Design of a new Pneumatic Impact Actuator of a Split Hopkinson Pressure Bar Setup for Tensile and Compression Testing of Structural Adhesives

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Introduction

Adhesive joints have recently been used by sectors such as the automotive or the aerospace industries, since adhesive bonding is viewed as a lightweight alternative to welding, riveting and screwing connections, and can distribute loads uniformly without introducing stress concentration features, i.e., holes [1]. To determine the properties of adhesives at high-strain rates, special machines must be used, such as the Split Hopkinson Pressure Bar (SHPB).

The SHPB contains an actuation system, which launches the Striker Bar that generates the pulse wave, when hitting the Incident Bar. After the impact, the wave propagates towards the specimen. Then, the wave is partially reflected back, and the other part is transmitted to the specimen, which then is transmitted to the Output Bar. At the opposite end of the Output Bar, a Momentum Trap device absorbs the transmitted pulse. The elastic stress waves are measured with strain gauges on a Wheatstone bridge circuit [2].

The design of a pneumatic impact actuator, to be implemented in a tensile and compression SHPB machine is presented.

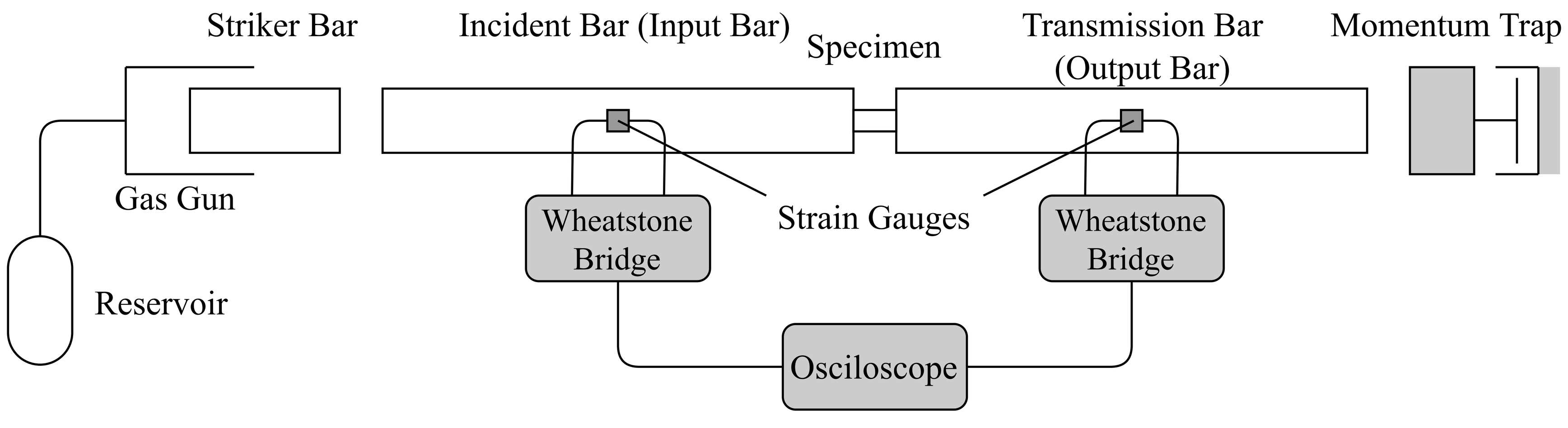
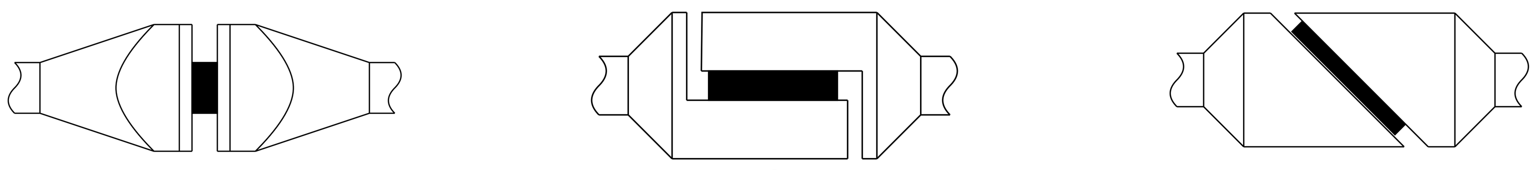


Figure 1 – Compression SHPB apparatus setup [3].

Design requirements

As with any machine design project, the design of a SHPB apparatus needs to follow several requirements:

- The pressure bars must be linearly elastic;
- The length of the Input Bar should be more than twice that of the Striker, to maintain the stress wave trapped in the Incident Bar;
- The impedances, $Z = F/\dot{x}$, of the Striker and Input Bars should be equal. The bars are of the same diameter and material [2, 3];
- This machine will test adhesive joint specimina at Mode I, Mode II, Mixed-Mode (Modes I + II), as well as bulk specimina.



