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SOME DYNAMIC MECHANICAL PROPERTIES
OF ARMCO 21-6-9 STAINLESS STEEL

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Some Dynamic Properties of Armco 21-6-9 Stainless Steel

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ABSTRACT

This paper describes a study in which the response of Armco 21-6-9 stainless steel, under conditions of uniaxial strain shock loading to 90 kilobars, is determined. The response was found to be characterized adequately by an elastic-plastic model. The compressive loading stress-strain path, the unloading path from a stress state, and the dynamic fracture strength of the material are considered.

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LIST OF SYMBOLS

A	Constant
B	Constant
C_l	Longitudinal Sound Speed
C_o	Bulk Sound Speed
C_s	Shear Sound Speed
f	Fringe Frequency
HEL	Hugoniot Elastic Limit
K	Bulk Modulus
N	Number of Fringes
P_h	Hydrostatic Pressure
s	Equation of State Constant
t	Time
U	Velocity
U_e	Elastic Wave Velocity
U_{fs}	Free Surface Velocity
U_p	Particle Velocity
U_s	Shock Velocity
V	Volume
Y	Yield in Uniaxial Stress
α	Strain Component in Uniaxial Stress
ϵ	Strain Component in Uniaxial Strain
ϵ_c^p	Plastic Compressive Strain
ϵ_t^p	Plastic Tensile Strain
λ	Wave Length
μ	Shear Modulus
ν	Poisson's Ratio
ρ	Mass Density
σ	Stress Component in Uniaxial Strain
σ_f	Dynamic Fracture (Spallation) Strength
τ	Time Required for Laser Light to Travel Around a Delay Leg

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INTRODUCTION

This report describes the results of plate impact experiments which produced stresses up to 90 kilobars (kbars) in Armco 21-6-9 stainless steel. The Armco 21-6-9, whose composition is listed in Table I, is an austenitic stainless steel of face-centered-cubic (fcc) crystalline structure. Data at stresses higher than 100 kbars have been reported for Types 304 and 304L stainless steels.⁽¹⁾ However, this present study was designed to investigate the response of the Armco stainless steel at lower stresses where the combined elastic-plastic effects are more prominent. The average compressive stress-strain path and the unloading path from a stress-state are determined. Measurements were made of the dynamic fracture strength, i.e., spall strength, of the material. The results of ultrasonic wave velocities and uniaxial stress compressive tests are also presented.

BACKGROUND

In a review article, Karnes⁽²⁾ discussed the plate impact configuration for determining the mechanical properties of materials at high strain rates. Plate dimensions are chosen such that all measurements are made while the target plate is in a uniaxial strain state. The total lateral strain is zero, and hence the normal dynamic strain, ϵ , is equal to the volumetric strain, by

$$\epsilon = \frac{V_0 - V}{V_0} = 1 - \frac{\rho_0}{\rho} \quad (1)$$

where V and ρ represent specific volume and density, respectively, and the zero subscripts represent initial values.

The stress state is three-dimensional, with the lateral stresses

being equal for the case of transverse isotropy. In order to better describe the stress state, the stress-strain (Y, α) behavior from a conventional static uniaxial stress compressive test has been considered. Wood⁽³⁾ showed that if Y is a function of the plastic compressive strain, ϵ_c^P , then for the uniaxial strain state, the stress, σ , in the direction of propagation is of the form

$$\sigma = K \epsilon + 2/3 Y(\epsilon_c^P) \quad (2)$$

where K is the adiabatic bulk modulus, $K \epsilon$ is the spherical or hydrostatic component of the stress, and $2/3 Y(\epsilon_c^P)$ is the deviatoric component.

For isotropic materials in which the stress-strain path is independent of the rate of loading, the stress, Y_o at which yielding first occurs in the uniaxial stress compressive test is related to the Hugoniot elastic limit, HEL, in the uniaxial strain state by

$$HEL = \left(\frac{1 - \nu}{1 - 2\nu} \right) Y_o \quad (3)$$

where ν is Poisson's ratio.

