Chapter 3
Evaluation of Various Pulse Shaper Materials for Tension Split-Hopkinson Bar Experiments

Sydney C. Resnick and Nathan C. Spulak

Abstract The high velocity impact used to generate the stress-strain waves during a split-Hopkinson bar test can result in undesired oscillations in the incident wave, creating complicated loading and force imbalance on the specimen. Additionally, for some tests (such as on low-impedance or brittle materials), it is necessary to increase the rise time of the incident wave in order to achieve dynamic force equilibrium prior to significant deformation or specimen fracture. Pulse shapers consisting of a ductile material can be placed between the striker and incident bars in order to decrease these wave oscillations and increase the rise time. This allows dynamic force equilibrium to be more easily achieved, but often results in lower strain rate loading on the specimen. The effect of pulse shapers constructed from various different materials and thicknesses are investigated when used for tension split-Hopkinson bar tests. The tension test setup uses a hollow striker bar that impacts a flange on the end of the incident bar to generate the tension incident wave, and this setup necessitates the use of hollow ring-shaped pulse shapers attached to the flange. Pulse shapers of copper, nylon, and rubber materials with various thicknesses are used to evaluate the effectives of each pulse shaper in altering the oscillations, rise time, and pulse duration of the incident wave.

Keywords Split-Hopkinson bar · Pulse shaping · Tension · Elastic wave analysis

Introduction

Split-Hopkinson bar (SHB) tests are a widely utilized method for studying material behavior under high strain rate loading. Such information is necessary for applications such as automotive and aerospace vehicle crashworthiness, military and defense, and projectile or debris impacts. The SHB test, developed by Kolsky in the 1940s [1], involves a specimen placed between an incident and transmitter bar. A third striker bar is accelerated and impacts the incident bar, generating a stress-strain wave in the incident bar that then loads the specimen at high strain rates. However, due to the nature of the impact, the resulting stress waves can exhibit significant oscillations, leading to oscillatory loading on the specimen and potentially distorting the experimental data. Additionally, in some cases it is necessary to increase the rise time of the incident, such as for low impedance materials or brittle materials, in order to allow for dynamic force equilibrium to be achieved before significant deformation or fracture of the specimen occurs. To mitigate these oscillations and increase the rise time, pulse shapers may be employed to change the shape of the incident wave and improve the accuracy of the measured material properties [2]. The material properties, thickness, and shape of the pulse shaper will affect the behavior of the resulting incident wave. Copper, known for its high ductility and energy absorption capacity due to its ability to plastically deform, is a commonly used material for pulse shapers in SHB testing. Less commonly used materials include polymers and elastomers, such as nylon and rubber. This study investigates the effect of various different pulse shaper materials and thicknesses for tension SHB experiments utilizing a hollow striker bar impacting a flange on the end of a solid incident bar. Such a test setup requires utilizing ring-shaped pulse shapers as opposed to the more commonly used solid cylindrical pulse shapers.

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Experimental Methods

SHB tests are conducted in the tension configuration utilizing a hollow striker bar to generate the incident wave. The specimen is attached to both the incident and transmitter bar, and the hollow striker bar is accelerated using a pressure vessel to strike a flange on the end of the incident bar. Upon impact, a tensile stress wave is generated that travels down the incident bar to the specimen, at which point a portion of the wave is reflected back in the opposite direction along the incident bar as a compression wave, while the remainder of the wave is transmitted through the specimen and travels down the transmitter bar. Strain gages on the incident and transmitter bars measure the waves, which are subsequently converted to strain and stress values. The test setup is illustrated in Figure 1 (a).

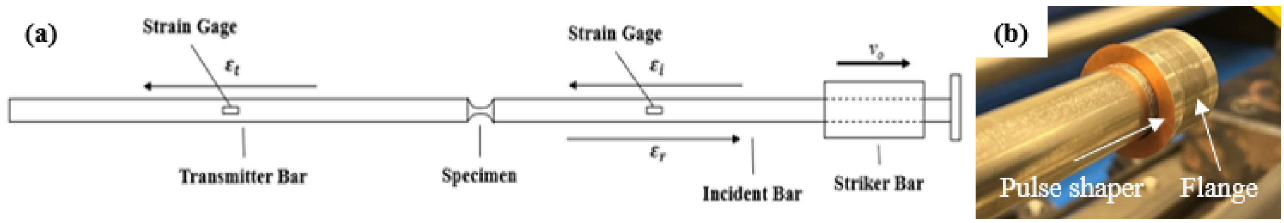

Fig. 1 (a) Experimental setup for a tension split-Hopkinson bar test, and (b) impact flange with ring-shaped pulse shaper

