Experimental Study of the Mechanical Behavior of Magnesium Under Dynamic Loading Using Split Hopkinson Pressure Bar Technique

Spencer Smith
University of Utah

Coauthor: Dr. J. L. Ding

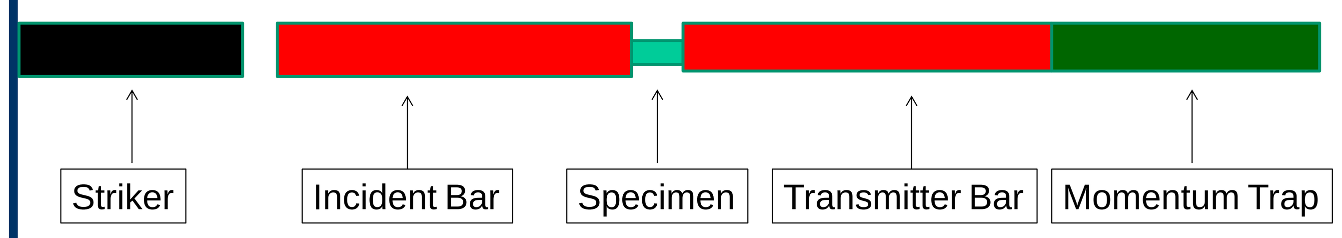
Acknowledgements: Ilhan Yu, Jialong Ning, Yueqi Hu

Advised by Dr. J. L. Ding
School of Mechanical and Materials Engineering

1. Background and Objectives:

Because of its light weight, magnesium is an attractive material for mechanical designs in which weight is an important design criterion. Light weight materials are critical for automotive, aerospace, biomedical, and defense industries. Many applications in these industries also require the materials to perform under high strain rates, such as in automotive collisions or ballistic barriers. It is known that materials behave differently depending on how fast the material is loaded. Thus for proper selection and applications of the materials, understanding their mechanical behavior under dynamic loading is critical. The purpose of this research is to determine the characteristics of magnesium under high strain rates and compare our results to previously published results and to the results of low strain rate testing.

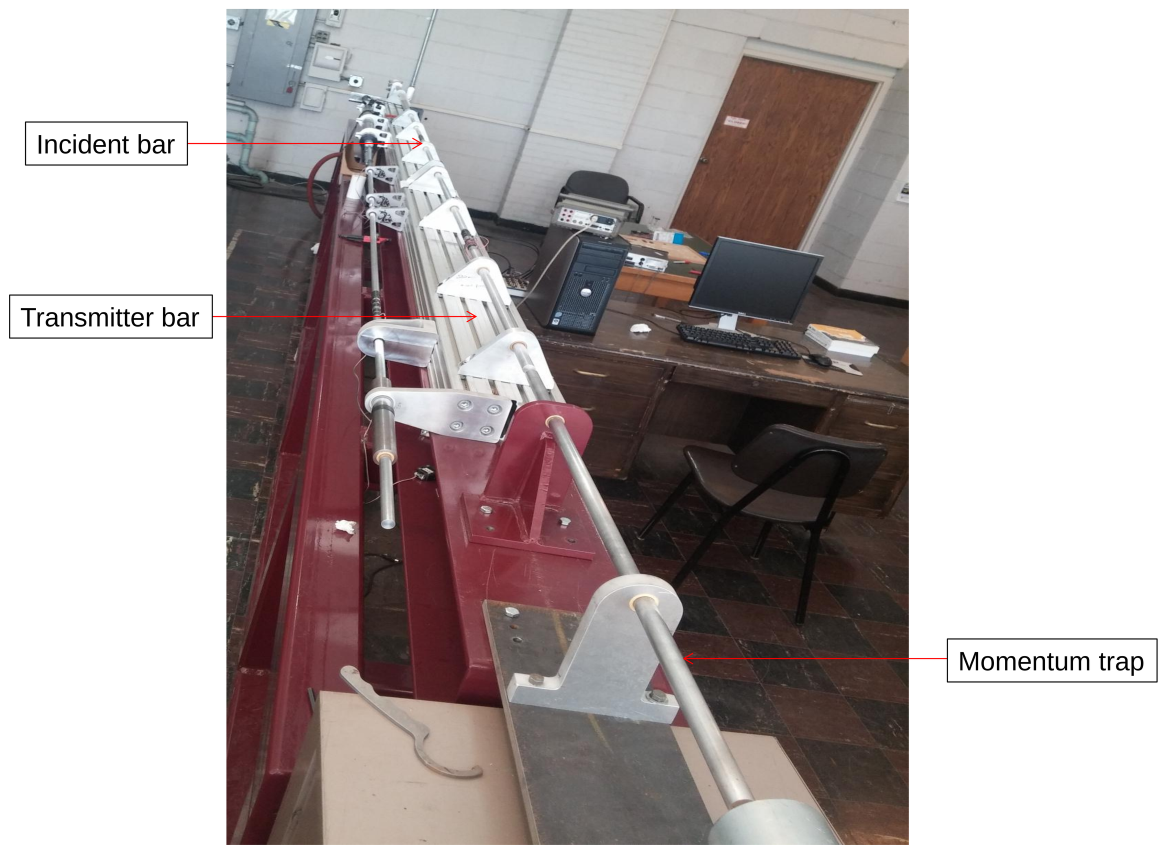
2. Testing Equipment: The Split-Hopkinson Pressure Bar