If equivalent conditions between the uniaxial stress and uniaxial strain states are given by equal plastic work, and if K is independent of mean pressure, Fowles⁽⁴⁾ has shown that the total dynamic strain, ϵ , is related to the quasi-static strain, α , by

$$\epsilon = 3/2 \alpha - \frac{Y(\epsilon_c^P)}{6K} \quad (4)$$

Thus one can find the corresponding values of σ and ϵ from given values of Y and α simply by the use of Equations (2) and (4).

There is experimental evidence that static data transformed by Equations (2) and (3) will accurately predict the dynamic response of

some real materials. Precipitation hardened 6061-T 6 aluminum, which has an fcc crystalline structure, demonstrates good agreement.⁽⁵⁾ In 4340 steel, which has a bcc crystalline structure, the degree of agreement depends on the material hardness.⁽⁶⁾ However, experience gained from these limited observations do not indicate that there will be a correlation for the Armco stainless steel between its crystalline structure and/or material hardness and the applicability of static compression data to calculations of its dynamic response.

In the plate impact experiment, the strain is not measured directly. However, if the free surface velocity-time history can be precisely measured, a complete analysis of the wave propagation problem results in the average stress-strain path which produced the wave shape for the particular thickness of material used. Consider the case where the plates are of the same material but of different thicknesses. Let the two flat plates have free rear surfaces and the velocity of impact be great enough such that the tension in the thicker target plate results in spall. The tension is produced by the interaction of the rarefaction waves originating at the two free surfaces. In such an experiment, target free surface motion will be affected by the following.

1. The arrival of the elastic compressive portion of the stress wave.
2. The interactions associated with the compressive plastic wave and the reflected elastic rarefaction wave, i.e., the free surface motion is affected simultaneously by both the loading and unloading characteristics of the material.

3. Interactions associated with the arrival of the rarefaction wave from the free back surface of the thin impact plate.
4. The free surface wave interactions which result from the release of tension as a spall surface is created.

EXPERIMENTAL TECHNIQUES

The dynamic response of the Armco stainless steel was measured under uniaxial-strain shock loading conditions. Peak stresses of 20 to 90 kilobars were produced using a gas gun to impact flat projectile plates against flat stainless steel targets. Table II lists some of the details of the eleven experiments conducted using the gas gun.

A general description of the gas gun and the methods used to measure the projectile velocity at impact, the time of impact at the center of the target, and the angle between the projectile and target faces at impact are given in Reference 7. In experiments SS-2 through SS-9, the projectile nose and the target were both Armco stainless steel. The target-to-projectile nose thickness ratio was equal to 2, and both had free rear surfaces. Spall (dynamic tensile fracture) will occur in this type of experiment provided the impact velocity is sufficiently high. Velocity interferometer (VI) instrumentation, developed by Barker⁽⁸⁾, was used to determine the velocity of the target free surface by providing a fringe count proportional to the Doppler Shift of a laser light beam reflected from the surface. The free surface velocity, $U(t)$, at time t is given by

$$U(t) = \frac{\lambda}{2\tau} N(t) \quad (5)$$

where λ is the laser wave length, τ is the time required for the light

to travel around a delay leg, and $N(t)$ is the number of fringes produced up to time t . The oscillograph record from VI instrumentation for experiment SS-3 and the corresponding target free surface velocity history are shown in Figure 1.

In experiment SS-10, the particle velocity history of the interface between a stainless steel target and a backing transparent sapphire window material was measured. The sapphire window, which is elastic up to stresses of approximately 100 kbars, has a shock impedance of $446 \text{ kbar-}\mu\text{sec-mm}^{-1}$.⁽⁹⁾ This is close to the elastic shock impedance of the stainless steel, and thus almost the entire incident stress wave is transmitted into the window material. This is in contrast to the free surface experiments in which the stress wave was totally reflected as an unloading wave upon reaching the target free surface. Thus, in the window experiment, the compressive and release characteristics are isolated much better than in the free surface experiments since a more direct measurement of the particle velocity, uncomplicated by significant reflections at the interface, is made. Since a correction is required to account for the change in index of refraction with stress in the window material, the velocity of the interface is

$$U(t) = \frac{\lambda}{2\tau(1 + \Delta f/f_0)} N(t) \quad (6)$$

where $\Delta f/f_0$ is the fractional change in fringe frequency resulting from the change in index of refraction, and has a value of approximately 0.78 for sapphire.⁽⁹⁾ The oscillograph record and corresponding interface particle velocity-time profile for experiment SS-10 are shown in Figure 2.