Pulse shapers are incorporated by removing the end cap of the incident bar and sliding a hollow shaper onto the end flange, as illustrated in Figure 1 (b), where it will interface with the striker bar upon impact. Copper pulse shapers with thicknesses of 0.005 inches, 0.045 inches, 0.09 inches, and 0.125 inches are used, as well as nylon pulse shapers with thicknesses of 0.062 inches and 0.25 inches and rubber pulse shapers of 0.13-inch thickness. The resulting effects on the incident wave rise time, duration, and oscillations (categorized by the initial percent overshoot) are analyzed for each pulse shaper material and thickness.

Experimental Results

The stress versus time data for the initial incident wave, generated using copper, nylon, and rubber pulse shapers of varying thicknesses are presented in Figure 2. The baseline data, recorded with no pulse shaper, serves as a reference for assessing the effects of the pulse shapers.

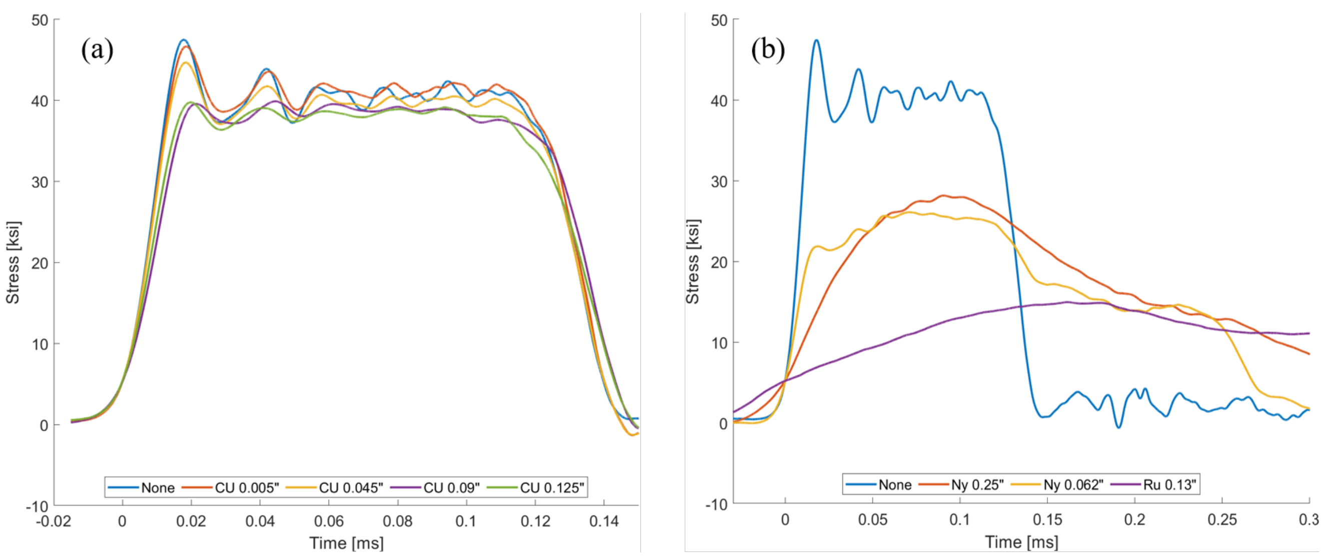

Fig. 2 Effect of various pulse shapers on incident wave: (a) copper pulse shapers, and (b) nylon and rubber pulse shapers

For the copper pulse shapers, the thickness had little impact on the wave duration. However, the thicker copper pulse shapers did reduce the amount of oscillations, as well as decrease the overall wave amplitude while still maintaining the overall square-wave shape. The nylon and rubber pulse shapers, by comparison, are able to increase the wave duration and significantly increase the rise time. Yet they also significantly decrease the wave amplitude and change the overall shape of the incident wave such that it no longer resembles a square wave.

