DESIGN OF A SPLIT HOPKINSON PRESSURE BAR

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Abstract. *This paper aims to clarify some important aspects about the design of a Split Hopkinson Pressure Bar (SHPB) apparatus. This machine is used to obtain the stress-strain relations at different high strain rates. The already well-established theory of the SHPB is presented and the major variables for the design of a SHPB are throughly explored. A study case is shown, highlighting the major variables one needs to deal with in order to properly design the SHPB.*

Keywords. *Hopkinson bar, elastic waves, material characterization, high strain rates.*

1. Introduction

The scientific community has always sought to model the behavior of the different kinds of existing materials. Elastic and elasto-visco-plastic material models were developed and have been extensively used in the description of the behaviour of metals. All these models need to rely on parameters that should always be measured so experimental apparatus have been extensively developed. Among these rigs, the traditional tensile test machine is the major equipment for measurement of quasi-static material properties, while the Split Hopkinson Pressure Bar (SHPB) became the chief experimental technique to obtain dynamic material properties.

The Split Hopkinson Pressure Bar experimental technique, also known as Kolsky Bar, was invented by Kolsky in 1949. The apparatus consists of a specimen, the tested material, sandwiched between two elastic bars (see Fig. 1). A right-traveling compressive stress pulse is generated in the input bar. When the pulse reaches the bar-specimen interface, it is partially transmitted through the specimen and partially reflected. The reflected and transmitted pulses are measured by strain gages located in the input and output bars. The recorded signals can be used in the data analysis to determine the strain history of the specimen. The compressive pulse is generated by the impact of a striker bar against the input bar. The striker is usually accelerated by a gas gun specially developed for this purpose. For additional details the reader is referred to Zukas et al. (1983).

Since its invention, the SHPB has undergone several modifications. It was adapted to do tensile tests (Lindholm et al., 1968), torsion tests (Bassim et al., 1999), simultaneous compression and torsion (Lewis et al., 1973), fracture dynamics (Klepaczko, 1979), among other variations. Harding (1980) presents several of these variations the SHPB has undergone over the time. In particular, Nemat-Nasser et al. (1991) developed novel techniques to the SHPB, which allow the execution of compression tests followed by tension, allowing the analysis of the Bauschinger effect under high strain rates. The techniques shown in Nemat-Nasser et al. (1991) allow also the execution of dynamic recovery experiments, in which the specimen is subjected to a pre-assigned stress pulse and then recovered without additional loading for post-test microstructure analysis. Tests with the SHPB under conditions of high temperature have been also reported (Muller, 1972).

Meng et al. (2003) has used a wave separation technique to reduce time-shifting distance between bar-specimen interface and strain gage station, therefore minimising wave dispersion and attenuation in the SHPB test. The employed wave separation technique consists of a two-point strain measurement method able to split the incident and reflected waves.

As part of a program to characterize material behaviour under dynamic conditions, a SHPB is being designed in the authors institution, which demanded for a mathematical analysis of the wave propagation in bars, as presented in sections 2, 3 and 4 of this article. Section 5 will deal with the data analysis of the various signals generated in a dynamic test using a SHPB. The instrumentation required in a typical experiment will be described in section 6, with section 7 presenting a case study to meet some design constrains.

2. Mathematical modeling

The basic equations in which the principle of the SHPB is based can be obtained when assuming that the stress waves travel through the specimen fast enough so that the propagation time interval is small when compared to the total test time. This allows for several reflections to occur in the ends of the tested specimen so that it can be assumed that the specimen presents a uniform state of stress and strain. Moreover, the hypothesis of a uniaxial stress state is implied, which can be guaranteed through the use of lubricant (normally MoS_2) between bars and specimen. Finally, it is assumed that the stresses and velocities in the specimen ends are transmitted through the incident (input bar) and transmitter (output bar) bars without dispersion. Adopting the same material and cross sectional area for both input and output bars, simple expressions for stress, strain and strain rate in the specimen are now obtained.

