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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 928

THE INFLUENCE OF PLASTIC DEFORMATION AND OF HEAT TREATMENT

ON POISSON'S RATIO FOR 18:8 CHROMIUM-NICKEL STEEL

By R. W. Mebs and D. J. McAdam, Jr.
National Bureau of Standards

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SUMMARY

An effective value of Poisson's ratio for 18:8 Cr-Ni
steel was computed from values of tensile and torsional
moduli of elasticity obtained in earlier investigations
by use of an appropriate formula. A study was made of
the variation of Poisson's ratio with prior plastic ex-
tension of the annealed alloy and with annealing tempera-
ture for the cold-drawn alloy.

With prior extension of the fully annealed alloy up
to about 12 percent elongation, the effective value of
Poisson's ratio at zero stress (μ_o) rises; whereas at
other stress values $(\mu_{25}$ and $\mu_{50})$ it remains approxi-
mately constant. The rise of μ_o is attributed to the
anisotropic nature of the internal (residual) stress pro-
duced during prior plastic extension coupled with the
fact that the planes of maximum shear stress in torsional
loading are differently oriented than in tensile loading.
For the cold-drawn alloy, however, μ_o is lower than for
the fully annealed alloy.

After annealing the cold-drawn alloys at various
temperatures in the stress-relief annealing range, μ_o
and μ_{50} are approximately equal and nearly constant.
Apparently, the removal of lattice expansion effects by
annealing at higher temperatures, at which recrystalliza-
tion occurs, causes an increase of μ_o, probably because
of the change from a preferred orientation of the cubic
[100] direction of grains, parallel to the specimen axis,
to a random distribution.

INTRODUCTION

An investigation of the elastic properties of high strength aircraft metals has been conducted at the National Bureau of Standards during the past 8 years under the sponsorship of the National Advisory Committee for Aeronautics. Reports have been presented upon the tensile elastic (references 1, 2, and 3) and the torsional elastic (reference 4) properties of metals. The elastic properties studied were: (a) the proof stresses which produce various proof sets and (b) the elastic modulus and its variation with applied stress. The relationship of these indices to cold work and to annealing treatment also was investigated. The method of obtaining correlated stress-strain and stress-set curves and of deriving the elastic properties from these curves is given in the afore-mentioned publications (references 1, 2, 3, and 4).

The present paper correlates the tensile and shear elastic secant moduli of 18:8 Cr-Ni steel, by deriving from them an effective value of Poisson's ratio. This effective value becomes identical with the classical value (ratio of unit lateral contraction to unit axial extension under axial loading in the elastic range) only for isotropic material obeying Hooke's law. The effective value of Poisson's ratio as defined in this paper cannot be used for computing stresses under conditions of multi-axial strain beyond the range of validity of Hooke's law, or for anisotropic material. It may be used, however, as an index of anisotropy - that is, an index for a change in properties with direction. The significance of variations in the effective value of Poisson's ratio with the degree of cold work or with thermal treatment is discussed in the present paper.

MATERIAL, TESTS, AND METHOD OF COMPUTATION

Bar stock 18:8 Cr-Ni steel was used in preparing specimens for the tensile tests (references 1, 2, and 3); whereas tubular stock material was selected for the torsion tests (reference 4). In order to obtain reliable values of Poisson's ratio from tensile and torsional modulus data, the materials tested in tension and torsion should be of nearly the same chemical composition,

structure, and hardness. A "half-hard" rod material and the "hard" grade tubular material were selected for this evaluation; in an earlier report (reference 4) it was shown that of the cold-worked rod and tubular materials, these two were in the most nearly equivalent cold-worked condition. Rockwell hardness readings for both metals gave values ranging from C39 to C42. Moreover, microscopic examination of the cross sections of the tubular and rod material in the "as-received" condition indicated similar microstructure. Table 1 shows that the compositions of these two materials do not differ greatly.

