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HIGH-PRESSURE RANGE SHOCK WAVE DATA FOR SYNTACTIC FOAMS

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Abstract. Syntactic foams [SF] are a porous composite material resulting from the mixture of Hollow Glass Micro Spheres [HGMS] with a polymeric binder. Beyond a set of technological advantages over the polymer considered alone, SF present as an essential feature the possibility to control in wide limits the amount, the shape and the size of the pores and for that reason are being used for benchmarking in the area of shock wave [SW] behavior of porous materials. In this paper, SW loading experiments of SF samples were performed in order to assess the high-pressure range Hugoniot equation of state as a function of the SF initial density. Hugoniot data were assessed coupling the SW velocity within the SF samples with the SW velocity in a reference material or with manganin gauge results. The results obtained present a significant variation with the initial specific mass and can be described with appreciable precision by the Thouvenin/Hofmann Plate Gap model, while the concordance between the experimental results and the Grüneisen model seems to be very dependent on the Grüneisen coefficient values.

Keywords: Syntactic Foams, Hugoniot, Plate Gap Model.
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INTRODUCTION

Syntactic Foams [SF] are a porous composite material that result from the mixture of Hollow Glass Micro Spheres [HGMS] with a polymeric binder. There is a set of well know advantages over the polymer considered alone that makes this material suitable for application in areas as ablative products for rocket coatings and engine thrust reversers, honey comb replacements in composites of thin sections subjected to point loads and in structures where water penetration is a problem: stealth (radar and sonar invisible) products, anticorrosion systems for under water applications, deep immersion buoyancy (submarines and off-shore platforms) and electromagnetic shields for aerospace structures and micro satellites. Beyond that, this kind of material presents as an essential feature the possibility to control the amount, the shape, the size and even the relative position of the pores, being for that reason used for benchmarking in the area of shock behavior of porous material. It is also because of those features that these kinds of materials are called Syntactic Foams, with the word syntactic, from the Greek *syntáxis*, meaning ordered, at least in comparison with the great majority of the other kinds of foams. Despite of the very interesting properties and extremely wide range of application areas, this material has not received much more attention from people working in the shock compression of condensed matter beyond that given by Maw et al. [1], Salisbury et al. [2] and Ribeiro et al. [3]. Intending to contribute to the increase of knowledge of its high-pressure SW behavior, in this paper Hugoniot data, assessed coupling the SW velocity within the SF samples with the SW velocity in a reference material, or using manganin gauges results, will be presented as a function of the foam initial density and compared with the predictions of Mie-Grüneisen and Thouvenin models.

EXPERIMENTS

Material description

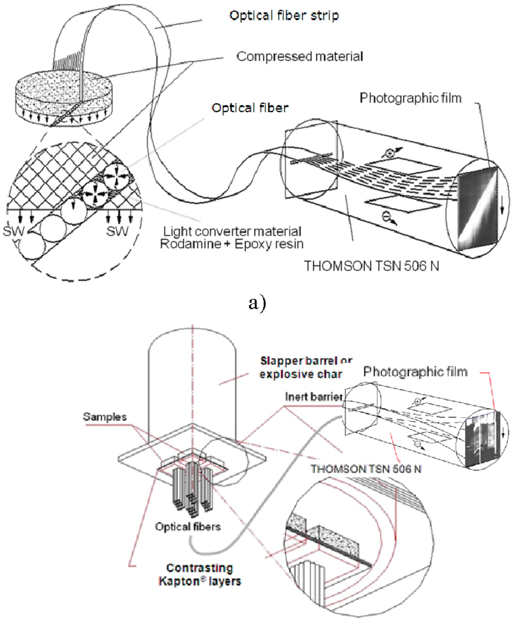
HGMS from AKZO-Pennsylvania Quartz Corporation (Q-CEL 300) and from 3M (K-20) were used with polyester resin (AROPOL FS-6944 Ashland Chemical Spain) and epoxy resin (EP 520 - HD 523 Ashland Chemical Spain), respectively, in the SF preparation.

