High Strain-Rate/Temperature Experiments Relevant to Friction Stir Welding of HSLA-65

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Abstract

High Strength Low Alloy Steel, grade 65 (HSLA-65) is to be used to build naval ships because of its high strength/weight ratio. Friction stir welding (FSW), will be used to connect the HSLA-65 plates. FSW is superior to other types of welding because of its low energy consumption, lower deformation and better quality of welds. During processing, peak temperatures up to 1250˚C and strain-rates up to 2000/s may develop. This research involves investigating the dynamic stress-strain response of HSLA-65 under conditions relevant to the friction stir welding process. Preliminary experiments using the Split Hopkinson Pressure Bar have been carried out up to 800˚C at strain-rates from 1000/s to 2000/s. In addition, the friction coefficient at the tool/material interface during FSW has an effect on the amount of heat generated during FSW while also affecting tool life. Related research involves designing and testing an apparatus to measure the friction coefficient between the tool (e.g. tungsten rhenium) and the HSLA-65 work piece to determine the dynamic friction coefficient relevant to such operations.

Introduction

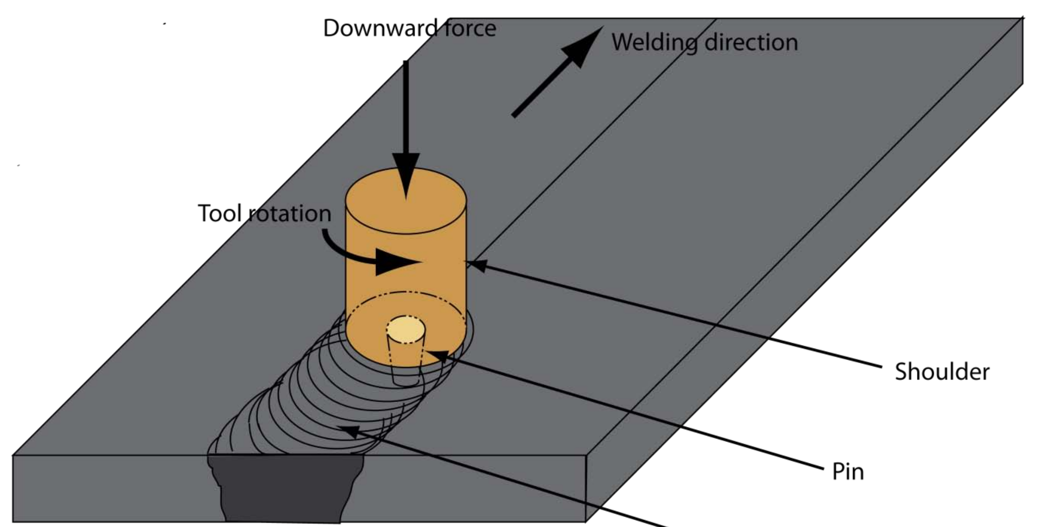


Figure 1: Schematic drawing of Friction Stir Welding

- Solid state welding technique
- Material gets welded due to local heating caused by
  - a) friction between tool and work piece
  - b) severe plastic deformation of work piece

Experimental Method

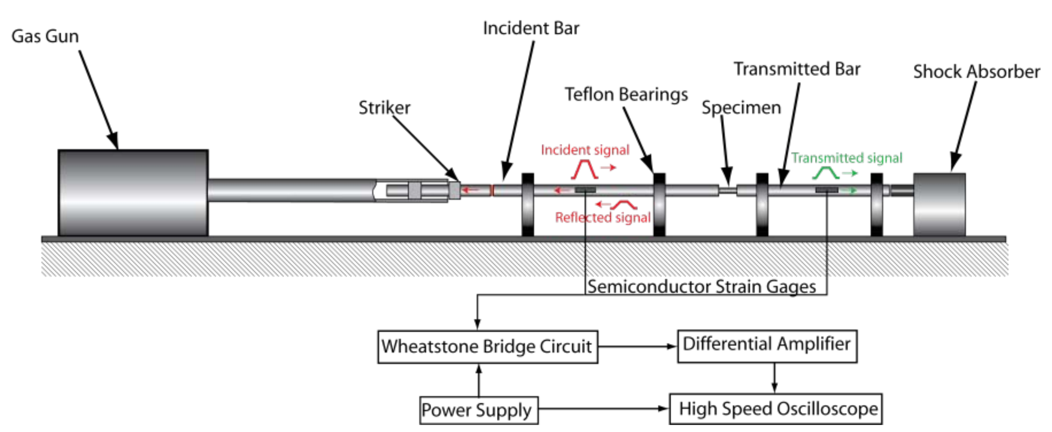


Figure 2: Schematic of Split-Hopkinson Pressure Bar (SHPB)