In the present report, the influence of two variables upon the effective value of Poisson's ratio is being investigated: namely, (a) the influence of cold work and (b) the influence of annealing temperature. In order to determine the influence of cold work, data were obtained from previous tests upon tensile (reference 2) and torsional (reference 4) specimens which had been fully annealed, and then extended various amounts. Tensile tests had been made upon a single specimen after annealing at 1830° F for 1/2 hour, and at various stages of its subsequent plastic extension, up to the point of local contraction. Torsional tests had been made upon a series of tubular specimens which were annealed at 1900° F for 1 hour and each extended a different amount in tension, ranging from zero to 20 percent. Previous work has shown that this difference in annealing temperatures, 1830° and 1900° F, is not significant. The influence of annealing temperature was studied by selecting data from tests upon cold-drawn rod and tubular specimens (references 2 and 4) which had been annealed at various temperatures ranging from room temperature up to 1900° F; the "as-received" specimens are considered as annealed at 100° F.

The effective value of Poisson's ratio, μ, was calculated from

$$\mu = \frac{E}{2G} - 1 \tag{1}$$

where E and G are taken as the secant tension and shear moduli, respectively (references 5 and 6). The secant modulus used in this paper is obtained by dividing the total stress by the elastic portion of the total strain - that is, total strain corrected for permanent set. For purposes of design the use of Poisson's ratio calculated in this way is limited only to those metals

which are isotropic with respect to elastic properties
and have stress-strain characteristics that conform
closely to Hook's law. However, for purposes of showing
the relative influence of such variables as plastic de-
formation and heat treatment upon the torsional and ten-
sile elastic properties of a single material - that is,
to detect any anisotropic change in the metal - the use
of such an effective value may have certain advantages
over the use of values obtained by direct measurement.
As will become evident later in this report, the direc-
tional variation of the influence of internal stress
could never have been detected by direct measurements of
Poisson's ratio on cylindrical specimens.

Owing to the sensitivity with which stress-strain
and stress-set measurements were made (references 1 to 4),
it was frequently possible to observe a decrease in the
secant modulus with increase in stress. Thus, the ten-
sion and shear moduli, and therefore μ, require specifi-
cation of the stress at which they are calculated. Nádai
has suggested (reference 7) that the stress-strain curve
for a metal in pure shear can be approximately derived
from its stress-strain curve in tension by multiplying
tensile stresses by $1/\sqrt{3}$ and tensile strains by 1.5. In
this report, therefore, values for the tensile modulus (E)
are obtained at zero stress, and where practicable, at
25,000 and 50,000 pounds per square inch; the corresponding
shear modulus (G) values were obtained at zero stress, and
at 14,450 and 28,900 pounds per square inch. The modulus
values at zero stress are necessarily extrapolated values,
but may be determined quite accurately from derived curves
showing the variation of modulus with stress (references 1
to 4).

THE VARIATION OF EFFECTIVE POISSON'S RATIO WITH EXTENSION

OF FULLY ANNEALED 18:8 Cr-Ni STEEL

First will be considered effective values of Poisson's
ratio calculated for 18:8 Cr-Ni steel rods and tubes which
had been fully annealed and then extended. Values of μ
were calculated over an extension range of 20 percent, the
maximum used for the tubular specimens (reference 4). Spec-
imens tested in tension had been extended over a somewhat
greater range (references 1 and 2).

The variations of the tension secant modulus E and the shear secant modulus G, with extension of the fully annealed metal, are shown in figure 1. These curves were drawn through the mean positions of the data derived from experiment. They may be considered as basic curves devoid of oscillations due to variations in rest interval and extension spacing, associated with individual tests. Curves showing the variation of μ with the amount of prior extension also are shown in figure 1; they are derived from the basic modulus curves by the use of equation (1). The stresses (in thousand pounds per square inch), at which E, G, or μ is measured, are denoted by subscript numbers; the subscript number for μ corresponds to the associated tensile stress.

Because of the much greater variation with stress of the tensile moduli than the torsional moduli, the value of μ decreases with increase in stress. The value of μ_0 is found to increase with extension of the annealed metal, rising from an initial value of about 0.32 to a constant value of about 0.40 after an extension of about 12 percent. The values of μ_{25} and μ_{50} remain nearly constant at about 0.32 and 0.24, respectively, over the observed range of prior extension. The values of μ_0, μ_{25}, and μ_{50} for this metal as annealed, and after 10 and 20 percent prior extension, are given in table 2.

