CALIBRATION OF THIN-FOIL MANGANIN GAUGE IN ALOX MATERIAL

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The purpose of this program was to develop a calibration curve (stress as a function of change in gauge resistance/gauge resistance) and to obtain gauge repeatability data for Micro-Measurements stripped manganin thin-foiled gauges up to 6.1 GPa in ALOX (42% by volume alumina in Epon 828 epoxy) material. A light-gas gun was used to drive an ALOX impactor into the ALOX target containing four gauges in a centered diamond arrangement. Tilt and velocity of the impactor were measured along with the gauge outputs. Impact stresses from 0.5 to 6.1 GPa were selected in increments of 0.7 GPa with duplicate tests done at 0.5, 3.3 and 6.1 GPa. A total of twelve tests were conducted using ALOX. Three initial tests were done using polymethyl methacrylate (PMMA) as the impactor and target at an impact pressure of 3.0 GPa for comparison of gauge output with analysis and literature values. The installed gauge, stripped of its backing, has a nominal thickness of 5 μm . The thin gauge and high speed instrumentation allowed higher time resolution measurements than can be obtained with manganin wire.

INTRODUCTION

Manganin alloy has been used widely as an in-material stress gauge in planar shock wave experiments. Gauges of the wire design have been studied by Lee¹ and have been used in numerous physics and engineering applications. Because of the physical size of the manganin wire, 76 μm diameter, this design responds relatively slowly to an input shock and the gauge output is dependent on the material in which the gauge is mounted. The thin foil manganin gauge construction, as reported by Rosenberg,² is much thinner, 5 μm , and provides a better temporal representation of the

shock in materials. This design, with gauge backing in place, is reported² to be insensitive to the target material. Rosenberg² reported that the calibration curve for the thin foil manganin gauge showed distinct elasto-plastic behavior with a linear part from 0 to 1.5 GPa. The slope of the elastic part of the calibration was $\sim 50 \text{ GPa}/(\Omega/\Omega)$. The higher stresses were represented by a fourth-order polynomial fit. The target and impactor materials used in the Rosenberg work were PMMA, copper, magnesium and aluminum, all homogeneous in nature.

The work presented here develops a shock response calibration curve for commercial foil

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gauges that have the customary Kapton® backing removed and the gauges imbedded in ALOX. Four gauges were installed in each target to obtain redundant gauge outputs from the same test input.

EXPERIMENTAL TECHNIQUE

The plane impact experiments were conducted in the Sandia National Laboratories 63-mm diameter light gas gun described by Sheffield.³ Impact velocity was measured using five coaxial pins that were shorted by a metallic ring around the projectile. The pins were separated by 10 mm in the axial direction and the last pin was 25 mm in front of the target assembly face. The accuracy of the impact velocity was $\pm .5\%$. The impactor tilt was inferred using the output from the four manganin gauges, equally positioned around the target axis. The acceptable tilt of the impactor was established a priori to be less than 100 ns closure across the gauge element (3.175 mm).

Figure 1 is a schematic of the projectile and target used in this calibration program. The impactor material was PMMA made by Rohm and Haas for the three preliminary tests and ALOX made at Sandia's plastic shop for the twelve calibration tests. The impactor was nominally 2.5 mm thick and was backed by a 5-mm thick disk of carbon foam which had a nominal density of 0.2 g/cm.³ This backing material reflects a very small percentage ($\sim 4\%$) of the shock wave reaching it from the impactor. The sabot to carry the impactor was made of either aluminum or syntactic foam filled nylon. Using the same material for the impactor and target produced a symmetric impact with the resultant particle velocity in the material equal to one-half the projectile velocity. The stress level in the impacted material was determined from the known Hugoniot curves for ALOX⁴ and the measured impact velocity by the impedance-match technique. The manganin gauges were

sandwiched between two pieces of PMMA or ALOX, respectively. The first piece, the buffer, was nominally 5 mm thick and the second, the target, was 25.4 mm. The polycast backer was used to support the instrumentation cable connection.

Commercial manganin gauges (Micro-Measurements Model No. VM-SS-110FB-048, Part No. C-941028-A) were used in this study. The gauges are etched foil with 48 Ω nominal resistance. The foil was 5.0 μm thick and the Kapton® backing was removed after the gauges were glued to the respective target. The total thickness of the gauge installation between the buffer and the target was nominally twice the gauge thickness. The manganin gauge had two thin ribbon extensions for attachment to the instrumentation cable which were coated with a thin layer of copper ($\sim 5 \mu\text{m}$ thick) to reduce output caused by resistance change of the leads during the impact.

FIGURE 1. Schematic of Test Hardware

PRELIMINARY TESTS

A series of three tests were conducted at the beginning of this study to validate the

experimental process. The material, PMMA, which has been characterized for shock loading⁵ was used in a symmetrical impact to produce 3.0 GPa shock loading. The manganin gauges were stripped of the backing and were installed in the same manner as for the ALOX experiments.

The preliminary experiments were conducted to provide data for comparison with calculated gauge response to assess overall experiment accuracy. A calculated stress-time history in the PMMA target was directly compared with the 5 μm thick manganin output to determine the correlation. The calculations used measured impact velocity in conjunction with a rate dependent PMMA model,⁵ while the manganin resistance change data were converted to stress using Rosenberg's equation.² Comparison of calculations and experiment are shown in Fig. 2. A high frequency oscillation was evident on the leading of the experimental data, which was attributed to manganin/PMMA equilibration. Recording system frequency response (~ 20 MHz) negated the ability to directly track manganin response. The 5 μm thick manganin foil was not included in the calculations.

FIGURE 2. Experimental results and calculational comparison for manganin foil gauge embedded in PMMA showing overall agreement until 1.9 μs

Overall agreement was observed between gauge response and calculations based on

shock wave rise, amplitude and release. Manganin unloading response deviated from the one-dimensional calculations at about 1.9 μs . The shock wave arrived at the gauge connection to the instrumentation cable at approximately 2.8 μs .

RESULTS

Twelve tests were conducted with ALOX material for the impactor and target. Duplicate tests were run at 0.5, 3.3 and 6.1 GPa. Single tests were run at 0.7 GPa increments between these values. Four gauges were recorded at each level for a total of 48 gauges. Forty-eight measurements were obtained with two gauges losing leads early in the response time. Figure 3 shows gauge output as a function of stress level. A third order, least squares fit to these data is shown. The equation that describes the change in gauge resistance (dR) divided by the initial gauge resistance (R) is $P(\text{GPa}) = 5.5027 * (dR/R) - 0.2063 * (dR/R)^2 + 0.0061 * (dR/R)^3$. The correlation factor (R^2) is 0.9986 for this data fit. This calibration is valid for pressures between 0.5 and 6.1 GPa.

FIGURE 3. Results of the manganin foil gauge embedded in ALOX

DISCUSSION

The calibration shows similar characteristic elastic response up to about 1.5

GPa as reported by Rosenberg.² The elastoplastic response is also similar to Rosenberg data up to 3.3 GPa. At stress greater than 3.3 GPa the gauge in ALOX shows a larger change in resistance than seen in the homogeneous materials of Rosenberg's work. At 6.1 GPa the difference is around 15%. This difference is attributed to non-homogeneous response of the aluminum oxide filled epoxy at these higher stresses. The gauge repeatability was excellent; note that there are eight data points at 0.5 and 3.3 GPa and seven points at 6.1 GPa.

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