- Stress calculated from transmitted signal
- Strain rate calculated from reflected signal
- Strain calculated by integrating strain rate

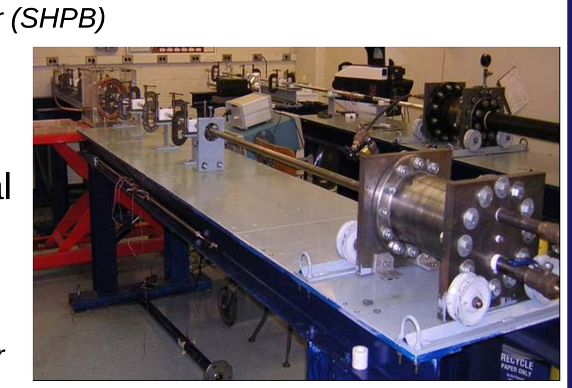


Figure 3: Photograph of Split-Hopkinson Pressure Bar

High Temperature SHPB experiments

- **Heat specimen to temperature without heating incident/transmission bars**
- Bringing the bars in contact with the heated specimen results in the specimen losing heat rapidly by conduction to the bar before the experiment is performed

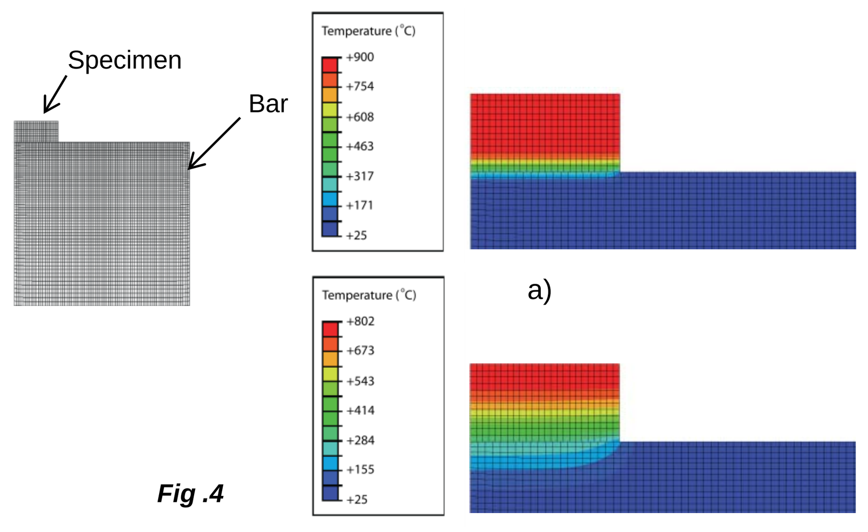


Fig .4

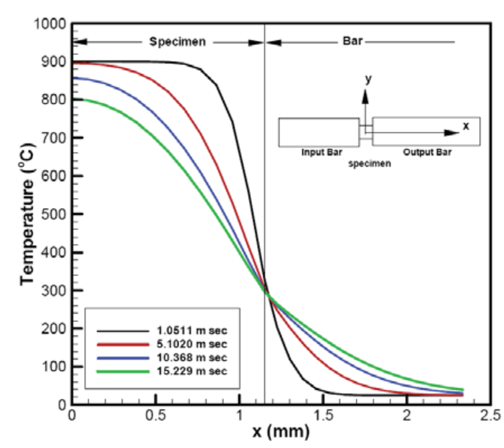
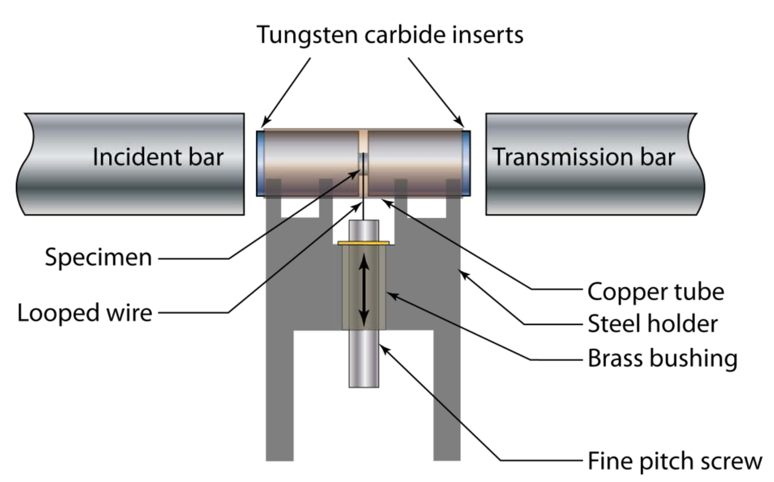


