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Anelastic behaviour of materials under multiaxial strains

Part 3 *Order–disorder transition, Snoek effect and Poisson's ratio in AISI-1080 steel*

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Data on Young's modulus and Poisson's ratio obtained in AISI-1080 steel, in the temperature region between about 300 and 600 K, are presented. The measurements have been performed in longitudinal excitation and several harmonics were used, to obtain Poisson's ratio from the measured resonant frequencies. The maximum observed in the temperature dependence of Young's modulus, for the fundamental resonant frequency, is attributed to a stress-induced disordering of carbon atoms in the octahedral interstices of the martensitic matrix. The increases of Young's modulus with temperature are described in terms of expressions deduced in the paper, which are based on Landau theory of second-order phase transitions. The critical temperature is related to the M_s temperature which characterizes the martensitic phase transition. Finally, the temperature dependence of Poisson's ratio is described in terms of a theory of anelastic behaviour under multiaxial strains, based on the standard anelastic solid model.

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1. Introduction

A strongly temperature-dependent internal friction has been observed in iron for many years (see Ch. 1 of Nowick and Berry). In fact, an internal friction peak and a modulus relaxation, Δ_E, where E is Young's modulus, occur around room temperature, when the frequency of vibration is of the order of one cycle per second. According to the very well known Snoek model [2, 3] this anelasticity is associated with the stress-induced preferential distribution of carbon or nitrogen atoms in the primary solid solution of alpha-iron. Kimura [4], on the other hand, observed a Δ_E effect and an internal friction peak in Fe–C alloys that he attributed to the ferromagnetic compound cementite, which has a Curie point at 488 K. Mild steels also disclose an anomalous magnetic after-effect which cannot be understood from magnetic considerations alone, as was first demonstrated by Ewing [5]. Moreover, in careful observations of both the magnetic and the mechanical after-effect in carbonyl iron, Richter [6] demonstrated the very close relationship between the mechanical and the magnetic after-effects. In fact, both effects have the same heat of activation (of the order of 82 kJ mol^{-1}) and the same temperature coefficient for their magnitude, i.e. -0.003, near room temperature. Of importance was Richter's observation that a strong magnetic field suppressed the magnetic after-effect but had no influence upon the mechanical after-effect. It was therefore evident that their common origin was of a mechanical rather than of a magnetic nature. In nearly random or at least partially disordered ferromagnetic alloys there is ample evidence for the existence of a coupling between magnetization and the equilibrium state of short-range order. Since magnetization is a directional quantity, the coupling is such that the equilibrium atomic arrangement in each domain exhibits a degree of directional ordering. In general, it can be expected that such ordering will be accompanied by a strain, as in fact has been demonstrated for the case of carbon or nitrogen in alpha-iron by De Vries *et al.* [7].

In the theoretical analysis of relaxation phenomena [1], it is often convenient to describe the magnitude of the relaxation in terms of a quantity known as the relaxation strength, which is defined by

$$\Delta_M = (M_U - M_R)/M_R \qquad (1)$$

where M_U and M_R are the unrelaxed and relaxed moduli, respectively. When the relaxation arises from a stress-induced preferential distribution of solute

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atoms, it may be shown that the temperature dependence of the relaxation strength is given by [8]

$$\Delta_M = T_0/(T - \lambda T_0) \qquad (2)$$

where T is the absolute temperature, λ is a numerical coefficient taking account of the interaction between solute atoms which correspond to the Weiss factor in the theory of ferromagnetism and T_0 is a temperature-independent term which increases with the concentration of solute atoms and the tetragonal distortion introduced in the lattice due to the presence of these atoms. Equation 2 is inapplicable at temperatures below λT_0. However, before this temperature is reached from above, there is a critical temperature below which there will be a spontaneous ordering of the solute atoms under zero stress. At this temperature, the interaction between the solute atoms reduces the energy of one of them if it goes to an interstice having a tetragonal axis parallel to the preponderant axis of the other atoms. This is analogous to the Curie temperature below which the magnetic moments of the atoms, or rather the spins of the electrons in a ferromagnetic domain, are oriented in such a way as to point all along the same direction at zero magnetic field. The critical temperature, T_c, for such a self-induced preferential distribution of interstitial solute atoms in body-centred cubic lattices has been computed by Zener [8] to be