Shown above is a schematic diagram of the Split-Hopkinson Pressure Bar setup. It consists of 4 bars of the same diameter. The striker is propelled down a barrel by compressed gas and impacts the incident bar. The specimen is then smashed between the incident and transmitter bars because of the stress wave caused by the striker impacting the incident bar. The momentum is then captured by the momentum trap and dissipated by a soft material that the momentum trap runs into. The stress wave created by the experiment are observed via strain gauges on the incident and transmitter bars. With the strain gauge measurements we can determine the stress-strain relationship of the Specimen.

3. Design and Development of the Split Hopkinson Bar Tensile Test Setup:

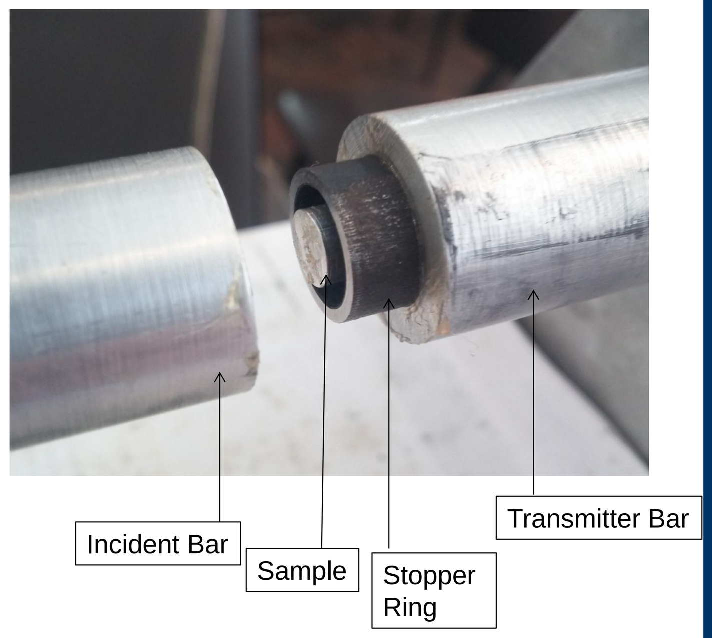
Shown below are the pictures of the overall experimental setup. The incident bar's length is 7 ft. and the transmitter bar's is also 7 ft. 4 different strikers were made to achieve different speeds and strain rates. The striker lengths are 3, 2, 1 and 0.5 ft. The momentum trap is 3 ft. long. All of the bars are made from PM M-48 steel. The test results from the steel bars were not valid and we believe this is so because the strength of the steel bars are much higher than the magnesium samples. All the data used for this poster was acquired using the aluminum bars that were already in the lab from earlier experiments



4. Stopper Rings:

How the crystal structure changes under different strain rates is a topic beyond the scope of this research, but work was done to aid in later research on this topic. For this type of research it is desirable to stop the deformation of the specimen at certain strains to observe how the crystal structure has changed. Stopper rings were made to stop the deformation of a 6mm long sample at 3% strain and 10% strain. The stopper rings are made from 4130 steel that has been quenched and tempered. The quenching and tempering was done in the Material Science department at WSU. For the quenching the steel was heated to 900 degrees Celsius for 2 hours then quickly cooled in room temperature water. After it was cooled in water it was heated to 200 degrees Celsius for 2 hours for the tempering and then slowly cooled to room temperature by the ambient air.

10% strain stopper and 3% strain stopper from left to right



5. Extraction of Stress, Strain, Strain Rate from the Strain Gage Data :

The strain gauge data recorded from the incident and transmitter bars can be converted to stress, strain, and strain rate using the following formulae[1].

