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GENERAL DYNAMICS | CONVAIR

Report No. 8926-103

Material - Nickel Base Alloy - Hastelloy R-235, 10 Per Cent Cold Worked

Effect of Stretching and Heat Treatment on Mechanical Properties

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Abstract

The effect of stretching to 17 and 26 per cent permanent set, followed by heating at 1500°F for various times, upon the longitudinal and transverse room temperature mechanical properties of 0.062 inch thick 10 per cent cold worked Hastelloy R-235 nickel base alloy was determined. Generally, increased stretching resulted in increased tensile strengths and decreased compressive yield strengths. As received 10 per cent cold worked Hastelloy displayed the Bauschinger effect only in the longitudinal direction, but additional stretching to 17 per cent permanent set introduced the effect in the transverse direction. Stretching to 26 per cent permanent set resulted in increases in compression yield strength, but did not eradicate the Bauschinger effect. Only heat treatment (1500°F for 2 hours) served to eradicate the Bauschinger effect from the cold worked material. This heat treatment resulted in slight decreases in the strength of the cold worked materials.

Reference: Ciuntoli, A., Bergstedt, P., Turner, H. C., "Effect of Tensile Deformation and Heat Treatment Upon the Mechanical Properties of 10% Cold Worked Hastelloy R-235," General Dynamics/Convair Report MP 59-106, San Diego, California, 3 June 1959. (Reference attached.)

STRUCTURES & MATERIALS LABORATORIES

CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

SAN DIEGO

REPORT MP 59-106

DATE 3 June 1959

MODEL REA 8029

TITLE

REPORT NO. MP 59-106

EFFECT OF TENSILE DEFORMATION AND HEAT TREATMENT UPON THE MECHANICAL PROPERTIES OF 10% COLD WORKED HASTELLOY R-235

MODEL: REA 8029

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INTRODUCTION:

In Convair Report No. MP 58-290 it was found that Hastelloy R-235 cold worked 10% by the producer displayed the Bauschinger effect* in the direction of rolling. An investigation was carried out to discover how to overcome this effect. At that time it was found that heat treating the alloy at 1500°F for 2 hours could effect a complete recovery of compression yield strength.

During the investigation it was also found that appreciable gains in all mechanical strength values, with little effect on ductility, were realised when stretched material was heat treated. The gain in strength appeared to be directly influenced by the amount of permanent tensile deformation introduced in the material. The present work is intended to show whether increased tensile deformation and increased heat treating time will further increase the room temperature strength of the alloy with a retention of acceptable ductility.

OBJECT:

To determine what effect tensile deformations of 17%** and 26%** permanent set, followed by heat treating at 1500°F for various times, have upon the longitudinal and transverse room temperature mechanical properties of 10% cold worked Hastelloy R-235.

CONCLUSIONS:

1. The as received (10% cold worked) material displayed the Bauschinger effect in the direction longitudinal to rolling, and no Bauschinger effect in the direction transverse to rolling; i.e., the longitudinal compression yield strength was lower than the tensile yield strength, but the transverse compression yield strength was greater than the tensile yield strength.

2. Increasing tensile plastic deformation increased the tensile yield and ultimate strength and decreased the elongation of as received material.

3. Stretching as received material to 17% permanent deformation transverse to the rolling direction introduced the Bauschinger effect in this direction; the same degree of deformation parallel to the direction of rolling did not produce any further reduction of compression yield strength.

* The Bauschinger effect was shown by a relatively low compression yield strength compared to the tensile yield strength.

** These values represent 50% and 75% of the available room temperature elongation at fracture over a 2-inch gage length for each direction to rolling.

CONCLUSIONS: (Cont'd)

4. Further stretching as received 10% cold worked material to 26% permanent deformation resulted in an increase in compressive yield strength in both directions; however, the compression yield strength was still less than the as-received tensile yield strength.

5. The maximum strength for each condition of plastic deformation and complete recovery from the Bauschinger effect was obtained with a 1500°F heat treatment for 2 hours.

6. As heat treatment time at 1500°F was increased past 2 hours, the strength for all conditions of plastic deformation decreased slightly.

MATERIAL:

All tests were performed on a 0.063 inch thick sheet of 10% cold worked Hastelloy R-235 produced by the Haynes Stellite Company from their heat number RV-7269.