THE VARIATION OF POISSON'S RATIO WITH ANNEALING TEMPERATURE

FOR COLD-DRAWN 18:8 Cr-Ni STEEL

Values of μ were calculated for cold-drawn 18:8 Cr-Ni steel rods and tubes in the "as-received" condition, and after annealing at temperatures ranging from 300° F to about 1800° F (rod and tubular specimens were annealed at maximum temperature values of 1830° F and 1900° F, respectively).

The variation of the tension modulus E and the shear modulus G with the temperature of annealing of the cold-drawn alloy is shown in figure 2. The curves are drawn through the mean positions of experimentally derived data. Curves are drawn for the tension modulus at zero stress and at 50,000 pounds per square inch and for the torsion modulus at zero stress and at 28,900 pounds per square inch.

Because of the nearness of these pairs of curves, values
at intermediate stresses were not plotted. There also are
plotted in figure 2 values of μ calculated from corre-
sponding tension and shear modulus values by use of equa-
tion (1).

Over a range of annealing temperature from room tem-
perature to 1000° F, there is no significant variation of
μ_0 or μ_{50}; these two curves are nearly coincident.
With further increase in annealing temperature, μ_0
rises from a value of 0.22 and attains a value of about
0.31 for the fully annealed metal.

DISCUSSION

The elastic properties of a polycrystalline metal
having small grains, the orientations of which are ran-
domly distributed, are generally considered isotropic.
Appreciable variation of μ from the value obtained upon
a metal in its isotropic, fully annealed condition, may
indicate an anisotropic condition with respect to elastic
properties in the metals tested.

Figure 1 shows that μ_0 increases from the original
value of 0.32 to 0.40 with prior extension of the annealed
metal of between 12 and 20 percent. The rod and tubular
materials were of similar composition (table 1). Extrapo-
lation of the modulus-temperature curves in figure 2
indicates that the difference in annealing treatments of
the fully annealed rod and tubular materials is insignifi-
cant. The rise of μ_0 therefore suggests that small
plastic extensions produced some elastic anisotropy in the
alloy. Since μ_{25} and μ_{50} show values more nearly with-
in the usual range, it would be implied that such anisot-
ropy becomes less evident upon application of a moderate
stress. At greater values of extension than found in fig-
ure 1, it might be expected that μ_0 would decrease from
the maximum value of 0.4 and approach the value (0.22) ob-
tained for the cold-drawn metal plotted at 100° F in fig-
ure 2. This also would be indicated by the rapid lowering
of E_0 for the half-hard alloy at large extensions (ref-
erence 2) subject to the condition that no prominent
reversals would be found in the curve of G_0 upon increas-
ing the extension range shown in figure 1 beyond 20 percent.

It was shown in an earlier report (reference 2) that during the initial portion of the extension range the influence of residual internal stress predominated in causing a rise of E_0. No such important initial rise of G_0 with extension is found (fig. 1). It should be noted that, in tension, maximum shear occurs along planes diagonal to the length of the tube; whereas, in torsion, shear occurs along planes parallel and transverse to the length of the tube. Thus, the planes along which maximum shear stress occurs are the same during the prior extension and during tension testing, but different during the prior extension and during torsion testing. The difference in influence of the internal stress factor upon subsequent tension or torsion tests might therefore be explained as due to the directional effect of any residual stress upon further deformation. With appreciable increase in stress during such testing, the residual internal stress would become negligible in comparison to the applied stress, or may be relieved, and the evidence of elastic anisotropy would disappear, as indicated by the lower values found for μ_{25} and μ_{50}.

Figure 2 indicates that within the range of preheating or annealing temperatures of from 100° F up to about 1000° F, Poisson's ratio (μ_0 or μ_{50}) is maintained within the narrow range of 0.21 to 0.22; at higher temperatures μ_0 increases and reaches a value of about 0.31 at 1800° F. The relief of internal stresses which occurs within the lower temperature range obviously does not affect the value of Poisson's ratio. The rise of μ_0 at higher temperatures, however, indicates that other factors are effective.

