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No. 928

THE INFLUENCE OF PLASTIC DEFORMATION AND OF HEAT TREATMENT ON POISSON'S RATIO FOR 18:8 CHROMIUM-NICKEL STEEL

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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 extension of the annealed alloy and with annealing temperature 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_0) rises; whereas at other stress values (μ_{25} and μ_{50}) it remains approximately constant. The rise of μ_0 is attributed to the anisotropic nature of the internal (residual) stress produced 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_0 is lower than for the fully annealed alloy.

After annealing the cold-drawn alloys at various temperatures in the stress-relief annealing range, μ_0 and μ_{50} are approximately equal and nearly constant. Apparently, the removal of lattice expansion effects by annealing at higher temperatures, at which recrystallization occurs, causes an increase of μ_0, 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 multiaxial 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

$$\mu = \frac{E}{2G} - 1 \qquad (1)$$

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 deformation and heat treatment upon the torsional and tensile 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 directional 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 tension and shear moduli, and therefore μ, require specification 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). Specimens 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 corresponding tension and shear modulus values by use of equation (1).

Over a range of annealing temperature from room temperature to 1000° F, there is no significant variation of μ_o or μ_{50}; these two curves are nearly coincident. With further increase in annealing temperature, μ_o 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 randomly 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_o 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). Extrapolation of the modulus-temperature curves in figure 2 indicates that the difference in annealing treatments of the fully annealed rod and tubular materials is insignificant. The rise of μ_o therefore suggests that small plastic extensions produced some elastic anisotropy in the alloy. Since μ_{25} and μ_{50} show values more nearly within the usual range, it would be implied that such anisotropy becomes less evident upon application of a moderate stress. At greater values of extension than found in figure 1, it might be expected that μ_o would decrease from the maximum value of 0.4 and approach the value (0.22) obtained for the cold-drawn metal plotted at 100° F in figure 2. This also would be indicated by the rapid lowering of E_o for the half-hard alloy at large extensions (reference 2) subject to the condition that no prominent reversals would be found in the curve of G_o upon increasing 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_o. No such important initial rise of G_o 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_o or μ_{50}) is maintained within the narrow range of 0.21 to 0.22; at higher temperatures μ_o 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_o 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_o 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_o 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] orientation would tend to lower the tensile modulus and increase the shear modulus, thus causing a decrease of the effective value of Poisson's ratio μ_o during cold work. However, preliminary results of torsion tests upon nickel and monel tubing indicate that severe cold working causes an increase of μ_o 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 expected by annealing at temperatures below the recrystallization 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 susceptibility 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 structure during severe cold work is quite small, and should therefore not affect the moduli of elasticity to any measurable 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	Designation	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