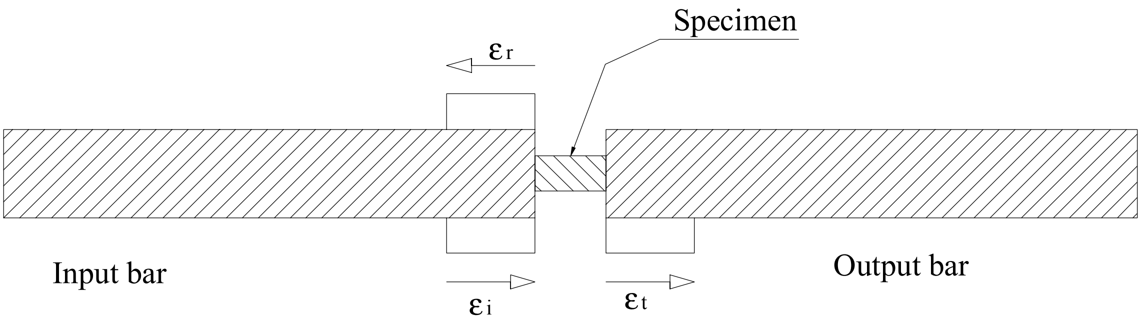

Figure 1. Working principle of the SHPB.

Consider Fig. 1, in which the incident, reflected and transmitted pulses, ε_i, ε_r and ε_t, are shown. The displacements, u, at the ends of the specimen are given by (Zukas et al., 1983 and Johnson, 1973)

$$u_1 = \int_0^t c_0 \varepsilon_1 dt \tag{1}$$

and

$$u_2 = \int_0^t c_0 \varepsilon_2 dt , \tag{2}$$

where $c_0 = \sqrt{E/\rho}$ is the velocity of the elastic wave in the bars and the subscripts 1 and 2 refer, respectively, to the left and right end of the specimen. Equations (1) and (2) can be rewritten as a function of the incident, reflected and transmitted pulses:

$$u_1 = c_0 \int_0^t (\varepsilon_i - \varepsilon_r) dt \tag{3}$$

and

$$u_2 = c_0 \int_0^t \varepsilon_t dt . \tag{4}$$

Observe that in this article, compressive stresses and strains have positive sign. In view of an assumed uniform state of stress and strain in the specimen thickness, its strain, ε_s, is given by the expression below:

$$\varepsilon_s = \frac{u_1 - u_2}{L_s} , \tag{5}$$

where L_s represents the specimen length. Substituting Eq. (3) and (4) into Eq. (5) the strain the specimen is subject to is given by:

$$\varepsilon_s = \frac{c_0}{L_s} \int_0^t (\varepsilon_i - \varepsilon_r - \varepsilon_t) dt . \tag{6}$$

The forces acting on the specimen ends are obtained from:

$$P_1 = EA(\varepsilon_i + \varepsilon_r)$$
and (7)
$$P_2 = EA\varepsilon_t ,$$

where E and A are the elastic modulus and the cross sectional area of the incident and transmitter bars, respectively. Since the specimen is in equilibrium, $P_1 = P_2$, so that, from Eqs. (6) and (7), it follows:

$$\varepsilon_i + \varepsilon_r = \varepsilon_t \tag{8}$$
and
$$\varepsilon_s = \frac{c_0}{L_s}\int_0^t (\varepsilon_i - \varepsilon_r - \varepsilon_r - \varepsilon_i)\,dt \ . \tag{9}$$

The stress, strain and strain rate acting on the specimen can then be calculated by the following equations:

$$\varepsilon_s = \frac{-2c_0}{L_s}\int_0^t \varepsilon_r \, dt \ , \tag{10}$$

$$\sigma_s = E\frac{A}{A_s}\varepsilon_t \ , \tag{11}$$

$$\dot{\varepsilon}_s = \frac{-2c_0}{L_s}\varepsilon_r \ , \tag{12}$$

where A_s is the cross sectional area of the specimen. Note that one needs to know the bar elastic modulus, density, cross-section area and the specimen geometry, in order to fully characterize the material response to dynamic loads provided the reflected and transmitted waves can be measured. These waves are nowadays measured with transient recorders, which capture the strain gauge signals fixed in the bars (see section 6). It should be kept in mind, as pointed out by Zukas et al. (1983), that the stresses, strains and strain rates calculated by the above expressions represent only average values.

3. Equations for the design of the SHPB

Stress, strain and strain rate within the specimen are the most important requirements to be taken into account when designing a SHPB. These variables are connected with the material to be tested, e.g., steel, non-ferrous metals, ceramic and with the strain rate range aimed. These requirements are closely connected to some design variables as the length of the stress pulse, the level of stress in the bars, the cross sectional areas of bars and specimen, the impact velocity, among others.

