Chapter 9
Development of a Novel Method for Simultaneous Measurements of Multiple Constant Elevated Strain Rates

Derryk Daignault, Tyler Robertson, and Nathan Spulak

Abstract A key challenge in dynamic testing is the fact that the material specimens exhibit non-uniform deformation and changing geometries throughout the experiment. This creates variations in the instantaneous true strain rate of the material during the experiment, making it difficult to accurately characterize the material rate sensitivity. To address this, novel high rate split-Hopkinson bar experiments are designed using finite element analysis with Ansys LS-DYNA, taking advantage of strain localization in order to simultaneously induce multiple constant strain rates on a single experimental specimen. Use of these novel test designs and analysis methods will enable the stress vs. strain behavior at multiple truly constant strain rates to be obtained from a single experiment, allowing for both more efficient and more accurate characterization of material rate sensitivity.

Keywords Strain rate · Strain localization · Split-Hopkinson bar · Digital image correlation · Finite element analysis

INTRODUCTION

It is necessary to characterize material deformation and fracture behavior at high strain rates for a variety of applications, including vehicle crashworthiness and high velocity impacts, in order to accurately design structures for use in such scenarios. A key experimental technique for determining the material response at elevated strain rates is the split-Hopkinson bar (SHB) technique, which is capable of loading specimens at elevated strain rates on the order of 10^3 s^{-1} under dynamic force equilibrium and with uniform engineering strain rates [1]. Yet SHB experiments are typically not capable of achieving constant true strain rates on the material specimen, as shown in Figure 1 [2].

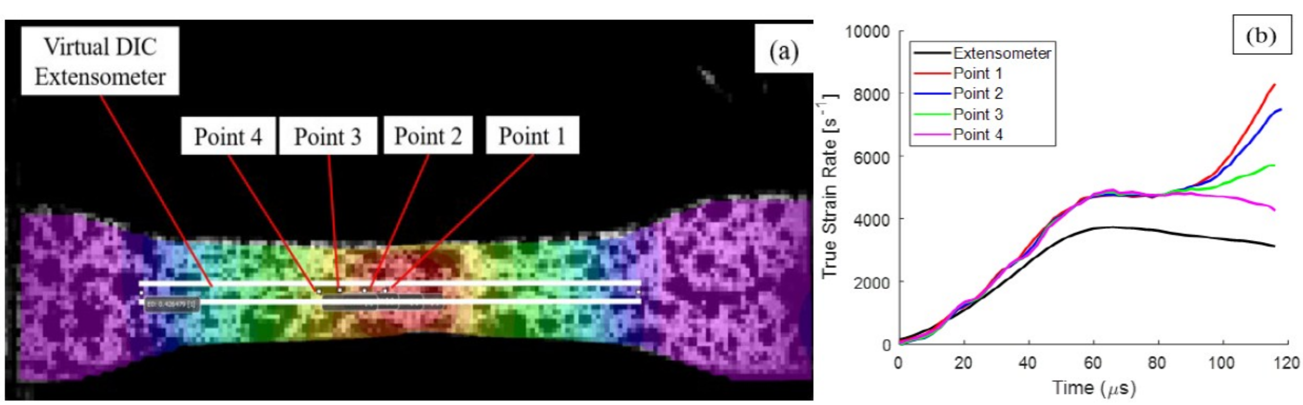

Fig. 1 Tension split Hopkinson bar experiment on additively manufactured 316L stainless steel. The true strain rate does not remain constant with respect to time and varies significantly across the specimen once necking occurs

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This is due in part to the changing specimen gauge length for either tension and compression tests, which will result in a variation of the true strain rate as the test progresses. However for tests where strain localization occurs, such as necking in tension tests, the localized strain rate drastically increases, resulting in strain rates that are not constant with respect to time or spatially across the specimen. Typical SHB analysis methods utilizing solely the average strain rate may not fully capture the material's deformation response and rate sensitivity due to the multiple strain rates that occur during such tests. Therefore a novel approach taking advantage of this strain localization phenomenon has been pursued, to generate multiple different localized true strain rates across the specimen that are each constant with respect to time.

EXPERIMENTAL DESIGN

Multiple tension test specimen designs are evaluated using the finite element analysis (FEA) software Ansys LS-DYNA. The specimens are desired to have immediate strain localization from the onset of the test, and a constant localization rate such that the true strain rate remains constant at discrete locations along the specimen. Example specimen geometries are shown in Figure 2, with either a smooth gauge (SG) variation or a sharp V-notched (VN) gauge variation.

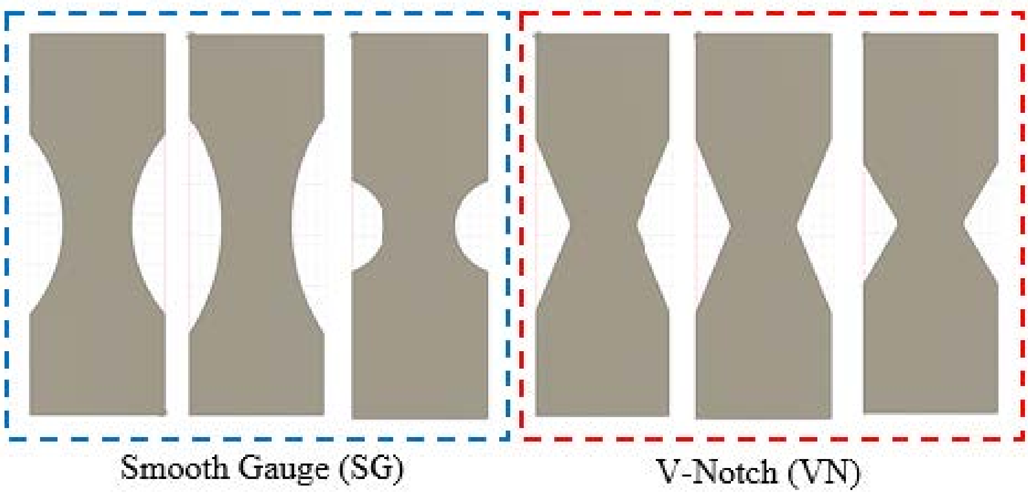

Fig. 2 Examples of specimen geometries with varying cross-sectional geometries, to induce immediate strain localization and constant true strain rates at discrete locations along specimen

