QUALIFICATION OF A RAMP-WAVE GENERATOR

Michel Perez

► To cite this version:

Michel Perez. QUALIFICATION OF A RAMP-WAVE GENERATOR. Journal de Physique Colloques, 1988, 49 (C3), pp.C3-713-C3-719. 10.1051/jphyscol:19883101 . jpa-00227729

HAL Id: jpa-00227729

<https://hal.science/jpa-00227729>

Submitted on 1 Jan 1988

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

QUALIFICATION OF A RAMP-WAVE GENERATOR

M. PEREZ

Centre d'Etudes de Gramat, F-46500 Gramat, France

Resume - On présente un matériau générateur de rampe de compression quasi-isentropique. Ce matériau est élaboré par les techniques de la Metallurgie des Poudres sous la forme de disques plans de 2 mm d'épaisseur, qui présentent une variation quasi-linéaire de la densité et de l'impédance acoustique en fonction de l'épaisseur. L'efficacité de ce matériau a été prouvée, notamment dans le tantale où une rampe de contrainte de 84 GPa et de 910 ns de temps de montée, a été mesurée à 1,84 mm de profondeur. Un modèle de comportement hydrodynamique de ce matériau est également présenté.

Abstract - A material has been developed for generating a quasi-isentropic compression wave in plate impact experiments. This material has been realized using powder metallurgical techniques in the form of plates 2 mm-thick, which have a quasi-linear variation in density and acoustic impedance according to their thickness. The efficiency of this material has been proved, particularly in tantalum where a ramp-wave of 84 GPa and a 910 nanoseconds rise time has been measured at 1.84 mm propagation distance. A hydrodynamic model of this material is also presented.

1 - INTRODUCTION

The equations of state of solid materials used in the range 0-100 GPa and beyond are usually based on the Hugoniot adiabat. These equations are used, particularly in numerical computer codes, to describe the material's behavior in thermodynamic states often off Hugoniot. A ramp-wave generating material, like the PILLOW /1/ developed by the Sandia Laboratories, open up wide possibilities in this field in that they allow compression of solids according to a quasi-isentropic process. The ramp-wave generating material which is the subject of this paper is designated by the acronym MIVAR (Matériau d'Impédance Variable). This material has a gradually decreasing acoustic impedance, and has been developed by a powder metallurgical techniques.

2 - DESCRIPTION OF THE MIVAR

The MIVAR is a composite material developed in collaboration with the Material Research Center of the Ecole des Mines in Paris /2/, in the form of plates 2 mm-thick and 50 mm-diameter. It has a quasi-linear variation in density and in acoustic impedance according to its thickness, with a density limit of between 18.1 and 18.2 and an acoustic impedance ratio between the two faces of 29. This material has three constituent parts. The first two parts, based on metal powders, have been elaborated by a technique known as "slurry paint technique" combined respectively with sintering and H.I.P.. These two parts are bonded together, and the third part consists of plastic layers deposited by a spray painting technique. The MIVAR is developed on a tungsten alloy base 2 mm-thick, which has a density equal to 18.1. This base plate has a dual purpose : it both guarantees the levelness of the MIVAR during its fabrication, particularly during the H.I.P. process, and makes it possible to withstand the ramp-wave produced in the target struck by the MIVAR.

The basic principle of the MIVAR is that it allows for the substitution of the matter loaded by a single shock wave, with progressive loading by a series of longitudinal waves of weak amplitude. This principle is illustrated on figure 1 in cases where target material loading is either by an impactor whose acoustic impedance de-

Figure 1 - Schematic representation of a plate-impact experiment in case where target material loading is either by an impactor whose acoustic impedance decreases in steps (a) or one with gradually decreasing impedance (a'). Experimental concepts (a,a'), acoustic impedance profiles of MIVARs (b,b'), X-t planes (c,c'), ramp-wave profiles in the targets (d,d').

creases in steps or one with gradually decreasing impedance. In this latter case, the target is loaded by successive weak compression waves which propagate through the target as a compression ramp-wave. Let us now consider the case of solid target materials. For loading that causes stresses beyond the yield limit, plastic waves are generated. Because of the irreversible nature of this phenomenon always present, the loading of solids by means of MIVAR type generators is called quasi-isentropic.