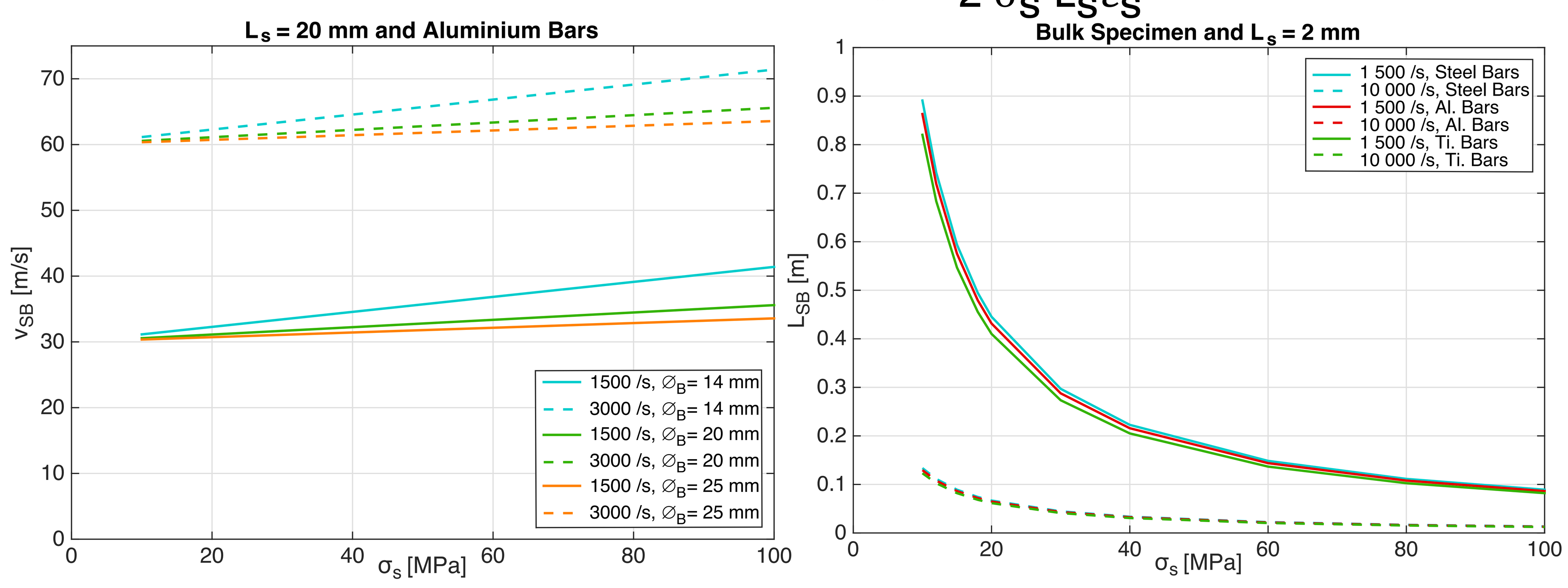
(a) *(b)* *(c)*

Figure 2 – Specimen for: *(a)* Mode I, *(b)* Mode II, *(c)* Mixed-Mode.

Furthermore, two behaviour laws were created:

Striker Bar Velocity: $$v_{SB} = 2\, c_B \left(\left| \frac{L_S\, \dot{\varepsilon}_S}{2\, c_B} \right| + \left| \frac{A_S\, \sigma_S}{A_B\, E_B} \right| \right)$$

Striker Bar Length: $$L_{SB} = \frac{G_C\, c_B}{2\, \sigma_S\, L_S \dot{\varepsilon}_S}$$



(a) *(b)*

Figure 3 – Requirement results: *(a)* v_{SB} for aluminium bars and specimen of length L_s = 20 mm and (b) L_{SB} for bulk specimen of length L_s = 2 mm.

From these plots, the following was chosen for the apparatus design:

- Stainless Steel pressure bars of diameter $Ø_B$ = 20 mm;
- Striker Bar Length, L_{SB} = 250 mm;
- Maximum Striker Bar Velocity, v_{SB} = 25 m·s^{-1};

