Analysis of Rate-Sensitive Material Deformation

Kevin McAuliffe, Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, SURF 2005 Fellow
Georgia Tech Mentor: Dr. Min Zhou, ME/MSE

Introduction

The rate sensitive behavior of materials undergoing high strain rate deformation is very important in engineering applications. These applications involve structural impacts, machining, metal forming, and the effects of an earthquake on a structure. For example, what happens to a bullet casing as it impacts an object? Unfortunately, knowledge is limited on these types of behaviors, and as a result, it is critical to characterize them for ascertaining performance of future materials undergoing high strain rate deformations.

One way to characterize this behavior is to use a Split Hopkinson Pressure Bar (SHPB).The SHPB is an apparatus that is capable of testing the effects of high strain rates on material response. In this instance, the tensile SHPB will be used, along with a high-speed digital camera, and an oscilloscope to test how varying high strain rates affect Aluminum 6061 and Steel 1045 tensile behavior.

Procedure

The tensile SHPB setup consists of a pressure chamber, incident bar, transmission bar, and two strain gauges. Initially a specimen is screwed in between the two bars, while the pressure chamber is evacuated. Then the pressure chamber is pressurized with air to a certain level by use of a regulator and is then sealed. Finally, the pressure is released, forcing the striker bar to impact the end cap and push the incident bar backwards at a high rate until it impacts a steel stopper. This impact helps intensify the stress wave that is created. The stress wave propagates along the length of the two bars, and uniformly through the specimen, which plastically deforms the specimen to failure, while elastically deforming the two bars. As the wave interacts with the specimen, part of the wave is reflected back through the incident bar, while the rest continues through the transmission bar.

The stress through the incident bar and transmission bar is recorded through four strain gauges, two mounted diametrically on each bar. This set up increases output signal strength, and ensures that the output is solely axial strains. These two stress waves are stored on an oscilloscope as voltage vs. time, and analysis is performed using Matlab. Lastly, the high speed digital camera is activated by the oscilloscope as the recorded stress waved intensity reaches a set trigger level. The digital camera pictures allow for slow speed analysis of the high speed deformation.

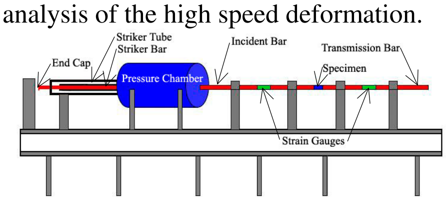

Fig.1: SHPB tensile configuration

Results and Discussion

As the strain rate increases for Aluminum 6061 and Steel 1045, the ultimate tensile strength (UTS) increases by 60 MPa and 160 MPa respectively. Steel 1045 experiences a separate phenomenon from Aluminum 6061, as its failure strain reduces as strain rate increases. The material experiences necking at the speed of sound as viewed through the camera.

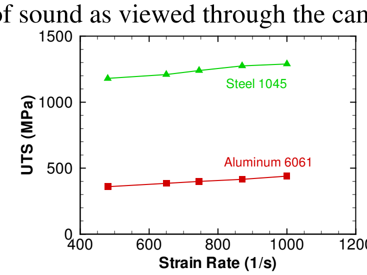

Fig. 2: UTS vs. Strain Rate for Steel 1045 and Al 6061

Steel shows the ability to withstand more stress than Aluminum, which correlates to the individual material properties. Aluminum is softer and a more ductile metal than steel, and therefore fractures at lower stresses. The increase in UTS exhibits that materials in high strain rate loading will withstand more stress than materials loaded under quasi-static rates. This increase is caused by strain hardening being more prominent in high strain rate situations. Yet, this ability to withstand higher stresses can only be maintained for a smaller frame of strain. The very fast necking viewed through the image analysis of the high speed camera shows that the necking happens at such a high speed that it is almost synonymous with fracture.

Conclusion

The metal alloys when experiencing high strain rates, exhibit higher UTS, but in the case of steel fails at reduced strains. This result occurs more distinctly for steel than for aluminum. As well, due to the high strain rates, both materials neck and fracture near the speed of sound.

References

K.Minnaar. Comparison and Analysis of Dynamic Shear Failure Behavior of Structural Metals, Georgia Tech M.S. Thesis. (1997).

G.Ingram. Experimental Characterization of the Effect of Inertia on Ductility, Georgia Tech M.S. Thesis. (2003)

I would like to thank the NSF, Surf Program, and Dr. Min Zhou for giving me the opportunity to participate in this research experience. I would also like to thank the PhD Students in the Material Properties Research Laboratory their help: Vikas Tomar, Ambarish Kulkarni, & Wuwei Liang.