Experimental technique

Both explosive shock and electric accelerated plate impact were used for high-pressure shock loading. An impedance matching technique, measuring the SW propagation velocity in the samples and in a reference material shock loaded in the same conditions, or manganin gauge pressure time histories, were used for the Hugoniot data determination. The main element of the diagnostic technique for measuring the SW velocity is an optical fiber strip with 64 independent channels with 250 µm of diameter each [4]. This fiber can be inserted within the samples as it is shown schematically in Fig. 1 a) or placed under the samples and orientated toward the incoming SW as can be seen in Fig. 1 b).

TABLE 1. SF samples composition and densities.

Name	HGMS	Resin	HGMS /Resin, w/w	ρ, g/cm^3
RP5	Q-Cel	Polyester	5	0.970
RP10	Q-Cel	Polyester	10	0.849
RP25	Q-Cel	Polyester	25	0.642
EP17	K-20	Epoxy	17	0.690
EP22	k-20	Epoxy	22	0.625



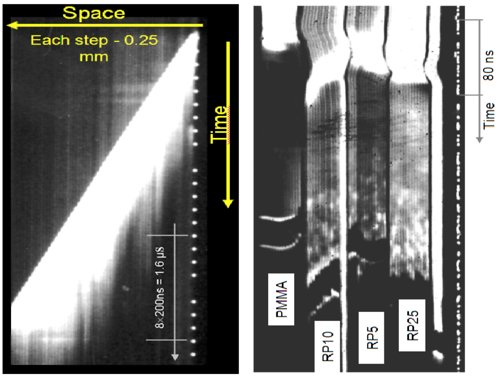
a)

b)

Figure 1. Experimental techniques used to measure the SW velocity within the samples and reference materials using an optical fiber strip.

In the first of the described configurations the simultaneous compression of the sample, the fibers and a light converter material placed between them allow the monitoring of the shock propagation and the evaluation of its velocity at each 250 µm of propagation. In the second case, used just for thin samples, with thickness less than 1 mm, the semi-transparency of the samples and the emission of the light during the propagation of the SW within the samples, is used to determine the propagation time in the samples and, by this way, once the thickness is known, the average propagation velocity.

Typical streak records obtained with the setup shown in Fig. 1 a) and b) can be seen in Fig. 2 a) and b), respectively. Streak records like the ones shown in Fig. 2 a) allow the evaluation of the SW velocity with the propagation distance and, fitting a 2nd order polynomial to that data, the extrapolation of the velocity for the sample input surface. Streak records like the one shown if Fig. 2 b) allow only the evaluation of an average SW velocity. Once the SW propagation velocity in the samples and in a reference material is known, it is possible, using the well know impedance matching technique [5], to calculate the Hugoniot data. Experiments involving the use of two manganin gauges have also been performed. In order to increase the gauges survivability, as shown in Figs. 3 and 4, 125 and 250 µm thick layers of Kapton were used between the gauges and the sample.



a) b)

Figure 2. Typical streak records obtained with experimental configurations shown in Fig. 1 a) and b) respectively.

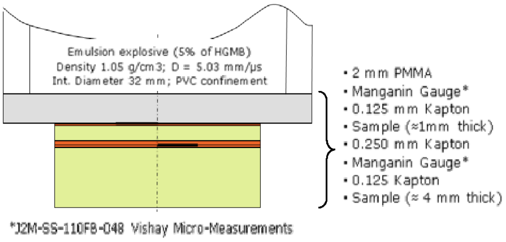


Figure 3. Experimental setup involving the use of manganin gauges.

The typical pressure-time histories obtained with this experimental configuration are shown in Fig. 4. Due to the complex reflection phenomena between the 2 mm thick PMMA buffer plate, the 125 µm Kapton layer and the foam, is difficult to use the data from the input gauge for SW amplitude evaluation, so, for that reason, that was evaluated based on the results of transmitted gauge signal. The pressure value considered for Hugoniot calculations is the mean value of the oscillations observed, after a first spike, for the transmitted gauge results. The propagation velocity is evaluated from the time difference between the two manganin gauge results discounting the time for the propagation in the Kapton layers.

