

Instructions for Performing a Split Hopkinson Pressure Bar Experiments

Compression SHPB:

Specimen preparation:

1. The specimen dimensions should follow the below relation:

$$\frac{L}{D} = \sqrt{\frac{3\nu}{4}}$$

where L is the length, D is the diameter and ν is the Poisson's ratio of the specimen.

2. Make sure the faces of the specimen are parallel and flat (use step collet while machining metal specimens to get parallel faces). The diameter of the specimen after the test should be smaller than the diameter of the pressure bars.

Selecting the bar:

1. Determine the impedance ($\rho c A$) of the specimen.

where ρ is the density, $c = \sqrt{\frac{E}{\rho}}$ is the wave speed and A is the area.

2. Then select the pressure bars (steel or Aluminum) closer to the impedance of the specimen. We also have different diameters for the pressure bars.

Note: The basic thumb rule is that we use steel bars for the harder materials (metals etc..) and Aluminum bars for the softer materials (polymers, foams etc..).

3. After the pressure bars are selected, make sure the end faces of the bars are flat and parallel.
4. Align the pressure bars and striker on the mounting frame.

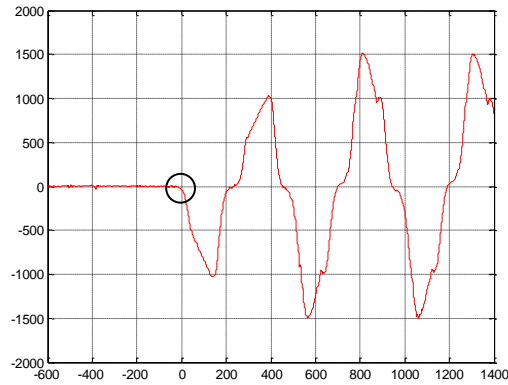
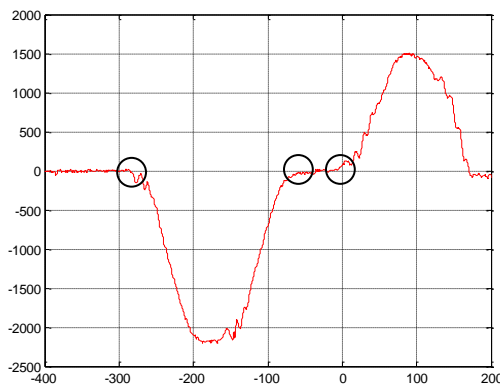
Experimental procedure:

- (a) Give all required connections. Connections include: Connect the BNC cables from the amplifier to the oscilloscope. Check the right channels and connect them. Make sure the amplifier (2310A) and oscilloscope are grounded. Do not change any settings on the amplifier. The amplifier has been calibrated for 350 ohms strain gages. Please refer to manual if you wish to make any changes and let everyone in the lab know before you make any changes. Turn ON the amplifier and oscilloscope.
- (b) The excitation voltage and gain are set to 10V and 100 respectively. Turn the reset switch ON for all the four channels.
- (c) Check the resistance on the strain gauges and they should read around 350 ohms.
- (d) Set the voltage levels, trigger position, data duration time (2ms-4ms), for all the four channels in Oscilloscope. These values depend on the experiments.
- (e) Balance the Wheatstone bridge for all the four channels by turning the reset button.

