



PRELIMINARY RESULTS ON THE CONSTRUCTION AND INSTRUMENTATION OF A HOPKINSON PRESSURE BAR

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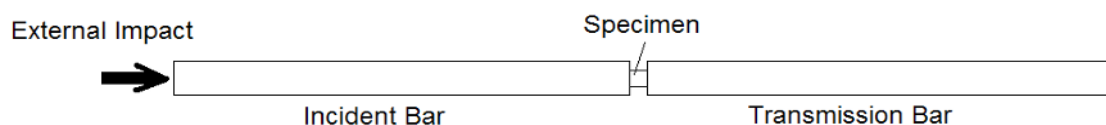
Abstract

In recent years, it was identified the need for the testing of ultra-high strength steels used in the automotive industry. The design of parts used in the mechanical systems subjected to high strain rates demands stress x strain data dynamically evaluated. To achieve such high strain rates the split Hopkinson pressure bar uses longitudinal trapezoidal mechanical waves traveling along a bar and striking the sample at the speed of sound of the bar material. This work aims to present the preliminary results of the design and construction of a split Hopkinson pressure bar testing device. A classic split Hopkinson pressure bar device was built and it was instrumented to experimentally determine the striker speed and special strain gauges were used to record the local and instantaneous strain on the bar at a high strain rate. The results were promising. The wave signals were recorded in digitally recorded and evaluated.

INTRODUCTION

Classically, structural designs make use of data relating to the mechanical properties of materials obtained with very low deformation rates. Thus, strain rates between $1/s$ and $10^{-4}/s$ are common, in both tensile and compression tests. The results lend themselves very well to the design of structures with static loads. However, there are working conditions that require projects that deal with applied loads with high deformation rates. In these situations, the material is loaded with the passage of a stress wave, whether tensile, compressive or torsional, depending on the experimental arrangement. This type of loading occurs when projectiles hit a target or in impacts during vehicle collisions. The results of these tests are presented analogously to quasi-static mechanical tests, based on the quantitative analytical evaluation of the shapes of the waves that travel through the device, affected by the sample of the material investigated. The strain rates in these devices can reach up to $10^4/s$. Impact tests have a long historical evolution, first with Hopkinson and then with Kolski who created the device by positioning two elastic bars on both sides of the sample and then hitting one of the bars with a third bar, called an striker bar. Thus the striker bar hits a first bar, the input bar; it transmits the impact to the sample; which transmits it to the transmitted bar. This scheme is schematically shown in Figure 1. When the wave arrives at the interface between the input and output bar, part of the wave is reflected back to the input bar and part is transmitted through the sample to the transmitted bar.

Figure 1. Schematic drawing of a Kolski impact bar (SHPB).

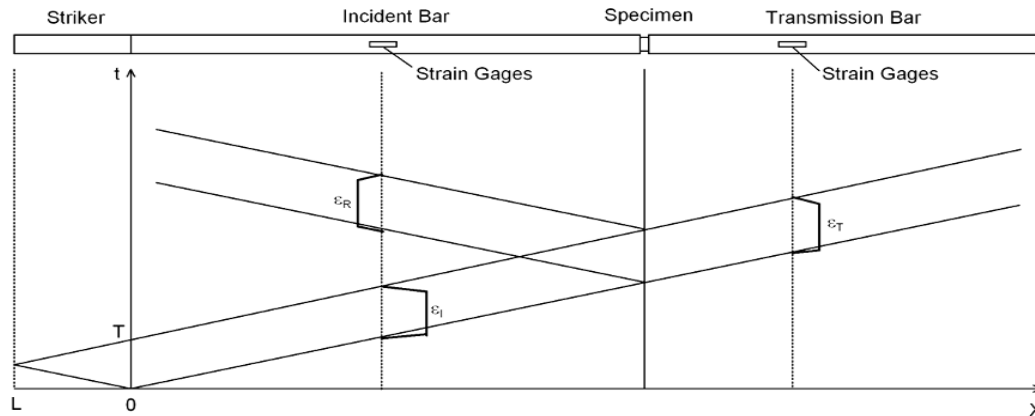


The option to use a mechanical wave as an “actuator” on the sample leads to two considerations: the first, the practical difficulty in generating a mechanical wave suitable for the loading; the second, the analytical ease in determining the strain rate of the sample material and its force response.