3 - EXPERIMENTAL RESULTS

We shall present here the results of two plate-impact experiments in which the MIVAR is accelerated in a smooth-bore gun to collide with a planar target material.. These experiments were performed by means of a compressed gas gun /3/ for test number 1018, and a powder gun /4/ for test number 24. The characteristics of these experiments are given in table I.

Table I - Test conditions and experimental results.

test number	MIVAR thickness (mm)	target material	impact velocity (m/s)	measured particle velocity (m/s)	calculated stress (GPa)	rise time (ns)
1018	1.92	fused silica	564	515	5,86 ⁽¹⁾	1280
24	1.99	Ta/LiF	2005	1772	84 ⁽²⁾	910

⁽¹⁾ calculated from the stress-particle equation of fused silica given in ref.5.

⁽²⁾ calculated from the measured Ta-LiF interface velocity given in the table, by the impedance matching technique between tantalum /6/ and LiF /7/ target materials.

Figures 2 and 3 show the experimental arrangements and the particle velocity profiles measured with a VISAR interferometer. It should be noted that the ramp-wave is smooth for higher impact velocities. The different steps occurring in the ramp on figure 2 were confirmed by complementary experiments not shown here. These results raise a question about the method of fabrication of the MIVAR because its three constituent parts may be at the origin of these three quasi-steps. Furthermore the particle velocity profile of the figure 3 exhibits both an initial shock wave and a disturbance at mid-amplitude which will be interpreted by means of the numerical simulations presented in section 4 following.

As regards the interpretation of the unloading wave profiles, it can be concluded that : 1) the release wave for the test n°1018, which occurs 1.8 microseconds following the impact (fig. 2), is initiated at the interface between the impactor and the projectile material (2024 Al) ; 2) while the decaying particle velocity for the test n°24, which occurs after 1.1 microseconds (fig. 3), is assumed due to a loss of transparency of the LiF window as the shock wave reaches its free-surface.

4 - NUMERICAL SIMULATIONS

We have formulated constitutive equations of the MIVAR, both in order to interpret the previous experiments and to optimize the MIVAR characteristics for the future. The behavior of the MIVAR is assumed to be hydrodynamic, and the governing equations are restricted to the one-dimensional flow. Therefore, the numerical simulations will be restricted to experiments for which the hydrodynamic assumption is acceptable, that is to those in which impact velocities are high enough.

4.1. - Theoretical model

There are, to our knowledge, two radically differing approaches to the problem of perceiving the stress wave response of a composite material like the MIVAR. The first, illustrated in Drummheller's work /8/, is a micromechanical approach which considers the composite as a heterogeneous material constituted of several phases, and simulates its behavior by means of a computer code conceived for the treatment of multi-phase flows. We have not used this approach as it requires both an adequate computer code and an accurate formulation of the complex mechanical interactions between the constitutive phases. The second approach is macromechanical and considers the composite as a macroscopically homogeneous material. The density, the Hugoniot adiabat, even the Grüneisen's gamma of the composite material are deduced from those of its constituents, from assumptions which are the basis for the theory developed by Tsou and Chou /9/ in the case of fibered or layered composites, by Mc Queen et al /10/, Munson and Schuler /11/ and Hopkins /12/ in the case of powder mixtures. We have used this second approach for the simplicity of its formalism, and particularly the theoretical formulation derived by the two last investigators.

The model is based on the following four fundamental assumptions : 1) we suppose that the MIVAR is constituted of 25 macroscopically homogeneous and isotropic layers ; 2) we suppose that the shock behavior of the MIVAR is hydrodynamic ; 3) we suppose that the pressure is uniform in the different components of a layer ; 4) finally, we suppose that the mass fractions of the components of a layer remain unchanged during the MIVAR's compression.