PROCEDURE:

Strips, 1" x 18" for compression and 1" x 12" for tension specimens, were taken in both the longitudinal and transverse directions to rolling. All the strips were gridded at 1/4" intervals over their entire lengths.

The conditions tested are shown in Table I. Where plastic deformation was required, the work was done in a 60,000 lb. Tinius Olsen Universal Testing Machine.

The uniform elongation was measured at 1/2 inch intervals using a steel rule graduated to 0.01 inches and a 40 X binocular microscope. The accuracy of measurement was felt to be of the order of ± 1%.

After deforming, all strips requiring heat treatment were heat treated in an air-circulating laboratory furnace for the various times shown in Table I.

Three compression specimens were taken from each of the 1" x 18" strips. The compression specimen configuration can be found in Report No. MP 58-290. Standard flat tensile specimens having a 1/2 x 2-1/4 inch gage section were made from the 1" x 12" strips.

All testing was done with a 120,000 lb. Tinius Olsen Universal Testing Machine. A supporting fixture was used in compression tests to prevent buckling (reference: Report No. MP 58-266).

RESULTS:

The mechanical properties of Hastelloy R-235 for the various conditions investigated are shown in Table I.

Figure 1 represents the effect of tensile deformation on the mechanical properties of heat-treated and non-heat-treated material in the direction of rolling. The effects of the same variables on the properties transverse to rolling are represented in Figure 2.

The effect of time at 1500°F on the mechanical properties of material stretched in the direction of rolling to 17% and 26% permanent set is shown in Figure 3. The effect of time at 1500°F on the mechanical properties of material stretched in the transverse direction to 17% permanent set is shown in Figure 4.

DISCUSSION:

Material, as received, displayed the Bauschinger effect in the longitudinal direction of rolling. This is shown by a low compression yield strength compared to the tensile yield strength. No Bauschinger effect was noticed in the transverse direction of rolling.

Stretching the as received, 10% cold worked, material to 17% permanent set in the longitudinal direction of rolling increased the tensile yield and ultimate strengths 47.5 ksi and 23.8 ksi, respectively. A reduction of elongation from 34.3% to 20.7% also occurred. The compression yield strength was not affected, and it remained approximately 81 ksi.

Material from the transverse direction stretched to the same deformation showed approximately the same change in properties with one notable exception. In this case the 17% permanent set introduced the Bauschinger effect as shown by the reduction of the compression yield strength from 100.5 ksi to 85 ksi.

Increasing the permanent set, for the direction longitudinal to rolling, to 26% served to further increase the tensile yield and ultimate strength of the unheat-treated material to 169.3 ksi and 173.1 ksi, respectively. The elongation continued to drop to 14.2%. Material taken in the direction transverse to rolling behaved in the same manner with gains in strength of the same order of magnitude. It is of interest to note that the 26% permanent set resulted in a slight increase in compression yield strength compared to the 17% permanent set value.

DISCUSSION: (Cont'd)

A heat treatment of 1500°F for 2 hours further increased the tensile yield and ultimate strengths above the corresponding non-heat-treated conditions. However, the amount of increase for each condition was less as permanent deformation increased. For example, as received material showed an increase of yield strength from 102.9 ksi to 147.2 ksi after heat treatment. For material stretched to 26% permanent deformation and then heat treated at 1500°F for 2 hours the gain in yield strength was from 169.3 ksi to 180.5 ksi. In any event, the highest strength levels were reached with material stretched to 26% permanent deformation and heat treated at 1500°F for 2 hours.

It appears that permanent deformation increased the mechanical properties of the alloy both before and after heat treatment. However, the response to heat treatment decreased as permanent deformation increased.

Material stretched to 17% permanent deformation displayed good uniform elongation. As measured over 1/4 inch increments, the material deformed uniformly to within ± 1% of the desired elongation. Upon stretching to 26% permanent deformation, the material had uniform elongation within ± 2% of the required elongation.

Material with sheared edges could not be stretched to 17% or 26% permanent set. Evidently the shearing operation introduced sufficient cold work at the edges of the strips so that the elongation was substantially reduced over the as received elongation. Machining the sheared edges, however, seemed to eliminate the superficial cold work so that the material was successfully stretched to as high as 26% permanent deformation.

The data from which this report was written are recorded in Material and Processes Laboratory Note Book 3038.

TABLE I - TENSILE AND COMPRESSIVE MECHANICAL PROPERTIES OF STRETCHED AND HEAT TREATED HASTELLOY R-235 .