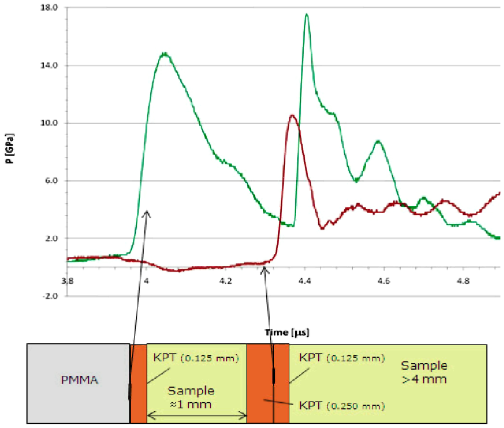


Figure 4. Manganin pressure-time histories for the input and transmitted waves.

Results and Discussion

Hugoniot data evaluated as described above is presented in the graphic of the Fig. 5 in the U_s-U_p plane. Excluding the very low U_p range, the results show a linear behavior for all the densities.

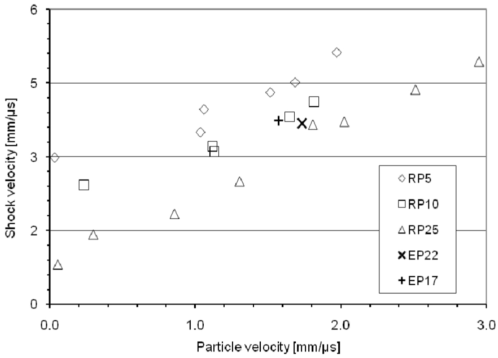


Figure 5. Shock Hugoniot data in the U_s-U_p plane.

Together with the experimental data in the P-v plane, in the graphics of the Fig. 6, are also shown the Hugoniot curves predicted by the Grüneisen and by the Thouvenin/Hofmann models. Both models are very well known and detail descriptions can be found elsewhere [5-7]. Data description by the Thouvenin/Hofmann model can be considered good but data description by Grüneisen cannot be considered so. One of the reasons for that can be related to the extreme dependence of the results obtained with this model on the Grüneisen coefficient values, as stated by Oh *et al.* [8], small errors in that coefficient can lead to big errors in the calculated pressure. In both (Grüneisen and Thouvenin) models all the solid material properties necessary for the porous Hugoniot calculation were determined by mass averaging.

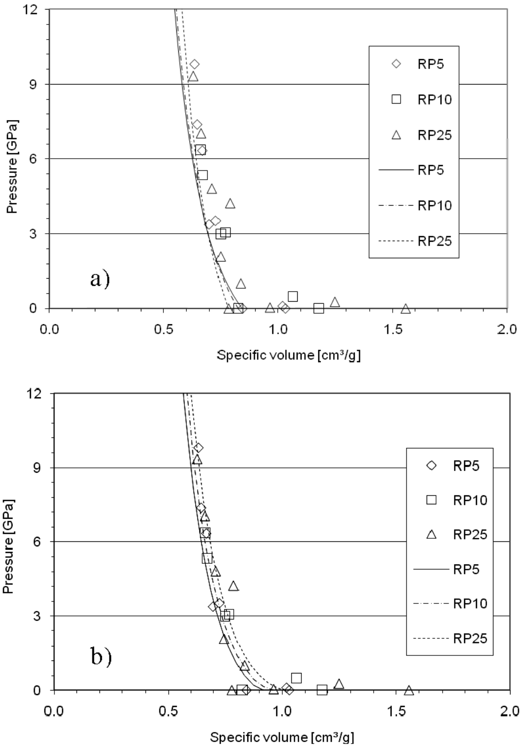


Figure 6. Experimental data and Mie-Grüneisen a) and Thouvenin/Hofmann (or Plate Gap) b) Hugoniot calculations in P-v plane.

The values of the Grüneisen coefficients were evaluated using Eq. 1, where α is the linear thermal expansion coefficient, K is the isentropic bulk modulus and C the specific heat, and engineering data available in material properties databases.

$$\Gamma = \frac{3\alpha \times K}{C}, \qquad (1)$$

The values of Γ used for the calculations shown on the Fig. 6 a) were, 0.933, 0.915, and 0.870 respectively for RP5, RP10, and RP25 samples.

CONCLUSIONS

Shock waves were used for dynamic loading of polyester and epoxy based SF samples in the pressure range from 0.2 to 10 GPa. The results obtained show significant differences arising from the initial densities of the SF samples, as expected. Data description by the Thouvenin/Hofmann model can be considered good while the Grüneisen description, with the Γ values used, does not match so well the experimental results.

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