We propose the formulation of a constitutive equation for the MIVAR whose parameters can be adjusted for each one of the layers. Mc Queen et al /10/ utilized a Mie-Grüneisen equation of state in which the parameters were derived from those of the components, assuming an interpolation rule between the values of the parameters for the individual components, based on the mass fraction of the constituents. For the room temperature Grüneisen's gamma, Hopkins /12/ points out that this interpolation procedure is unjustified. To avoid this area of uncertainty, we use a strictly mechanical formulation of the constitutive equation, such as that utilized by Hopkins. This formulation implicitly states that the thermal effects are ignored in the shocked MIVAR.

The density of a given layer of the MIVAR is given by the following equation in which α_i^j is the volume fraction of the i^{th} constituent of the j^{th} layer, ρ_i is the density of the i^{th} constituent, n is the number of constituents in the layer and N is the number of layers of the MIVAR :

$$\rho^j = \sum_{i=1}^n \alpha_i^j \rho_i, \quad j = 1, N \quad (1)$$

The ratio of this equation formulated at ambient pressure to the same equation formulated at a different pressure, defines implicitly the required equation of state. After reduction /13/, we obtain :

$$\frac{\rho_o^j}{\rho^j} = \sum_{i=1}^n \alpha_{o,i}^j \frac{\rho_{o,i}}{\rho_i}, \quad j = 1, N \quad (2)$$

in which the subscript "o" refers to conditions at ambient pressure. In order to express the pressure in this equation, we have defined the constituents of the MIVAR by a Murnaghan type equation whose parameters A_i and B_i are identified on the

Hugoniot adiabats of the constituents :

$$P = A_i \left[\left(\frac{\rho_i}{\rho_{0i}} \right)^{B_i} - 1 \right] \quad (3)$$

The equations (2) and (3) define the equations of state of the MIVAR's layers. Rearranging these two equations we obtain :

$$\frac{\rho_0^j}{\rho^j} = \sum_{i=1}^n \alpha_{0i}^j \left(\frac{P}{A_i} + 1 \right)^{-\frac{1}{B_i}}, \quad j = 1, N \quad (4)$$

This relatively simple model is characterized by the following four parameters : the volume fractions and the densities of the constituents at ambient pressure, respectively α_{0i}^j and ρ_{0i} , and the two parameters A_i and B_i .

4.2 - Numerical results

The above equation of state was introduced into a one-dimensionnal finite-difference computer code. To illustrate the capabilities of this model a representative calculation is presented here and compared to experimental result of the test number 24 defined in table I and figure 3. The volumetric behavior of the materials nitene 181, lithium fluoride, and tantalum, were described in terms of a Mie-Grüneisen type equation of state. Furthermore the shear behavior of tantalum was taken into account using an elastic-perfectly plastic model following the method formulated by Wilkins /14/. The physical constants of these materials are given in table II.

Table II - Data for impactor (MIVAR apart) and target equations of state^{1,2}

material	ρ_0 (g/cc)	C_0 (m/s)	S	γ_0	Y_0 (GPa)	G_0 (GPa)	Ref.
nitene 181	18.1	3970	1.23	1.43	-	-	/15/
LiF	2.64	5148	1.353	1.69	-	-	/16/
tantalum	16.66	3360	1.239	1.63	0.96	68.8	/17/

⁽¹⁾ $u_s = C_0 + Su_p$: u_s and u_p are respectively the shock velocity and particle velocity.

⁽²⁾ ρ_0 is the initial density, γ_0 is the Grüneisen's gamma, Y_0 is the yield strength, and G_0 is the shear modulus.

The comparison between computational and experimental results is depicted on figure 4. The computation is stopped at the peak of the particle velocity profile because the model cannot represent the remaining particle velocity as discussed in section 3. The initial shock reproduced by the calculation corresponds to the elastic wave traveling in the tantalum, which has been confirmed by computation runs performed elsewhere. On the other hand, one can see that the large disturbance at mid-amplitude of the experimental profile is not reproduced by the simulation. It is very probable, as discussed by Barker /1/, that the initial acceleration of the MIVAR during launching (about 3.10^5 m/s²) initiates tensile stresses that cause the MIVAR

Figure 2 - Measured particle velocity for experiment n°1018.