HEAT TREATMENT	% PERMANENT DEFORMATION		LONGITUDINAL TO DIRECTION OF ROLLING .2% Fcy KSI	.2% Fty KSI	Ftu KSI	ELONG % IN 2"	TRANSVERSE TO DIRECTION OF ROLLING .2% Fcy KSI	.2% Fty KSI	Ftu KSI	ELONG % IN 2"
NONE	NONE		79.7	102.4	139.1	33.0	97.2	94.5	134.3	36.0
			81.3	101.2	137.3	35.0	101.9	97.7	137.6	36.5
			82.0	102.3	134.6	35.0	102.3	97.4	137.0	32.5
		AVE.	81.0	102.9	137.0	34.3	100.5	96.5	136.3	35.0
1500°F - 2 HOURS	NONE		152.7	148.9	188.2	19.0	157.1	146.9	182.6	17.5
			149.0	147.2	186.2	17.0	156.6	147.7	182.6	17.0
			148.9	145.5	187.4	19.5	158.2	147.3	182.3	17.0
		AVE.	150.2	147.2	187.3	18.5	157.3	147.3	182.5	17.2
NONE	17% (1A)		79.0	152.5	161.9	20.5	84.7	149.8	159.1	17.5
			81.8	149.9	160.9	20.0	82.8	143.2	154.0	17.0
				148.8	159.7	21.5	78.4	152.2	160.8	17.0
		AVE	80.4	150.4	160.8	20.7	82.0	148.4	158.0	17.2
1500°F - 2 HOURS	17%		179.6	168.9	199.6	16.0	176.9	169.1	197.8	11.0
			178.0	175.6	203.3	12.5	176.4	168.1	194.4	11.5
			174.9	173.8	201.7	12.0	172.1	168.8	194.6	13.0
		AVE	177.5	172.8	201.5	13.5	175.1	168.7	195.6	11.8
1500°F - 3 HOURS	17%		178.2	168.9	201.3	15.0	174.7	169.6	197.4	11.5
			177.7	169.0	201.4	13.0	173.2	169.2	197.1	13.0
			178.2	166.4	199.4	16.5	172.1	169.0	195.5	13.0
		AVE	178.0	168.1	200.7	14.8	173.3	169.3	196.7	12.5