- (f) Check whether the bars are well aligned or not, and also the projectile should be well aligned to the impact end of the incident bar.
- (g) Then make sure that the bars are moving freely, if not apply WD-40 lubricant and adjust the screws of the clamps.
- (h) Clean the interfaces of the bar and the projectile with Kim wipes and ethyl alcohol.
- (i) Push the projectile to the end of the barrel of gas gun assembly with a flexible poly rod.
- (j) Measure the dimensions of both specimen and pulse shaper. Dimensions include: diameter and thickness.
- (k) Select the striker depending on the strain rate you are trying to get. You can vary strain rate by using different pressures and different striker bars. Make sure the pulses are not getting overlapped. If the pulses are getting overlapped, use the shorter striker bar. (Thumb rule: The longer the striker, the lower the strain rate. The higher the pressure, the higher the strain rate).
- (l) Lubricate both faces of the test specimen with Molybdenum disulfide lubricant and sandwich the specimen between the bars and align the specimen with respect to bar center.
- (m) Place the pulse shaper at the impact end of the incident bar with a thin layer of Dow Corning lubricant (if you are using lead pulse shaper) and align it with respect to bar center. We generally use clay and lead pulse shapers. These give us very good results for harder materials, but for the softer materials, you can try different pulse shapers. These include paper, copper etc..
- (n) Release the nitrogen gas from the gas tank into the gas gun chamber until the required pressure level is achieved.
- (o) Arm the oscillation to capture the strain gage voltage signals and make sure the arm holds until you release the projectile. If the arm is not holding, adjust trigger levels. (Note: if you are getting high noise in your signals more than 20mv, turn off the tube lights before the experiment).
- (p) Once again, ensure that the specimen is well aligned between the bars and verify the status of the trigger hold before pressing the solenoid valve release button.
- (q) Press solenoid valve control box button to release the projectile.
- (r) Save captured voltage pulses onto a USB drive for further analysis of the data.
- (s) A MATLAB program is written to read the data from the pulses and analyze the pulses using the one-dimensional wave theory stress and strain equations. After the experiments are performed, the pulses are used along with the MATLAB program to determine the equilibrium and true stress-strain plots of the specimen.
- (t) After the experiment is completed, turn off the cylinder and make sure all the left over nitrogen gas in the gas chamber is released.
- (u) After the data is transferred from the oscilloscope to USB drive, verify that in your computer and turn off the amplifier and oscilloscope.

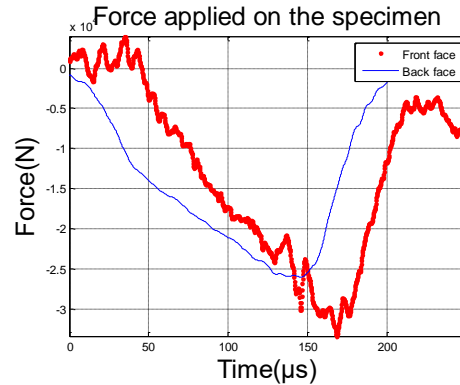
Analyzing the results:

1. There are two MATLAB codes to analyze the data. 1. Verify_Equilibrium and 2. Steel/aluminum_SHPB. Use the appropriate codes to analyze the data. Depending on the bars you used, the respective code has to be used.
2. Make sure the code has the right properties and dimensions of the pressure bars you used. These include diameter, wave speed, and diameter.
3. If we use hollow tubes, make sure you have the right dimensions in the code. For solid bars, dimensions for the hollow tube should be zero.
4. First run the verify equilibrium code. Make sure the data you get from the oscilloscope has the following names for the four channels. TEK00000, TEK00001, TEK00002, and TEK00003. The code recognizes these names. Make sure the codes and the data are in the same folder.
5. TEK00000 and TEK00001 represent incident and reflected pulses (channel 1 and channel 2). TEK00002 and TEK00003 represent the transmitted pulse (channel 3 and channel 4). The code averages channel 1 and channel 2. And channel 3 and channel 4.
6. The code converts the voltage output to microstrains and balances.
7. Default values for filtering are given in the code. For incident and reflected pulse, default value of 0.2 ($fn=0.2$) is used and for transmitted pulse, a value of 0.05 ($fn=0.05$) is used. Depending on the noise you get, change the values of fn . The value of ' fn ' ranges from 0.001 to 0.99. Higher value of ' fn ' means, the pulses were not filtered. Decrease the value of ' fn ' if you would like to filter more. You can use different values for incident and transmitted pulses.
8. When you run the code, you get two figures. Figure 1 gives the incident and reflected pulses. Figure 2 gives the transmitted pulse.

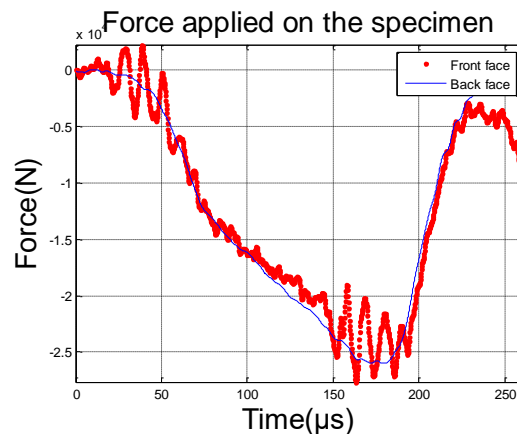


9. Note the incident starting time, incident end time, reflected starting time and transmitted starting time as shown in the above figures. You can zoom the pulses by pressing 'zoom in' button at the top to get the right times. Then go to MATLAB main window and press 'ENTER'.
10. Input the values you found out and press 'ENTER'.
11. Now you will get 3 more figures. Figure 3 shows the incident, reflected and transmitted pulses. Figure 4 shows the incident, reflected and transmitted pulses you picked on before. Figure 5 shows the force ratio. Front face represents the forces calculated on the incident and reflected pulses. Back face represents the force calculated on the transmitted pulse. Ideally, these two fronts and back face should match perfectly.