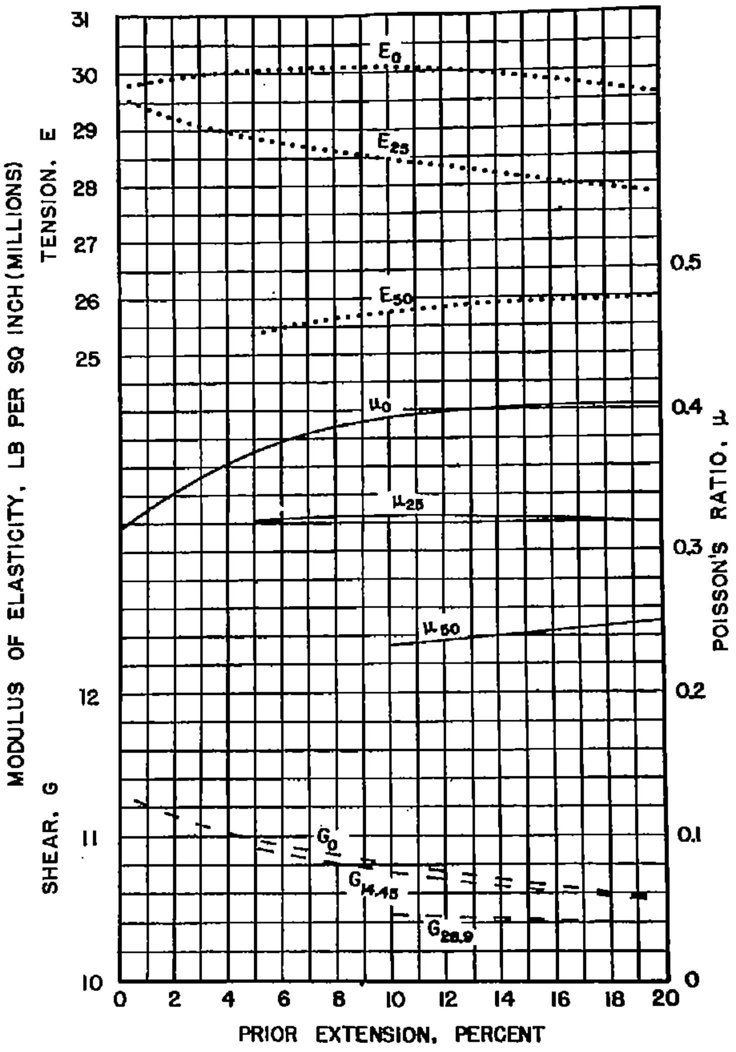

Figure 1.- Influence of prior extension on the tensile and shear moduli of elasticity and Poissons's ratio, annealed 18:8 Cr-Ni steel.

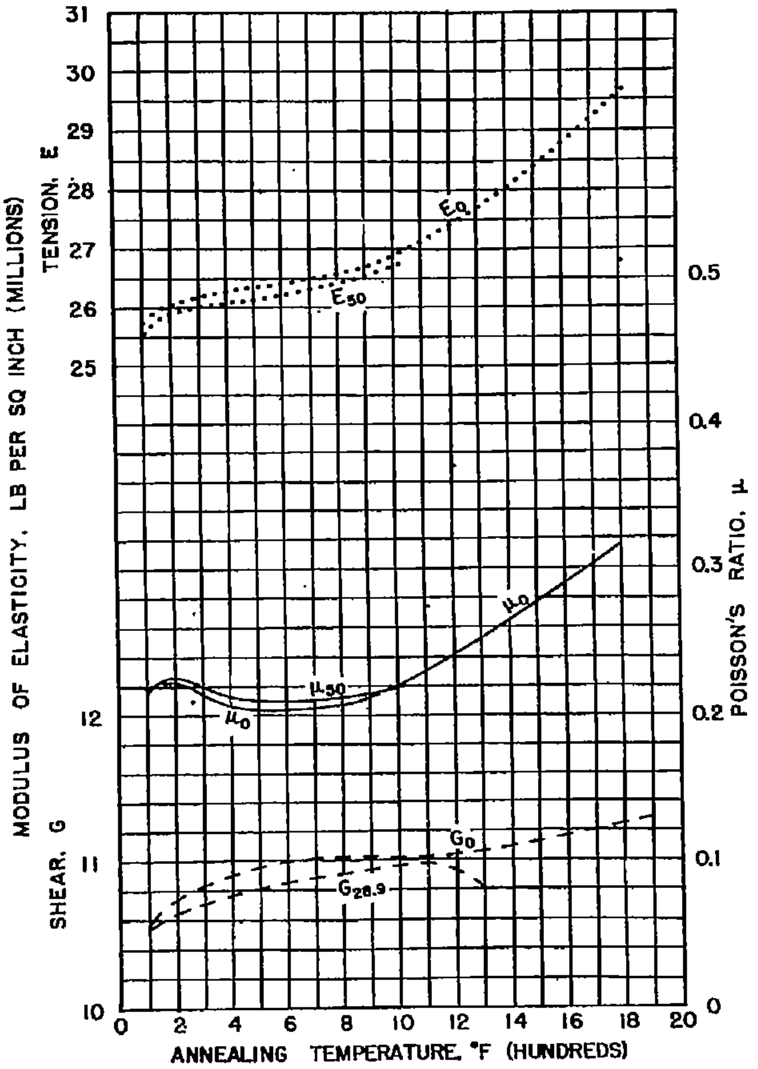

Figure 2.- Influence of annealing temperature on the tensile and shear moduli of elasticity and Poisson's ratio, cold drawn 18:8Cr-Ni steel.