It is evident from the velocity profiles in Figures 1b and 2b that the stainless steel supports a structured wave consisting of an initial

elastic precursor followed by a plastic wave. The Hugoniot elastic limit (HEL) is the amplitude of the elastic precursor. In order to obtain a very accurate measurement of the HEL, an additional experiment, SS-13, using quartz gage instrumentation⁽¹⁰⁾, was performed. A 4340 Rc 54 steel projectile nose was impacted against a stainless steel target. The stress pulse generated by the impact propagated through the stainless steel target and interacted with an x-cut quartz crystal mounted on the rear surface of the target. The output current of the quartz gage was measured across a termination resistor and recorded. Using the data reduction method described in Reference 11, a HEL of approximately 8.3 kbars was calculated.

DISCUSSION OF EXPERIMENTAL RESULTS

In this section, the Armco 21-6-9 stainless steel data and previously reported data on Type 304 stainless steel⁽¹⁾ are used to develop and verify: (1) the compressive stress-strain path, (2) the subsequent unloading from a stress state, and (3) the spallation strength of the Armco stainless steel.

As discussed previously, once the velocity-time history is measured precisely, complete solutions of the wave propagation problem, assuming a specific form of the elastic-plastic constitutive relations, can be used to find the average stress-strain path which produced that wave shape. The calculation of the complete stress-strain paths of the Armco stainless steel follows the method of Barker, Lundergan, and Herrmann.⁽¹²⁾ It is assumed that a continuous stress profile can be approximated by a series of small stress steps, and that the Hugoniot jump equations apply for each stress step. Each stress jump is assumed to propagate at a constant velocity appropriate for that stress level,

i.e., the material is assumed not to be strain rate dependent. The stress-strain path in loading is then estimated using these assumptions and neglecting wave interactions near free surfaces. The estimated stress-strain path is used to solve the wave propagation problem numerically. Because of the approximations used in arriving at the estimated stress-strain path, adjustments may be necessary to determine the most satisfactory stress-strain relation. The stress-strain path is varied until the computed and measured free surface velocity histories reach the desired agreement.

Compressive Stress-Strain Path

Elastic Deformation -- It is evident from linear elasticity theory⁽¹³⁾ that the elastic compressive stress-strain path is given by

$$\sigma = (K + 4/3 \mu) \epsilon \quad (7)$$

where K and μ are the adiabatic bulk and shear moduli, respectively.

The initial slope of the elastic stress-strain path, $K + 4/3 \mu$, is related to the velocity of the elastic precursor, U_E , by

$$(K + 4/3 \mu) = \rho_o U_E^2 \quad (8)$$

The initial density $\rho_o = 7.83$ g/cc and the measured elastic wave velocity $U_E = 5.80$ mm/ μ sec (average of several experimental values) resulted in an initial elastic slope of 2630 kbars.

Plastic Deformation -- The plastic contribution to the compressive stress-strain path is defined by Equation (2). In order to evaluate the spherical component of the stress, $K \epsilon$, for the Armco stainless steel, several assumptions were necessary. It was assumed that $K \epsilon$ could be

represented by a shock hydrostat⁽¹⁴⁾ of the form reported for Type 304 stainless steel.⁽¹⁾ The data for the Type 304 material were measured at high pressures and are suitably represented, as are many other materials^(16, 17), by a linear shock velocity, U_s , particle velocity, U_p , relation at these high stresses so that the shock hydrostat is the Hugoniot and take the form⁽¹⁵⁾