Fig. 5

Figure 4: Axisymmetric FE simulation of cold contact times a) 1.0511 ms b) 15.229 ms

Figure 5: Temperature distribution in the specimen vs. distance after contact with the bars (Shazly, 2005)

- To prevent cold contact between the specimen and the bars, the specimen is sandwiched between two cylindrical tungsten carbide inserts
- Tungsten carbide inserts are impedance-matched to SHPB maraging steel bars, producing no effect on wave speed



Specimen dimensions

Diameter : 4mm

Length : 2mm

Figure 6: Specimen and WC inserts

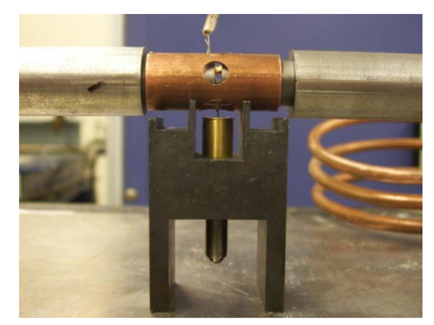


Figure 7: Setup showing specimen and inserts placed in the copper tube placed on a steel holder

- Tungsten carbide inserts are slip fit into a copper tube
- The steel holder which supports the tube is designed for small contact area to prevent heat loss
- The copper tube and the tungsten carbide inserts are concentric with the bars
- Screw has very fine pitch (80 tpi) to enable adjustment of specimen concentricity

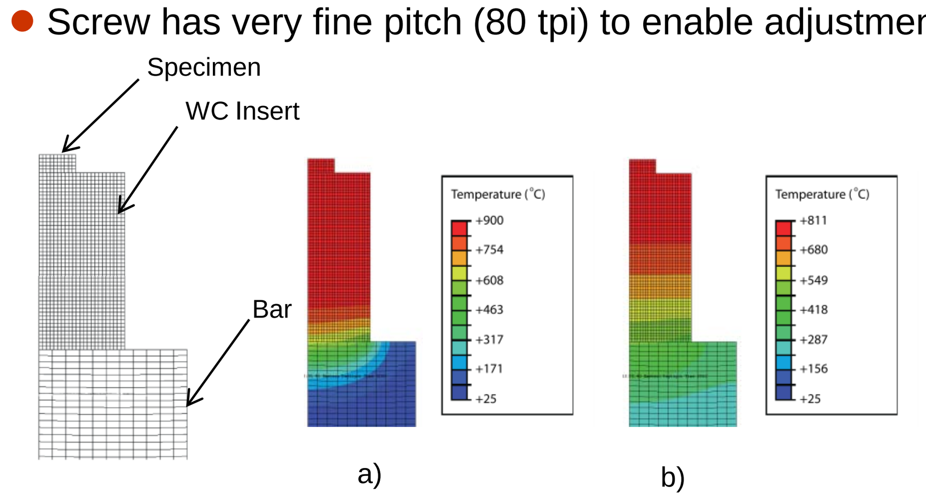


Fig. 8

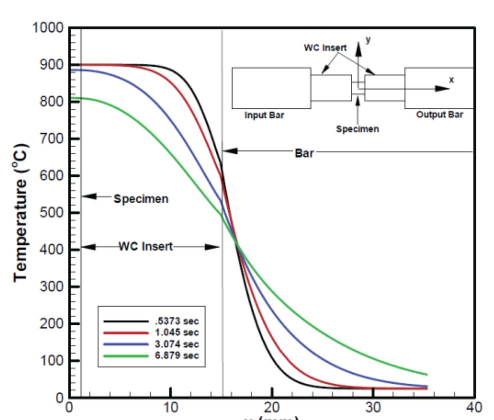


Fig. 9

Figure 8: Axisymmetric FE simulation of cold contact times a) 1.0511 ms b) 15.229 ms

Figure 9: Temperature distribution in the specimen and WC inserts vs. distance after contact with the bars (Shazly, 2005)