$$T_c = 1.05\lambda T_0 \qquad (3)$$

and he pointed out that the persistence of the tetragonal structure of freshly quenched martensite at room temperature can be interpreted only as due to such self-induced preferential distribution of carbon atoms in iron [9]. On assuming λ to be of the order of magnitude of unity, the critical temperature for such a spontaneous ordering rises, according to Zener, to above room temperature as the carbon content in iron reaches 0.14 wt %. The solubility of carbon in iron is extremely small and segregation will take place even at room temperature when a fair amount of carbon is put into iron in solid solution. The reversibility is frequently destroyed by this segregation process and after an anneal at high temperatures, below the ferrite–austenite phase transformation temperature, the martensitic phase is not restituted.

Phase transitions were dealt with, in the beginning, by phenomenological theories which described the phenomena simply on a macroscopic scale containing many atoms. In 1937 Landau established his theory of second-order phase transitions [10]. In order to deal with phase boundaries, the theory has been generalized to Ginzburg–Landau theory by adding a term depending on the gradient of the order parameter. Furthermore, Landau theory has been applied, only recently and with reasonable success, to martensitic phase transitions [11].

It is the purpose of this paper to present results on the relaxation behaviour of both Young's modulus and Poisson's ratio in AISI-1080 steel, in the temperature region between about 300 and 600 K. It will be shown that both the Snoek relaxation and ordering phenomena contribute to the relaxation observed. The results will be interpreted in terms of the Snoek effect, a relaxation of Young's modulus produced by the martensitic phase transition, which will be expressed in terms of expressions developed in the paper and based on the Landau theory of phase transitions, and of a theory of anelastic behaviour under multiaxial strains which has been developed elsewhere [12]. Finally, a connection between the relaxation of both moduli and the martensitic phase transition is suggested.

2. Theory

Landau in his theory of second-order phase transitions [13, 14] assumed the free energy to be an analytic function of the order parameter and of temperature. Therefore, he expanded the free energy density function F, with respect to the order parameter ξ, into a power series

$$F(\xi, T) = F_0(T) + A\xi + \frac{\alpha}{2}\xi^2 + C\xi^3 + \frac{\beta}{4}\xi^4 \qquad (4)$$

where the coefficients are analytic functions of the temperature T. If ξ, as usual, is chosen in such a way that the high-temperature phase, without external field, corresponds to vanishing ξ, then we must have a minimum of F at $\xi = 0$ for $T > T_c$ and consequently $A = 0$. In order to get a second-order phase transition at T_c the minimum of F must shift continuously for $T < T_c$. Therefore α must change its sign at T_c with $\alpha > 0$ for $T > T_c$. The simplest possibility to get this behaviour is

$$\alpha = a(T - T_c) \qquad 0 < a = \text{constant} \qquad (5)$$

Furthermore, $C = 0$ and $\beta > 0$. Landau assumed β to be a constant and, consequently, the simplest energy function showing a second-order phase transition is given by

$$F(\xi, T) = F_0(T) + \frac{a(T - T_c)}{2}\xi^2 + \frac{\beta}{4}\xi^4 \qquad (6)$$

with a, β, $T_c > 0$ as constants.

