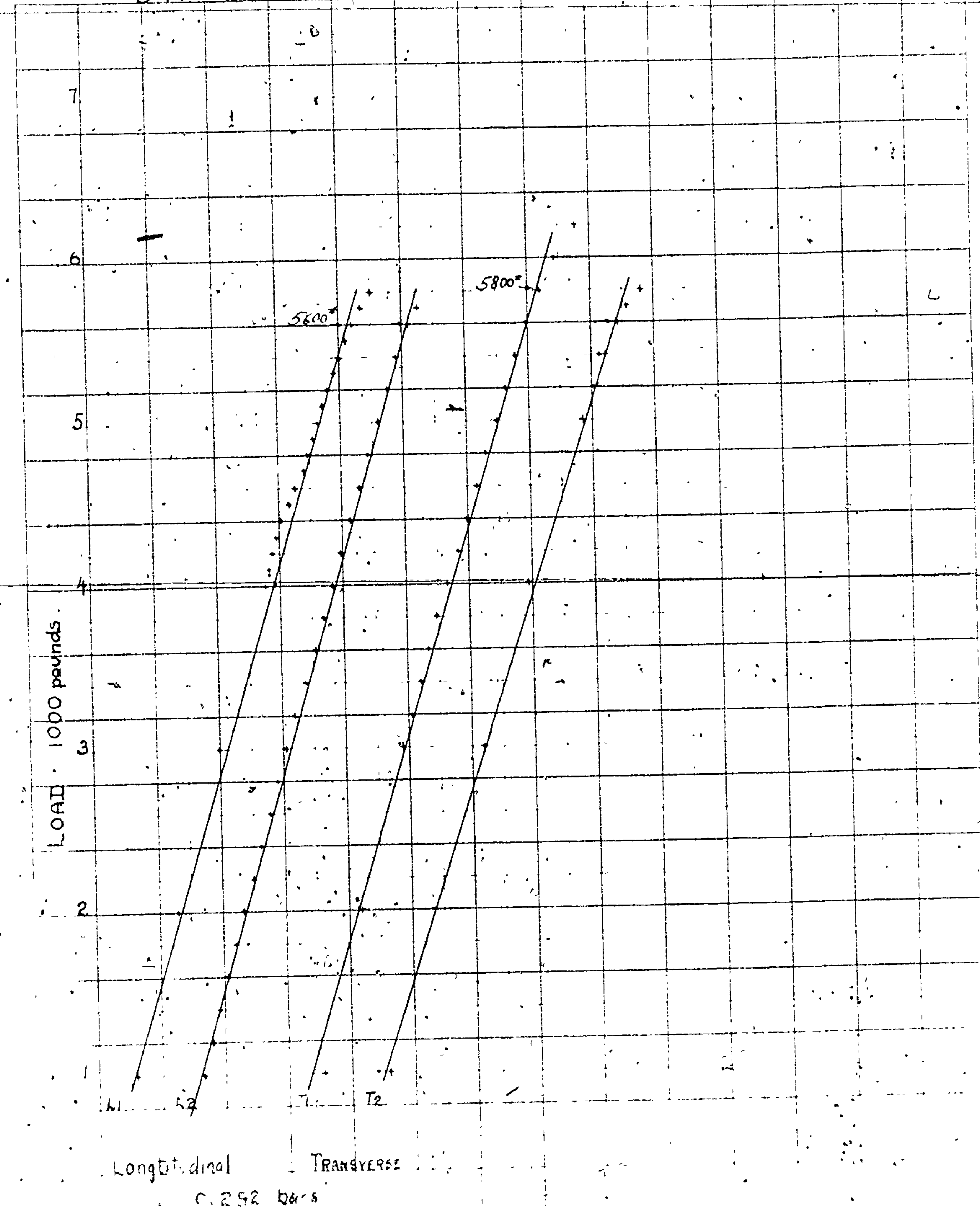
Observed Tensile Properties of "K" Monel, "S" Monel and Inconel and Monel

