DETERMINATION OF THE COMPERSSION STRENGHT OF HEA IN HIGH STRAIN RATES TESTS

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Abstract: *The new manufactured alloy based on the high entropy principle was submitted to a testing program involving both static and dynamic regime. The high strain rates were obtained by using a Split Hopkinson Pressure Bar. Basic mechanical properties, like elastic modulus and compressive strength, were determined. The tested alloy exhibit high yield strength and a brittle behavior.*

Keywords*: HEA, SHPB, compression test;*

1. Introduction

High entropy alloys (HEA) represent a new class of alloys that consist of 5 or more metallic elements in equiatomic proportions [1]. HEA concept is based on the Boltzman equation from statistical thermodynamics, where multielement alloys with equiatomic proportions develop preponderant solid solution structures, due to the increased configurationally entropy. The elements mostly used in the development of HEA alloys, due to their properties, are Al, Co, Cr, Fe, Mn and Ni [2]. Due to their similar characteristics, transitional elements are often used as the core elements for building high entropy compositions. Elements with different atomic sizes, such as Al and Si are used to further strengthen the material and/or to tailor composition-property relationship.

Most of the high entropy compositions studied have average to high densities due to the composition rich in transitional elements. In order to achieve improved performances in automotive and aerospace applications high entropy alloy structures need to maintain their properties at low densities. A new category of low weight high entropy alloys (LWHEA) emerged and was already studies by few authors.

Present work discusses the results of a mechanical testing program done on samples obtained from an AlCuSiZnMg alloy (3.59 g/cm^3).

2. Theoretical aspects of SHPB tests

Use of the SHPB installation, in classical configuration, will induce a dynamic uniaxial stress state in the tested specimen by the means of two rods impact, Fig.1. The impact will generate an elastic impulse. In the ideal conditions and when the aspects like wave dispersion and attenuation are neglected the wave will have a “step signal” shape, the intensity and the duration being related to the impact velocity and the projectile length. The axial stress attained in such wave is

$$\sigma_0 = \rho \cdot c_0 \cdot \frac{v_0}{2}, \tag{1}$$

where ρ is the SHPB bars density and c_0 the speed of sound for the same bars, and the wave duration is

$$t = \frac{2l_{pr}}{c_0} \tag{2}$$

where l_{pr} is the lenght of the projectile.

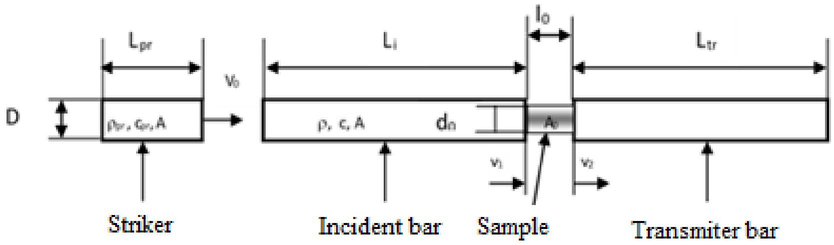

Fig. 1 Classical configuration of SHPB [3]

The elastic wave generated by the impact travels through the incident bar, reaches the specimen and a complex transmitting/reflecting process, dominated by the geometrical dimensions and mechanical properties of sample, is started. Through this process the sample is deformed as long as on it’s both ends act increasing forces. While sample suffers only small deformations, in the elastic domain, the forces on the sample ends can be estimated by calculation of the repeated wave reflections/transmissions which occurs at the both ends of the sample.