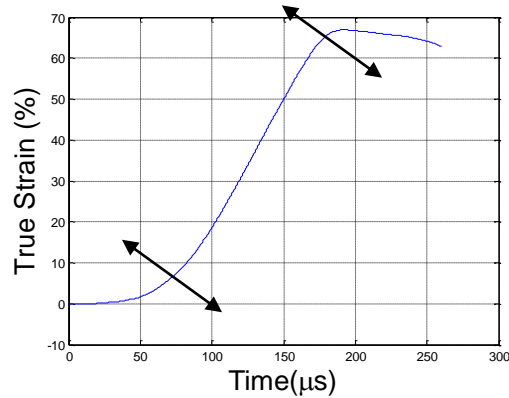
12. Various factors decide the equilibrium. These include type of material tested, strain rate etc..
13. Make sure the incident and reflected pulses start at the same time on Figure 4. On the first trial, you might end up something as below



14. Go back to the times you found for the incident, reflected and transmitted pulses. Never change the times of reflected and transmitted pulses. Shift the incident pulse to either side and try for different values until you get decent equilibrium. For the case shown above, by shifting the time of the incident pulse, the below equilibrium was obtained.



15. Save this figure in to the respective folder. Also save the new times of the pulses.
16. Now open the SHPB code and make sure you have the same value for filter as in the verify_equilibrium code.
17. Enter the specimen thickness and diameter in inches.
18. Again, you get two figures. Figure 1 gives the incident and reflected pulses. Figure 2 gives the transmitted pulse.
19. Go to main 'MATLAB' window and enter the final times here.
20. You get Eng. stress strain curve (Figure 3) and True stress-strain curve (Figure 4).
21. Follow the directions of the Figure 4.
22. Pick two points to calculate the slope. You can pick at the initial elastic region of the true stress-strain curve.
23. You will end up with figure 5. Pick two points at the linear region as shown below.

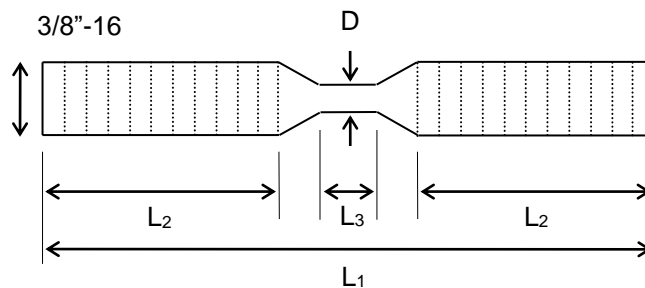


24. Go to MATLAB main window and you can see the strain rate. Note down this value. Next you will end up with final figure (Figure 6). This is eng. strain rate vs. time.
25. Be careful when you pick up the strain rate points. Consider the following points
 - a. Make sure the region you pick is in the equilibrium.
 - b. For foam materials, you might not get very good equilibrium and constant strain rate. So calculate the strain rate over the entire loading duration.

Tensile SHPB:

Procedure:

1. The specimen dimensions are given below. These dimensions vary with the material tested. For metals, the below dimensions can be used. To perform experiments at lower strain rate, increase the gage diameter (D) to 0.2". For plastics, use gage length of 0.2" and gage diameter of 0.2".



