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CARBON STRESS GAGE COMPARISON

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CARBON STRESS GAGE COMPARISON

ABSTRACT

Carbon piezoresistive stress gages manufactured by Effects Technology, Inc.,* and Dynasen, Inc., were evaluated with a 3-in.-diam gas gun using a flyer plate to provide a square-wave pressure input. Carbon gages were used to measure the stress history in-situ of a material under uniaxial stress conditions. The gages were assembled into a stress transducer made of 4340 steel. The input stresses ranged from 3 to 18 kbars. A plot of peak $\Delta R/R_0$ versus kilobars was made for the gages from the two manufacturers.

INTRODUCTION

Several piezoresistive stress gages (carbon, manganin, etc.) are presently used for a wide variety of stress measurements. Carbon in particular offers an advantage, at least to ≈ 100 kbars, over manganin in that the sensitivity is approximately ten times greater. The resistance change as a function of stress is nonlinear when compared to manganin.

To evaluate the performance of the carbon gages, gas-gun experiments were conducted with gages from the two present manufacturers of carbon gages, Effects Technology, Inc., and Dynasen, Inc. Of interest were both the repeatability of the gage calibration from gage to gage and the dynamic response characteristics of the gage. The dynamic stresses were obtained by impacting a transducer which contained the carbon gages, with a flyer plate. The input stresses ranged from 3 to 18 kbars.

GAS GUN

Each transducer was impacted by a thin 'flyer plate' carried by a missile propelled by compressed gas (Fig. 1). The missile is supported by two Teflon bearings; these bearings maintain the precision needed at impact and reduce the sliding friction in the barrel. With these bearings we have been able to obtain a missile velocity as low as 20 ft/sec.

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

Fig. 1. Compressed-gas gun (3-in. bore).

The flyer plate imparts a theoretically square stress wave to the transducer with a pulse width proportional to the plate thickness. The flyer plate is sealed to the missile in such a way to prevent the compressed gas from leaking by it. The target chamber and barrel are evacuated before each firing to provide an impact in a vacuum.

Before each shot is fired the misalignment between the flyer plate and missile was measured with an autocollimator and the missile resting in a granite vee block. After this misalignment was determined, the transducer was adjusted to match the flyer plate misalignment. Instead of making the flyer plate and the missile perpendicular to each other, we manufacture the flyer plate to a flatness of 0.0001 inch and assemble it into the missile.

With this procedure and the tolerances on the flyer plate, we have measured the tilt between the flyer plate and the transducer at less than 0.25 minute of arc, using tilt pins and a raster scope.

The missile velocity is measured by two sets of redundant quartz pins spaced a known distance apart. These pins start and stop counters that give the time for travel over this known distance. These pins also trigger the oscilloscopes and the power supply for the carbon gage.

The missile impacts the transducer before either of the Teflon bearings have left the barrel, thus keeping the missile aligned before impact. After impact the missile is stopped by a series of deformable aluminum rings that deform absorbing the energy of the missile. The rings also prevent damage to the missile, permitting its reuse; only the flyer plate, transducer, and rings are expended for each shot. With this system to stop the missile we are limited at present to a maximum velocity of about 500 ft/sec.

STRESS TRANSDUCER ASSEMBLY

In assembling a transducer containing the carbon gages we experienced some difficulty in obtaining minimum glue thickness and in maintaining flatness of the target relative to the transducer body. We found that the required results were obtained by bonding the target plate, carbon gages, and shims together in one step (Fig. 2).

We found the shims to be necessary to keep the target plate parallel with the body. For all the transducers, the shim thickness was 0.004 in. and the nominal carbon gage thickness was 0.0035 inch. When the shims are used, the epoxy* is thicker over the gage area. For a stress-measuring transducer the epoxy should be very thin to minimize internal reflections and increase the rise time of the gage. However, we felt that the thick epoxy (less than 0.0005 in.) over the carbon gage was of less consequence than having the target plate tilted relative to the transducer body, as it was when the transducer was assembled in two steps.

*The epoxy used was Shell Epon 815 with D.T.A. catalyst which has a viscosity close to that of water. It was cured for 12 hours at room temperature.

Fig. 2. A typical carbon stress transducer.

To assemble the transducer in one step, the carbon gages and shims were first preattached to the body with a minimum amount of Eastman 910; this prevented the gages and shims from moving when the target plate was put on. The target plate was also manufactured to a flatness of 0.0001 in. as was the transducer body. After this step the thickness was measured to insure that the 910 did not add unnecessary thickness under the gage or shim.

The epoxy was then spread on both sides of the carbon gages and shims, making sure there were no bubbles. The target plate was put on and the transducer was placed in a clamping fixture to keep the target and body flat and parallel while the epoxy was curing. A force of 75 lb ($\approx 40 \text{ lb/in.}^2$) was applied to the transducer to squeeze out as much epoxy as possible.

After the epoxy had cured the completed transducer was checked to verify that the flatness of 0.0001 in. was maintained across the target face.

