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REPORT

**THE EFFECTS OF IRRADIATION,
COLD WORK, AND ANNEALING
ON THE MARTENSITE CONTENT OF TWO
AUSTENITIC STAINLESS STEELS**

BY

J. W. CARTER

AUGUST, 1966 DATE

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OF TWO AUSTENITIC STAINLESS STEELS

INTRODUCTION

The purpose of this study is to investigate the effects of cold work, thermal exposure, chemical composition, and neutron irradiation on the deformation-induced martensitic transformation in two austenitic stainless steels.

AISI 304 and 348 SS are in a metastable austenitic state at room temperature. AISI 304 undergoes a spontaneous transformation to martensite around 76 °K while AISI 348 transforms at a somewhat lower temperature. Martensite formation can also be made to occur at room temperature by deformation.

These steels are important materials in reactor components and fuel cladding. If the martensite platelets in the austenite matrix are unstable under thermal exposure and irradiation, significant changes in mechanical properties can occur during service. Tensile strength and rupture life are sensitive to phase instability in an alloy.

The investigation consists of three experiments. The first experiment investigates the relationship between the fluctuations in tensile strength and in martensite content of AISI 304 and 348 SS with 300 °C hot water exposure for extended periods of time. Secondly, the relationship between cold work and martensite content and the effect of annealing on this relationship are studied. Finally, the effect of irradiation on martensite content and on strain energy require-

ments for martensite formation are investigated.

SUMMARY

The results of this study include:

- Fluctuations in the tensile strengths of cold worked AISI 304 and 348 SS exposed to 300 °C hot water appear to be related to corresponding changes in the concentration of martensite in the material.
- The deformation induced martensitic transformation of γ (fcc) to α' (bcc) follows the Austin-Rickett autocatalytic equation.
- Annealing at 300 °C leads to changes in the amount of α' in a cold-worked AISI 304 and 348 SS.
- Within the limits of accuracy of the measuring device used (an Aminco-Brenner Magnegage), neutron irradiation at 300 °C does not affect the ratio of strains caused by martensitic transformation and by slip at room temperature.
- ✕ ● The strain energy required to transform a unit amount of austenite to martensite in irradiated material is much greater than in unirradiated material.
- ✕ ● A low neutron dose at 300 °C does not significantly change the amount of martensite present in previously cold-worked specimens compared to the changes caused by thermal effects alone.

REVIEW OF THE LITERATURE

Austenitic stainless steels are in a metastable state below what is commonly known as the M_D^* temperature.⁽¹⁾ These steels undergo a strain-induced transformation to martensite below the M_D temperature, and a spontaneous transformation below the M_S^{**} temperature. Since the martensitic transformation is diffusionless, the transformation product has the same chemical composition as the original austenite. Although the transformation occurs almost entirely athermally, if martensite is deformation induced, isothermal conditions may prevail.⁽³⁾ Finally, martensite generally has a fixed orientation with respect to the parent phase, with the martensite plates tending to lie on the {111} and {225} habit planes⁽²⁾ of the austenite matrix.

The transformation of austenite to martensite is thought to be a shear transformation with nucleation occurring at strain embryos, often screw dislocations.^(3,8) A homogeneous shear of the austenite lattice takes place along the invariant habit plane,⁽⁴⁾ followed by a dilatation. The whole process occurs in approximately 3×10^{-7} sec.⁽⁵⁾

Nuclei are usually present in adequate numbers to start the transformation. The energy barrier between the austenite (γ) and martensite (α') must be overcome, however, before martensite formation can take place. For this

reason, α' does not form at the thermodynamic equilibrium temperature, T_E .^(3,6) Either supercooling of about 200 to 300 °C, or deformation of the austenite is necessary to supply the 200 to 400 cal/mole necessary to surmount the energy barrier.

Martensite can be formed by deformation as long as the material is below the M_D temperature, but it cannot be formed by deformation above this temperature. This has led some investigators to suggest that the M_D temperature and T_E , the thermodynamic equilibrium temperature, are identical.⁽³⁾ However, it has also been claimed, with good experimental justification, that due to the nature of the deformation-induced transformation, the two temperatures will generally be quite different.⁽¹⁾

The martensite transformation competes with slip as a means of deformation under an applied stress.⁽⁷⁾ If the critical resolved shear stress for martensite formation is less than that for slip, martensite will be formed before slip can occur. Conversely, slip will occur and relieve the stress if the critical resolved shear stress (CRSS) for slip is less than that for martensite formation. This fact helps to explain the disparity between M_D and T_E . It is possible that as temperature increases, the CRSS for slip decreases while the probability of relaxation of the martensite strain embryos increases.⁽¹⁾ Under these conditions, the stress necessary to form martensite is never reached in the interval between the M_D and T_E temperatures.⁽¹⁾

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* The M_D temperature is defined as that temperature above which no amount of plastic deformation will produce martensite.