The situation changes considerably if an external field is applied. The case where the external field is fixed and the temperature is changed will be considered first. In this case, two classical interaction terms, $\frac{1}{2}\gamma\sigma\xi^2$ and $-\chi\sigma\xi$, where γ and χ are positive constants and σ is the external field, can be added to the free energy [15]. The term $-\chi\sigma\xi$ is a classical volumetric elastic interaction (Ch. 16 of [1]) which causes the anelastic behaviour represented by the standard linear solid model. It gives a good description of all the anelastic phenomena produced by point defects. The term $\frac{1}{2}\gamma\sigma\xi^2$ represents a magnetostrictive interaction which has been used with relative success in phase transitions controlled by spin reorientation without important volumetric changes [16]. In addition, the pure elastic energy term should be added to the expression for the free energy, leading to

$$F(\xi, T) = F_0(T) + \frac{\alpha}{2}\xi^2 + \frac{\beta}{4}\xi^4 + \frac{\gamma}{2}\xi^2\sigma - \chi\xi\sigma - \frac{\sigma^2}{2E_0\varrho} \qquad (7)$$

where E_0 is Young's modulus and ϱ the density of the material. Moreover, it follows from the thermodynamics of non-equilibrium processes that the establishment of equilibrium is determined by the kinetic condition [17, 18]

$$\frac{d\xi}{dt} = -K\frac{\partial F}{\partial \xi} \tag{8}$$

In the absence of an external field, that is for $\sigma = 0$, Equations 7 and 8 lead to the specific spontaneous order described by

$$\begin{aligned} \xi_0^2 &= -\alpha/\beta \qquad \text{for } T \leqslant T_c \\ \xi_0^2 &= 0 \qquad \text{for } T > T_c \end{aligned} \tag{9}$$

In the presence of an alternative mechanical stress σ of frequency ω there appears an alternative component of the order parameter ξ_p ($\ll \xi_0$) caused by the change in the exchange interaction. If $\xi_p \sim \exp(i\omega t)$ then from Equations 7 and 8 it is easy to show that

$$-\varrho\frac{\partial^2 F}{\partial \sigma^2} = \frac{1}{E} = \frac{1}{E_0} - \frac{\varrho K(\gamma\xi_0 - \chi)^2}{2\alpha K + i\omega} \qquad \text{for } T < T_c \tag{10}$$

and

$$-\varrho\frac{\partial^2 F}{\partial \sigma^2} = \frac{1}{E_0} + \frac{\varrho\chi^2}{\alpha K - i\omega} \qquad \text{for } T > T_c \tag{11}$$

On separating real and imaginary parts, expressions for the dynamic elastic modulus E and the logarithmic decrement δ which characterizes the internal friction are obtained. For $T < T_c$ this separation leads to

$$E = E_0\left(1 - \frac{\Delta_E}{1 + \omega^2\tau^2}\right) \tag{12}$$

and

$$\delta = 2\pi\Delta_E\frac{\omega\tau}{1 + \omega^2\tau^2} \tag{13}$$

where

$$\Delta_E = -E_0\varrho(\gamma\xi_0 - \chi)^2/2\alpha = KE_0\varrho(\gamma\xi_0 - \chi)^2 \tag{14}$$

and

$$\tau = -1/2\alpha K = -1/2aK(T - T_c) \tag{15}$$

At low temperatures

$$\Delta_E \simeq E_0\varrho\gamma^2/2\beta = \text{constant} \tag{16}$$

and Equation 12 leads to a classical standard linear solid model where E decreases on increasing the temperature. At high temperatures, that is, when $T \to T_c$

$$\Delta_E \simeq -E_0\varrho\chi^2/2\alpha \tag{17}$$

and Equation 12 leads to

$$E = E_0\left[1 + \left(\frac{E_0\varrho\chi^2 K}{\omega}\right)\left(\frac{\omega\tau}{1 + \omega^2\tau^2}\right)\right] \tag{18}$$

which is similar to the expression for the internal friction produced by a standard linear solid [1]. The relaxation of the modulus together with the two limiting expressions for low and high temperatures are shown, qualitatively, in Fig. 1, as a function of $\omega\tau$. The actual shape of the curves depend on the ratio between the three terms in the expression for Δ_E.