Tables 1 and 2 show the dimensions of the stress transducers tested. Figure 3 defines the dimensions used for the two tables. From these two tables the epoxy thickness can be seen to be 0.0001 to 0.0002 in. over the shims.

Table 1. Transducer specifications for Effects Technology gages. The dimensions X_t , X_{tot} , X_B , Y_1 and Y_2 are defined in Fig. 3.

Shot No.	Initial gage resistance (Ω)		Flyer plate thickness (in.)	X_t (in.)	X_{total} (in.)	X_B (in.)	Y_1 (in.)	Y_2 (in.)	Gage thickness (in.)		Resistance to ground (M Ω)
	1	2							1	2	
175	49.39	49.75	0.1266	0.0888	1.591	1.499	0.285	0.260	0.0035	0.0035	35×10^4
176	50.60	50.00	0.1266	0.0888	1.593	1.500	0.271	0.258	0.0035	0.0035	30×10^4
177	48.84	49.84	0.1266	0.0888	1.592	1.499	0.287	0.237	0.0033	0.0033	30×10^4
178	48.49	49.17	0.2545	0.0888	1.592	1.499	0.305	0.280	0.0032	0.0032	30×10^4
179	49.60	50.00	0.2545	0.0887	1.592	1.499	0.237	0.309	0.0031	0.0032	50×10^4
180	49.47	49.33	0.2545	0.0887	1.592	1.499	0.275	0.275	0.0034	0.0035	40×10^4
186	49.18	49.72	0.126	0.08895	1.593	1.500	-	0.275	-	0.0036	100×10^4
192	48.70	48.65	0.2545	0.0767	1.581	1.498	0.275	-	0.0033	-	9×10^3
193	50.04	48.83	0.2545	0.0769	1.580	1.498	0.292	0.243	0.0033	0.0032	Gage 1: 7×10^3 Gage 2: 3×10^3

ELECTRONICS

All carbon gages were powered by a Sandia Manganin gage power supply Model Number 50-600-75. The gage current was 2A. For all shots the power was applied to the gage approximately 10 μsec before the stress signal arrived, and was on for 50 μsec .

Calibration steps were obtained for each gage by means of a decade resistance box. The decade box was set at a specific resistance, and the power supply pulsed at this

Table 2. Transducer specifications for Dynasen gages. The dimensions X_t , X_{tot} , X_B , Y_1 and Y_2 are defined in Fig. 3.

Shot No.	Initial gage resistance (Ω)		Flyer plate thickness (in.)	X_t (in.)	X_{total} (in.)	X_B (in.)	Y_1 (in.)	Y_2 (in.)	Gage thickness (in.)		Resistance to ground (M Ω)
	1	2							1	2	
174	53.18	52.37	0.1266	0.0887	1.594	1.500	-	0.172	-	0.0035	2×10^4
181	48.55	48.05	0.2545	0.0856	1.589	1.498	0.367	0.387	0.0035	0.0036	8×10^4
185	48.87	48.82	0.2545	0.0856	1.591	1.499	0.340	0.350	0.0034	0.0039	Gage 1: 5×10^2 Gage 2: 20×10^2
188	48.66	48.73	0.2545	0.0860	1.589	1.4995	0.250	0.259	0.0035	0.0035	5×10^3
189	48.59	48.76	0.2545	0.0859	1.5890	1.4998	0.258	0.302	0.0035	0.0035	8×10^2
190	48.87	50.05	0.2545	0.0770	1.5806	1.4998	0.357	0.372	0.0035	0.0035	Gage 1: 8×10^2 Gage 2: 3×10^3
191	51.17	56.61	0.2545	0.0780	1.5798	1.4998	0.270	-	0.0035	-	8×10^2
194	49.24	48.87	0.2545	0.0768	1.5790	1.4975	0.225	0.220	0.0030	0.0030	5×10^3
195	46.68	48.14	0.2545	0.0771	1.580	1.4990	0.200	0.225	0.0030	0.0030	2×10^3

change was photographed with the oscilloscope. The decade box was then changed to a new value and the process was repeated. The film was not removed from the oscilloscope until the last resistance change, usually five steps, depending on the expected gage output. The oscilloscope film then displays a series of parallel lines, each representing a $\Delta R/R_0$ change. These steps are used for the calculation of $\Delta R/R_0$.

The performances of all gages were recorded with a Tektronix 556 dual-beam oscilloscope with suitable preamplifiers to give an ≈ 30 nsec rise-time. The initial gage resistance (R_0) was measured before each gun shot. The resistance was measured with and without the cable connecting the gage to the power supply. Tables 1 and 2 show the initial gage resistance.

INPUT STRESS CALCULATIONS

As previously mentioned, these gun experiments were designed to produce a simple square-wave pressure input to the gage. The flyer plate and transducer target material were 4340 steel, heat treated to R_c (Rockwell scale c) = 35, which has a Hugoniot elastic limit of approximately 25 kbars. In all our shots, the stresses were well below the elastic limit so that single shock and release waves were generated. Flyer plate thickness (see Tables 1 and 2) was chosen to give just over one or two microseconds between the pressure rise and the release to zero pressure from the back side of the unbacked flyer plate. The gages were installed on the transducer so that the edge rarefactions would not reach them until well over 2 μ sec after the initial shock arrival.