Figure 2 shows the descriptive wave or pulse chart of a SHPB device. Usually, the mechanical pulse continues to be reflected, passing through the sample, until it loses

its energy. Ideally, as previously shown, only the first pulses recorded on the incident input bar, the reflected input bar and the transmitted bar are used. [3]

Figura 2. Wave chart illustrating the phenomenon of elastic wave propagation in a SHPB device.



EXPERIMENTAL

The assembly of the mechanical components was carried following the CURRENT technical practices, requiring several adjustments and machining so that the device could be assembled for the first tests. An equivalent path was followed to build the data acquisition system, using a circuit with an operational amplifier and filters to reduce the electric line noise. A switched-mode power supply and battery were adopted for the project to improve the circuit's voltage stability. This circuit contains voltage sources, two Wheatstone bridges and voltage amplifiers for the strain gages glued to the input and transmitted bars.

The main features of the SHPB (Split Hopkinson Pressure Bar) device can be seen in Table 1.

Tests of the device were performed using an aluminum plate as a sample, without regard to the mechanical strength of the alloy, its composition and the work hardening state. The material of the three bars of the SHPB device certainly has a higher yield strength than the yield strength of the material of the target. The yield strength of SAE 1045 steel is between 450-560 Mpa, while the yield strength of the very common 1100 aluminum alloy is 96.5 Mpa.

Table 1. Main features of the SHPB (Split Hopkinson Pressure Bar) device under development.

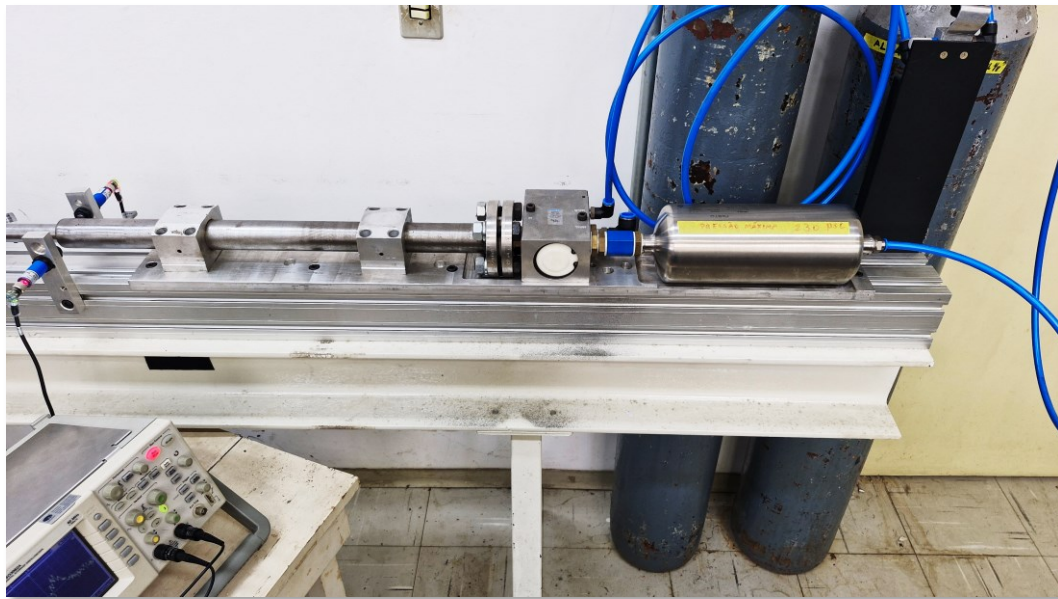
Item	Sizes	Characteristics
Estrutura de suporte	6 m	Carbon steel W beam
Stricking bar	0,4 m	cold drawn diam. 25 mm h9 SAE 1045 steel
Input bar	1,6 m	idem
Transmitted bar	2,0 m	idem
Input bar bearings	3 pieces 200 mm apart	Axial bearing
Transmitted bar bearings	5 pieces 200 mm apart	Idem
Pneumatic cannon barrel	0,6 m	Schedule 40 steel tube with a PTFE lining
Flanges		SAE 1045 steel
Trigger valve		VI/03-03
Pneumatic reservoir		Cód. CRVZS-2
Trigger button		Cód. Festo V/0-3/1/8
Propellant gas	16 bar	Nitrogen
Trigger gas	1 bar	Idem
Strain gages	8x5mm	350 Ohms
Balistic chronometer	350x11x280 mm	1-999 m/s

Two strain gages were glued aligned to the axis of the input and transmitted bars, using anaerobic cyanoacrylate adhesive, using the conventional technique for gluing these components; on the transmitted bar positioned 200 mm after the sample and; on the input bar 900 mm before the sample, to avoid overlapping of the incident and reflected waves.