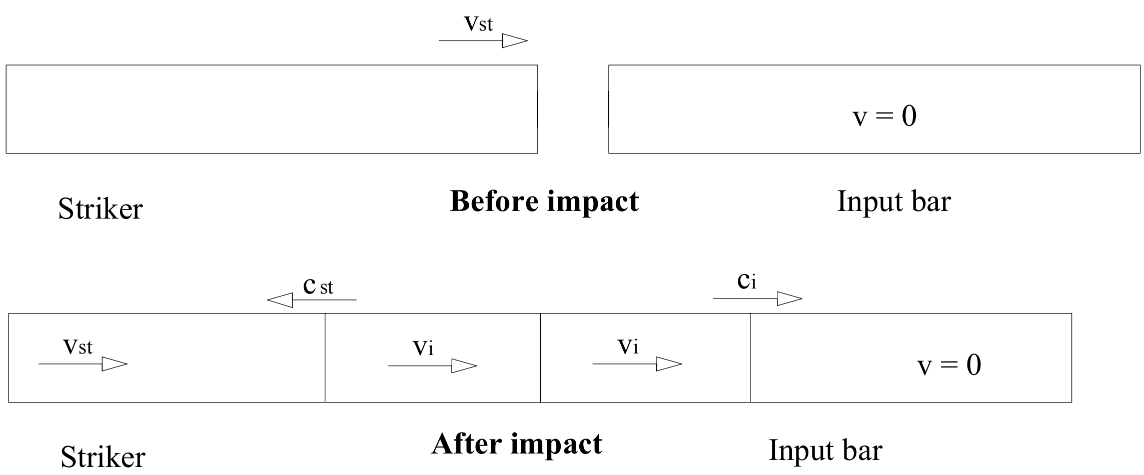

Figure 2. Stress pulse generation.

Consider Fig. 2 in which the coaxial impact between the striker and input bar can be observed. Before the contact between the bodies, the striker travels with a velocity v_{st} while the input bar stays at rest. During the impact, the force acting on the striker and bar in the common interface is equal and so is the velocity, v_i ($0 < v_i < v_{st}$, after impact). If σ_{st} and σ_i are the stresses generated in the striker and input bar, respectively, the following expression is valid:

$$A_{st}\sigma_{st} = A\sigma_i \,, \tag{13}$$

where A_{st} is the striker cross sectional area. The stresses σ_{st} and σ_i are related with the velocity in the common interface[1] according to

$$\sigma_{st} = \rho_{st} c_{st} \left(v_{st} - v_i\right) \tag{14}$$

and

$$\sigma_i = \rho c_0 v_i \,, \tag{15}$$

where ρ_{st} and ρ are the densities and c_{st} and c_0 are the velocities of the elastic wave in the striker and in the input bar. Substituting Eqs. (14) and (15) in Eq. (13) one has:

$$v_i = \frac{\beta v_{st}}{1+\beta} \,, \tag{16}$$

where

$$\beta = \frac{A_{st}\rho_{st}c_{st}}{A\rho c_0} \,. \tag{17}$$

Substitution of the above equations in Eqs. (14) and (15) allows the calculation of the stress in the striker and input bar:

$$\sigma_{st} = \frac{\rho_{st} c_{st} v_{st}}{1+\beta} \tag{18}$$

and

$$\sigma_i = \frac{\rho c_0 \beta v_{st}}{1+\beta} \,. \tag{19}$$

The striker and the input bar remain in contact until the pulse generated in the striker reflects from its end as a tensile pulse, traveling towards the contact interface. The time, t_p, needed by the pulse to return to the contact interface is equal to:

$$t_p = \frac{2L_{st}}{c_{st}} \,,$$

where L_{st} is the length of the striker. Therefore, the pulse length, L_p, generated in the incident bar is given by:

$$L_p = c_0 t_p = 2L_{st}\frac{c_0}{c_{st}} \,. \tag{20}$$

which is a determinant parameter of the strain level in the specimen, as shown below.