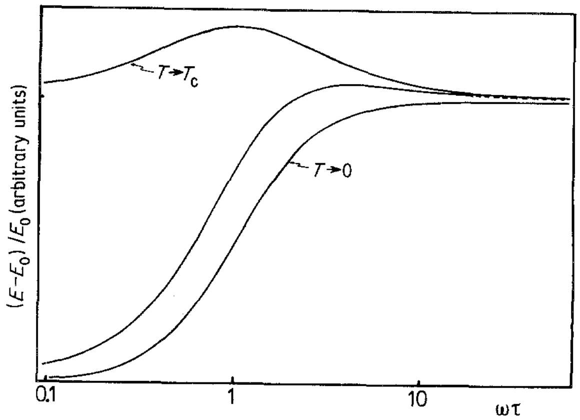

Figure 1 Theoretical relaxation curves for Young's modulus produced by a phase transition.

Finally, the order parameter ξ_0 is zero for $T = T_c$ but $\xi = \xi_0 + \xi_p \neq 0$ for $T < T_c$. The second-order phase transformation is absent under an external elastic field but the order parameter tends to zero as the external field also goes to zero [11].

3. Results

The longitudinal resonant frequencies were measured by using the "free–free" or floating beam resonant method. The experimental details, the equipment used and the way the different magnitudes are measured, are given elsewhere [19–22]. Briefly, Young's modulus is obtained from the classical equation

$$f_n = \frac{n}{2L}\left(\frac{E}{\varrho}\right)^{1/2}\left(1 - \frac{n^2\pi^2 r^2 \nu^2}{4L^2}\right) \tag{19}$$

where f_n is the resonant frequency of order n (1, 3, 5, 7, . . . for the configuration used), L is the length and r the radius of the cylindrical specimen and ν is Poisson's ratio. It should be pointed out that good values are obtained for Young's modulus, as calculated from the measured frequencies, by using only the approximate equation

$$E = \varrho(2L/n)^2 f_n^2 \tag{20}$$

which neglects the correction term within parentheses in Equation 19. Poisson's ratio can be obtained also from Equation 19 by measuring the resonant frequencies at two different harmonics, n and n^*, and solving for ν, that is

$$\nu = \left(\frac{n^* f_n - n f_{n^*}}{n^{*3} f_n - n^3 f_{n^*}}\right)^{1/2}\frac{2L}{r} \tag{21}$$

on assuming that E is independent of frequency. The detailed iterative procedure used to obtain E and ν, by the method just described, is given elsewhere [22]. Finally, specimens of AISI-1080 steel approximately 150 mm long and 7.03 mm in diameter were tested. The densities of all the specimens, determined with a pycnometer at 299 K, were $7.8116 \pm 0.0005\,\mathrm{g\,cm^{-3}}$. The temperature was controlled, between room temperature and 600 K, with a proportional controller which gave an accuracy of ±2 K.

Fig. 2 shows Young's modulus as a function of temperature for six different harmonics. A drastic change in E with temperature can be observed for the

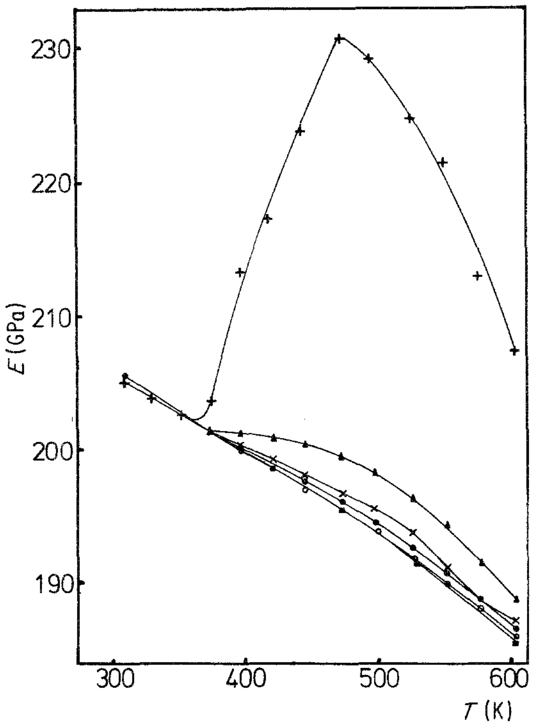

Figure 2 Young's modulus as a function of temperature, at different harmonics, for AISI-1080 steel. *n* indicates the order of the harmonic used, in longitudinal excitation: n = (+) 1, (▲) 3, (×) 5, (●) 7, (○) 9, (■) 11.