** The M_S temperature is the temperature below which austenite transforms to martensite spontaneously.

Angel⁽¹⁾ discovered that the martensite content of a deformed austenitic stainless steel was related to true strain by a modification of the Austin-Rickett equation

$$\ln \frac{f}{1-f} = n \ln \epsilon + k = \ln \frac{\Delta M}{\Delta M - \Delta M_T} \quad (1)$$

where

- f = fraction transformed
- $= M/M_T = \Delta M/\Delta M_T$
- ΔM = Magnetic reading at a true strain of ϵ
- ΔM_T = Maximum magnetic reading at a given temperature of deformation
- n, k = Constants.

In a series of experiments with several representative 18 Cr-8 Ni type steels, Angel found that the value of n was approximately equal to 3 and was independent of both chemical composition and temperature. However, the constant k was dependent on both the chemical composition and temperature.

Given a set of ϵ vs. ΔM (magnetic reading in arbitrary units) data, it is necessary to assume $n = 3$ and $k = 0$ to calculate ΔM_T . Since k is not necessarily equal to zero, the ΔM_T calculated does not represent the true maximum reading but only the maximum for that particular temperature and composition. Therefore, the fraction transformed given by the expression $\Delta M/\Delta M_T$ is the fraction of martensite that can be produced by deformation at that temperature. Determination of the absolute amount of martensite requires either quantitative measurement by X-ray diffraction or metallography, or, if the maximum magnetic reading can be measured on a sample deformed well

below its M_D temperature, this reading can be accurately assumed to be equivalent to a true 90% martensite. From Angel's data, it appears that deformation of 50% strain or more below -50 °C will produce close to 90% martensite in all 18-8 austenitic stainless steels. The crucial point is to reduce the temperature sufficiently low so that the transformation to martensite will go to completion without substantial stress relief by slip.

Once this maximum ΔM_T is determined, it is possible to take the ratio of $\Delta M_T/\Delta M_{Tmax}$ and calculate the maximum possible amount of martensite that can be formed at the higher temperature. A good approximation of the amount actually formed can also be calculated.

The autocatalytic effect is attributed to the formation of new embryos from prior slip and martensite formation. The resulting lattice strains provide enough energy to allow other embryos to transform. Consequently, martensite formation occurs before the average strain reaches the critical value. Although some martensite formation is stimulated by the early stages of strain, other embryos in the macroscopic volume are prevented from growing because they either possess low energy or are unfavorably oriented with respect to the strain. The average applied strain required to activate these embryos is greater than the critical value, and a stabilizing effect sets in. As initial martensite platelets partition the austenite, the possible size for future platelets decreases and the surface energy per mole of martensite increases. When these stabilizing effects counter-

balance the strain effects, the transformation stops. The limiting value for transformation is about 90% martensite (observed only at low temperatures!), and beyond this limit slip becomes the primary deformation mechanism.

From the above discussion, it is apparent that the deformation-induced martensite transformation is somewhat sensitive to the temperature of deformation. In general, the farther below its M_D temperature an austenitic stainless steel is, the more martensite will be produced by a given amount of cold work and the higher the limiting martensite content will be. Unfortunately, the M_D temperature is rather hard to measure in actual practice. For comparison of these two materials, consider the M_{D30} temperature as defined by Angel⁽¹⁾ at which 50% martensite is formed in tension by a 0.30 true strain. A high value for M_{D30} will lead to a high response to deformation.

Angel determined the effect of the various alloying elements on the M_{D30} temperature by regression analysis of several stainless steels. His equation, using the percentage of elements by weight, is

$$M_{D30} (^{\circ}\text{C}) = 413 - 462(\text{C} + \text{N}) - 9.2(\text{Si}) \\ - 13.7(\text{Cr}) - 9.5(\text{Ni}) \\ - 18.5(\text{Mo}) - 8.1(\text{Mn}) \quad (2)$$

It should be noted that the M_{D30} temperature and the formula for calculating it apply only to specimens pulled in tension. However, the relative values of the M_{D30} temperature are probably constant for different

modes of deformation.