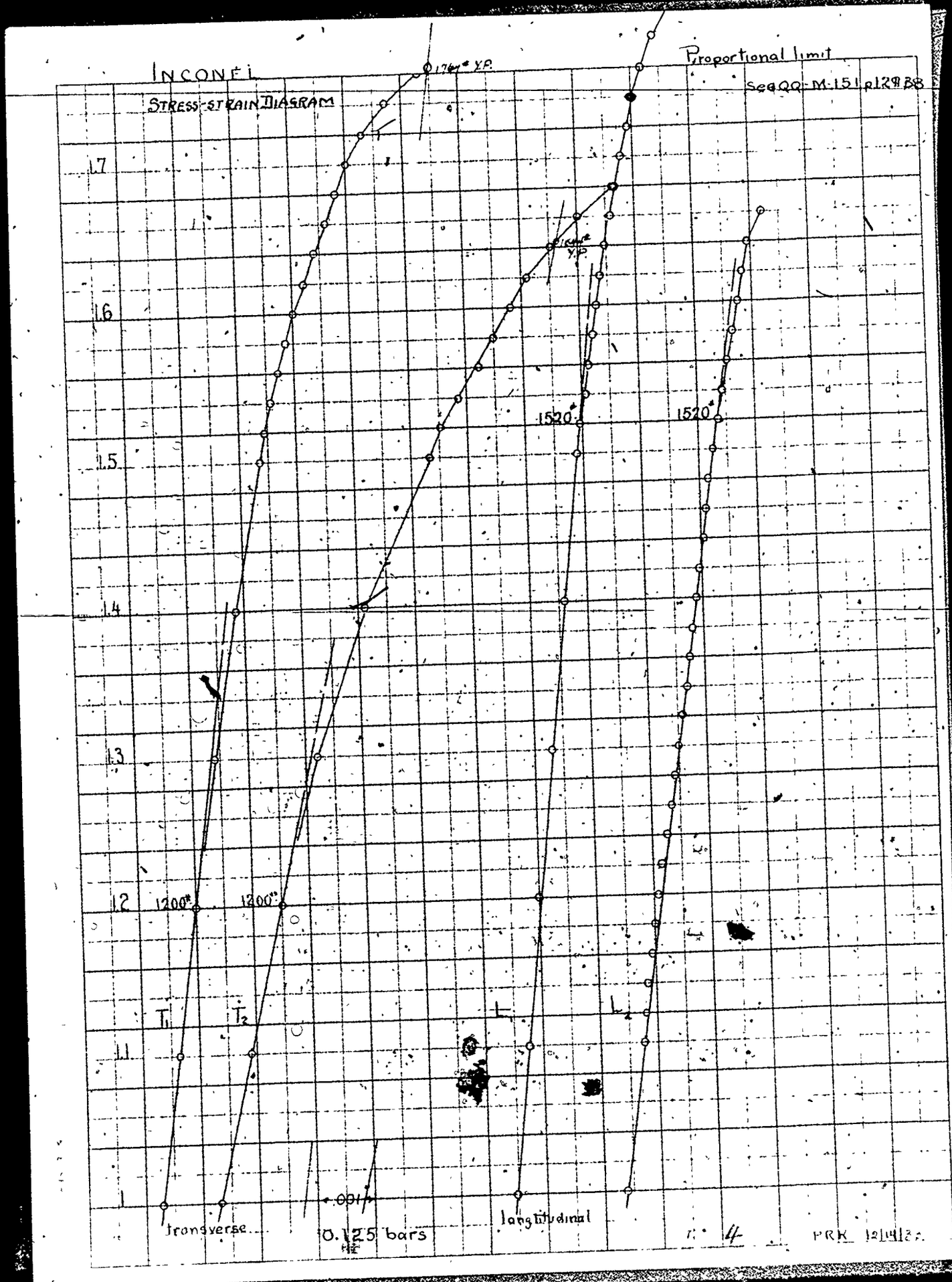
	Proportional Limit	Yield Strength 0.5% Set	Tensile Strength	Elongation	Reduction of Area	Brinell Hardness	Tensile Charpy Impact
	1000 psi			Per Cent		Number	Ft. Lbs.
K Monel	(6" x 1 1/8" dia. rod)		0.252 bar - 1" gage				
Longitudinal	92-104	141	163-165	17	30.8-31.4	311	31.4-32.6
			0.125 bar - 1/2" gage				
Longitudinal	98-106	140-141	163	15.6-18.8	28.4-30.9		
Transverse	103-117	137-140	159-163	12.4-13	18.7		
S-Monel	(6"x3-11/16 O.D. x 2 1/2 I.D. centrifugal casting)			0.252 bar - 1" gage			
Longitudinal	112		114-117	2	0	321	4.0-4.2
Transverse	112-116		134-135	2-3	0		
Inconel	(6" x 2 3/8 O.D. x 1 7/8 I.D. Tube)			0.125 bar - 1/2" gage			
Longitudinal	124		150-152	9-14	27.2-37.6	156-245	
Transverse	98	134-143	146-149	9-9.8	36.0-41.6		
Monel Metal	(43" x 2 3/8" dia. rod)		0.505 bar				
Longitudinal	38		83	42.0	63.2		
	(43 1/2" x 5 1/8" O.D. x 4 1/2 I.D.)			0.125" bar			
	41	47.2	90	46	63.1		