The strain gage terminals were connected to the Wheatstone bridge, which had its signal amplified to be recorded on a DSO3062A digital oscilloscope, with the capacity to store the screen signal, graphically and digitally.

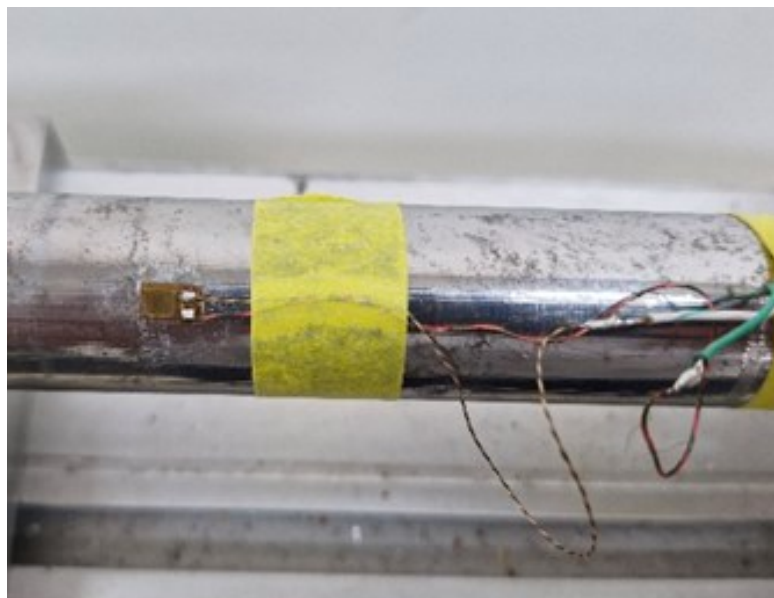
A Festo V/0-3/1/8 valve, manually actuated by a button, actuates the pneumatic cannon. This design was adopted in order to avoid possible electromagnetic interference. In practical tests, measures are adopted to minimize electromagnetic effects that may interfere with the strain gage signals. The pneumatic cannon barrel was constructed from a schedule 40 tube lined internally with a layer of PTFE (Fluoropolymer known as Polytetrafluoroethylene), welded to a flange, to be connected to the trigger valve. The assembly can be seen at Figure 3.

Figure 3. Assembly of the pneumatic parts on the chassis.



The installation of the strain gages on the input bar and the transmitted bar is shown in Figure 4.

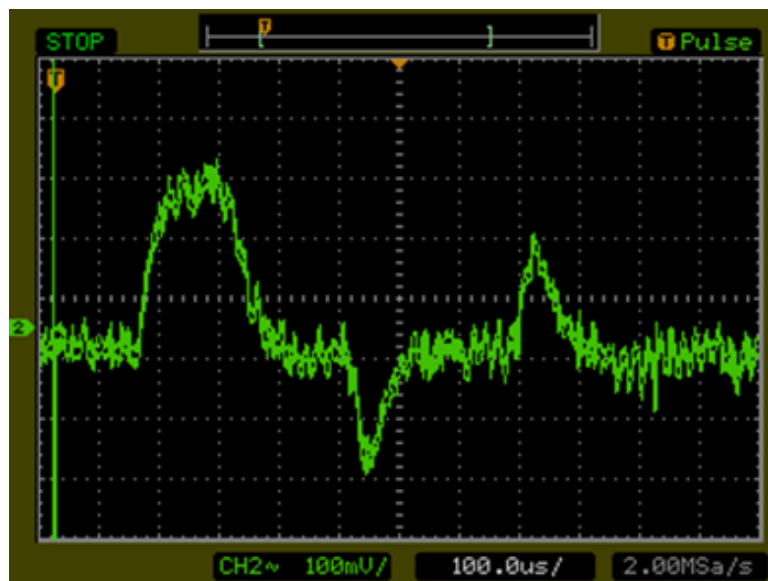
Figura 4. Strain gage glued on one of the bars.