$$P_h = K \epsilon = \frac{\rho_o C_o^2 \epsilon}{(1 - s \epsilon)^2} \quad (9)$$

where C_o is the zero stress intercept and s is the slope of the U_s , U_p curve. In defining the shock hydrostat of the Armco stainless steel, the value of s was taken from the Type 304 data and C_o was calculated from ultrasonic measurements on the Armco stainless steel using

$$C_o = \left[C_l^2 - 4/3 C_s^2 \right]^{1/2} \quad (10)$$

where C_l and C_s are the ultrasonic longitudinal and shear wave velocities, respectively (Table III). Since the dynamically determined C_o is 1.1 percent greater than the ultrasonically determined C_o for the Type 304 (see Table III), the ultrasonically determined C_o of the Armco stainless steel was increased by the same percentage. Thus the values of $C_o = 4.5$ mm/ μ sec and $s = 1.5$ were used in Equation (9) to define the spherical component of the stress, $K \epsilon$, for the Armco stainless steel.

The validity of this approach is based on the fact that Type 304 is an austenitic stainless whose composition differs very little from that of the Armco 21-6-9 stainless steel (Table I).

For a rate-independent material, the data from conventional uniaxial stress compression tests might be used to evaluate the second term on the

right-hand side of Equation (2), which is the deviatoric component of stress, $2/3 Y(\epsilon_c^P)$. This is not the case for the Armco stainless steel. The stress, Y_0 , at which yielding began in the uniaxial stress tests (at 0.2 percent strain) was about 3.85 kbars (Figure 3). With a Poisson's ratio of 0.287 (calculated from the relation between the elastic constants K , μ , and ν)⁽¹³⁾ the HEL would be 6.45 kbars, based on Equation (3). However, a HEL of 8.3 kbars was measured in experiment SS-13. Thus, the uniaxial stress compression data cannot be used to evaluate the yield as a function of plastic strain. Since the HEL is 8.3 kbars and ν is 0.287, from Equation (3) the stress at which yielding must begin is $Y_0 \simeq 5.0$ kbars in the shock wave experiments.

In view of the lack of agreement between yield points, free surface velocity histories of several of the experiments were used as a guide to obtain the yield function in compression, $Y(\epsilon_c^P)$. The approximate compressive stress-strain curves, as determined from the free surface velocity histories, were transformed to the uniaxial stress state using Equations (2) and (4). The elastic component of strain was subtracted from the data (Young's modulus was taken to be 28×10^6 psi). The resulting curves of the yield stress as a function of plastic compressive strain, ϵ_c^P , are shown in Figure 4. All the curves do not superimpose and they all bend toward the hydrostat at the peak stresses; these facts indicate that Armco stainless steel is strain-rate dependent.

Computer Fits of Elastic-Plastic Deformations -- Assuming the calculated shock hydrostat to be correct, adjustments were made in $Y(\epsilon_c^P)$ until the entire wave propagation problem solution from the SWAP-7 com-

puter code⁽¹⁸⁾ matched the experimental curves to a close approximation.[†] Initially, two simple forms of the yield or work hardening function were tried. First, $Y(\epsilon_C^P)$ was set to be a constant, i.e., the material was assumed to have an elastic-perfectly plastic response. Second, $Y(\epsilon_C^P)$ was set to increase linearly with plastic strain, i.e., the material was assumed to have an elastic-linear hardening response. Neither of these were adequate, i.e., the computed curves did not match the details of the experimental curves to the degree desired.

The form of $Y(\epsilon_C^P)$ that does give satisfactory agreement between the measured and computed free surface motions is shown as the dashed curve in Figure 4. This curve is the result of applying rate-independent data reduction assumptions to a rate-dependent material. The computer solutions of the wave propagation problems are compared with the experimental results of four experiments in Figures 5, 6, 7, and 8. The fact that the degree of agreement between calculated and experimental curves varies with experimental conditions can also be attributed to using a rate-independent yield function to describe a rate-dependent material.