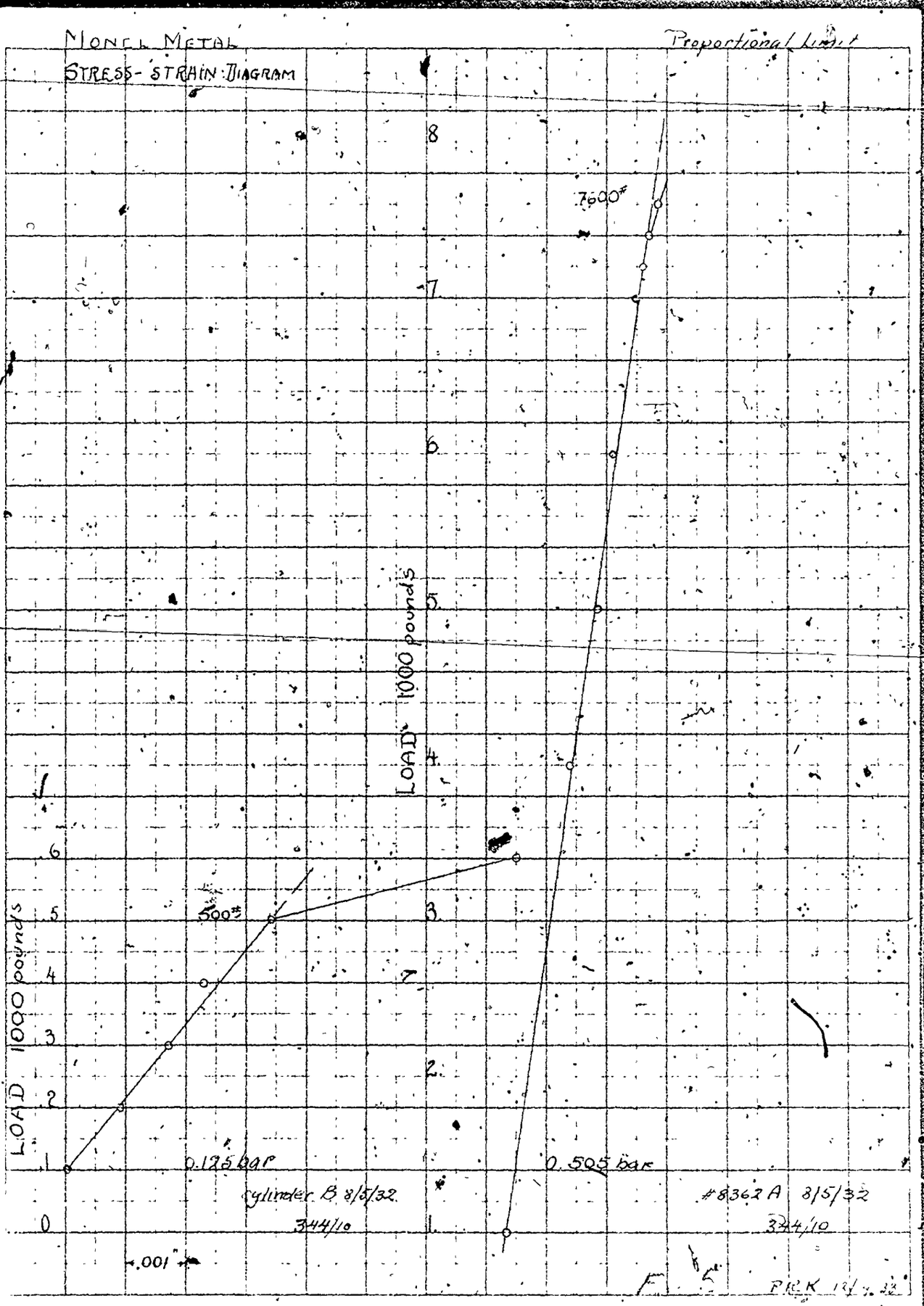

THE EFFECT OF MODIFIED MONEL METALS ON GLYCERINE-WATER 50.50 SOLUTIONS
1.5
1.0
0.5
0.25
0
10
20
30
40
50
TIME ELAPSED DAYS
S Monel
Inconel
Monel
K Monel


K MONEL METAL
STRESS-STRAIN DIAGRAM
Proportional limit - see QQ M 151 - p128 386
LOAD 1000 pounds
5200#
4600#
1440#
1300#
1260#
1200#
K1
K2
Change of Scale
0.252 bars
longitudinal
T1
T2
L1
L2
d 125 bars
transverse
longitudinal

S MONEL STRESS-STRAIN CURVES




INCONEL
STRESS-STRAIN DIAGRAM
Proportional limit
See QQ-M-151 p 129 B8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
1200#
1200#
1520#
1520#
T1
T2
L1
L2
.001"
transverse
0.125 bars
longitudinal
PRK 12/14/62


Monel Metal
Stress-Strain Diagram
Proportional Limit
7600#
500#
LOAD 1000 pounds
LOAD 1000 pounds
0.125 bar
Cylinder B 8/5/32
344/10
0.505 bar
#8362 A 8/5/32
344/10
.001"