fundamental frequency, which disappears gradually for the other harmonics. The fundamental resonant frequency is of the order of 17 kHz and the intersection point of the slopes traced on both sides of the peak leads to 420 K. If it is assumed that the relaxation behaviour is associated with jumps of carbon atoms and the relaxation time is given by an Arrhenius-type expression, that is

$$\tau = \tau_0 \exp(\Delta H/kT) \qquad (22)$$

with $\tau_0^{-1} = 1.8 \times 10^{-14}\,\mathrm{sec}^{-1}$ and $\Delta H = 80.56\,\mathrm{kJ\,mol}^{-1}$ (activation energy) [1], the maximum of the Snoek peak, obtained from the condition $2\pi f\tau = 1$, would be located at 440 K. This temperature is very close to the one obtained from the middle point of the raising part of the peak for Young's modulus, for the fundamental frequency, shown in Fig. 2. The relaxation behaviour of Young's modulus, however, does not follow the general trend expected for a Snoek peak, where E should decrease with temperature. Furthermore, the relaxation decreases as the frequency increases, being negligible for the highest harmonics. Therefore, the magnitude of the relaxation depends not only on temperature but also the frequency of the external field plays an important role.

Fig. 3 shows Poisson's ratio as a function of temperature, obtained by combining a different pair of harmonics. The combinations shown have been selected due to the fact, as illustrated by Fig. 2, that Young's modulus does not show strong variations for these frequencies. Furthermore, the maxima of the curves of Fig. 3 shift to higher temperatures when the average frequency of the two overtones used increases. Finally, it is interesting to point out how the small variations in Young's modulus, shown in Fig. 2, are magnified in Poisson's ratio.

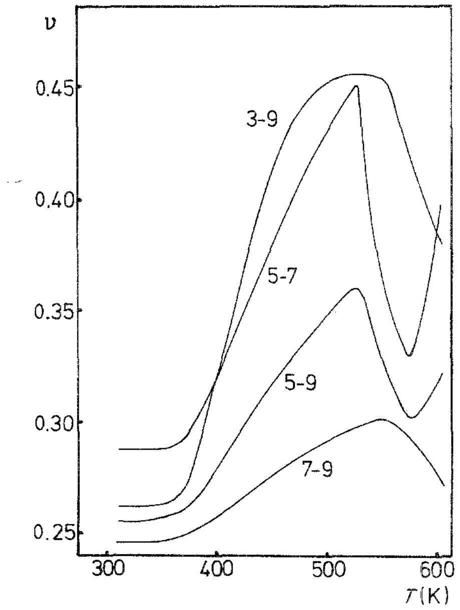

Figure 3 Poisson's ratio as a function of temperature, at different combination of harmonics, for AISI-1080 steel. The numbers on each curve indicate the pair of harmonics used to obtain ν.

4. Discussion

It is proposed that the observed relaxation behaviour for Young's modulus is produced by the martensitic phase transition occurring in the specimen. In fact, according to Equation 15 the relaxation time for a phase transition varies as $(T - T_c)^{-1}$. A plot of E against $\log \omega\tau$ is then equivalent, at constant frequency, to a plot of E against $\log [C/(T - T_c)]$ where C is a constant. Such a plot, for the curve corresponding to the fundamental frequency of Fig. 2, is shown in Fig. 4. C has been chosen, arbitrarily, to locate the curve of Fig. 4 in the same range of the abscissa as Fig. 1. Furthermore, a critical temperature of 488 K, to be discussed later on, has been used. It should be noticed that only data for T lower than 488 K have been taken from Fig. 2 to represent the curve shown in Fig. 4. A comparison between Figs 1 and 4 shows that the relaxation of Young's modulus follows the general trend expected for a phase transition. No additional information can be obtained since there are too many unknown parameters in the theory, and only a qualitative comparison is possible between the experimental curve and the predictions of the theoretical model.