The pulses were recorded using a digital oscilloscope, which allows the recording of a screen image and the acquisition of voltage data from the amplifier circuit in a database file, with an acquisition rate of 2Msa/s.

Figures 5 and 6 show the waves recorded on the input bar and the transmitted bar.

Figure 5. Pulses recorded on the oscilloscope screen at the input bar. The widest pulse on the left is the input pulse, the one that arrived first. The second pulse, inverted, is the pulse reflected at the interface with the sample. The third pulse is the former second reflection of the pulse at the interface of the striker bar with the input bar.

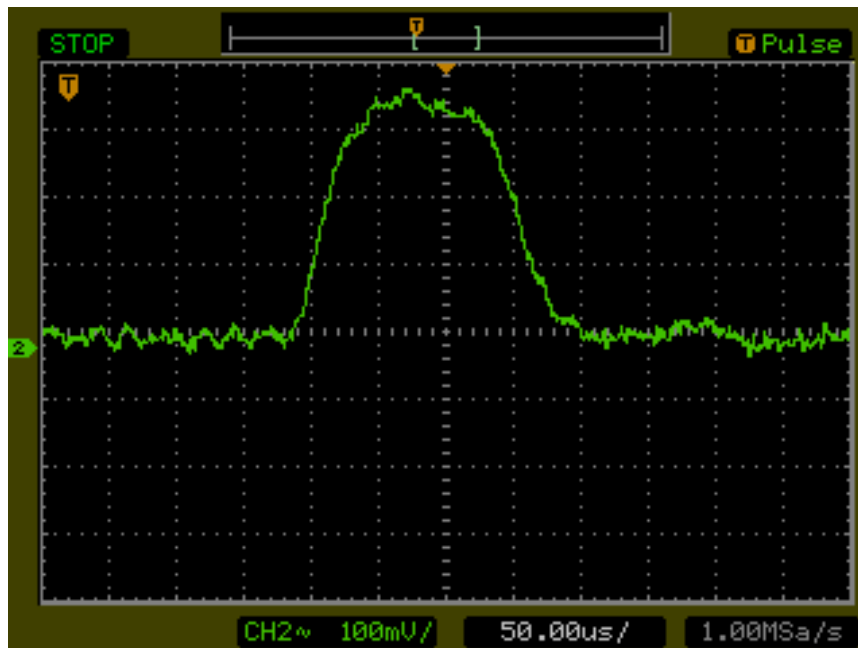


The interval between the two wavefronts of the input and reflection is 360 μ s; with the round trip distance being approximately 1.8 meters, the calculated speed for the mechanical pulse is 5000 m/s, a value close to the speed of sound in steel. The same procedure generated the same speed value for the third observed pulse.

The presence of interference in the signals can be observed, the source of which has yet to be determined. The shape of the transmitted pulse can also be observed, which would need to be longer to approximate a trapezoidal pulse. The use of a longer strike bar could solve this problem, but would require a much higher operating pressure of the pneumatic system.

The recording of the transmitted wave is shown in Figure 6. The acquisition rate was lower, as was the temporal resolution. The spurious signals are present, but with lower amplitude and the pulse has a shape that approaches trapezoidal.

Figure 6. Transmitted bar wave signal, pulse, recorded on the transmitted bar note that the acquisition rate was lower, as was the temporal resolution. The spurious signals are present, but with lower amplitude and the pulse has a shape that approaches trapezoidal.



CONCLUSION

- The process of building the parts, assembling and operationalizing the SHPB device required a recursive approach, carrying out tests, evaluating results, redesigning, assembling and new tests, so that it was possible to record mechanical pulses through an oscilloscope.
- Apparently the solutions presented in the literature are customized solutions for each equipment. Therefore, some of them, such as the ballistic chronometer, did not offer good results. Neither did the use of laser – photo transistor assemblies prove to be an efficient solution. Both had random read failures.
- To record the signals, a digital oscilloscope was used with a very small recording interval, requiring a large number of shots to be successful.
- There are electrical interferences in the strain gauge signals whose source needs to be determined, in order to obtain signals that can be analyzed later.

- The pulses are quite narrow. It is necessary to evaluate the causes of this phenomenon, so that they can approximate the shape of a trapezoidal pulse. This phenomenon can have mechanical (harmonics in the bar) or electrical causes.

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