These effects are numerically categorized by calculating the pulse duration, percent overshoot, and rise time of the wave for each pulse shaper type. The pulse duration is calculated by taking the peak measurement, halving it, and taking the duration from the point it initially reaches 50% of the peak to the point it falls back to 50%. The baseline duration when no pulse shaper is used is 122.10 μs and the most deviation from this baseline is seen when using the 0.09 inch shaper. The pulse shaper of 0.005 inches had a duration of 122.93 μs, a 0.686% increase. The 0.045-inch-thick pulse shaper had a duration of 122.89 μs, or an increase of 0.645%. The 0.09-inch-thick pulse shaper had a duration of 125.89 μs, or 3.1% increase. Finally, the 0.125-inch-thick pulse shaper had a duration of 125.66 μs, increasing by 2.92%.

The effect of the copper pulse shapers on the rise time is shown in Figure 3, which shows only the initial rise of the incident wave for each copper pulse shaper. The rise time of the wave is calculated as the time it takes for the wave to go from 10% to 90% of the peak value. The baseline with no pulse shaper has a rise time of 14.68 μs. The 0.005-inch-thick shaper has a rise time of 15.49 μs, increasing by 5.5%. The 0.045-inch-thick shaper produces a rise time of 15.19 μs, increasing by 3.5%. The 0.09-inch-thick shaper has a rise time of 17.7 μs, demonstrating a more significant increase of 20.5%. Lastly, the 0.125-inch-thick shaper had a rise time of 16.38 μs, an increase of 11.6%.

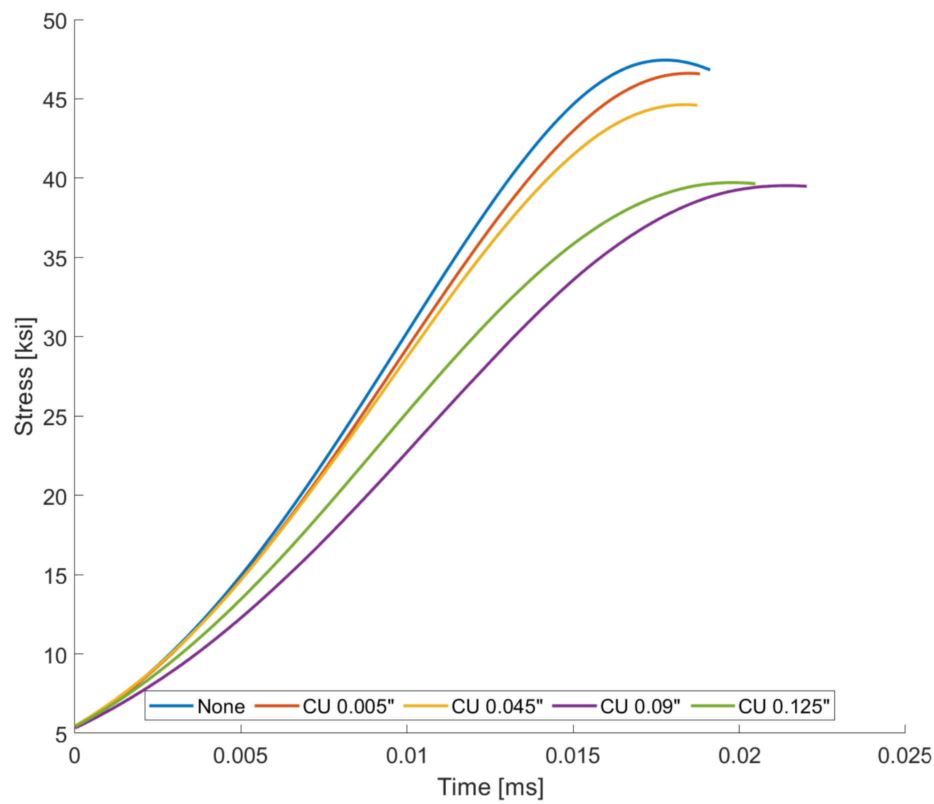

Fig. 3 Initial rise time of incident wave for various copper pulse shaper thicknesses

The percent overshoot of the wave is calculated by first determining the average value of the wave after the initial peak has subsided, in order to obtain a value of the steady-state wave amplitude. The percent overshoot is then determined as the percentage difference between the initial peak amplitude and the steady-state amplitude. With no pulse shaper, the wave had a 14.9% overshoot. The 0.005-inch-thick shaper saw an overshoot of 12%, the 0.045-inch-thick shaper had overshoot of 11.4%, the 0.09-inch-thick shaper had a significantly lower overshoot of 3.28%, and the 0.125-inch-thick shaper had an overshoot of 3.91%.

