SAND2009-5735C

DESIGN OF A SAMPLE RECOVERY ASSEMBLY FOR MAGNETIC RAMP-WAVE LOADING

S. Chantrenne[2], J. L. Wise[1], J. R. Asay[1], M. E. Kipp[1], and C. A. Hall[1]

[1]*Sandia National Laborarories, P.O. Box 5800, Albuquerque NM 87185*
[2]*Science Application International Company, 2109 Air Park Rd SE, Albuquerque NM 87185*

Abstract. In order to generate new properties of metals exposed to high pressure states, it is desirable to study samples loaded in one-dimensional strain. Previous work to obtain these ideal conditions, involve a technique where the sample was recovered at late times to examine its microstructure. In those experiments, the shock-loading was produced by impacting the sample with a flyer plate. In the present work, we modified the sample recovery assembly and optimized it for ramp wave loading. We describe the 2-D calculations performed with the ALEGRA MHD code that led to improved recovery assembly efficiency. Preliminary comparisons of the simulations with measurements of the sample deformation from an experiment indicate excellent agreement.

Keywords: Recovery, stress, Alegra, fracture.
PACS: D 62.50.+p, 07.35.+k

INTRODUCTION

Study of properties of materials under dynamic loading requires investigation at strain rates ranging from quasi-static to the limiting values of shock compression. Targets loaded in one-dimensional strain are favored to generate new theory because samples are exposed to a very well defined loading. However, in an experiment, many late-in time processes affect the target, such as plastic deformation due to lateral release or spallation within the sample. By using shock recovery techniques first developed in the late 1950's[1], ideally, the material sample is recovered without having been subject to radial release waves. Damage and material structure are assessed by post-examination of the material. So far those experiments were performed for a number of pressure loading devices, in particular on gas/powder launchers using flyer plates [2]. In this work, we propose to subject the material to a ramp pressure wave, produced by the compact strip-line current generator Veloce [3]. The pressure load is provided by the magnetic pressure produced by an intense current into a strip line panel configuration as shown in Figure 1. The ramp loading permits a non-shock response of the sample to be examined.

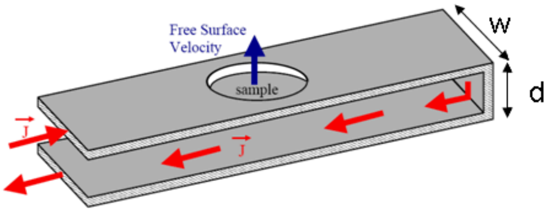

Figure 1. Strip line load configuration

In the past, a soft shock-recovery technique designed for gas guns confirmed that samples with low residual plastic strain could be reproducibly recovered using that method [2, 5-7]. We adapt that concept for application to magnetic ramp loading using 2-D magneto-hydrodynamic calculations to minimize the late-time undesirable processes.

MATERIAL MODELS AND SIMULATION DESCRIPTION

To optimize the design for the ramp wave application, numerical simulations were performed with the ALEGRA code [4]. ALEGRA is an Arbitrary-Lagrangian-Eulerian (ALE) finite-element code that models dynamic mechanical response and shock propagation in a resistive magneto-hydrodynamic (MHD) environment. For the soft recovery design optimization, a set of Eulerian simulations in cylindrical coordinates were driven with a pressure waveform, using only the hydrodynamic part of the code. The full MHD capability was used for a second set of simulations where the results were directly compared to experimental data. In this latter case, a planar configuration along the length of the panel was used, with a spatial resolution up to 10 µm.

The success of this type of simulation is highly dependent on the material models employed. Standard Mie Gruneisen equation of state models from the ALEGRA material library were used for aluminum and copper [8]. A classical elastic-plastic constitutive model was also employed [9] and aluminum and copper strength parameters were drawn from reference [10]. Finally, for the MHD calculations, electrical and thermal conductivities were treated with the Lee-More-Desjarlais model, which were previously used in accurate 3-D simulations of the panels [3].

In a hydrodynamic code such as Alegra, materials behave as if they were welded. Thus, if two materials are moving apart from each other in an ALE or Eulerian mesh, tension will form in the elements containing the material interfaces and work to restrain the motion. In order to model the contact and friction between two surfaces, an inter-material fracture algorithm is used that inserts void at the interfaces, releasing the pressure and effectively allowing the materials to separate. For single-material elements, a fracture model allows spallation within the material when a specified (negative) fracture pressure is reached.

SHOCK RECOVERY ASSEMBLY DESIGN

In the past, a soft shock-recovery scheme designed for gas guns confirmed that samples with low residual plastic strain could be reproducibly recovered using that technique [2, 5-7]. We used this gas gun soft-recovery concept as a starting point for our simulations. The scaled shock-recovery assembly is shown in Figure 2.

Our optimized design uses a 25 mm wide and 3 mm thick panel of aluminum (1100). The sample and all the assembly components are in copper. The sample (5 mm Ø and is 1 mm thick) is contained in a holder cavity, and is protected by a 0.25 mm coverplate.