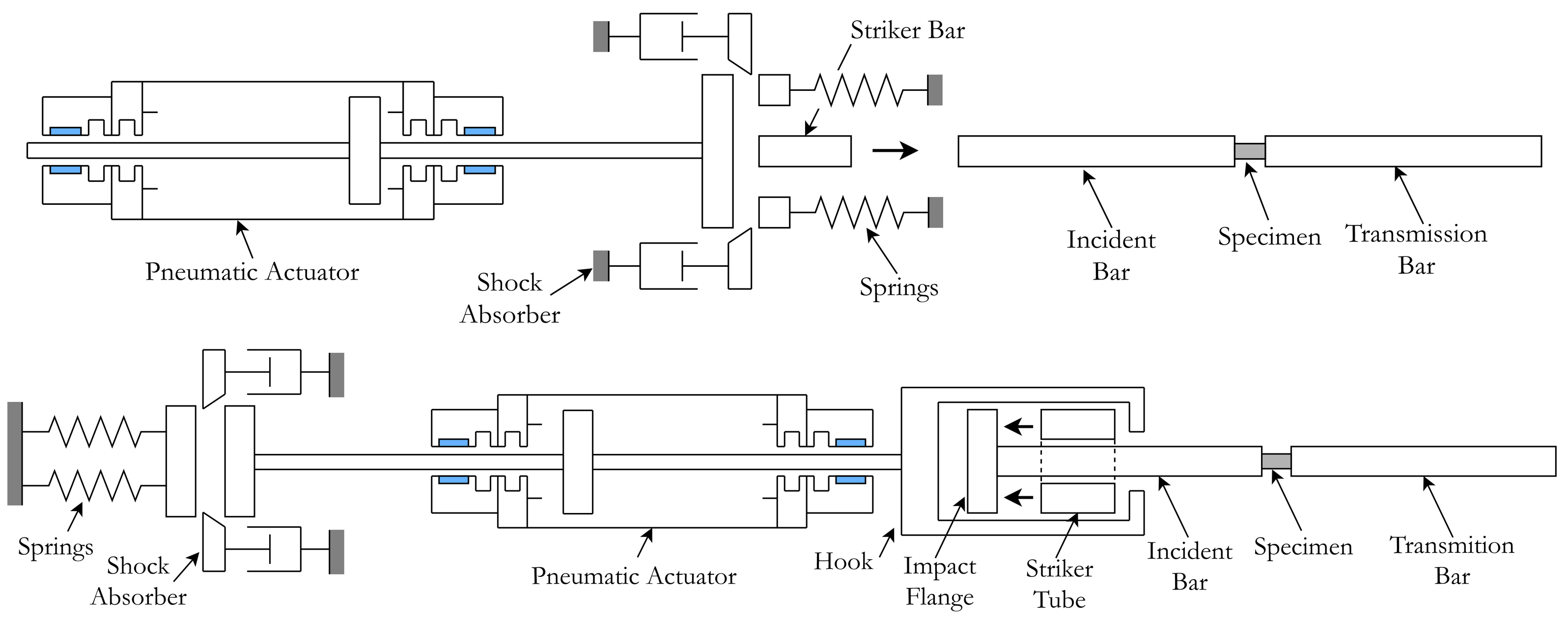


Figure 4 – Proposed SHPB Setup for tensile and compression tests.

Modelling and design of the actuator

To validate the actuator's architecture, functional simulations were performed with models based on physical laws and where the relevant design features were considered, such as:

- No physical contact between the rod/piston and the static elements, which means that there are air leakages;
- A reservoir, that guarantees high mass flow without fluctuations;
- Each chamber needs to have an initially sealed antechamber, to avid air flowing directly to the exhaust channels.

Note that one does not have a guarantee if the air in each chamber behaves adiabatically, or isothermally.