The stress pulse set in the incident bar by the striker impact reaches the specimen and it is partially reflected and partially transmitted. The intensity of the transmitted pulse, σ_t, which is a design variable, must guarantee to load the specimen with a specific stress level, σ_s. According to Eq. (11), the stress transmitted is given by

$$\sigma_t = \frac{A_s}{A}\sigma_s \,. \tag{21}$$

The reflected pulse, σ_r, is a design variable proportional to the strain rate in the specimen (see Eq. (12)). On its turn, the strain rate is also a design requirement so that

$$\sigma_r = \frac{E L_s}{-2c_0}\dot{\varepsilon}_s \,. \tag{22}$$

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[1] Elastic impact between two bars is presented at length by Johnson (1973).

In order to satisfy the requirements expressed in Eqs. (21) and (22), the incident pulse that travels through the input bar is

$$\sigma_i = \frac{A_s}{A}\sigma_s + \frac{EL_s}{2c_0}\dot{\varepsilon}_s\,, \tag{23}$$

obtained using Eqs. (8), (21) and (22). Now, if expression (19) is substituted into Eq. (23), the impact velocity, v_{st}, a design variable can be obtained as a function of the design requirements σ_s e $\dot{\varepsilon}_s$, according to

$$v_{st} = \frac{1+\beta}{\rho c_0 \beta}\left(\frac{A_s}{A}\sigma_s + \frac{EL_s}{2c_0}\dot{\varepsilon}_s\right). \tag{24}$$

This equation allows the calculation of the striker velocity so a given strain rate and stress level in the specimen is achieved.

The last design requirement to be satisfied is the maximum deformation to which the specimen is subjected. Accordingly to Eq. (10), the strain in the specimen is directly proportional to the intensity of the stress pulse and to the time duration of the incident pulse. Assuming that the reflected pulse is constant, the duration time of the pulse, t_p, is given by

$$t_p = \frac{\varepsilon_s L_s}{-2c_0\varepsilon_r}. \tag{25}$$

which, together with Eq. (20), gives a relation between the length of the pulse (design variable) and the required specimen's strain:

$$L_p = \frac{\varepsilon_s L_s}{-2\varepsilon_r}. \tag{26}$$

According to the conventional SHPB technique, the length of the input and output bars must be greater than the length of the greatest pulse that will be transmitted by them. This requirement is necessary to avoid superposition of the stress pulse with its own reflections in the strain gage stations. The two-point strain measurement technique used in (Meng et al., 2003) allows a significant reduction of the space occupied by the bars. The size of the striker necessary to obtain the required strain can be determined from the pulse length (see Eq. (20)).

The previous analysis presumes that the striker, incident and transmitter bars work in the elastic regime, therefore it must be checked in the design phase if the stresses are below the yield limit of the material. The equations presented here are sufficient for the calculation of the main design variables of the SHPB.

4. Calculation in the critical operational conditions

The SHPB has two critical operational conditions: tests at high strain rates and tests at low strain rates. In the first case, the maximum strain rate that can be reached depends on the maximum stress supported by the bars with no yield. Because of this, the materials to be chosen for the construction of the bars must have high yield strength. Titanium, whose yield stress is approximately between 1000 to 1200 MPa, maraging steel, tool steels or heat treated alloy steels are materials that meet this requirement.

The maximum strain rate of the test can be also increased through the reduction of the specimen length (see Eq. 12). Unfortunately the reduction of the specimen is bounded by the limitations imposed by its manufacturing. Some researchers use to do the tests with a thin sheet as compression specimen, aiming at increasing the strain rate and consequently reducing the intensity necessary for the stress pulse. Also, for a small relation L_s/d_s (where d_s is the specimen diameter), the friction in the specimen ends leads to a non-uniaxial stress state, which could invalidate the data.

It is worth to remind that the equations derived above were obtained from the hypothesis that the stress state in the specimen was uniaxial. Staab et al. (1991) used a tension version of the SHPB to investigate the influence of the ratio L_s/d_s on the results. They showed that the length to diameter ratio affected the results only when L_s/d_s was smaller than 1.6. For larger values, the results were practically indistinguishable.

In the case of a low stain rate test, the limitation is imposed by the length of the bars. As already said, if the conventional SHPB set-up is adopted, the length of the largest pulse that can be transmitted should be smaller than the length of the input and output bars. However, if the set-up suggested by Meng et al. (2003) is used, then a significant reduction of the bar length can be achieved. Therefore, when the designer defines the size of the bars, the maximum length of the stress pulse is automatically set.