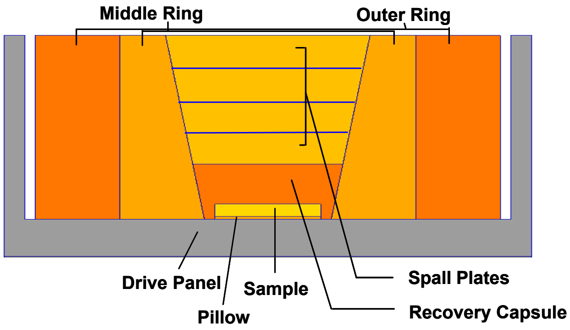

Figure 2. Conceptual design of the shock-recovery assembly conceived by Gray, *et al.*

The side rings are designed to trap the radial release waves that originate at the edges of the fixture, while the spall plates reduce the amplitude of the longitudinal release, so that the sample is ideally recovered with minimal secondary loading.

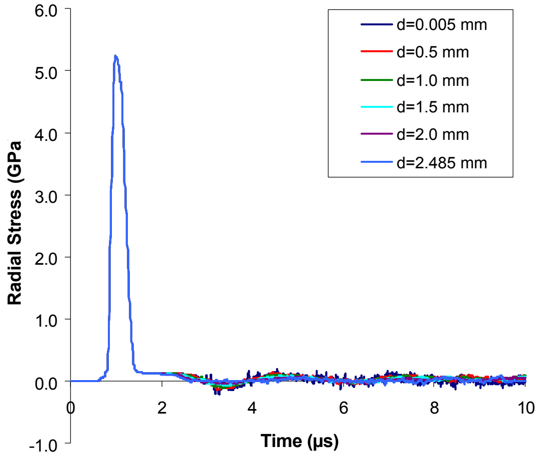

Figure 3. Residual radial stress at several positions from the center in the sample

The design was optimized for a 600 ns pressure pulse drive, with a 4 GPa peak pressure. The dimensions of the assembly components were optimized such that both longitudinal and radial residual stress were reduced to less than 1% of the original peak strain, as shown in Figure 3. This was achieved by reducing the final velocity of the sample and the capsule around it to less than 1 m/s. Finally, the spall plate thicknesses were adjusted to minimize the final internal energy in the sample. Figure 4 shows the soft recovery assembly after the first 10 µs: the two external rings have separated from the central assembly, preventing peripheral release waves from coming back into the sample. Also, the spall plates captured part of the momentum, reducing the magnitude of the longitudinal release wave

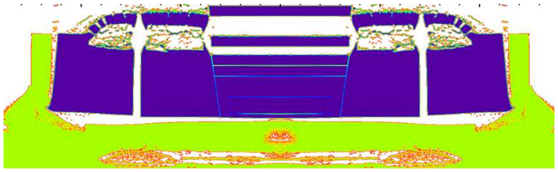

Figure 4. Recovery assembly after the first 10 µs

Minor spaces on the order of a µm produce radial waves in the simulations, suggesting that the assembly machining tolerances would have to be adequately tight and assembly with lubrication grease will be needed to limit residual strains to less than 1 %.

MODEL VALIDATION: COMPARISON WITH EXPERIMENTAL DATA

In order to assess the validity of the model used for these calculations, the results were compared to experimental data. In the experiment, one panel (bottom panel) was loaded with the soft recovery assembly. The free surface of the opposite panel was instrumented to measure the free surface velocity. The current which produced the magnetic pressure is shown in Figure 5 and was utilized to drive the simulations. The 600 ns pressure pulse as used for our previous calculations is not presently available with our current generator Veloce. Instead, after the main double current pulse, the current oscillates for a while and decreases to close to zero at about 13 µs, after which remains a residual current on the order of 50 kA. Therefore, the longitudinal release is not happening before the radial release waves come back from the periphery and the residual stress in the sample cannot be reduced to less than 1%. However, the present experimental configuration allowed us to confirm the feasibility of the soft recovery concept with a ramp-wave loading. A single pressure decreasing to zero should be available in the near future.

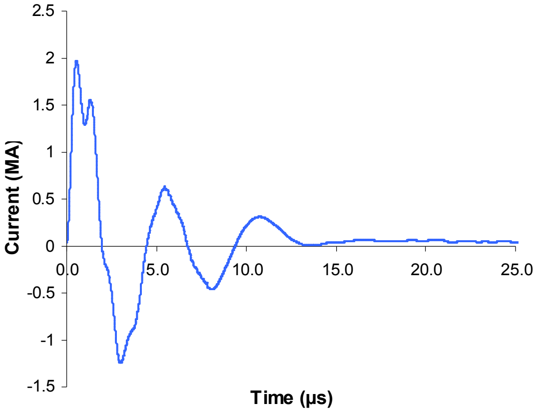

Figure 5. Present generator Drive current

The comparison of measured and calculated free surface velocity of the panel free surface is shown in Figure 6. The agreement is very good for the first 2 µs, including the leading elastic precursor (from the load transiting the aluminum panel). Later in time, the lack of agreement happens after spallation has occurred in the panel and may be due to inaccurate fracture and interface models.