In earlier reports (references 2 and 4), the influence of the lattice expansion factor and the reorientation factor upon elastic properties was noted. Lattice expansion, which occurs during cold working, tends to lower both tensile and shear moduli. However, the quantitative influence of this factor upon these two indices is not determinable. It can be shown, however, that the rise in μ_0 during soft annealing may be due to the influence of the removal of the preferred orientation produced by previous cold work. It was shown in an earlier report (reference 2) that the rapid decrease of E_0 at large extensions would be assisted by preferential orientation of the [100] crystal directions parallel to the axis of the specimen, such as occurs in some face-centered cubic

metals when deformed as in wire drawing (reference 8).
It is evident by examining the space models for tensile
and shear moduli (figs. 49 and 52, reference 2), which
are similar to those for most face-centered cubic metals,
that an approach to a predominantly cubic [100] orienta-
tion would tend to lower the tensile modulus and increase
the shear modulus, thus causing a decrease of the effec-
tive value of Poisson's ratio μ_0 during cold work.

However, preliminary results of torsion tests upon nickel
and monel tubing indicate that severe cold working causes
an increase of μ_0 for these metals. This rise can be
attributed to the predominance of the octahedral [111]
orientation in the axial direction following severe cold-
drawing of these metals (reference 2).

Removal of the lattice-expansion effects may be ex-
pected by annealing at temperatures below the recrystalli-
zation range, as was found by Smith and Wood (reference 9)
for iron; within this range there is negligible variation
of μ. The removal of preferred orientation effects,
however, would occur chiefly during recrystallization and
would thus explain the rise of μ during softening of the
18:8 Cr-Ni steel, as shown in figure 2.

Consideration has been given to the possibility that
the variations in Poisson's ratio in figures 1 and 2 may
be due in part to the increase of the ferromagnetic sus-
ceptibility of 18:8 Cr-Ni steel during cold work. Although
this increase can be quite easily detected with a permanent
magnet, it is generally believed that the relative quantity
of material changing over from austenitic to ferritic struc-
ture during severe cold work is quite small, and should
therefore not affect the moduli of elasticity to any meas-
urable extent.

National Bureau of Standards,
    Washington, D. C., December 4, 1943.

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TABLE 1.- CHEMICAL COMPOSITION OF 18:8 Cr-Ni STEEL

Material	Desig-nation	Chemical Composition (percent)			
		C	Cr	Ni	Fe
Bar stock (Cold-drawn "half-hard")	DM	0.10	18.82	9.38	Diff.
Tubular stock (Cold-drawn "hard")	TC	.07	18.5	10.4	Diff.

TABLE 2.- POISSON'S RATIO FOR 18:8 Cr-Ni STEEL

Material and condition	Poisson's ratio		
	μ_0	μ_{25}	μ_{50}
As cold-drawn	0.22	----	0.22
Cold-drawn, annealed 900° F. . . . . . :	.21	----	.21
Cold-drawn, fully annealed	.32	----	----
Cold-drawn, fully annealed, extended 10 percent	.40	0.32	.24
Cold-drawn, fully annealed, extended 20 percent	.40	.32	.25

MODULUS OF ELASTICITY, LB PER SQ INCH (MILLIONS)
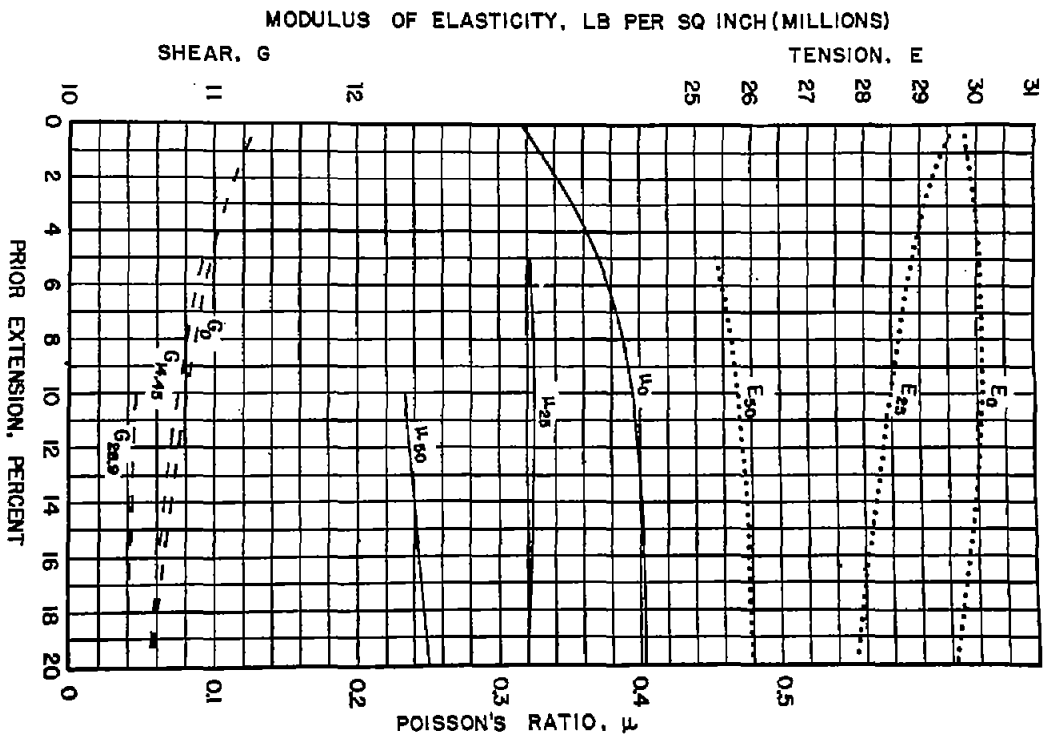
Figure 1.— Influence of prior extension on the tensile and shear moduli of elasticity and Poisson's ratio, annealed 18:8 Cr-Ni steel.