Unloading Stress-Strain Path

The experimentally measured free surface motion is not only affected by the compressive stress-strain path, but also by the unloading path as the material unloads from a stress state. It was assumed for the computer calculations that the Armco stainless steel unloaded elastically to the shock hydrostat defined by Equation (9) and then under-

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[†]In the SWAP-7 calculations, the Poisson's ratio was assumed to be a constant $\nu = 0.287$ for all stress levels. The validity of using a constant ν independent of stress level is discussed in Appendix A.

went reverse yielding. The reverse yielding, i.e., tensile yield, was assumed to be a function of plastic tensile strain, ϵ_t^p , and to be of the form

$$Y(\epsilon_t^p) = A \left[1 - \exp(B \epsilon_t^p) \right] . \quad (11)$$

The form of Equation (11) incorporates the Bauschinger effect and has been shown to represent the unloading behavior of 6061-T6 aluminum.⁽⁸⁾ For the Armco stainless steel, the values $A = 7.0$ kbars and $B = -500$ were used. The reverse yielding varies from 0 to 7 kbar with increasing plastic tensile strain. The calculated curves in Figures 5, 6, 7, and 8 include the effect of this unloading path.

Complete Loading and Unloading Stress-Strain Path

The compressive loading and the subsequent unloading from a stress state have been defined separately in the previous two sections. These average stress-strain paths of the Armco 21-6-9 stainless steel are combined and are shown graphically, for two different peak stresses, in Figure 9. Figure 9 also includes the shock hydrostat used in the numerical calculations and the compressive stress-strain path calculated using uniaxial stress compression data.

Spallation

Spallation is defined as a complete or partial separation of a material resulting from the tension induced by the interaction of two rarefaction waves.^(19, 20) In this study on the Armco stainless steel, the objectives were to bracket the spall strength and to determine whether the spall is time dependent.

The magnitude of the tensile stress σ_f , causing fracture was approximated from⁽²¹⁾

$$\sigma_f = \rho_o U_e \frac{\Delta U_{fs}}{2} \quad (12)$$

where ρ_o is the initial density of the stainless steel, U_e is the elastic wave velocity, and ΔU_{fs} is the total change in free surface velocity between its maximum value and its reversal point. In this study, the velocity interferometer data indicated the creation of a spall surface; either by a reversal in the direction of the free surface velocity during the unloading portion of the profile (Figure 1) or by a complete loss of signal from the photomultiplier tubes. The signal loss occurred on the higher velocity experiments in which the surface reflectivity was destroyed by the wave from the spall plane.

Equation (12) considers the material unloading to be elastic. It was felt that this assumption, for these calculations, would be adequate for the purpose of bracketing the Armco spall strength and determining significant time dependence. Table IV lists some of the parameters of five experiments and the spall stress as calculated from Equation (12). These results indicate that the spall strength of the Armco 21-6-9 stainless steel is bracketed between 35 and 40 kbars. Since the variation in σ_f is small, the Armco stainless steel probably does not have significant time-dependent spall characteristics in the stress range investigated.

The free surface velocity history from experiment SS-3 has a well defined reversal point. Computer calculations of this experiment using the stress-strain path discussed earlier and spall strengths of 35, 37, and 40 kbars are shown in Figure 10. The range of 35 to 40 kbars for the spall strength brackets the reversal point.

CONCLUSIONS

The experimental and calculational results presented in this paper suggest the following conclusions.

1. The experimentally observed Hugoniot elastic limit and dynamic work-hardening of the Armco 21-6-9 stainless steel do not agree with its static yield and work-hardening properties.
2. Neither the elastic-perfectly plastic nor the elastic-linearly plastic stress-strain models describe the compressive loading response of the Armco stainless steel. An empirical work-hardening function, i.e., variation of the yield stress with plastic strain, was used to describe the material response.
3. Strain-rate effects in the Armco stainless steel are responsible for the fact that a single rate-independent stress-strain curve does not describe equally well the material response at different stress levels. Perhaps these rate effects are also partially responsible for the spreading out of the release wave shapes. However, this smearing can be accounted for by using a rate-independent theory which includes a Baushinger effect.
4. A single-valued (35-40 kbars) time-independent spall strength suitably describes the response of the Armco stainless steel in the stress range investigated.