Equation (26) shows that the maximum specimen strain (design requirement) is directly proportional to the pulse length. If the test is to be done at high strain rate, the reflected pulse ε_r is large and therefore the pulse length can be small. In this operational condition, the maximum required specimen strain is easily reached. But when the strain rate is low, the reflected pulse has reduced intensity and therefore the length L_p must be large to ensure that the required strain is reached.

In general, for low strain rates, the maximum specimen strain cannot be large, because high strains require large values of L_p, sometimes impractical due to the available room for the SHPB installation. Equation (26) could give the false impression that the reduction of the specimen length would imply in a reduction of the necessary pulse length, but this is not true. For a constant strain rate, an alteration in L_s implies in an equal change in the reflected pulse intensity and therefore the action of both effects would cancel each other.

5. Data analysis

The data analysis of the conventional SHPB set-up consists simply in the integration of the recorded ε_r signal and in solving Eqs. (10) to (12) in order to obtain the stress, strain and strain rate to which the specimen was subjected during the test.

The set-up proposed by Meng et al. (2003), which makes use of a two-point strain measurement technique has, in addition to the data analysis of the conventional SHPB, some specific operations required by such technique. In the new set-up, two strain gages are placed on the input bar close to each other and near bar-specimen interface (see Fig. 3). This minimizes wave dispersion and attenuation in the SHPB test and allows a reduction of the bars length. As the measurement of strain happens in two different points, it is possible to separate the superposed incident and reflected pulses.

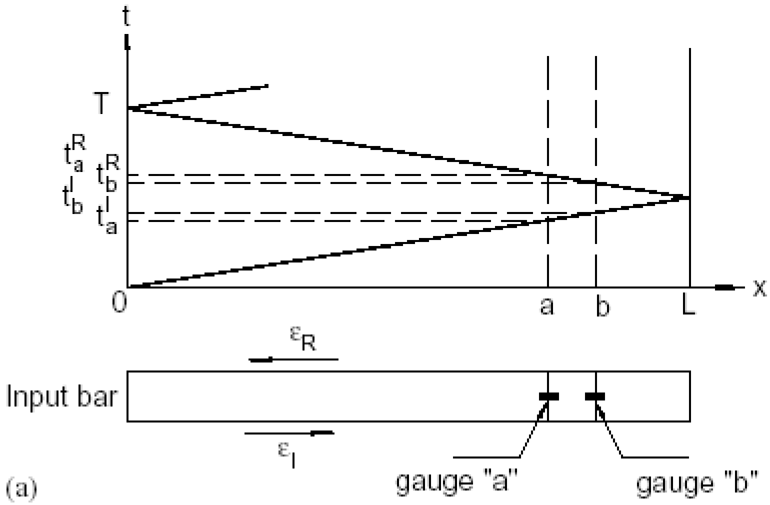

Figure 3. Lagrangian diagram for longitudinal waves in the incident bar (Meng et al., 2003).

The wave separation technique is based on following relations:

$$\varepsilon_b^I(t)=\varepsilon_a^I(t-\Delta t), \tag{27}$$

$$\varepsilon_a^R(t)=\varepsilon_b^R(t-\Delta t) \tag{28}$$

and

$$\Delta t=t_b^I-t_a^I=t_a^R-t_b^R=(b-a)/c_0 , \tag{29}$$

where $\varepsilon_a^I(t)$ and $\varepsilon_b^I(t)$ are the incident strain pulse, ε_i, at points a and b; $\varepsilon_a^R(t)$ and $\varepsilon_b^R(t)$ are the reflected strain pulse, ε_r, at points a and b; t_a^I and t_b^I are the time when ε_i reaches points a and b; t_a^R and t_b^R are the time when ε_r reaches points a and b. Equations (27) and (28) are only valid when the pulse shape change is negligible. The algorithm to separate the incident and reflected pulses is:

$$\varepsilon_b^I(t)=\varepsilon_a^I(t-\Delta t), \tag{30a}$$

$$\varepsilon_b^R(t)=\varepsilon_b(t)-\varepsilon_b^I(t)=\varepsilon_b(t)-\varepsilon_a^I(t-\Delta t), \tag{30b}$$

$$\varepsilon_a^R(t)=\varepsilon_b^R(t-\Delta t) \tag{30c}$$

and

$$\varepsilon_a^I(t)=\varepsilon_a(t)-\varepsilon_a^R(t)=\varepsilon_a(t)-\varepsilon_b^R(t-\Delta t), \tag{30d}$$

where $\varepsilon_a(t)$ and $\varepsilon_b(t)$ are the strains measured by the strain gage stations located at *a* and *b*. This algorithm is used with the conditions described below:

a) For $t<t_a^I$: The pulse does not reach points *a* and *b*, therefore $\varepsilon_a(t)=\varepsilon_b(t)=\varepsilon_a^I(t)=\varepsilon_b^I(t)=\varepsilon_a^R(t)=\varepsilon_b^R(t)=0$.