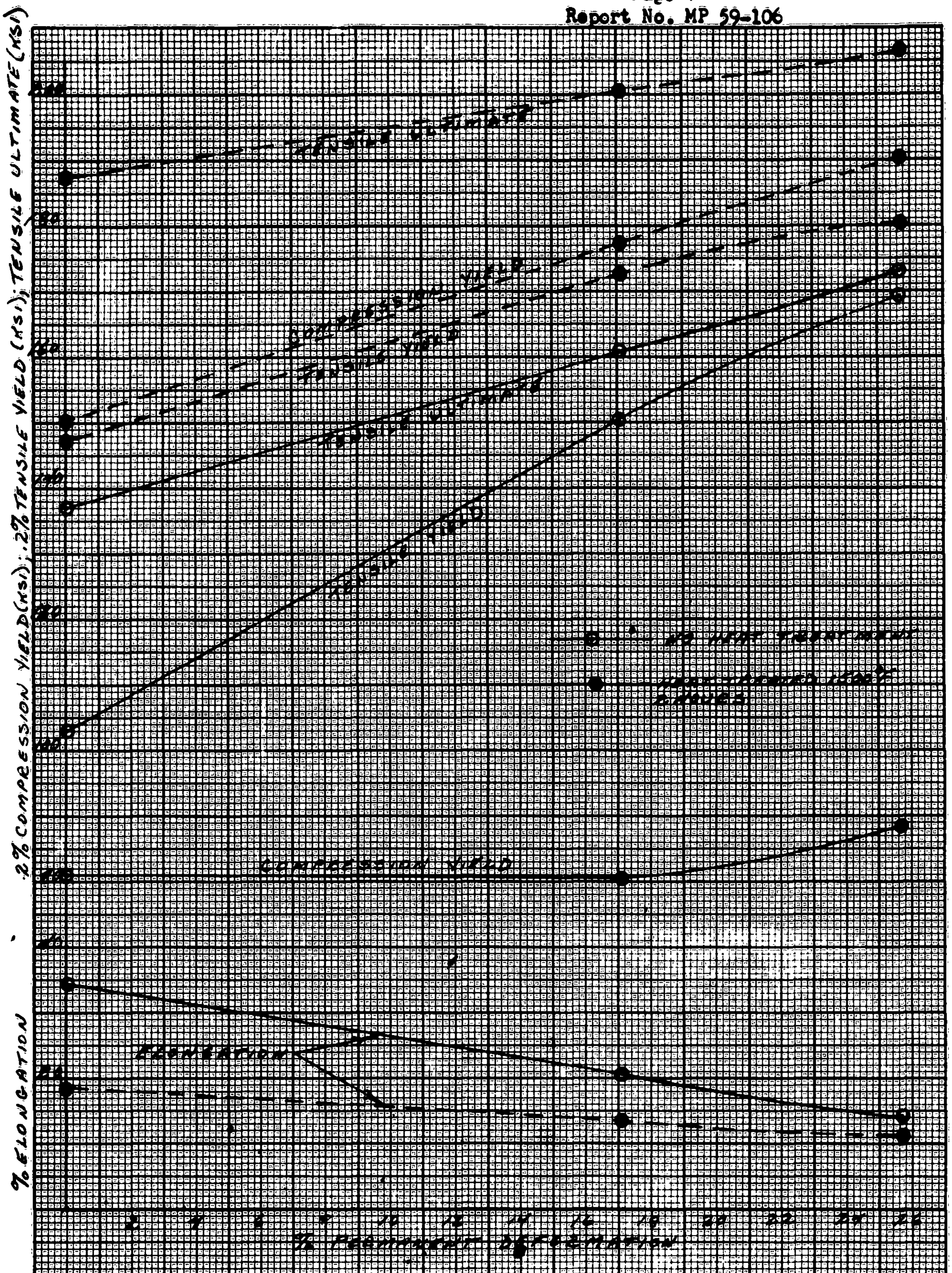
TABLE I - CONTINUED

HEAT TREATMENT	% PERMANENT DEFORMATION		LONGITUDINAL TO DIRECTION OF ROLLING .2% Fcy KSI	.2% Fty KSI	Ftu KSI	ELONG % in 2"		TRANSVERSE TO DIRECTION OF ROLLING .2% Fcy KSI	.2% Fty KSI	Ftu KSI	ELONG % in 2"
1500°F - 4 HOURS	17%		176.6	159.1	195.7	16.0		175.6	166.0	195.1	13.0
			179.3	162.6	195.8	15.5		187.7	161.5	193.3	15.0
			172.9	168.9	201.0	14.0		181.1	163.8	193.7	14.0
		AVE.	176.3	163.5	197.5	15.2		181.5	163.8	194.0	14.0
NONE	26% (1B)		93.6	169.6	172.4	14.5		91.6	166.0	169.2	12.5
			85.0	167.4	172.4	16.0		95.2	161.7	166.8	13.5
			86.7	170.8	174.5	12.0		92.7	165.2	169.8	13.0
		AVE	88.4	169.3	173.1	14.2		93.2	164.3	168.6	13.2
1500°F - 2 HOURS	26%		191.5	177.9	204.6	11.5		179.3	172.8	202.2	10.5
			188.8	180.0	207.0	12.0		184.0	179.9	204.4	10.0
			190.8	183.7	208.6	10.5		181.0	183.8	205.6	9.5
		AVE	190.4	180.5	206.7	11.3		181.4	178.8	204.1	10.0
1500°F - 3 HOURS	26%		187.5	178.8	204.8	12.0	SEE NOTE (2) FOR THIS GROUP OF VALUES	80.6	134.0	150.6	23.5
			186.5	182.9	207.9	11.5		86.2	129.1	148.9	22.0
			185.4	177.4	205.7	10.5		76.4	139.6	153.9	21.0
		AVE	186.5	179.7	206.5	11.3		82.1	134.2	151.1	22.2
1500°F - 4 HOURS	26%		181.1	173.2	204.2	12.0	SEE NOTE (3) FOR THIS GROUP OF VALUES	162.6	161.1	189.9	14.0
			195.5	172.3	202.6	11.0		162.1	163.6	190.8	15.5
			178.2	173.1	202.8	11.0		163.4	163.8	191.8	13.5
		AVE	184.9	172.9	203.6	11.5		162.7	162.8	190.8	14.3

1A - THIS REPRESENTS 50% OF THE AS RECEIVED ELONGATION
1B - " " 75% " " " " "

