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Data-Reduction Uncertainties in Kolsky Bar Experiments on Metals

Bo Song, Erik Nishida, Edmundo Corona

Sandia National Laboratories, Albuquerque, NM 87185, USA

Since its development, the fundamental concept of Kolsky bar method for material testing of metals has not changed, but advancements have been made over the years to improve the quality of data obtained [1]. The alignment of the Kolsky bar system is the fundamental requirement to obtain clean signals. The specimen geometry has been designed to minimize the inertia effect in the specimen during dynamic loading. Recently, pulse shaping has become a common practice to achieve dynamic stress equilibrium and constant strain rate conditions in order to attain more accurate and reliable results. However, the dynamic stress-strain response, particularly at small strains, obtained from the Kolsky bar experiments is still inaccurate. For example, it has been challenging to measure the Young's moduli for metals in Kolsky bar experiments [2]. In the past years, several experimental, analytical, and numerical approaches have been made and claimed to effectively correct the measurement of Young's moduli for metals in Kolsky bar experiments. Stress wave dispersion, early stress equilibrium, and elastic indentation to the ends of the pressure bars have been accepted as main error sources in stress-strain measurements at small strains [3-5]. Accordingly, the stress wave dispersion has been either numerically corrected or experimentally minimized with pulse shaping technique [1, 6]. The pulse shaping technique also enables early stress equilibrium [4]. An analytical method has been developed to correct the elastic indentation effect [5]. However, it is still difficult to identify the dominant one among the three sources. In this study, we employed finite element analyses to analyze the effects of the wave dispersion, early stress equilibrium, and elastic indentation on the measurement of Young's moduli of metals. A correction to the conventional data reduction for Kolsky bar experiments is also proposed.

The schematics for finite element analytical models with and without a pulse shaper are shown in Fig. 1. It consists of a steel striker with a diameter of 0.75 in. and a length of 5 in. at the left of the model travelling to the right with a striking speed of 267 in/s. The striker impacts an incident bar with the same diameter but a length of 144 in. The transmission bar had the exact same dimensions as the incident bar. The pulse shaper used in this study was an annealed C11000 copper disk with a diameter of 0.25 in and a thickness of 0.04 in. The specimen sandwiched between the incident and transmission bar was 0.125 in. thick and 0.25 in. in diameter. In the model, the striker, incident and transmission bars had the same Young's modulus of 30×10^6 psi and density of 7.48×10^{-4} slug-ft/in^4, giving an elastic wave speed of 200,267 in/s. Both incident and transmission bars were meshed with a region A (coarse mesh) and a region B (fine mesh) of equal lengths. Figure 2 shows the detail of the transition from a coarse mesh in region A to a fine mesh in region B. It is noted that the region B refers to the specimen end. In this study, we used a typical linear elastic-plastic description for the specimen material with a Young's modulus of 30×10^6 psi as the input for simulation, as shown with the red dash lines in Fig. 3. The strain signals for the incident, reflected, and transmitted waves at the strain-gage locations on the incident and transmission bars were calculated with the numerical simulations and then applied to a conventional Kolsky bar data reduction procedure to calculate the stress-strain curve from the three waves and to compare with the input stress-strain description.

Three cases (wave dispersion, pulse shaper, and elastic indentation) were numerically studied. The results show that the wave dispersion produced significant oscillations in the resultant stress-strain curves, which is consistent with previous results in literature. Numerical correction of the wave dispersion can significantly minimize the oscillations. However, our results showed that the wave dispersion correction did not significantly improve the measurement of Young's modulus. Elastic indentation of the smaller specimen to the larger bar ends has been found to significantly influence the Young's modulus measurement. Through the indentation correction, the Young's modulus was improved, however, still not approached to the theoretic value yet. This indicates that the indentation played a key role in the measurement of Young's modulus but was not a sole source of error. Similarly, the pulse shaping also improved the measurement of Young's modulus, but still with error. It is interesting that, with the combination of pulse shaping and indentation correction, the Young's modulus became very close to the theoretic value. Figure 3 shows a comparison of Young's modulus measurements with and without pulse shaping and indentation correction. It is clearly shown that both pulse shaping and indentation correction are critical in accurately measuring Young's modulus. In addition, the pulse shaping removed the oscillation in the stress-strain response, as shown in Fig. 3. Since the pulse shaping technique has been recently accepted and utilized in Kolsky bar experiments, it is now highly desired to pay more attention during data-reduction to the indentation correction for dynamic stress-strain measurements at small strains, particularly the Young's modulus measurement for metals. We are now applying both pulse shaping and indentation correction in actual Kolsky compression bar testing of a 304L stainless steel.