To quantify the amplitudes of the stresses and the amount of wave reflected and transmitted at the interfaces is necessary to analyse the dynamics of the each end. At each sample-bar contact interface the speed of both materials is the same as long as is assumed an intimate contact of materials during the test. To meet the equilibrium conditions the forces on the left and the right of the interface must be equal. By imposing these two conditions, can be written equations that describe the effects of interfaces on wave propagation [4]. The equations sistem for the first reflection/transmision, between incident bar and sample, is:

$$\begin{cases} \dfrac{\sigma_0 - \sigma_1}{\rho c_0} = \dfrac{\sigma_1^{'}}{\rho^{'} c_0^{'}} \\ A(\sigma_0 + \sigma_1) = A^{'} \sigma_1^{'} \end{cases}; \tag{3}$$

The equations sistem for the second reflection/transmision, between sample and transmission bar, is:

$$\begin{cases} \dfrac{\sigma_1^{'} - \sigma_2^{'}}{\rho^{'} c_0^{'}} = \dfrac{\sigma_2}{\rho c_0} \\ A^{'}(\sigma_1^{'} + \sigma_2^{'}) = A \sigma_2 \end{cases}. \tag{4}$$

With the superscript index ‘ are identified the properties of the sample and the stress subscript index is associated with the number of the reflection/transmission. Using the same conditions a general formula for the n’th reflection/transmission can be obtain. Based on such data a theoretical force vs. time evolution can be drawn for both end ends of the sample. The ascending portion of forces evolution in time for a sample with low mechanical impedance is given in Fig. 2.

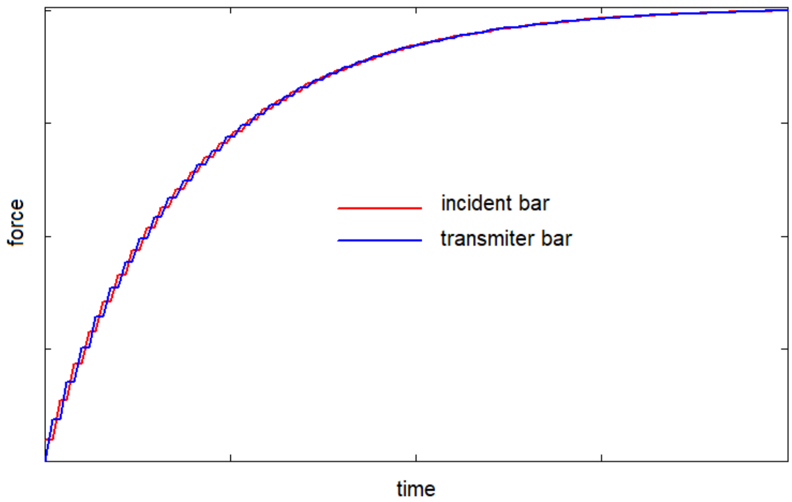

Fig. 2 Typical evolution of forces exerted by the bars on the sample

3. Preparation of SHPB tests

The SHPB developed in MTA is made of two steel bars of 20 mm diameter and 2000 mm length. The projectile of similar diameter and 400 mm length is accelerated in an air gun. The elastic deformation occurred in input and output bars is measured with strain gages mounted on both bars at a distance of 800 mm from the specimen. Each Wheatstone bridge is connected to an Ectron 778 conditioner. The output signals of the conditioners are recorded by a Picoscope 6403. The recorded voltage is converted in strain for both bars based on the strain gage sensitivity constants.

The manufactured samples were cylinders of 6 mm diameter and 6 mm length. Experimental data from the compression static tests performed with the samples of the same size on the universal testing machine TC100 were used to calculate the elastic modulus at $39*10^9$ Pa. The compression strength for static regime was estimated from the same test at 820 MPa and the engineering failure strain at 0.04.

Using the algorithm from the previous section was calculated the impact velocity necessary to reach in samples a stress slightly higher than the compression strength above mentioned. A value of 3.8 m/s was determined to be sufficiently high to achieve the wanted stress in the sample.

For the measurement of the impact velocity the high speed camera Photron ZA2 and the PFA image analysis software were used.

4. SHPB tests results and discussions

Several tests were performed with impact velocity around 3.8 m/s, for each test being recorded the impact and the signals emitted by Wheatstone bridges, see fig. 3. As regarding the samples integrity there were mixed results, some samples maintained their integrity while others present cracks and small pieces missing, fig. 4.