(2) AS RECEIVED MATERIAL STRETCHED 10% TOTAL DEFORMATION AND TESTED

(3) AS RECEIVED MATERIAL STRETCHED 10% TOTAL DEFORMATION HEAT TREATED 1500°F - 2 HOURS AND TESTED


% ELONGATION .2% COMPRESSION YIELD (KSI); .2% TENSILE YIELD (KSI); TENSILE ULTIMATE (KSI)
TENSILE ULTIMATE
COMPRESSION YIELD
TENSILE YIELD
TENSILE ULTIMATE
TENSILE YIELD
NO HEAT TREATMENT
COMPRESSION YIELD
ELONGATION
% PERMANENT DEFORMATION

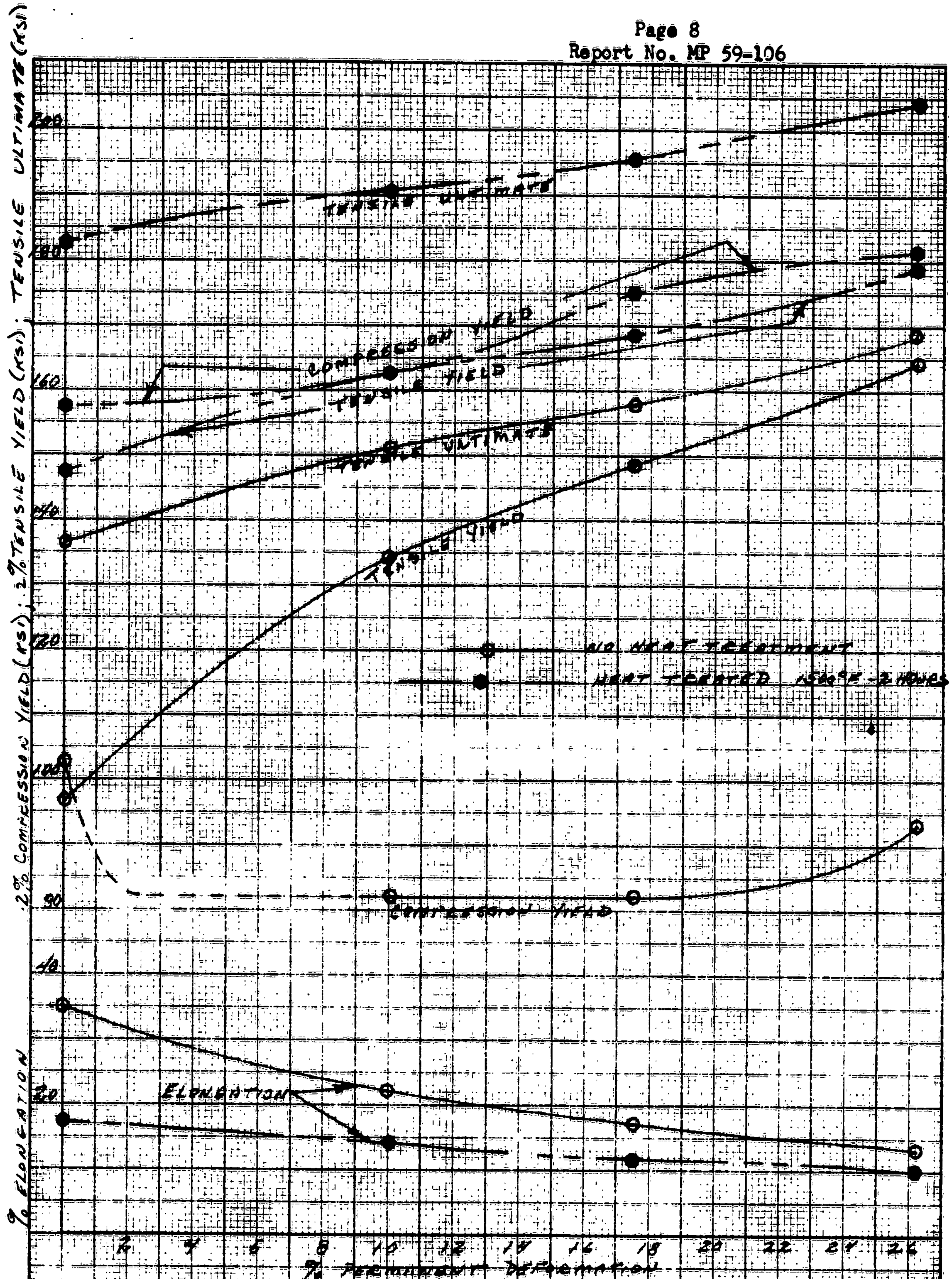
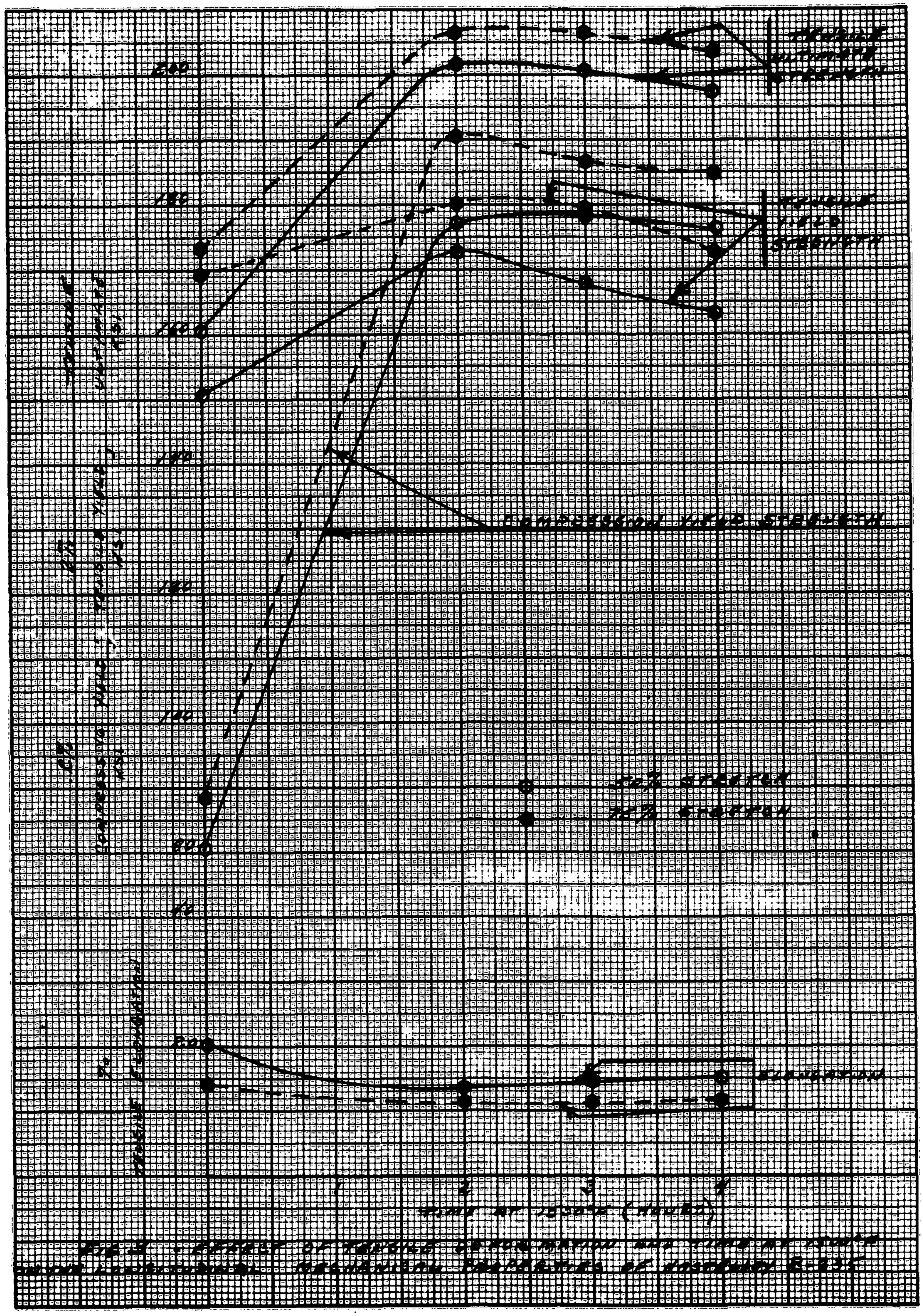


FIG. 2 - EFFECT OF PERMANENT TENSILE DEFORMATION ON THE TRANSVERSE MECHANICAL PROPERTIES OF HEAT TREATED AND UN-HEAT TREATED WASPALOY C-235 MATERIAL.