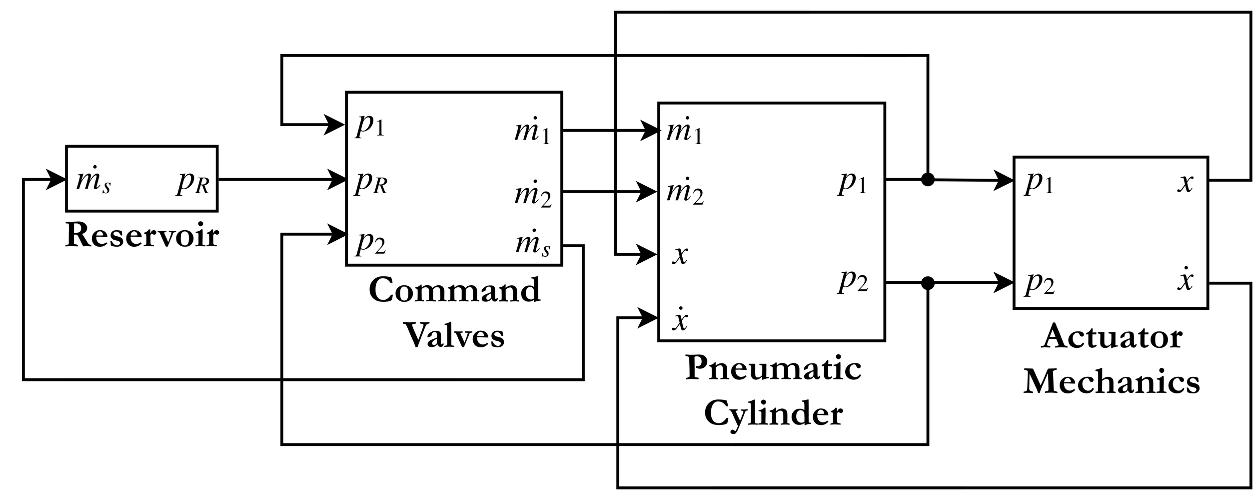
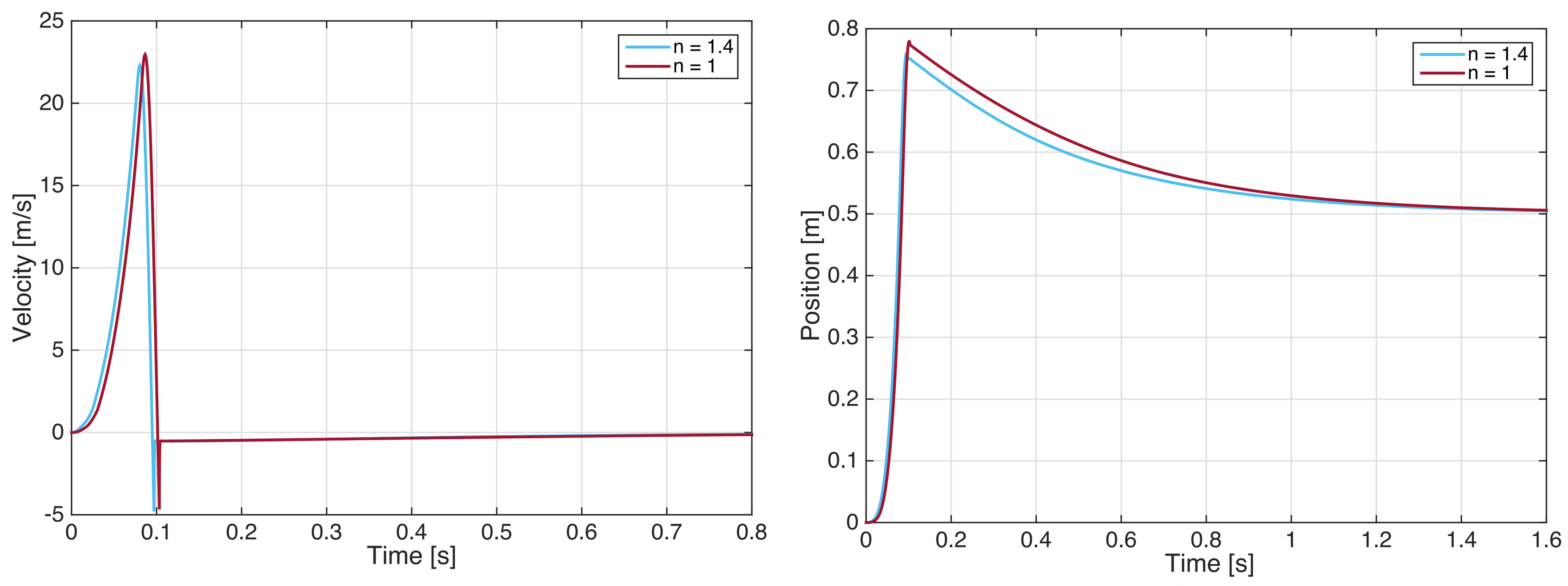


Figure 5 – Simplified functional model of the actuator.



(a) *(b)*

Figure 6 – Obtained results for the: *(a)* Velocity of the actuator, v_A and, (b) Position of the actuator, x_A, where the initial absolute pressure was 9 bar.

Conclusions

A study of the machine requirements was done, based on the mechanics of the SHPB behaviour. In order to validate the proposed actuator architecture, functional modelling and simulation of each subsystem were done. Afterwards, the actuator was designed with the defined geometric parameters of the functional simulations.

References

[1] da Silva, L.F.M, Öchsner, A. and Adams, R.D. Handbook of adhesion technology. 2nd edition. New York: Springer, 2018.

[2] A. F. Tenreiro, C. M. Silva, A. M. Lopes, P.. Nunes, R. Carbas, and L. F. M. da Silva, "Design of a new pneumatic impact actuator of a Split Hopkinson Pressure Bar (SHPB) setup for tensile and compression testing of structural adhesives," Mechanism and Machine Theory, vol. 159, p. 104289, 2021.

[3] W. Chen and B. Song, Split Hopkinson (Kolsky) Bar, 1st Edition. Boston, MA: Springer US, 2011.