Fig.3 Signal acquired by oscilloscope during the SHPB test were the sample preserves its integrity

Fig.4 Samples aspect after the SHPB test

The strain rate and stress occurred in the sample where calculated using the strain history recorded for both bars [5]. The maximum stress attained in samples span between 720 and 820 MPa, see fig.5. This situation indicates a scatter of the failure strain, between 0.02 and 0.04.

In order to estimate the proportionality limit of the tested material a comparison between the experimental data and the model developed in section 2 was done. The curves are matching till around 650 MPa, see fig. 6, value which is assumed as the proportionality limit (yield stress).

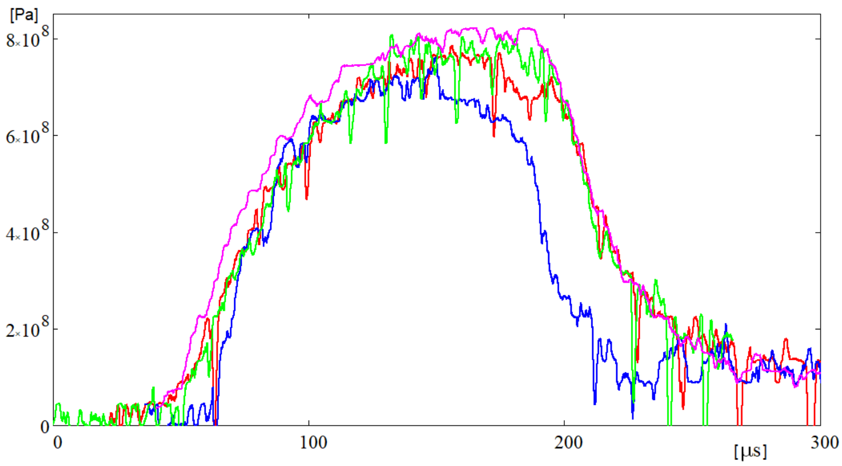

Fig. 5 The axial stress occurred in sample for several SHPB tests based on the signal acquired with the strain gauge bridge in the transmitter bar

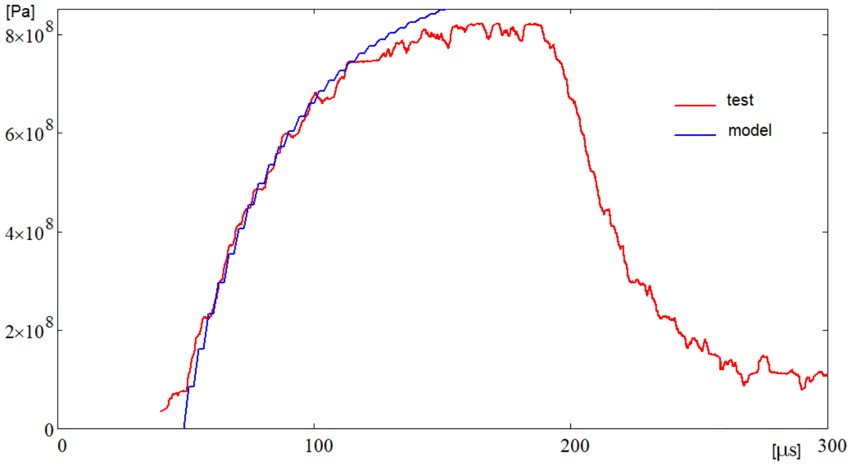

Fig. 6 Comparison between the experimental data and the mathematical model (at impact velocity 3.9 m/s)

5. Conclusions

Based on previous considerations, the following conclusions can be drawn:

- The tested HEA material exhibits a brittle behavior, with an high yield stress, over 650 MPa, and a small failure strain, between 0.03 and 0.04
- The mathematical model for the multiple reflections/transmissions at the sample interfaces, developed in the hypothesis of elastic sample, may be use as a tool for the determination of the proportionality limit (yield stress) in the high strain rates conditions

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