COMPRESSION YIELD STRENGTH
ELONGATION
1
2
3
4

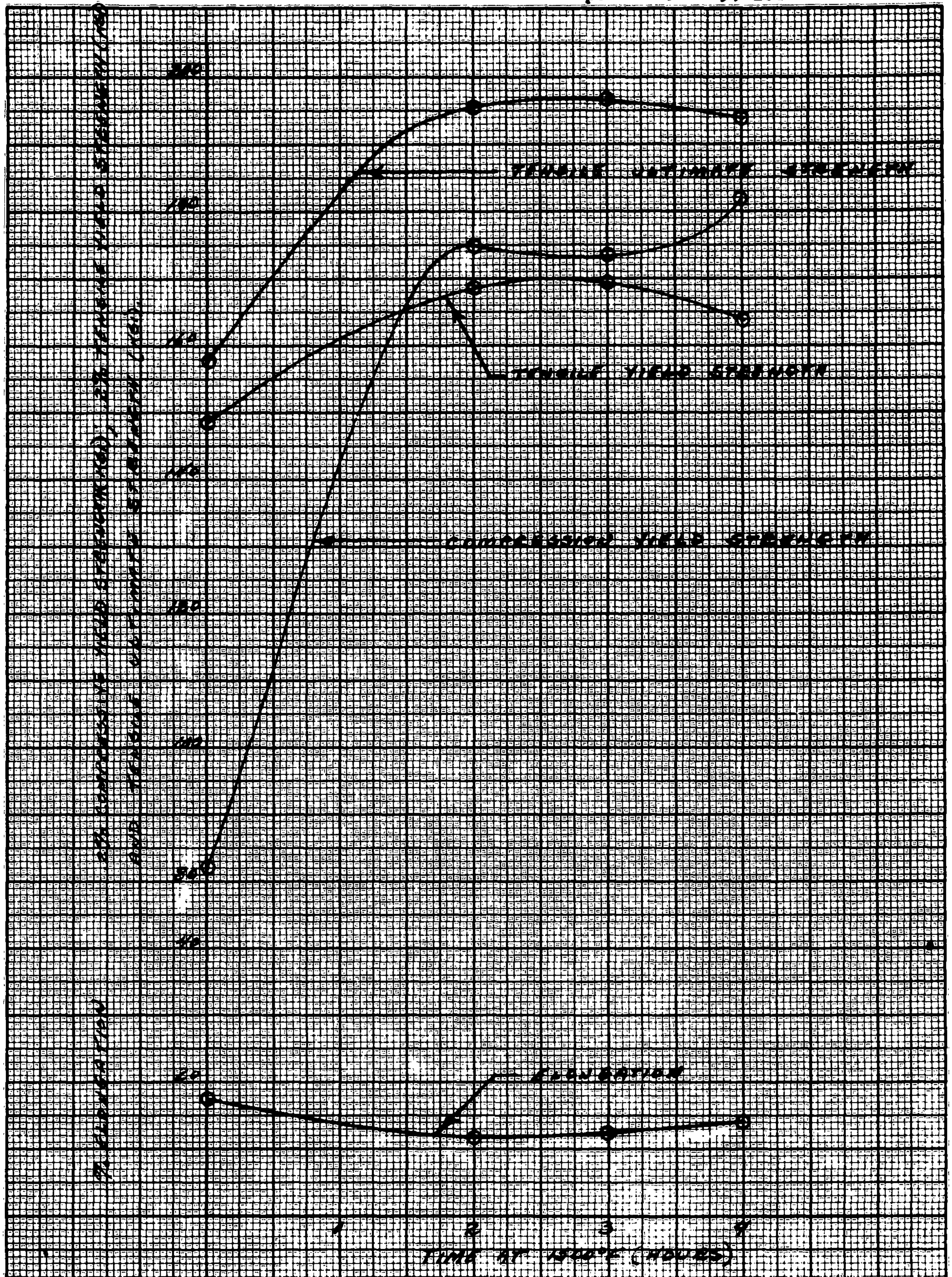


FIG 4 - EFFECT OF AGING TIME ON THE TRANSVERSE MECHANICAL PROPERTIES OF [illegible] STRETCHED TO [illegible] PERMANENT SET) [illegible] ELONGATION.