Fig. 3. Dimensions of carbon stress transducer. The thickness of the shims for all shots was 0.004 inches.

X_t = target thickness

X_{tot} = total transducer thickness including shims and epoxy resin

X_B = transducer body dimensions

Y_1, Y_2 = distance from edge of carbon to radius of body.

The peak stress generated in each shot was calculated using the following one-dimensional stress equation:

$$\sigma = 1/2 \rho_0 c_\ell V_m,$$

where σ is the stress imparted by the impact, ρ_0 is density of the material (7.838 g/cc), c_ℓ is the longitudinal sound speed of the material (5.826×10^5 cm/sec), and V_m is the velocity of the missile or flyer plate.

For the stress calculations it was assumed that the shock speed was equal to the longitudinal sound speed c_ℓ . For the stresses attained in these experiments this assumption should provide correct shock speeds to within about 1%.

DATA RESULTS

The oscilloscope Polaroid pictures were reduced by (1) using a film reader to digitize the scope record and (2) combining this digitized record with a computer code MDR (Manganin Data Reduction). The output from this code was plots of $\Delta R/R_0$ versus time.

Figures 4 through 12 show data plots ($\Delta R/R$) for the Effects Technology gages, and Figs. 13 through 21 show plots for the Dynasen gages. The shot numbers correspond to those in Tables 1-3. The numbers 1 and 2 on the plots refer to Gage 1 and Gage 2 on the transducer; generally we had two gages per shot. If the ordinate for each plot is multiplied by 100, then $\Delta R/R_0$ will be in percent. The values of the ordinate are negative, since the resistance of carbon decreases with increasing stress.

Table 3 lists the missile velocity, input stress and peak $\Delta R/R_0$ for each manufacturer. The $\Delta R/R_0$ is read from the above figures.

Finally, Figs. 22 and 23 are plots of $\Delta R/R_0$ versus stress, which are our actual data points plotted from the data tabulated in Table 3. The manufacturer's calibration is also given in these two figures by the solid line.

CONCLUSIONS

It can be seen that the Effects Technology gage more closely matches the manufacturer's curve than does the Dynasen gage. There is also less scatter in the Effects Technology gage. But it was not our purpose in this report to find out why one gage does or does not match the manufacturer's data, but only to present the data for comparison.

From our two plots it can be seen that either carbon gage could be used to measure stress, especially with these two calibration curves.

Table 3. Summary of gas gun shots.

Shot No.	V_{missile} (ft/sec)	Input stress (kbars)	$-\Delta R/R_0$ (%)	
			1	2
Effects technology gage				
175	150.15	10.45	25.6	25.5
176	191.43	13.32	29.1	28.9
177	95.51	6.65	19.5	19.4
178	102.55	7.14	19.6	19.9
179	147.95	10.29	25.4	25.4
180	121.70	8.47	21.9	21.9
186	146.40	10.19	-	25.2
192	68.98	4.80	15.1	-
193	221.5	15.40	31.7	31.3
Dynasen gage				
174	159.21	11.07	-	36.5
181	51.29	3.57	15.3	14.7
185	63.39	4.45	17.7	19.6
188	143.40	9.97	33.7	31.5
189	143.3	9.97	31.7	30.7
190	195.4	13.59	38.8	38.1
191	208.15	14.49	41.7	-
194	86.34	6.01	22.6	23.3
195	242.14	16.85	42.5	43.0

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Fig. 4. Data plot for Effects Technology gage, shot 175.

Fig. 5. Data plot for Effects Technology gage, shot 176.

Fig. 6. Data plot for Effects Technology gage, shot 177.

Fig. 7. Data plot for Effects Technology gage, shot 178.

Fig. 8. Data plot for Effects Technology gage, shot 179.

Fig. 9. Data plot for Effects Technology gage, shot 180.

Fig. 10. Data plot for Effects Technology gage, shot 186.

Fig. 11. Data plot for Effects Technology gage, shot 192.

Fig. 12. Data plot for Effects Technology gage, shot 193.

Fig. 13. Data plots for Dynasen gage, shot 174.

Fig. 14. Data plots for Dynasen gage, shot 181.

Fig. 15. Data plots for Dynasen gage, shot 185.

Fig. 16. Data plots for Dynasen gage, shot 188.

Fig. 17. Data plots for Dynasen gage, shot 189.

Fig. 18. Data plots for Dynasen gage, shot 190.

Fig. 19. Data plots for Dynasen gage, shot 191.

Fig. 20. Data plots for Dynasen gage, shot 194.

Fig. 21. Data plots for Dynasen gage, shot 195.

Fig. 22. The data points for resistance change ($-\Delta R/R_0$) vs stress for Effects Technology carbon gage (Model No. 50KK-400Au). Solid curve, manufacturer's calibration curve.

Fig. 23. The data points for resistance change ($-\Delta R/R_0$) for Dynasen carbon gage.
Solid curve, manufacturer's calibration curve.

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