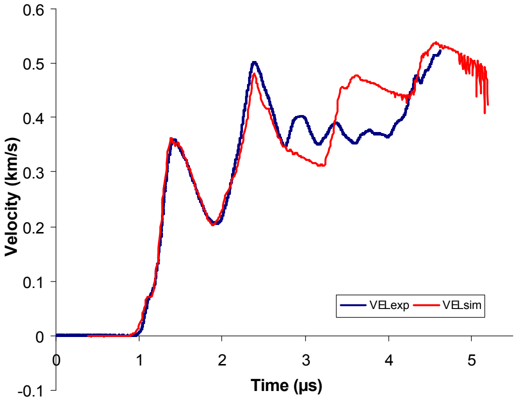

Figure 6. Comparison of measured and calculated velocity at the free surface of the panel

After the experiment, flatness measurements were performed on both sides of the coverplate and on the side of the sample that was initially in contact with the coverplate (the sample remained in the holder). These measurements were compared with the calculated displacements of Lagrangian tracer points located at the same positions on the sample and the coverplate. The simulations ran for 20 μs. The results obtained for the sample surface are shown in Figure 7. The agreement is remarkable, although these are only preliminary results: it is possible that the calculated deformation will increase if the simulation runs for a longer time (30 or 40 μs). Also, these are the results of 2-D calculations and it is very clear that the recovery assembly is subject to 3-D effects, requiring 3-D simulations to adequately represent the experiment. Finally, the simulations were performed in the plane along the length of the panel, but the flatness measurements were done at a random angle. For the coverplate, the order of magnitude of the deformation obtained by simulation is within 20% of that obtained experimentally.

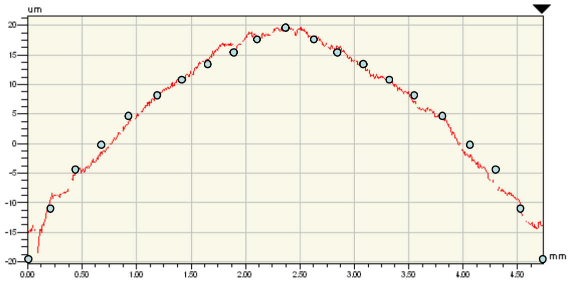

Figure 7. Comparison of the measured (red line) and calculated (blue dots) flatness of the sample

Finally, since the loading is of magnetic origin, one has to assess the thermal effects produced by the current diffusing into the panels and subsequently into the sample. The temperature rise during the pulse is about 18 K, relaxing to about 2 K above ambient at the conclusion of the event.

CONCLUSIONS

The application of sample recovery techniques to ramp-loading is very promising. Initial calculations confirm that the material sample can be exposed to a one-dimensional strain and isolated both from radial release waves and axial tensile waves. The comparison of the calculations to experimental results demonstrates that the model used is reasonably adequate for a preliminary investigation. High resolution 3-D simulations are needed to fully account for the geometry of the fixture and details of the magnetic loading conditions.

ACKNOWLEDGEMENTS

Funding was provided by Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

REFERENCES

1. C.S. Smith, Trans. Metall. Soc. AIME **214**, 574-589
2. G.T. Gray III, P.S. Follansbee & C.E. Frantz, Mater. Sci. Eng. A 111, 9–16. (1989) (doi: 10.1016/0921-5093(89)90192-5.)
3. T. Ao, J.R. Asay, S. Chantrenne, M.R. Baer, & C.A. Hall, Rev. Sci. Instrum. 79, 013903 (2008)
4. S.K. Carroll *et al.*, Technical report SAND2004-6541, Sandia National Laboratories, Albuquerque, NM, January 2005.
5. G.T. Gray III, in High-pressure shock compression of solids (ed. J. R. Asay & M. Shahinpoor), pp. 187–216. (1993) New York: Springer.
6. G.T. Gray III,in ASM handbook: mechanical testing and evaluation (ed. H. Kuhn & D. Medlin), vol. 8, pp. 530–538. (2000) Materials Park, OH: ASM International.
7. F. Llorca, F. Buy, & J. Farre, in Shock compression of condensed matter—2001 (ed. M.D. Furnish, N.N. Thadhani & Y. Horie), pp. 638–641. Melville, NY: American Institute of Physics.
8. G.I. Kerley, CTH ref. manual: the equation of state package. Technical report SAND98-0947, Sandia National Laboratories, Albuquerque, NM, 1998
9. J. Chakrabarty, "Theory of plasticity", McGraw-Hill Book Company, New York , 1987
10. D.J. Steinberg, LLNL Technical Report, UCRL-MA-106439, Change1, Feb. 13, 1991