In the more usual type of martensite, such as is found in carbon steels, the transformation proceeds directly from austenite to martensite; there are no intermediate phases that remain partly untransformed. However, the situation is somewhat different for austenitic stainless steels, where an HCP transition phase is formed.^(2,9,10) The transformation thus proceeds $\gamma(\text{FCC}) \rightarrow \epsilon(\text{HCP}) \rightarrow \alpha'(\text{BCC})$. The ϵ phase is apparently completely faulted austenite.⁽⁸⁾ The FCC and HCP structures are identical in packing efficiency and differ only in the way layers of atoms are stacked on each other. A proper shift of these layers by one atomic spacing will yield the HCP structure from the FCC and vice versa.

Usually, some of the ϵ phase does not transform to α' . This leaves an extremely metastable phase that is able to go back to γ if the temperature rises above T_E . It is also possible for the ϵ to transform to α' isothermally upon annealing below the T_E temperature. This behavior can lead to fluctuations in the amount of martensitic α' in an austenitic stainless steel.

Austenitic stainless steels exhibit changes in tensile properties as a function of cold work and exposure time at relatively low temperatures. Fluctuations in tensile strength have been detected in AISI 304 and 348 SS upon exposure to 300 $^{\circ}\text{C}$ hot water for long periods of time.⁽¹⁴⁾ These fluctuations vary with the initial amount of cold work in the material. Generally, an increase in the amount of cold work leads to an increase in the variations

in the tensile strength as a function of time.

The effect of irradiation on the martensitic transformation has been studied.⁽¹¹⁻¹³⁾ Reynolds, et al.,⁽¹¹⁾ using a magnetic technique, found that irradiation of cold-worked AISI 347 SS produced a small increase in the amount of martensite present. In their study, the amount found after cold-working to a 50% reduction in thickness was 0.19%. Upon irradiation to an integrated reactor power of 110 kW/cm², an increase of 0.057% was found.

Porter and Dienes⁽¹²⁾ found that irradiation of iron-nickel alloys lowered the M_s (martensite start) temperature. Changes in electrical resistivity and magnetic saturation induction occurred during irradiation. These changes were ascribed to phase separation or to the production of nickel-rich clusters caused by radiation enhanced diffusion of nickel through the lattice.

Armijo, et al., studied AISI 304 austenitic SS.⁽¹³⁾ They discovered that the magnetic technique of measuring saturation induction can lead to values of martensite content as much as a factor of 30 to 50 low, when compared to X-ray and metallographic observations. Within the limits of the X-ray analysis technique used, no increase in the amount of martensite was observed for an integrated flux of 1.25×10^{20} nvt (> 1 MeV). Simple magnetic measurements were used to qualitatively confirm this conclusion.

EXPERIMENTAL PROCEDURE

Several different experiments were performed to carry out the program of investigation. In the first experiment, the amount of ferro magnetic component formed in both AISI 304 and 348 SS was determined from specimens exposed to hot water (300 °C) for varying periods of time. The relative amounts of ferromagnetic material was determined with an Aminco-Brenner Magnegage, which measures the force required to lift a standard magnet away from the specimen.

The second experiment consisted of rolling samples of AISI 304 and 348 to varying degrees of cold work, and taking Magnegage readings between passes. Examining each specimen individually throughout the reduction process, representing different levels of cold work, eliminated data scatter inherent of a number of specimens rolled to different levels of cold work.

The third and major portion of the program involved rolling seven specimens each of AISI 304 and AISI 348 to varying degrees of cold work. Magnegage readings were taken on each sample to obtain an average value for a given level of cold work. Each sample was then cut into six pieces, and Magnegage readings were again taken on each of the smaller pieces.

Five sets of the small samples, consisting of one sample from each degree of cold work, were sealed in helium-filled glass tubes and placed in a furnace held at 300 °C. Tubes were subsequently removed from the furnace

after 1, 2, 4, 8, and 16 days at temperature. The annealed specimens were re-examined with the Magnegage. Those of particular interest were mounted in plastic and metallographically polished on Syntron polishers, and some mounted samples were subjected to X-ray analysis to check for α' and ϵ phases.