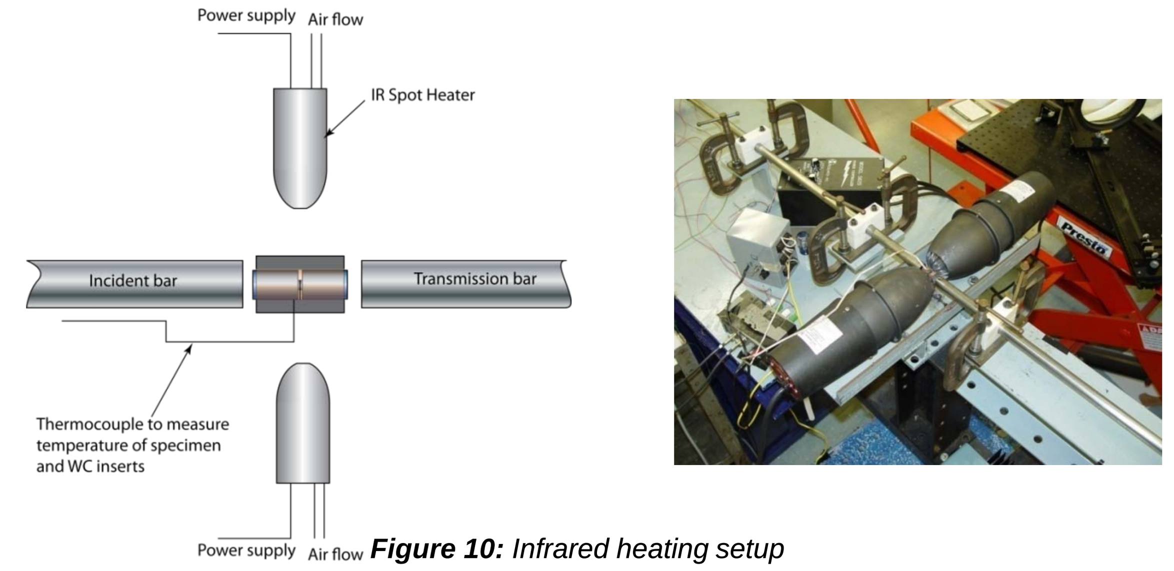


Figure 10: Infrared heating setup

- Infrared heaters heat the specimen/WC inserts up to 800˚C
- Induction heating is used for temperatures from 800˚C to 1200˚C