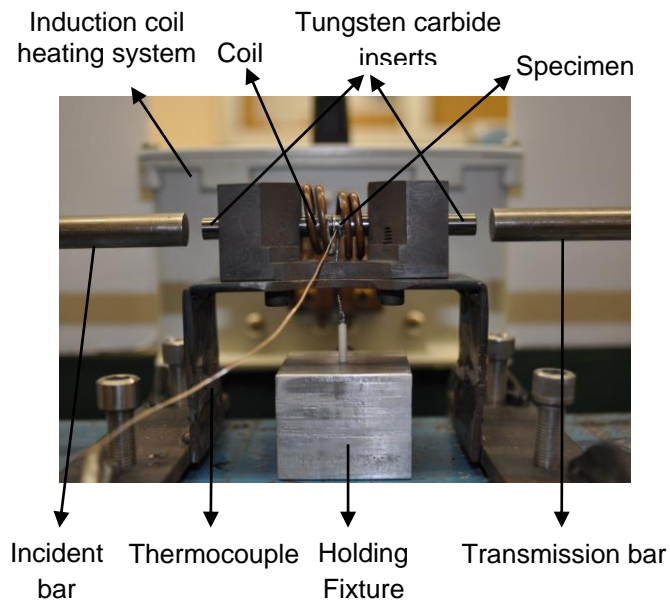
D (Diameter) = 0.15"
 L_1 = 1.5"
 L_2 = 0.56"
 L_3 (Gage length) = 0.20"

2. Selecting the bar is same as explained before.
3. Experimental procedure is also similar to the above. Here, you place the pulse shaper on the flange. You can use paper, clay or lead.
4. Different striker bars can be used to perform experiments at different strain rates. Make sure the striker bar slides freely on the bars.
5. The specimen will be threaded at both ends to the pressure bars. There is no need to use the lubricant.

6. The connections remain the same as explained before. You can use the same amplifier and oscilloscope, and same settings.
7. The MATLAB codes have been modified and use the appropriate code to perform your analysis. The steps to run the code is same as explained for compression SHPB.

Compression SHPB at elevated temperatures:

1. The tungsten carbide inserts will be used. The specimen will be sandwiched between these inserts.
2. The diameter of the specimen should be smaller than the inserts. The below figure shows the set up.



3. For experiments at elevated temperatures, the SHPB apparatus in conjunction with the induction coil heating system will be utilized as shown in Fig. 2.
4. A special fixture is used to load the specimen.
5. The inserts were used to eliminate the temperature gradient in the bars and thus protect the strain gages mounted on them.
6. The impedance of the inserts was matched with the bars; hence they do not disturb the stress wave profiles in the bar. The impedance matching requires the diameter of these tungsten carbide inserts to be smaller than the main pressure bars. This is the reason for the specimen diameter for high temperature testing being smaller than that for room temperature testing.
7. By varying the power, higher temperatures can be achieved.
8. The induction coil heating system has a power control box, remote to start and stop, a cooling unit and cooling supply (blue box) to reserve water. Make sure the blue box has sufficient distilled water. The copper coils are connected to the cooling unit and it is places around the inserts.
9. First turn ON the blue box, then the power supply. The power supply needs the larger output in the DPML lab.

10. Make sure the wheel on the cooling unit is pinning smoothly and fast. If not, do not do the experiment. Increase the power supply, to heat the specimen.
11. When the regulator is turned ON, it should give a click sound after around 30s. If it does not, turn it off and try again. If the problem persists, turn off the regulator and the problem can be determined.
12. Turning ON the power supply regulator, it will read 'cycle continuous' on the remote (smallest one), which is desired.
13. The system should already be set to manual power output again, which will allow to control the power. If it is not set, you can do by using the switch located to the immediate right of the dial on the regulator.
14. Make sure the dial on the regulator is zero, so there will be no immediate power output.
15. Now press 'start' button on the remote (small one that reads the display).
16. The bars were kept apart initially, later the specimen and carbide inserts were heated in isolation to the desired temperature (usually about 20-50°C higher than the test temperature) and soon after the bars were brought manually into contact with the specimen. The temperature of the specimen was monitored using a 0.127mm chromel-alumel thermocouple, which was spot welded onto the specimen.
17. In most of the experiments, it takes less than two minutes to heat the specimen to the required temperature and it takes less than 10 seconds to bring the pressure bars into contact with the tungsten inserts and fire the gun.
18. Once the temperature is reached, hit 'stop' on the display and turn off the regulator and the induction heater. Now trigger the oscilloscope. If you trigger the oscilloscope before, due to magnetic fields from the induction heater, you will see lot of noise.
19. Allow the cooling unit to run for some time so that it reaches room temperature.
20. All other experimental procedure, data capturing, and analyzing the results remain the same as explained in compression SHPB section.

Note:

1. Always make sure the yield strength of the material you are testing is never beyond the yield strength pressure bars.
2. For testing ceramics of high strength, we need to use inserts so as to protect the bars from plastic deformation.