In the final experiment, a AISI 304 SS irradiated in the ETR G-7 Loop, and an unirradiated sample were pulled in tension to determine if there was any difference between the samples in the amount of ferromagnetic phase formed with plastic strain. The samples were pulled to a given extension, removed from the grips, and examined with the Magnegage. Both samples were strained in this manner until they failed.

The AISI 304 and AISI 348 SS used in this program had the compositions given in Table I.

TABLE I. Chemical Compositions of Experimental Stainless Steels

	AISI 304 SS, wt%	AISI 348 SS, wt%
Chromium	18.56	18.54
Nickel	9.59	11.95
Columbium		0.81
Tantalum		0.11
Carbon	0.049	0.046
Manganese	1.21	1.67
Molybdenum	0.20	0.19
Phosphorus	0.029	0.018
Sulfur	0.018	0.018
Silicon	0.60	0.48
Nitrogen	0.028	0.025
Hydrogen	0.0014	0.0014
Oxygen	0.021	0.030
Cobalt		0.09
Copper	0.17	0.11
Boron	0.0008	0.0008

RESULTS

The first experiment was performed to determine if a relationship existed between changes in room temperature tensile yield strength of 25% cold-worked AISI 348 and 304 SS with hot water exposure at 300 °C and the martensite content as determined by the Magnegage. The deviations in Magnegage readings after 300 °C exposure from average readings for original material are plotted in Figures 1 and 2. There was sufficient similarity between the variations in yield strength and ferromagnetic force for both alloys to prompt additional investigation.

The second experiment involved successive cold working and Magnegage examination of both AISI 304 and AISI 348. Figure 3 shows a plot of ΔM (the change in the Magnegage reading in arbitrary units) versus ϵ (the true strain produced by cold working) for AISI 304. The same plot for AISI 348 is illustrated in Figure 4. The response of AISI 304 to plastic strain is much greater than that of AISI 348, due to the differences in the chemical composition of the two test materials.

In the third experiment, a series of bars were rolled to different final thicknesses before being measured magnetically. The data obtained are plotted in Figures 5 and 6 in accordance with the proposed log-autocatalytic relationship, (equation 1) for martensite formation with plastic strain. The experimental data agree quite well with the theoretical relationship.

FIGURE 1. Changes in Yield Strength and Magnetic Force for AISI 304 SS Exposed at 300 °C.

FIGURE 2. Changes in Yield Strength and Magnetic Force for AISI 348 SS. Exposed at 300 °C.

FIGURE 3. ΔM Versus ϵ for AISI 304 SS

FIGURE 4. ΔM Versus ϵ for AISI 348 SS.

FIGURE 5. Austin-Rickett Relationship for Cold Worked AISI 304 SS.

FIGURE 6. Austin-Rickett Relationship for Cold Worked AISI 348 SS.

An experiment was performed to determine the actual percent martensite in the cold worked specimens, by using the previously outlined concept of straining a sample below -50°C to form the maximum amount of martensite possible. Compared to other stainless steels with similar compositions, this would yield about 90% martensite. Samples of AISI 304 pulled in tension to 100% strain yielded a value of 953.4 on the Magnagage. Since the maximum extrapolation value for ΔM_T at room temperature is 411, AISI 304 forms not more than 39% martensite at room temperature. This maximum composition compares with a calculated martensite composition of 33% for the

highest amount of cold work imparted.

Actually, the maximum magnetic reading for the AISI 348 should be about the same as for the AISI 304. Therefore, the maximum percentage of martensite that can be formed by the AISI 348 at room temperature is 6.7%. Satisfactory agreement was observed for an actual amount of martensite, 2.4%, calculated for the highest cold work level.

The results of annealing the cold worked material at 300°C for various times are given below (the AISI 304 and AISI 348 being considered separately). Plots of martensite content versus cold work before annealing is presented for each set of specimens

along with data obtained after annealing. All the plots are based on the Austin-Rickett Equation.

The graphs representing AISI 304 for various annealing times are shown in Figures 7 through 11. The plots relating martensite content with cold work (both before and after annealing,) usually intersect so that the martensite content increases with annealing for high true strains, and decreases with annealing for low true strains.

The graphs representing AISI 348 for different annealing times are shown in Figures 12 through 16. The effects of annealing are similar to those for AISI 304.

The changes in magnetic force caused by annealing compared to the cold-worked values are shown (as a function of annealing time) for AISI 304 and 348 in Figures 17 and 18, respectively. The same cyclic variation of the magnetic force observed earlier for the tensile specimens is also observed here with slight differences.