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Table I

Composition of Armco 21-6-9 and Type 304 stainless steels

Armco 21-6-9

Element	C	Mn	P	S	Si	Cr	Ni	N	Fe
Percent by Weight	.05 Max	8-10	.06 Max	.03 Max	1.0 Max	18-21	5.5-7.5	.15-.40	Remainder

Type 304

Element	C	Mn	P	S	Si	Cr	Ni	Fe
Percent by Weight	.08 Max	2.0 Max	.04 Max	.03 Max	1.0 Max	18-20	8-11	Remainder

Table II - Parameters of Gas Gun Experiments

<u>Shot Designation</u>	<u>Projectile Nose</u>		<u>Target</u>		<u>Impact Velocity</u> (mm/ μ sec)	<u>Instrumentation[†]</u>
	Material	Thickness (mm)	Material	Thickness (mm)		
SS-2	Armco SS	12.647	Armco SS	25.217	.1213	VI, Free Surface
SS-3	Armco SS	6.342	Armco SS	12.647	.2464	VI, Free Surface
SS-4	Armco SS	12.779	Armco SS	25.250	.2451	VI, Free Surface
SS-5	Armco SS	12.649	Armco SS	25.248	.2458	VI, Free Surface
SS-6	Armco SS	12.827	Armco SS	25.100	.3740	VI, Free Surface
SS-7	Armco SS	12.659	Armco SS	25.255	.4466	VI, Free Surface
SS-8	Armco SS	12.649	Armco SS	25.260	.4426	VI, Free Surface
SS-9	Armco SS	3.150	Armco SS	6.299	.3469	VI, Free Surface
SS-10	Armco SS	1.562	Armco SS	6.320	.4554	VI, Window
SS-13	4340 Rc 54 (steel)	12.70	Armco SS	6.350	.1236	Quartz

[†]VI refers to velocity interferometer instrumentation.

Table III - Some Ultrasonic and Dynamic Data
for Stainless Steel

	<u>Armco 21-6-9</u>	<u>Type 304</u>
Density (g/cc)	7.83	7.896
Ultrasonic		
C_L (mm/ μ sec)	5.72	5.77
C_S (mm/ μ sec)	3.117	3.12
C_D (mm/ μ sec)	4.45	4.507
Dynamic		
U_e (mm/ μ sec)	5.8	5.81
C_D (mm/ μ sec)	---	4.557
s	---	1.5

Table IV - Spall Data

<u>Shot Designation</u>	<u>Impact Velocity</u>	<u>Thickness (mm)</u>		<u>ΔU_{fs}</u>	<u>σ_f</u>
	(mm/ μ sec)	Projectile	Target	(mm/ μ sec)	(Kilobars)
SS-3	.2464	6.342	12.647	.152	34.5
SS-4	.2541	12.779	25.250	.170	39.1
SS-9	.3469	3.150	6.299	.168	38.1
SS-7	.4466	12.659	25.255	.167	37.9
SS-8	.4426	12.649	25.260	.162	36.8

(a)

(b)

FIGURE 1. (a) OSCILLOGRAPH DATA FROM EXPERIMENT SS-3, AND
(b) THE CORRESPONDING FREE SURFACE VELOCITY HISTORY

(a)

(b)

FIGURE 2. (a) OSCILLOGRAPH DATA FROM EXPERIMENT SS-10, AND
(b) THE CORRESPONDING INTERFACE VELOCITY HISTORY

FIGURE 3. STATIC COMPRESSIVE STRESS-STRAIN CURVE FOR ARMCO 21-6-9 STAINLESS STEEL

FIGURE 4. ESTIMATED STRESS-STRAIN PATHS DETERMINED FROM FREE SURFACE MEASUREMENTS AND THE CURVE USED IN THE COMPUTER CALCULATIONS