Each specimen design is simulated, using the strain rate sensitive MAT-224 material model in LS-DYNA developed through testing of titanium 4Al-6V at various strain rates [3]. Simulations are performed with a mesh size of 0.2 mm, and two sets of boundary conditions are utilized. One boundary condition set utilizes a fully fixed boundary condition on one end of the specimen coupled with a constant velocity displacement on the other end to achieve tensile loading, representative of the experimental conditions for tests on hydraulic load frames. The other boundary condition set utilizes both ends of the specimen moving to represent the conditions observed in an SHB experiment, with the velocity profiles assigned to either ends of the specimen taken from representative SHB experimental data [2][4].

RESULTS

The simulated strain rate with respect to time at various points along a representative SG and a VN specimen is shown in Figure 3. Each line represents the local true strain rate at a single element along the centerline of the specimen gauge length. As can be seen, the simulations predict a range of strain rates across their length, with the peak strain rates occurring towards the center of each specimen where the gauge width is narrowest.

Neither specimen design achieves truly constant true strain rates at all locations. However there are specific locations where the simulated true strain rate does remain at a constant level as the test progresses, typically at a region just outside of the specimen center. The VN specimen geometry demonstrates a similar behavior as the standard dogbone tension specimen in Figure 1, with relatively constant strain rates initially followed by a rapid increase in the localized strain rate after the

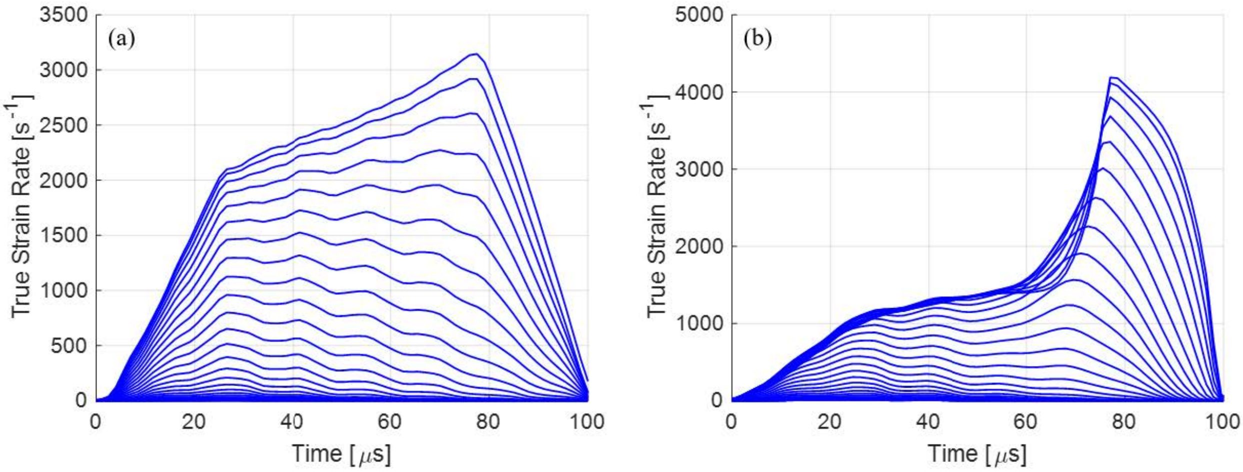

Fig. 3 Simulated strain rate at various discrete locations along specimen gauge length for (a) an SG type specimen design and (b) a VN type specimen design

onset of strain localization in the center. By contrast the SG specimen geometry shows less variation of the strain rate with respect to time as the test progresses, indicating a more consistent rate of strain localization during the test.

CONCLUSION

The SG and VN specimen designs show promising variation in the strain rate and the ability to achieve a constant true strain rate with respect to time at discrete locations on the material specimen. Future work involves performing experiments using these geometries at a variety of strain rates, and using digital image correlation (DIC) to determine the localized strains and strain rates across the specimen. The corresponding full-field stresses can be analyzed either through measurements of the changes to the local cross-section via DIC, or through advanced analytical methods such as the virtual fields method (VFM). These novel tests demonstrates a promising capability to measure high strain rate material deformation in a more accurate and more efficient manner.

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References

1. Kolsky, H. (1949). An investigation of the mechanical properties of materials at very high rates of loading. *Proceedings of the physical society. Section B*, *62*(11), 676.
2. Marler, T. E. (2024). *Quasi-static and dynamic tension testing of as-built and heat-treated additively manufactured 316L stainless steel*. The University of Alabama in Huntsville.
3. Haight, S., Wang, L., Du Bois, P., Carney, K., & Kan, C. D. (2016). Development of a titanium alloy Ti-6Al-4V material model used in LS-DYNA. *George Mason University, The George Washington University, NASA Glenn Research Center, Washington, DC, Report*.
4. Seidt, J. D. (2010). *Plastic deformation and ductile fracture of 2024-T351 aluminum under various loading conditions* (Doctoral dissertation, The Ohio State University).