

SHOCK-WAVE COMPRESSION OF Ni-Fe ALLOYS

TABLE I. Summary of shock-wave compression measurements on 30% and 36% Ni-Fe alloys.

n ^a (mm/μsec)	Specimen thickness (mm)	Impact Surface				Propagated Profile			
		n ^b (mm/μsec)	σ ^c (kbar)	U ^d (mm/μsec)	σ ^e (kbar)	(V/V ₀) ^f	σ ^g (kbar)	(V/V ₀) ^h	n ⁱ (mm/μsec)
30% Ni-70% Fe fcc									
0.2709	12.81	0.1355	38.5	5.05	4.6	0.9978	45.4	0.9688	0.1313
0.3737	9.538	...	34.4	5.14	4.1	0.9980	40.2	0.9719	0.1167
0.3247	9.538	...	30.0	4.99	3.9	0.9981	29.0	0.9784	0.0872
0.2921	9.525	...	30.0	4.97	2.9	0.9986	25.0	0.9806	0.0749
0.2483	9.525	...	25.8	4.98	3.9	0.9982	23.5	0.9823	0.0702
0.2324	9.525	0.0617	24.0	5.02-5.00	4.7	0.9977	20.7 ^k	0.9847	...
0.1234	12.81	0.0451	...	...	4.4	0.9980	15.9	0.9884	0.0465
0.0902	12.81	0.0396 ^l	14.91	...	...	...	...	0.9914 ^l	...
0.1380	...	...	...	...	...	...	...	...	...
Mean density 8.158 g/cm ³ ; C ₀ =5.01 mm/μsec ^m ; σ _e =4.37 kbar; U _∞ =5.027 mm/μsec									
30% Ni-70% Fe bcc									
0.2735	12.79	0.1368	5.14	...	...	...	49.8	0.9708	0.1347
0.1126	12.79	0.0563	...	...	...	...	21.8	0.9876	0.0578
0.0922	12.79	0.0461	...	...	...	...	17.9	0.9900	0.0471
Mean density 8.032 g/cm ³ ; C ₀ =5.23 mm/μsec; U _∞ =5.13 mm/μsec									
36% Ni-64% Fe fcc									
0.2853	12.72	0.1427	4.91	4.3	0.9977	44.2	0.9646	0.1452	0.0530
0.1878	12.74	0.0939	4.84	5.3	0.9972	30.8	0.9752	0.0968	0.0530
0.1090	12.74	0.0545	...	5.3	0.9972	18.2	0.9865	0.0530	0.0530
Mean density 8.077 g/cm ³ ; C ₀ =4.73 mm/μsec; σ _e =5.0 kbar; U _∞ =4.88 mm/μsec									

^a Measured impact velocity.
^b Particle velocity imparted to the specimen for symmetrical impacts.
^c Stress imparted to the specimen as measured by a quartz gage.
^d Wave velocity of elastic wave.
^e Hugoniot elastic limit.
^f Relative volume at Hugoniot elastic limit.
^g Maximum stress of plastic wave.
^h Computed relative volume of plastic wave.
ⁱ Maximum particle velocity of second plastic wave.
^j Final stress value was not recorded due to partial experimental failure.
^k The value shown was adjusted to agree with the input value.
^l Impact surface experiment only. The initial temperature of the sample was 130°C.
^m Low signal dilatational velocity as obtained by ultrasonic pulsing.
ⁿ Low signal shear-wave velocity as obtained by ultrasonic pulsing.

used. The velocity of the impacting surface is measured to ±0.5%; therefore, if like materials are used for the projectile and sample, the particle velocity imparted to the sample is known. Also, impacting with a quartz gage enables a measurement of the stress and particle velocity imparted to the sample at the impact face.^{14,15} These data provide independent measurements of the shock-wave behavior from that obtained at the conventional measuring station at the back side of the specimen. The redundancy achieved allows cross comparisons of data from a single experiment and greatly increases the confidence in the results since it serves as a quantitative measure of errors in the entire data recording and data reduction process as well as a verification of the assumptions made in reducing the data. Shock-wave velocity data are needed to compute the stress gauge record of the interface stress. These measurements are accomplished by the arrival times indicated by the impacting and back surface quartz Technical Publication No. 336, ASTM (1962).
¹⁴ W. J. Hahm, O. E. Jones, and R. A. Graham, ASTM Special Detonation, U.S. Naval Ordnance Laboratory (October 1965).
¹⁵ W. J. Hahm and R. A. Graham, Fourth Symposium on The alloys were obtained from the Carpenter Steel Company.