MODULUS OF ELASTICITY, LB PER SQ INCH (MILLIONS)
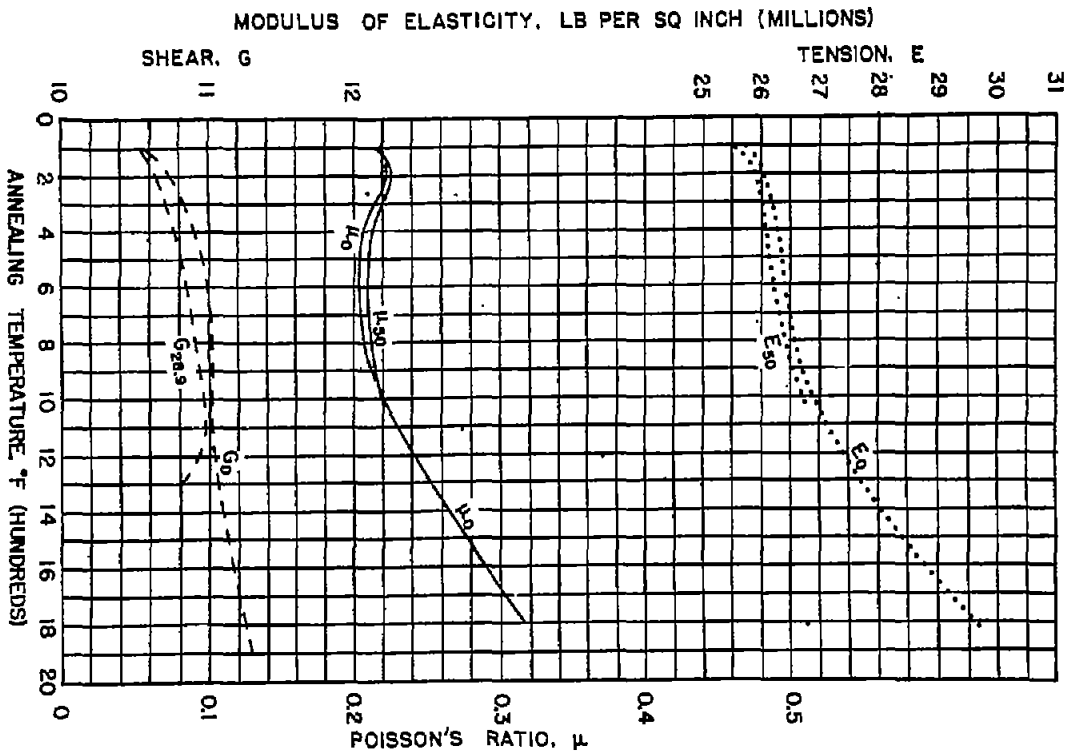
Figure 2.— Influence of annealing temperature on the tensile and shear moduli of elasticity and Poisson's ratio, cold drawn 18:8 Cr-Ni steel.

TITLE: The Influence of Plastic Deformation and of Heat Treatment on Poisson's Ratio
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