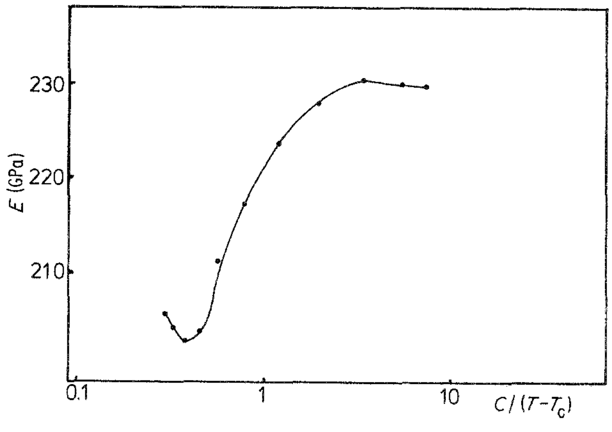

Figure 4 Plot of the curve for $n = 1$ of Fig. 2 as a function of $\log [C/(T - T_c)]$, with $T_c = 488\,\mathrm{K}$.

Furthermore, it is difficult to subtract the background which influences E at low values of $[C/(T - T_c)]$. The temperature chosen for T_c agrees approximately with the martensitic starting temperature, M_s, at which the martensitic transformation begins when the AISI-1080 steel is quenched [23]. In fact, the M_s temperature of many steels has been determined by direct measurements and it can be obtained approximately by using empirical formulae such as the one proposed by Grange and Stewart [24], that is

$$M_s(°\mathrm{C}) = 538 - 361(\%\,\mathrm{C}) - 39(\%\,\mathrm{Mn}) - 19(\%\,\mathrm{Ni}) - 39(\%\,\mathrm{Cr}) - 28(\%\,\mathrm{Mo}) \quad (23)$$

Equation 23 applies when all carbides are dissolved in the austenite, the carbon content is within the range of 0.20 to 0.85%, the molybdenum content is below 1% and the chromium content is lower than 1.5%. A complete austenization or solution of carbides, prior to quenching, is important since undissolved carbides will result in a higher M_s temperature than what would be indicated by the actual chemical composition. For a composition of 0.82% C and 0.7% Mn, appropriate to the steel used, Equation 23 leads to

$$M_s = 488\,\mathrm{K} \quad (24)$$

which is the temperature used for T_c.

Of equal importance is the information on the M_f temperature, that is on the temperature at which the reaction stops even though retained austenite may still exist. The values for M_f, however, are not generally available due to the difficulty in measuring small amounts of retained austenite (of the order of 5% or less). Grange and Stewart [24] have studied the influence of carbon content on the proportion of martensite formed at temperatures below M_s. For a 0.82% C steel the M_f temperature is approximately 361 K. As shown by Fig. 2, in fact, E starts to increase above by about 361 K and decreases rapidly above the M_s temperature, for the fundamental resonant frequency. This relaxation of the modulus might be produced by a stress-induced disordering of carbon atoms in the octahedral sites of the martensitic matrix. In fact, micrographs of the specimens show a perlitic structure with a high mechanical deformation and a martensitic structure partially annealed. Microhardness tests give values of the order of 473 to 476 HV_{300}, which are consistent with a partial tetragonality of the alpha-iron.