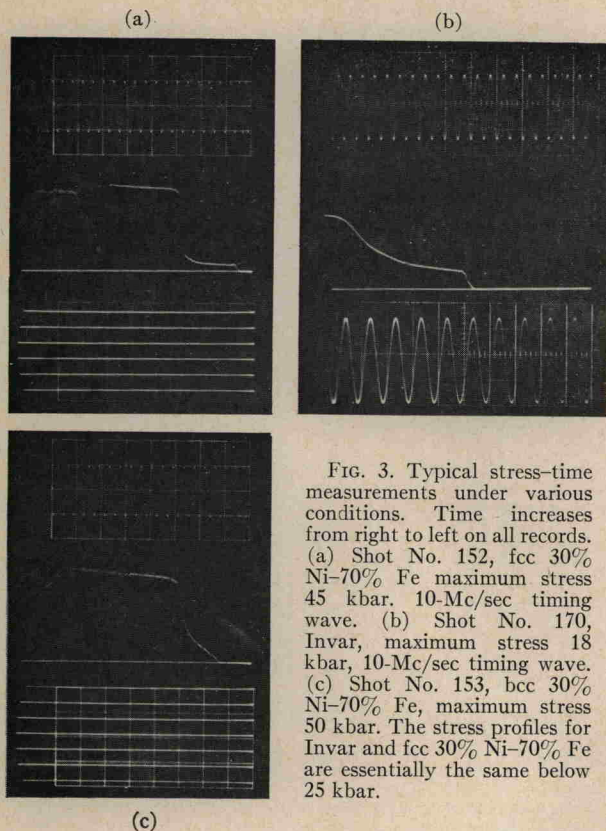


FIG. 3. Typical stress-time measurements under various conditions. Time increases from right to left on all records. (a) Shot No. 152, fcc 30% Ni-70% Fe maximum stress 45 kbar, 10-Mc/sec timing wave. (b) Shot No. 170, Invar, maximum stress 18 kbar, 10-Mc/sec timing wave. (c) Shot No. 153, bcc 30% Ni-70% Fe, maximum stress 50 kbar. The stress profiles for Invar and fcc 30% Ni-70% Fe are essentially the same below 25 kbar.

X-ray examination of the heat-treated samples showed that to the limit of detectability (5%) no minority phase was present. To determine atmospheric pressure elastic constants, typical samples were pulsed ultrasonically with results as shown in Table I. Chemical analyses were obtained on the samples which, for a given alloy, were all cut from the same bar of material. The mean value for the nickel content was 29.53% with a variance of 0.24%.

Since it was desired to measure the change in Curie temperature with pressure, it was necessary to measure the atmospheric-pressure Curie temperature for the 30% Ni-Fe alloy. This was determined by dilatometer measurements on bulk samples and x-ray lattice spacing vs temperature measurements. The value obtained for the Curie temperature from the thermal expansion measurements was $155^{\circ} \pm 3^{\circ}\text{C}$.

RESULTS

Typical stress-time profiles for various materials and various stress regions are shown in Fig. 3. The leading part of the profile results from the transition from elastic to plastic deformation. The sharp rise in stress for the second wave in Fig. 3(a) and the faster arrival time compared with that in Fig. 3(b) is that expected if the input stress is above the transition. Whereas, the slower rise in Fig. 3(b) is that expected if the stress input to the sample is below the transition.

The profile in Fig. 3(c) for the bcc alloy was obtained for an input particle velocity approximately equal to that in Fig. 3(a) for the fcc alloy. The bcc alloy shows a poorly defined precursor region, but, in any event, much faster arrival times are observed for all stress amplitudes as is indicative of lower compressibility.

The excellent time-resolution of the quartz gauge has revealed that few materials give idealized step function stress-time profiles. Hence, to reduce the stress-time profiles to stress-volume points the profile observed must be approximated by a series of small incremental steps constructed around the observed profile. This procedure has the further advantage that corrections can be made for the slightly variable response of the gauge. The solution for the incident stress from the measured interface stress was accomplished for each small increment of stress using the linear mismatch relations and the appropriate shock velocity for each step. The resulting final values can be checked against the measured input conditions to the sample as an over-all check of experimental errors and errors in data reduction. The data obtained on all experiments are tabulated in Table I. Most of the experiments were performed on fcc 30% Ni with less extensive experiments on 36% Ni and bcc 30% Ni.

The resulting stress-volume relations for the 30% Ni alloys are shown in Fig. 4. The cusp in the fcc curve at 4.3 kbar is the mean value observed for the Hugoniot

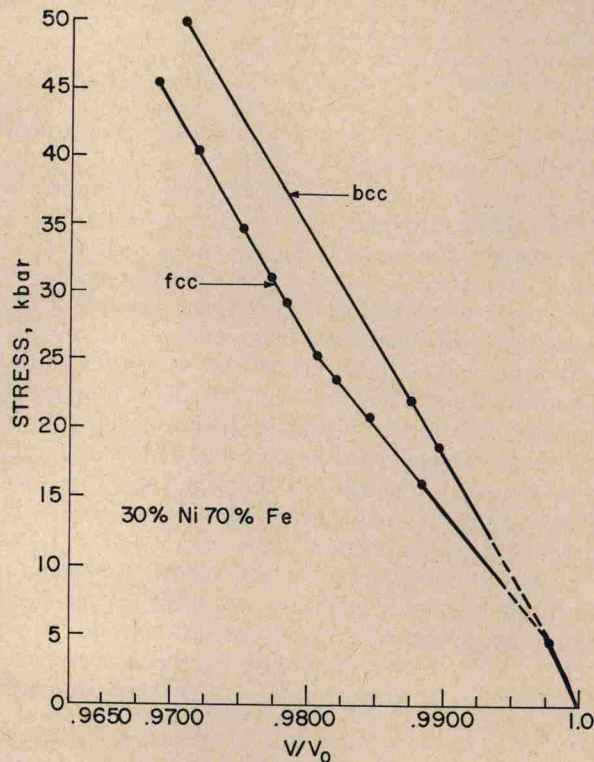


FIG. 4. Stress-volume relation for 30% Ni-70% Fe in the fcc and bcc phases.