b) For $t_a^I \le t<t_b^I$: The pulse reaches point *a* but not *b*, therefore $\varepsilon_a(t)=\varepsilon_a^I(t)=\varepsilon_i$ while the others remain equal zero.

c) For $t_b^I \le t<t_b^R$: The incident pulse passes through *a* and *b*, and the reflected pulse has not reached strain gage *b* yet. $\varepsilon_a(t)=\varepsilon_a^I(t)=\varepsilon_i$, $\varepsilon_b(t)=\varepsilon_b^I(t)=\varepsilon_i$ and $\varepsilon_a^R(t)=\varepsilon_b^R(t)=0$.

d) For $t_b^R \le t<t_a^R$: The reflected pulse passes through *b*, what causes the superposition of ε_i and ε_r at *b*. Thus, $\varepsilon_b^I(t)\, and\, \varepsilon_b^R(t)$ are given respectively by (30a) and (30b).

e) For $t\ge t_a^R$: Wave superposition occurs at strain gage *a* and therefore $\varepsilon_a^R(t)\, and\, \varepsilon_a^I(t)$ are calculated respectively by (30c) and (30d).

The incident and reflected pulses are obtained from $\varepsilon_a^I(t)\, and\, \varepsilon_b^R(t)$ after considering their phase difference $t_b^R-t_a^I$. Once ε_i and ε_r were calculated, the remaining data treatment is exactly equal to the conventional SHPB set-up.

6. Instrumentation

A typical SHPB instrumentation uses strain gages, an oscilloscope or a transient recorder, an electronic integrator or an operational amplifier, a trigger circuit, power supply and a velocity measurement system. In the conventional SHPB layout a couple of strain gages is placed in the middle of the input bar and another couple is placed in the middle of the output bar. Each strain gage of a couple is located at diametrically opposite sides of the bar. This allows canceling any bending effect present in the bars due to imperfect alignment between bars, specimen and striker. In the set-up described in (Meng et al., 2003) an additional strain gage couple must be placed in the incident bar.

The oscilloscope or the transient recorder is used to record the strain signals measured by the strain gage stations. The ε_r signal can be integrated either by an electronic integrator or an operational amplifier. The result of this integration is a signal proportional to the specimen strain, which can be input to the X-axis of a recording instrument. The ε_t signal is input in the Y-axis. This procedure allows direct visualization of the profile of the stress-strain curve of the material. The recorded signals can also be manipulated in a computer in order to perform the operations described by Eq. (10) to (12).

The velocity measurement system is intended to determine the striker impact velocity. The two most common measurement techniques employed are a time interval counter associated to either a magnetic pick-up or photocells and light sources.

The trigger circuit is used to control the amount of data recorded. It works in such a way that only one complete load event is registered.

Variations from the typical SHPB instrumentation described above can be found in the literature. Muller (1972) has used cylinder condenser gages to measure the strain pulses. These gages are sensitive to the radial surface displacements of the bars. According to Muller, the use of these devices was essential since the wire strain gages became damaged and unreliable under shock conditions. He also used a filter network consisting of a tuned conductance-capacitance filter and a low pass resistance-capacitance filter in order to attenuate the Pochhammer-Chree oscillations and eliminate noise.

Lindholm et al. (1968) used coaxial capacitance gages to measure the specimen radial strain which, associated with the measured reflected pulse, ε_r, allows the calculation of the dynamic Poisson's ratio. The radial strain measurement can be also used to check the axial strain measurement obtained by the gages on the input bar. Lewis et al. (1973) describe the instrumentation necessary for a biaxial test: simultaneous torsion and compression. Staab et al. (1991) have used two full Wheatstone bridges with two 350 Ω active gages each to detect flexural wave components in two perpendicular directions on the output bar. This measurement technique was able to monitor any bending moment transmitted through the specimen.