As indicated by Fig. 2, the disordering is not produced at unfavourable frequencies. In fact, the other harmonics were measured immediately after the fundamental and a disordered structure was found only for the first but not for the higher harmonics. Furthermore, no disordered structure was encountered immediately after the interruption of the cyclic external field, even if the temperature was maintained below the decomposition and precipitation temperatures. In addition, another classical behaviour of martensitic transformations was observed [25], as shown by Fig. 5, where the numbers indicate the harmonic used to obtain each curve. After the first rise in temperature, the specimen was maintained at 333 K for 12 and 44 h before the second and third rise, respectively. It is seen that the beginning of the transformation stabilizes with time and higher temperatures are needed to continue it. Furthermore, no changes are observed for the higher overtones. The increase of the M_f temperature is probably due to the diffusion of carbon atoms which decreases the solute concentration and consequently the interaction between defects.

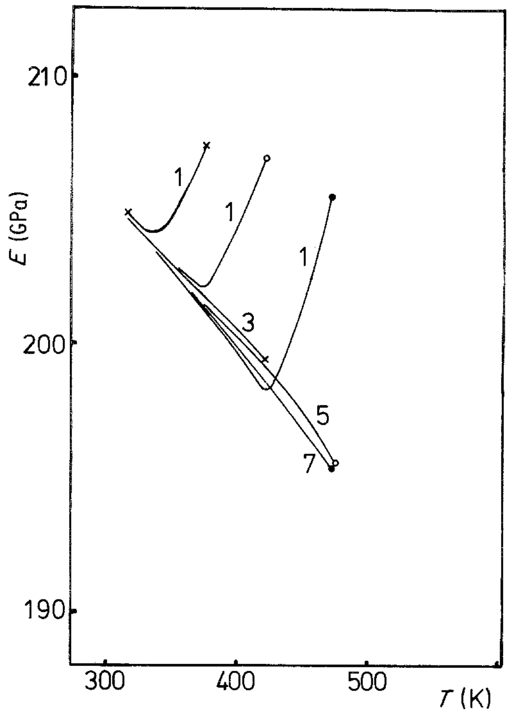

Figure 5 Stabilization of Young's modulus by annealing. (×) 1st rise, (○) 2nd rise, (●) 3rd rise. The second rise in temperature was made after maintaining the specimen for 12 h and the third for 44 h, at 333 K.

The relaxation of Poisson's ratio, shown in Fig. 3, can also be explained by a stress-induced reordering of carbon atoms. In fact, according to a theory of anelastic relaxation under multiaxial strains which has been developed elsewhere [12], the inflection point on Poisson's ratio occurs at $\omega\tau = 1/3^{1/2}$, for an extension along $\langle 1\,0\,0\rangle$ and a contraction along $\langle 0\,1\,0\rangle$ or $\langle 0\,0\,1\rangle$. For the classical texture obtained in a rod of a material with cubic symmetry, like the specimens used in this paper, the tensile stress is applied mainly along $\langle 1\,1\,0\rangle$ and the contraction occurs in a $[1\,1\,0]$ plane. For a tetragonal defect and after an integration over all the directions in this plane, taking into account the orientation dependence of ν [12], the following expression is obtained for Poisson's ratio:

$$\nu = \left[S^{\mathrm{I}}S^{\mathrm{II}} + (S^{\mathrm{I}} - \delta_{\mathrm{P}})\left(S^{\mathrm{I}} + \frac{1 - 3\pi}{4}\,\delta_{\mathrm{P}}\right)\omega^2\tau_{\mathrm{P}}^2\right] \Big/ \left[(S^{\mathrm{II}})^2 + (S^{\mathrm{II}} - \delta_{\mathrm{P}})^2\omega^2\tau_{\mathrm{P}}^2\right] \quad (25)$$

where

$$S^{\mathrm{I}} = \frac{3\pi}{4}\,s_{11} + 3\left(1 - \frac{\pi}{4}\right)s_{12} - \frac{3}{2}\left(1 - \frac{3\pi}{4}\right)s_{44} \quad (26)$$