$$\sigma(t) = E * \frac{A_b}{A_s} * \epsilon_t(t)$$

$$\dot{\epsilon}(t) = 2 * \frac{C}{l} * \epsilon_r(t)$$

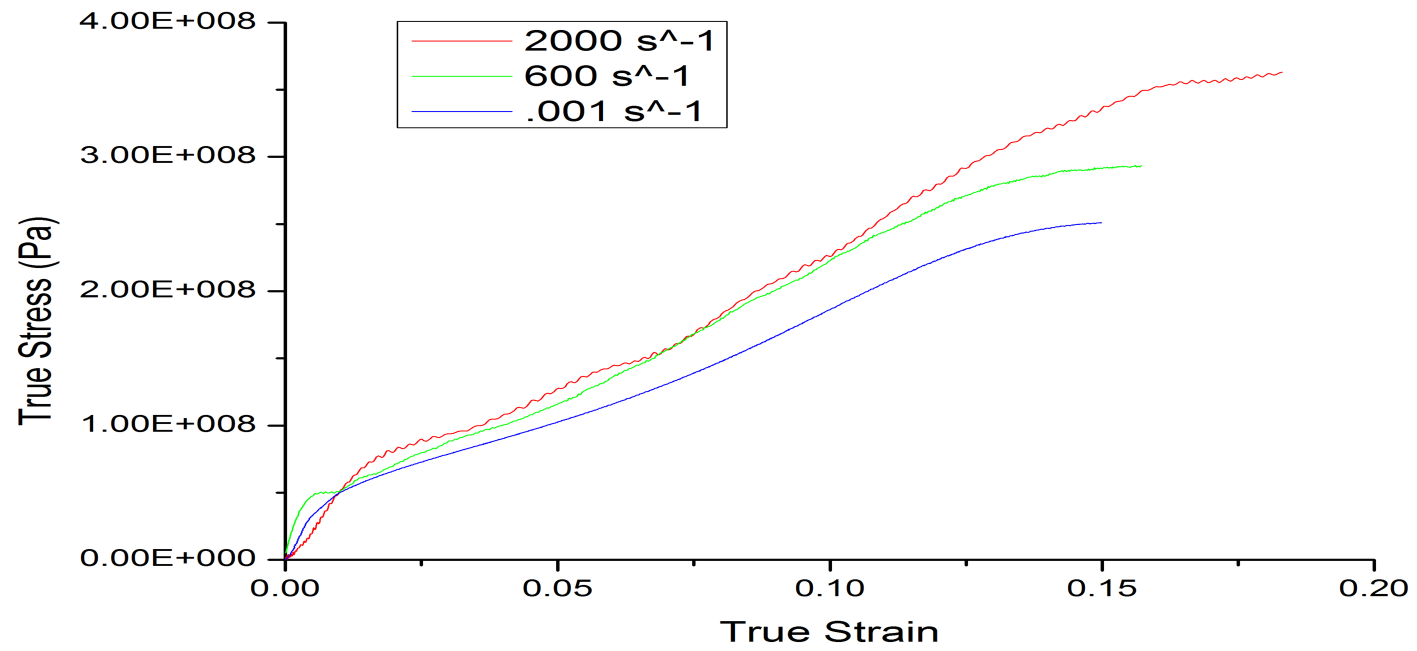
$$\epsilon(t) = \int_0^\tau \dot{\epsilon}(\tau)d\tau$$

Where $\sigma(t)$ is the stress in the specimen, E is the Young's modulus of the bars, A_b is the cross-sectional area of the bars, A_s is the cross-sectional area of the specimen, $\dot{\epsilon}$ is the strain rate of the specimen, C is the wave speed of the bar material, l is the length of the specimen, and ϵ is the strain of the specimen

4. Materials and Test Samples:

99.95% purity magnesium from Gallium Source was tested. The samples were cylindrical with a diameter of 6.5 mm and a length of 6 mm.

7. Deformation Behavior:



The above figure gives insight to the properties of the materials under different testing conditions. The yield strength of the samples does not change much between each strain rate. The differences in yield strength could be caused by error inherent in the testing methods or slight differences in the specimens. The most notable differences are in the Ultimate Strengths. The Ultimate strength increases as the strain rate increases. The most interesting part is that while Ultimate Strength increased from 600 to 2000 strain rate ductility also slightly increased. From .001 to 2000 strain rate the ultimate stress increased 44 percent. The ultimate stress increased 16% between .001 and 600 strain rate. This behavior is probably caused by extension twinning.[2]

8. Fracture Behavior:

Below are pictures of the samples broken at different strain rates. The lower strain rate samples tests yielded typical shear stress failure as indicated by the 45 degree fracture surface. The 2000 strain rate test crushed the sample more than the others because the stress wave had a longer duration causing the sample to be loaded long after it had already fractured.

.001 strain rate, 600 strain rate, 2000 strain rate from left to right

9. Conclusions/Future Research:

- A new testing setup was developed using steel bars. There should be further testing to determine the cause of the poor data. Other materials should be tested to see if strength of the magnesium is too low to test with the steel bars or if there is another cause
- The magnesium showed favorable strain rate sensitivity.
- Our current stopper setup is ready for future research on microstructure evolution during deformation.

10. References:

1. **B A Gama et al. (2004) Hopkinson bar experimental technique: A critical review. Appl Mech Review, vol. 47, no. 4 , 223-250**
2. **N Dixit et al. (2015). Microstructural evolution of pure magnesium under high strain rates. *Acta Materialia,87*, 56-67.**

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