Figure 3 - Measured interface velocity for experiment n°24.

Figure 4 - Experiment n°24 - comparison between experimental and numerical particle velocity versus time without numerical treatment of MIVAR spall.

Figure 5 - Experiment n°24 - comparison between experimental and numerical particle velocity versus time with numerical treatment of MIVAR spall.

to spall. Micrographic examinations carried out on other MIVARs revealed a deficiency in the adherence between the first two parts of the MIVARs. So we have added to the previous numerical simulation run, the numerical treatment of a void 0.1 mm-thick between these first two parts. It can be seen in figure 5 that this model provides a reasonably accurate representation of the experimental data.

5 - CONCLUSION

A ramp-wave generating material called MIVAR has been developed using a powder metallurgical technique known as "slurry paint technique". The efficiency of this material has been proved up to 84 GPa by plate-impact experiments where the MIVARs were projected against target materials in which particle velocities versus time profiles were measured by means of a VISAR interferometer. A model of hydrodynamic behavior of the MIVAR was elaborated and numerical simulations carried out using this model confirmed structural defects of this material. A more efficient MIVAR is presently under development.

ACKNOWLEDGEMENTS - The author thanks B. Jimenez and S. Chambaudie for undertaking the experiments and Y. Lagarde for his help in numerical simulations.

REFERENCES

- /1/ Barker, L.M., in : *Shock Waves in Condensed Matter*, ed. J.R. Asay et al. (North-Holland, Amsterdam 1984) 217.
- /2/ Jeandin, M., private communication.
- /3/ Chartagnac, P., et al., *Revue de Physique Appliquée (France)* **19** (1984) 609.
- /4/ Thiot, P., and Chartagnac, P., in : *38th Meeting of the Aeroballistic Range Association*, Tokyo Inst. of Technology editor (1987).
- /5/ Barker, L.M., and Hollenbach, R.E., *J. Appl. Phys.* **41** N°. 10 (1970) 4208.
- /6/ Marsh, S.P., ed., *LASL Shock Hugoniot Data* (University of California Press, Berkeley 1980) 136.
- /7/ Wise, J.L., and Chhabildas, L.C., in : *Shock Waves in Condensed Matter*, edited by T.M. Gupta (Plenum Press, New York 1986) 441.
- /8/ Drumheller, D.S., *J. Appl. Phys.* **53** N°. 2 (1982) 957.
- /9/ Tanc, F.R., and Choi, P.C., *J. Composite Materials* **4** (1970).
- /10/ Mc Queen, R.G., et al., in : *High Velocity Impact Phenomena*, ed. R. Kinslow (Academic Press, New York 1970) 263.
- /11/ Munson, D.E., and Schuler, K.W., in : *Shock Waves and the Mechanical Properties of Solids*, ed. J.J. Burke and V. Weiss (Syracuse University Press, New York 1971) 185.
- /12/ Hopkins, A.K., Air Force Materials Lab., Wright-Patterson Air Force Base, Ohio, Report TR-70-158, AD712082 (1970).
- /13/ Perez, M., Unpublished data.
- /14/ Wilkins, M.L., in : *Methods of Computational Physics*, **3**, eds. B. Alder et al. (Academic Press, New York) 211-283.
- /15/ Perez, M., Unpublished data.
- /16/ p_0 , C_0 , and S are from ref. 6 ; γ_0 is from Ref. 17.
- /17/ Isbell, W.M., Christman, D.R., and Babcock, S.G., U.S. Defense Nuclear Agency Report DASA 2501-6, AD741217 (1971).
- /18/ Steinberg, D.J., Lawrence Livermore National Laboratory Report UCID 20243 (1984).