Helical EMG Application for Material Rheology Studies: Opportunities, Results, and Perspectives

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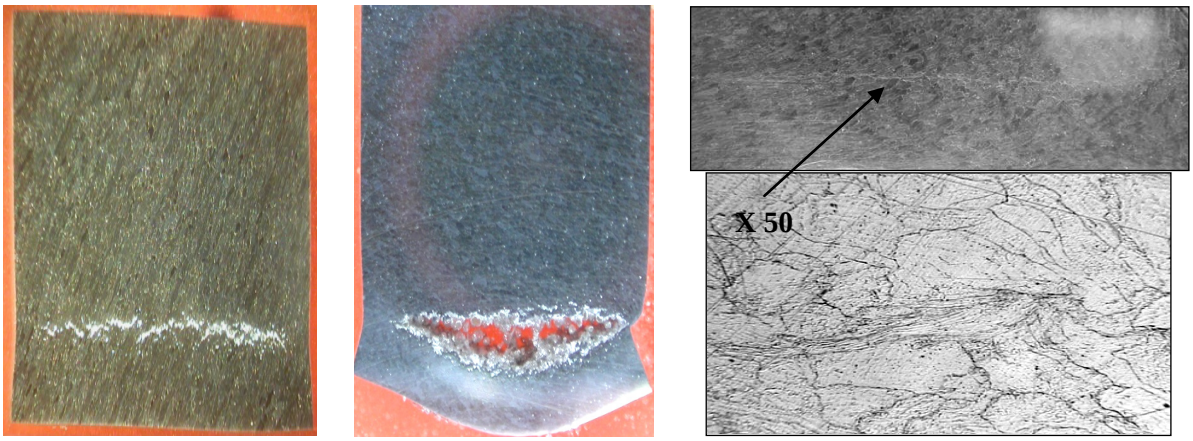
Introduction

The availability of a big class of pulsed power sources on the basis of helical explosive magnetic generators (HEMG) developed in the course of last decades at RFNC-VNIIEF [1] presents great opportunities to explore behavior of materials exposed to shock-wave and quasi-isentropic axisymmetric loading over a wide range of variations of amplitude-time characteristics of compression and extension pulses. The application of the magnetically driven cylindrical liners-impactors provides a unique opportunity to study the material damage mechanisms in converging geometry.

1. Pulsed power source on the basis of HEMG. The helical EMGs are the explosive devices that allow shaping powerful current pulses with the amplitude of tens of megamperes. At present in order to realize physical research and applied works a family of helical EMGs with the output energy to 30 MJ in the loads with inductance 30-3000 nH has been created and is used at RFNC-VNIIEF. The helical EMGs with the explosive current opening switches (EOS) are able to generate the current to ~20 MA for the time of ~ 1 mks in the liner loads; they are transportable and have a moderate cost.

2. Capabilities and advantages. The range of the condensed liner velocities to ~ 7 km/s is accessible to the pulsed power sources on the basis of HEMG [2], that testifies to rather much room for the studies of such rheological properties of materials as shear and spall strength, recollection of the damaged medium. The advantages of the technique of the materials loading with the use of the HEMG driven liners are: absence of the liner pushing by the explosion products, inertia-free magnetic field, a possibility to form a current pulse of required shape (amplitude, rise and fall time, duration), high symmetry of loading, post-shot recovery of the studied material samples for subsequent metallographic analysis.

3. «*R-Damage*» experimental series. The experimental series "R-Damage" conducted jointly by the LANL and VNIIEF teams in 2004-2011 has become the first experience of HEMG application for material rheology studies [3]. The objective of the experiments was to study the peculiarities of initiation and evolution of spall damage, as well as the recollection of the damaged medium under conditions of axisymmetric loading of the ALCAN aluminum targets by the converging liner. The liners were driven by the electromagnetic field produced by an explosive magnetic source of current on the basis of HEMG. A quasitrapezoidal current pulse of required duration was shaped in the liner with the use of the explosive current opening switches (EOS). A possibility to control the duration of the current pulse (pressure) made it possible to realize the regimes of loading of the studied targets both by a single shock wave and by two successive non-stationary shock waves. The application of the devices protecting the studied samples from explosive and shock action of the explosive magnetic source allowed conducting metallographic analysis of their post-shot condition to evaluate the nature and degree of damage (see Figure 1).



a) Initiation b) Full spall c) Recollection

Figure 1 – Photos of typical fracture zones.

Continuous recording of the time dependences of the targets' free surface velocity with the use of laser interferometry (from the moment of compression with a shock wave, through a spall-type damage, to recollection) together with the data from metallographic analysis allowed verifying the model of spall damage, as well as defining and verifying a simple model of recollection of the damaged medium.

4. Beryllium rheology studies. An increase of interest to such material as beryllium has been observed recently. To study its properties (shear and spall strength), it is logical to use the experience obtained in R-Damage series. In particular, it is proposed to use the scheme of the experiment setup in which the cylindrical beryllium targets are loaded by means of deceleration of the electromagnetically driven cylindrical aluminum liners against them. The range of pressures at the shock wave front in beryllium in this setup, under condition of the targets recovery for subsequent metallographic analysis, makes from 2 to 40 GPa and it can be realized due to loading by the aluminum liners with the velocities within the range from 300 m/s to 3,5 km/s. The experiments within this range of liner velocities can be conducted with the use of the pulsed power source on the basis of HEMG earlier used in "R-Damage" series.

References

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