7. Study case

This section aims to show how a typical SHPB design would be developed with the aid of the theory presented in sections 2, 3 and 4. Lets consider that a SHPB apparatus should be designed according to the requirements described as follows. The specimens to be tested will be made of a metallic material. The greatest strain rate required is 5000 s^{-1}. At this strain rate, the SHPB must be able to strain the specimen up to 50% at a maximum stress of 1500 MPa. The lowest strain rate adopted for the tests is 500 s^{-1}. In this test conditions the maximum specimen strain and stress are respectively 20% and 1500 MPa.

The first step in the design is the definition of the material and diameter of striker and bars and the definition of the specimen geometry (length and cross sectional area). If different specimen geometries were to be used in the tests, then the design must be done for the critical geometry, i.e., the one with greater length and cross sectional area. In this study case, assume that the striker and bars are made of high strength steel with a diameter of 25.4 mm. The specimen geometry is 10 mm in length and 5 mm in diameter. Once these choices are made and the design requirements are known, the remaining design variables can be determined in a straightforward manner simply by solving the equations from section 3.

As mentioned in section 4, the SHPB has two critical operational conditions: maximum and minimum strain rate tests. Accordingly, the design should be such that the requirements of both conditions are satisfied. The high strain rate test determines the greatest stress pulse to be transmitted through the bars. It also establishes the maximum impact velocity and the maximum energy required for the striker acceleration. On the other hand, the low strain rate test gives information about the minimum length of bars and the longer striker that must be used.

The results contained in Tab. 1 and 2 were obtained from the solution of Eq. (18) and (21) to (26). The energy required for the striker acceleration, E_{kin}, is given by the kinetic energy contained in the striker, which is function of the impact velocity and striker dimensions.

Table 1. High strain rate test.

σ_s [MPa]	ε_s [-]	$\dot{\varepsilon}_s$ [s^{-1}]	σ_i [MPa]	σ_r [MPa]	σ_t [MPa]	σ_{st} [MPa]
1500	50%	5000	1074.5	–1016.3	58.1	1074.5
v_{st} [m/s]	E_{kin} [J]	L_i [m]	L_t [m]	L_{st} [m]	L_p [m]	t_p [s]
53	1440	0.52	0.52	0.26	0.52	1×10^{-4}

Table 2. Low strain rate test.

σ_s [MPa]	ε_s [-]	$\dot{\varepsilon}_s$ [s^{-1}]	σ_i [MPa]	σ_r [MPa]	σ_t [MPa]	σ_{st} [MPa]
1500	20%	500	159.8	–101.6	58.1	159.8
v_{st} [m/s]	E_{kin} [J]	L_i [m]	L_t [m]	L_{st} [m]	L_p [m]	t_p [s]
7.9	127	2	2	1	2	4×10^{-4}

As can be seen in Tab. 1, the material to be chosen for the bars and striker must have yield strength higher than 1074.5 MPa. A maximum energy of 1.44 kJ must be yield to accelerate the striker. This information is used in a latter stage for the design of the gas gun. For example, if the available length for the striker acceleration is 2 m, then the firing pressure must be at least 14.2 bar (1.42 MPa). Table 2 shows that the incident and transmitter bars must have at least 2 m. The longer striker to be used in the tests has 1 m in length. Shorter strikers are adopted in high strain rate tests. Observe that for the tests conditions of Tab. 1 the necessary striker length is only 0.26 m. Even shorter strikers can be used if desired.

It is wise to implement the equations of section 3 in a computer program. In this way, it is easy to analyze what would happen with the design variables if other diameters and materials were chosen for the bars and striker. The influence of specimen geometry can be determined by the same method.

8. Conclusion

The SHPB testing technique allows compression, tension and torsion tests to be performed for a broad range of strain rates. Tests with strain rates varying from 100 to 10000 s^{-1} were commonly reported in the literature. Room limitations, the necessity of high strength materials for the construction of the bars and a high-pressure gas-gun poses difficulties for tests at higher strain rates.

It was shown that the design variables of a SHPB can be determined in a straightforward manner simply by solving the set of equations presented in section 3. The data treatment of this test is quite simple. The required instrumentation can be made simple and even so important material behaviour can be obtained.

The study case has shown a typical SHPB design. It was possible to have an idea of stress values and dimensions of components. The interested reader should also test some other variations in order to realize the influence of each design variable and design requirement.

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