and

$$S^{\mathrm{II}} = 3s_{11} + 5s_{12} + \tfrac{3}{2}s_{44} \quad (27)$$

s_{ij} are the compliances of the cubic crystal, and δ_P represents the intensity and τ_P the time for the relaxation of $(s_{11} - s_{12})$. The curve of ν against $\omega\tau_P$ described by Equation 25, has an inflection point, determined by $d^2\nu/d(\omega\tau_P) = 0$, at

$$\omega\tau_P = S^{II}/3^{1/2}(S^{II} - \delta_P) \simeq 1/3^{1/2} \qquad (28)$$

which is the same as for the simpler situation of an extension and a contraction along the principal axes.

On assuming that the standard linear solid is a valid model so that Equation 12 is applicable, and admitting that the transversal relaxation obeys Equation 25, and in addition that the relaxation times obey an Arrhenius relationship (Equation 22) far from the critical temperature, then for Young's modulus there is an inflection point at

$$\omega_E\tau_E = 1 = \omega_E\tau_0 \exp(\Delta H/kT_E) \qquad (29)$$

and for Poisson's ratio at

$$\omega_P\tau_P = \omega_P\tau_0 \exp(\Delta H/kT_P) = 1/3^{1/2} \qquad (30)$$

where the subindices E and P indicate the applied frequencies and the relaxation times for Young's modulus and Poisson's ratio, respectively. It has been assumed also that both relaxations are controlled by the same mechanism, that is τ_0 and ΔH are the same for both moduli. T_E and T_P are the temperatures at which the inflection points occur. On combining Equations 29 and 30 it is possible to calculate T_P in terms of the measured values for ω_E, ω_P and T_E, and $\Delta H = 80.56\,\mathrm{kJ\,mol^{-1}}$ as for Equation 22. This calculated value can then be compared with the value obtained experimentally. There are some problems, however, in obtaining the quantities to be used for the calculations. In fact, two frequencies are involved in ω_P and the inflection points in both Figs 2 and 3 are difficult to determine. On taking the values at which the maxima occur in both figures for T_E and T_P and the arithmetic average between the two harmonics involved for ω_P, Equations 29 and 30 lead to the values for T_P given by the third column of Table I. The experimental values are indicated in the fourth column. It is seen that the agreement between experimental and calculated values is reasonable, taking into account the approximations made, showing that the same mechanism controls the relaxation of both moduli. A maximum deviation occurs between the experimental and calculated values for T_P, for a combination between the third and the ninth harmonics, which should be expected since their frequencies are too far apart. The most reliable results are those corresponding to adjoining frequencies, where the assumptions made in constructing Fig. 3 are more valid.

TABLE I Theoretical and experimental values for the maxima of Poisson's ratio, shown in Fig. 3. n and n^* indicate the harmonics used to calculate ν with Equation 21

n	n^*	T_P (K) (theoretical)	T_P (K) (experimental)
3	9	534	513 to 553
5	7	534	528
5	9	539	528
7	9	543	550

5. Conclusions

The relaxation behaviour of Young's modulus and Poisson's ratio as a function of temperature, observed in AISI-1080 steel in the temperature region between about 300 and 600 K, is controlled by a stress-assisted reorientation of carbon atoms. The temperature dependence of Poisson's ratio is well described by a theory of anelastic behaviour under multiaxial strains, based on the standard anelastic solid model. The increases of Young's modulus with temperature, observed for data obtained at the fundamental resonant frequency, is produced by a stress-induced disordering of carbon atoms in the octahedral sites of the martensitic matrix. In fact this effect is well described, qualitatively, in terms of expressions deduced in this paper, which are based on Landau theory of second-order phase transitions. The critical temperature has been related to the M_s and M_f temperatures which characterize the martensitic phase transition occurring in the material. Finally, the phase transformation is reversible in temperature as long as the external field is applied and disappears when the external vibratory field is removed. The order–disorder evolution seems to be controlled also by jumps of carbon atoms, according to the Snoek model.

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