Since the initial magnetic force for AISI 348 is less than for AISI 304 for a given degree of cold work, the variations with time are also somewhat less. Furthermore, the pattern in the variation for AISI 348 differs from that of AISI 304. This is probably because of differences in the ratio of ϵ to α' as the amount of α' changes.

Typical microstructures of the martensite containing material are shown in Figure 19. Photograph a and b are of cold work material tempered at 430 °C for 1 and 3 hr, respectively, to delineate martensite. Photographs c and d are of untempered, cold-worked material. Martensite is also apparent

but not so well delineated. Photographs a, b, and c are of AISI 304, and photograph d is of AISI 348.

X-ray studies of the cold-worked material revealed the presence of ϵ and α' in addition to γ . Quantitative measurements were not successful due to low ratios of diffraction peak to background intensities.

Figure 20 compares the variations in magnetic force with tensile strain for AISI 304 both before and after irradiation to 4.7×10^{19} nvt (>1 MeV). Within the limits of accuracy of the Magnagage, there is no significant difference in the magnetic response to strain that can be attributed to irradiation.

Table II gives values of ferromagnetic force for both specimens irradiated to 4.7×10^{19} nvt (>1 MeV) at 300 °C and control specimens given a

TABLE II. Values of Ferromagnetic Force

Description	Control $\Delta M^{(1)}$	Irradiated ΔM
	AISI 304	
Transverse Direction ⁽²⁾ Annealed	0.02	0.88
Transverse Direction 25% Cold-Worked	29.0	31.67
	AISI 348	
Transverse Direction Annealed	0.25	0.58
Transverse Direction 25% Cold-Worked	1.09	0.53
Rolling Direction Annealed	1.0	0.83
Rolling Direction 25% Cold-Worked	0.25	0.17

(1) ΔM is the change in Magnagage reading due to either thermal exposure or irradiation.

(2) Direction of tensile strain with respect to principal sheet directions.

FIGURE 7. Effect of Annealing for 24 hr on the Austin-Rickett Relationship for Cold Worked AISI 304 SS.

FIGURE 9. Effect of Annealing for 96 hr on the Austin-Rickett Relationship for Cold Worked AISI 304 SS.

FIGURE 8. Effect of Annealing for 48 hr on the Austin-Rickett Relationship for Cold Worked AISI 304 SS.

FIGURE 10. Effect of Annealing for 192 hr on the Austin-Rickett Relationship for Cold Worked AISI 304 SS.

FIGURE 11. Effect of Annealing for 384 hr on the Austin-Rickett Relationship for Cold Worked AISI 304 SS.

FIGURE 13. Effect of Annealing for 48 hr on the Austin-Rickett Relationship for Cold Worked AISI 348 SS.

FIGURE 12. Effect of Annealing for 24 hr on the Austin-Rickett Relationship for Cold Worked AISI 348 SS.

FIGURE 14. Effect of Annealing for 96 hr on the Austin-Rickett Relationship for Cold Worked AISI 348 SS.

FIGURE 15. Effect of Annealing for 192 hr on the Austin-Rickett Relationship for Cold Worked AISI 348 SS.

FIGURE 16. Effect of Annealing for 348 hr on the Austin-Rickett Relationship for Cold Worked AISI 348 SS.

FIGURE 17. Changes in the Magnetic Force for Cold Worked AISI 304 SS Annealed at 300 °C.

FIGURE 18. Changes in the Magnetic Force for Cold Worked AISI 348 SS Annealed at 300 °C.

(a)

800X

(c)

800X

(b)

800X

(d)

800X

*FIGURE 19. Typical Microstructures of
AISI 304 and AISI 348 in the Martensitic
Condition.*

FIGURE 20. Magnetic Force Versus Tensile Strain for AISI 304 SS.

duplicate thermal history (555 hr at 300 °C).

Although there may be a small effect of irradiation on the increase in martensite in AISI 304, particularly in the annealed condition, there seems to be no consistent response to irradiation other than that caused by thermal effects alone for AISI 348.

DISCUSSION

The cold-working of austenitic stainless steels produces a ferromagnetic, BCC martensitic phase as well as an

HCP non ferromagnetic transition phase. Also, there is a slight fluctuation in the amount of α' in specimens annealed at 300 °C for extended periods of time.