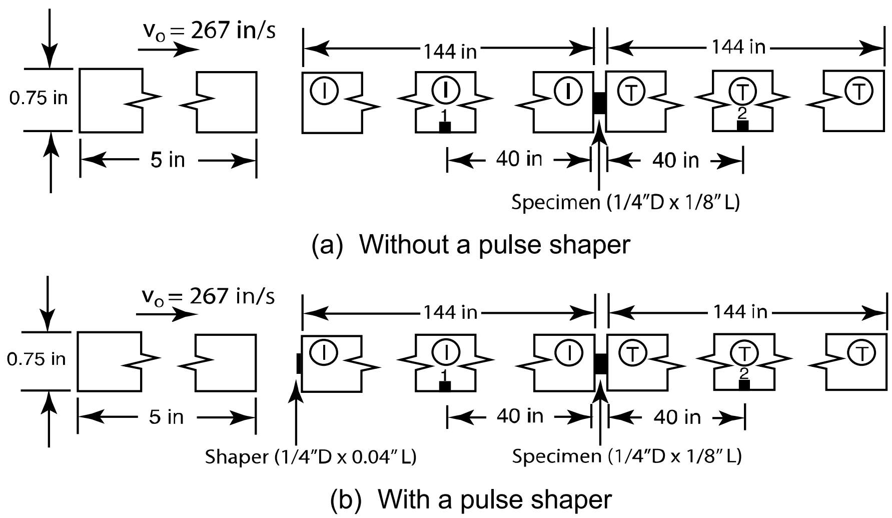

Figure 1. Schematic of high-temperature Kolsky tension bar system.

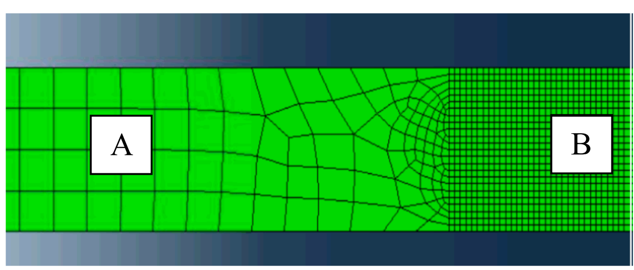

Figure 2. Illustration of finite element meshing

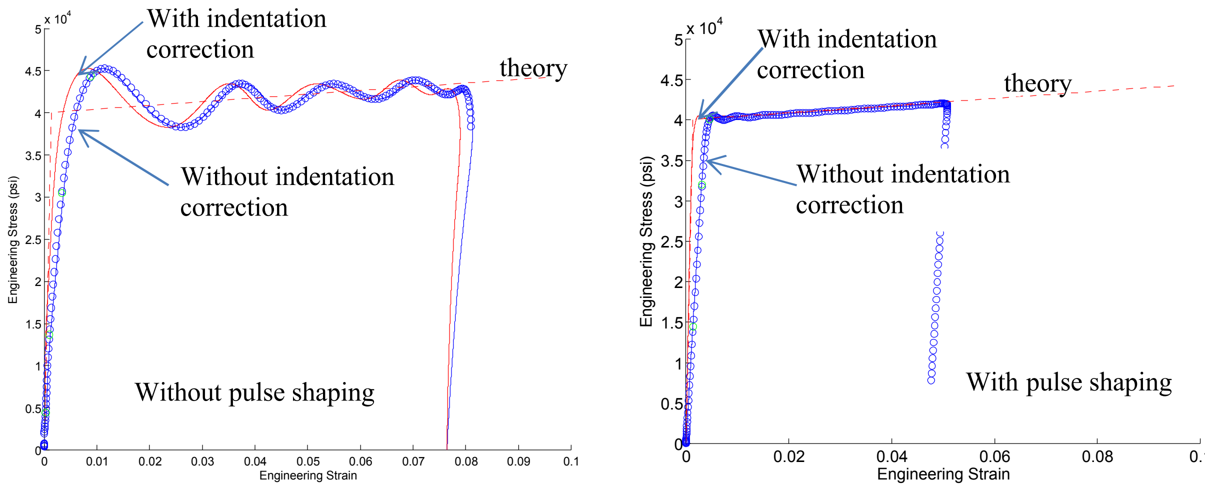

Figure 3. Comparison of Young's modulus measurements with and without pulse shaping and indentation correction

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REFERENCES

1. Chen, W. and Song, B., Split Hopkinson (Kolsky) Bar, Design, Testing and Applications. *Springer: New York* (2011).
2. Gray, G. T., *Classic Split-Hopkinson Pressure Bar Testing.* In: ASM Handbook, Mechanical Testing and Evaluation, Materials Park, OH, 8:462-476 (2000).
3. Zhao, H. and Gary, G., *On the Use of SHPB Techniques to Determine the Dynamic Behavior of Materials in the Range of Small Strains.* International Journal of Solids and Structures, 45:1185-1202 (1997).
4. Chen, W., Song, B., Frew, D. J. and Forrestal, M. J., *Dynamic Small Strain Measurements of Metal Specimen with a Split Hopkinson Bar*, Experimental Mechanics, 43:20-23 (2003).
5. Safa, K. and Gary, G., *Displacement Correction for Punching at a Dynamically Loaded Bar End*, International Journal of Impact Engineering, 37:371-384 (2010).
6. Follansbee, P. S., and Frantz, C., Wave Propagation in the Split Hopkinson Pressure Bar, Transactions of the ASME, Journal of Engineering Materials and Technology, 105:61-66(1983).