FIGURE 5. MEASURED VELOCITY HISTORY AND COMPARISON WITH COMPUTER PREDICTIONS FOR EXPERIMENT SS-2

FIGURE 6. MEASURED VELOCITY HISTORY AND COMPARISON WITH COMPUTER PREDICTIONS FOR EXPERIMENT SS-4

FIGURE 7. MEASURED VELOCITY HISTORY AND COMPARISON WITH COMPUTER PREDICTIONS FOR EXPERIMENT SS-8

FIGURE 8. MEASURED VELOCITY HISTORY AND COMPARISON WITH COMPUTER PREDICTIONS FOR EXPERIMENT SS-10

FIGURE 9. AVERAGE STRESS-STRAIN PATHS AT TWO PEAK STRESSES FOR ARMCO 21-6-9 STAINLESS STEEL

FIGURE 10. MEASURED VELOCITY HISTORY AND COMPARISON WITH COMPUTER PREDICTIONS FOR EXPERIMENT SS-3 TO VERIFY THAT THE SPALL STRENGTH σ_F IS BRACKETED BETWEEN 35 AND 40 kbars

APPENDIX A

In the computer calculations, Poisson's ratio, ν , was assumed to be a constant and independent of stress level. The validity of this assumption was examined by considering the pressure variation of the elastic constants. Rotter and Smith⁽²²⁾ investigated, using hydrostatic pressures up to 3.0 kbars and ultrasonic techniques, the pressure variation of the elastic constants of single crystal iron. The elastic constants of the iron increased linearly with hydrostatic pressure, P_h , and two of the results were

$$K = K_o + 5.99 P_h \quad (A-1)$$

$$\mu = \mu_o + 2.66 P_h \quad (A-2)$$

where K and μ are the bulk and shear moduli, respectively, and the zero subscript indicates initial conditions.

The applicability of these results to describe the dynamic response of the Armco stainless steel are shown in Table A-I. The last two columns in Table A-I list K as calculated from the dynamic shock hydrostat and Eq. A-1, respectively.

Table A-I

ϵ	$P_h = \frac{\rho_o C_o^2 \epsilon}{(1-\nu\epsilon)^2}$ (kbars)	$K = \frac{dP_h}{d\epsilon}$ (kbars)	$K = K_o + 5.99 P_h$ (kbars)
0.00	0.0	1586	1586
0.01	15.8	1684	1681
0.02	33.5	1789	1787
0.03	52.5	1902	1900
0.04	71.5	2023	2014

The values of K calculated by the two different methods agree very well. Based on this agreement it is assumed that Eq. A-2 is also valid for the Armco stainless steel at high stress.

The relation between the elastic constants K, μ , and ν is given in Eq. (A-3)⁽¹³⁾.

$$\mu = \frac{3K(1-2\nu)}{2(1+\nu)} \quad (A-3)$$

Thus, the initial condition shear modulus, μ_0 , has a value of 787 kbars since $K_0 = 1586$ kbars and $\nu_0 = .287$. Rearranging Eq. (A-3) yields

$$\nu = \frac{3K - 2\mu}{6K + 2\mu} \quad (A-4)$$

Eq.(A-4) is valid throughout the pressure range of interest provided the pressure variations of K and μ are included. Since the pressure variations of K and μ given by Eqs. (A-1) and (A-2) are assumed to be valid for the Armco stainless steel, solution of Eq. (A-4) gives ν as a function of pressure (Table A-II).

Table A-II

P_h (kbars)	$K = 1586 + 5.99 P_h$ (kbars)	$\mu = 787 + 2.66 P_h$ (kbars)	ν
0.0	1586	787	0.287
15.8	1681	829	0.288
33.5	1787	876	0.289
52.5	1902	927	0.290
71.5	2014	977	0.291

The value of Poisson's ratio, ν , changes by approximately one percent as the hydrostatic pressure increases from 0.0 to 71.5 kbars. Based on

these calculations, v was set to be a constant and independent of pressure in the computer calculations.

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