A linear trendline is fit to percent overshoot verses pulse shaper thickness for copper, as seen in Figure 4. This can be utilized for future testing, to select the appropriate pulse shaper thickness that results in the desired reduction in percent overshoot and wave oscillations.

In addition to copper, nylon and rubber pulse shapers are used, with notable differences observed in their effects on the incident wave. These materials result in more pronounced changes in wave characteristics, including a substantial reduction

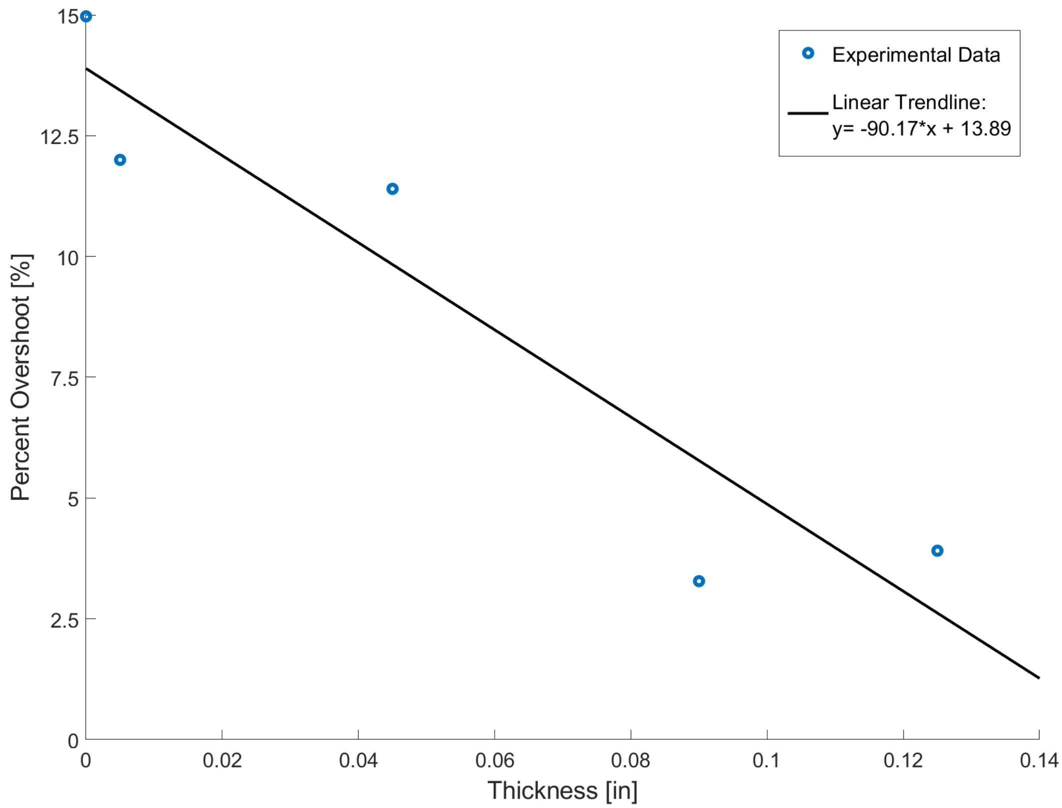

Fig. 4 Experimental data and linear trendline of percent overshoot as a function of pulse shaper thickness

in peak amplitude and pulse duration. These pulse shapers are a potential option for tests where an increased pulse duration or significantly increased rise time are required, such as tests on low impedance or brittle materials.

Conclusion

This study highlights the effect of various pulse shaper options on the incident waves generated by a hollow striker bar for tension split-Hopkinson bar tests. Copper pulse shapers, particularly those thicker than 0.05 inch, effectively reduced oscillations in the incident wave, resulting in lower peak values and overshoot. However, they had a much smaller effect on the rise time and minimal effect on wave duration. In contrast, nylon and rubber pulse shapers led to more substantial changes in wave shape, duration, and overshoot, making them potentially better suited for tests involving brittle or low impedance materials which require increased rise times. These findings underscore the importance of selecting the appropriate pulse shaper material and thickness for specific experimental needs, to achieve more accurate and reliable high-strain-rate testing.

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