As suggested earlier, the transformation of γ to α' martensite is of the log-autocatalytic form. Up to the point where depletion sets in, if the percentage of martensite is greater, the required specific strain to form additional amounts is less. The data from this investigation agree with those of previous investigations.

The fluctuations in the magnetic properties during annealing at 300 °C are less well understood. Upon annealing for a fixed time, all samples of a given material change their magnetic properties such that a log-log plot of the Austin-Rickett equation versus the original true strain is fairly linear. This means that the amount of change for a given sample is dependent upon the initial quantity of martensite present. The transformation of $\epsilon + \alpha'$ under these conditions is aided by the amount of α' initially present. While the effect of α' is reasonable, it is surprising that the dependence on the amount of α' present is so strong. One might expect the initial amount of ϵ to have a stronger effect on the formation of α' than it does. A graph from another study,⁽¹⁰⁾ depicting the amounts of ϵ and α' phases in AISI 304L stainless steel, is shown in Figure 21. The amount of ϵ rises to a peak at about 10% strain and then decreases.

It is reasonable to expect that the more ϵ is present, greater is the probability that some of it will go to α' . However, in the present study, it

appears that at the lower strains, where the quantity of ϵ is highest, the tendency for α' to revert back to ϵ dominates.

The slope of the curves for martensite-versus-strain after annealing is higher than that for as-rolled material, which suggests that while the Austin-Rickett relationship is still obeyed, some other mechanism is also at work. The amount of α' increases at the higher strains and decreases (or increases less rapidly) at the lower strains. Thus, above a certain strain, which varies with the annealing time, the transformation $\epsilon \rightarrow \alpha'$ predominates under the influence of the α' already present. Below this strain, there is, in many cases, a reversion back to what is probably ϵ .

With the modest amount of data and

the limited accuracy of the Magnegage, it is not possible to define mechanisms. However, the reversion to ϵ occurs in the range where a significant amount of ϵ is present, and suggests an ϵ dependency in the annealing behavior. As mentioned before, however, the fact that the Austin-Rickett relationship is still valid means that the α' dependency is still dominant.

The relatively large deviations from the Austin-Rickett relation at high strains for most of the annealed and unannealed samples of AISI 304 are difficult to explain satisfactorily. The first possibility is that the measurements are inaccurate. It is difficult to measure changes in magnetic force of AISI 304 at the high strains because the material has become extremely ferromag-

FIGURE 21. Amounts of Transformation Products as a Function of Strain.

netic. This necessitates using a very weak magnet to stay on the scale of the Magnegage. The AISI 348, which has a much lower magnetic response at a similar high strain, does not exhibit this behavior. The second possibility is that there may be deviations from the Austin-Rickett relationship at high strains. Further experiments with a more accurate measuring technique should make an explanation possible.

A most interesting observation in this study is that irradiation has no major effect on the response of martensite transformation to plastic strain. Irradiation (at least to the low dose achieved) not only has little effect on the stability of the martensite, but also has little effect on the relative amounts of martensite formed by plastic deformation in tension. The amount of martensite might be expected to change as either more or less deformation occurs by slip. Figure 20 shows that this is not so, since equal amounts of strain in both irradiated and unirradiated material produce equal amounts of martensite. The stress to initiate martensite formation is increased in the irradiated material, as is the strain energy input required to produce a given amount of martensite. However, the relative contributions of martensite transformation and slip, to yield a given amount of plastic deformation, remain the same. It can be concluded, therefore, that irradiation causes a strengthening of the lattice which causes a greater impedance to both slip and martensite transformation, but to the same relative extent as before irradiation.

CONCLUSIONS

- Relatively large fluctuations in the tensile strengths of AISI 304 and 348 SS exposed to 300 °C hot water appear to be linked to corresponding changes in the amount of martensite in the material.
- The deformation induced transformation of γ (fcc) to α' (bcc) follows the Austin-Rickett autocatalytic equation.
- Annealing of cold-worked AISI 304 and 348 SS leads to changes in the amount of ferromagnetic α' .
- Within the limits of accuracy of the Magnegage, neutron irradiation at 300 °C does not affect the ratio of strains caused by martensitic transformation and strains due to slip at room temperature. The energy required to strain the irradiated material is greatly increased over that required for the unirradiated material. A low neutron dose at 300 °C does not cause significant changes in the amount of martensite present in previously cold-worked specimens over that caused by thermal effects alone.

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