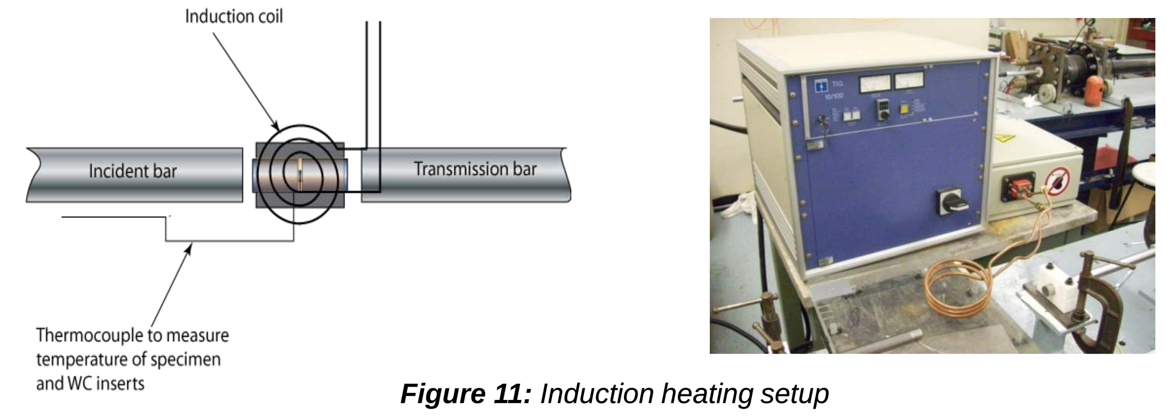


Figure 11: Induction heating setup

Results

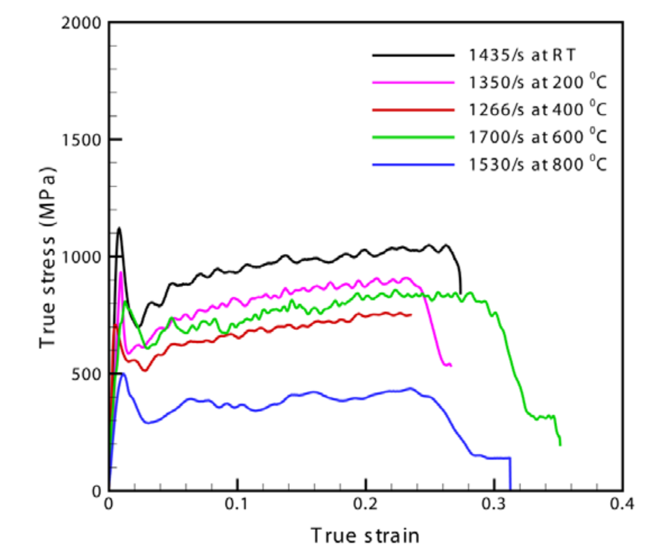


Figure 12: True stress-strain curves, avg. strain-rate 1500/s

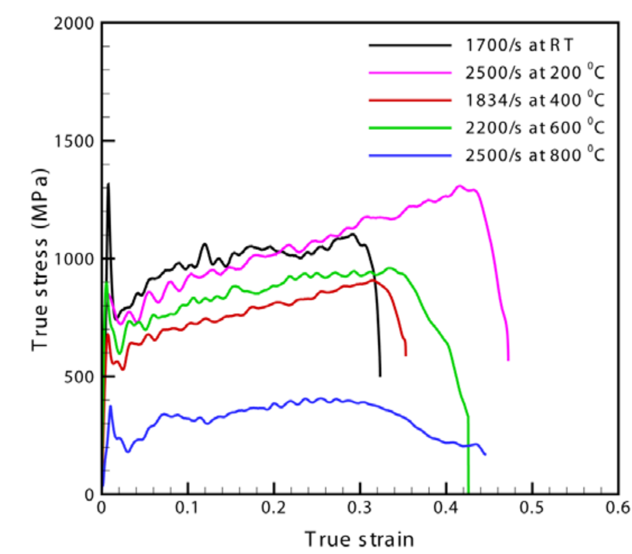


Figure 13: True stress-strain curves, avg. strain-rate 2100/s

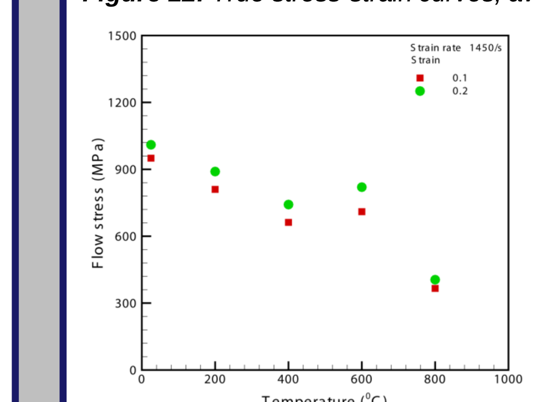


Figure 14: Flow stress vs. temperature, avg. strain-rate 1500/s

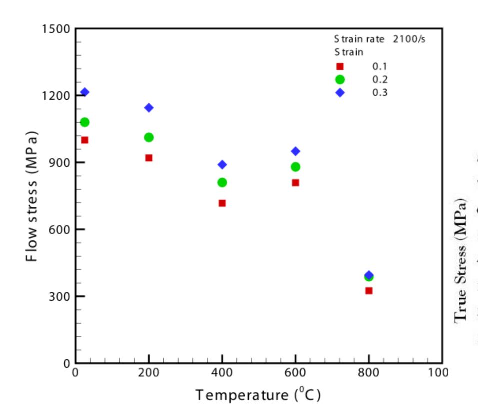


Figure 15: Flow stress vs. temperature, avg. strain-rate 2100/s

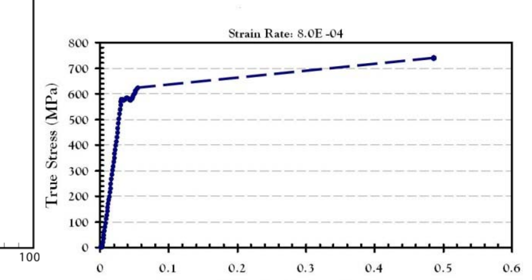


*Figure 16: Quasi-static true stress-strain curve, strain-rate 8*10⁻⁴/s*

- The flow stress at quasi-static strain-rates is significantly lower than at high strain-rates
- The flow stress at high strain-rates:
  - ➢ decreases gradually with temperature up to 400°C
  - ➢ increases with temperature from 400°C to 600°C (dynamic strain aging)
  - ➢ decreases sharply with temperature from 600°C to 800°C

Future Work

Dynamic Friction Experiment

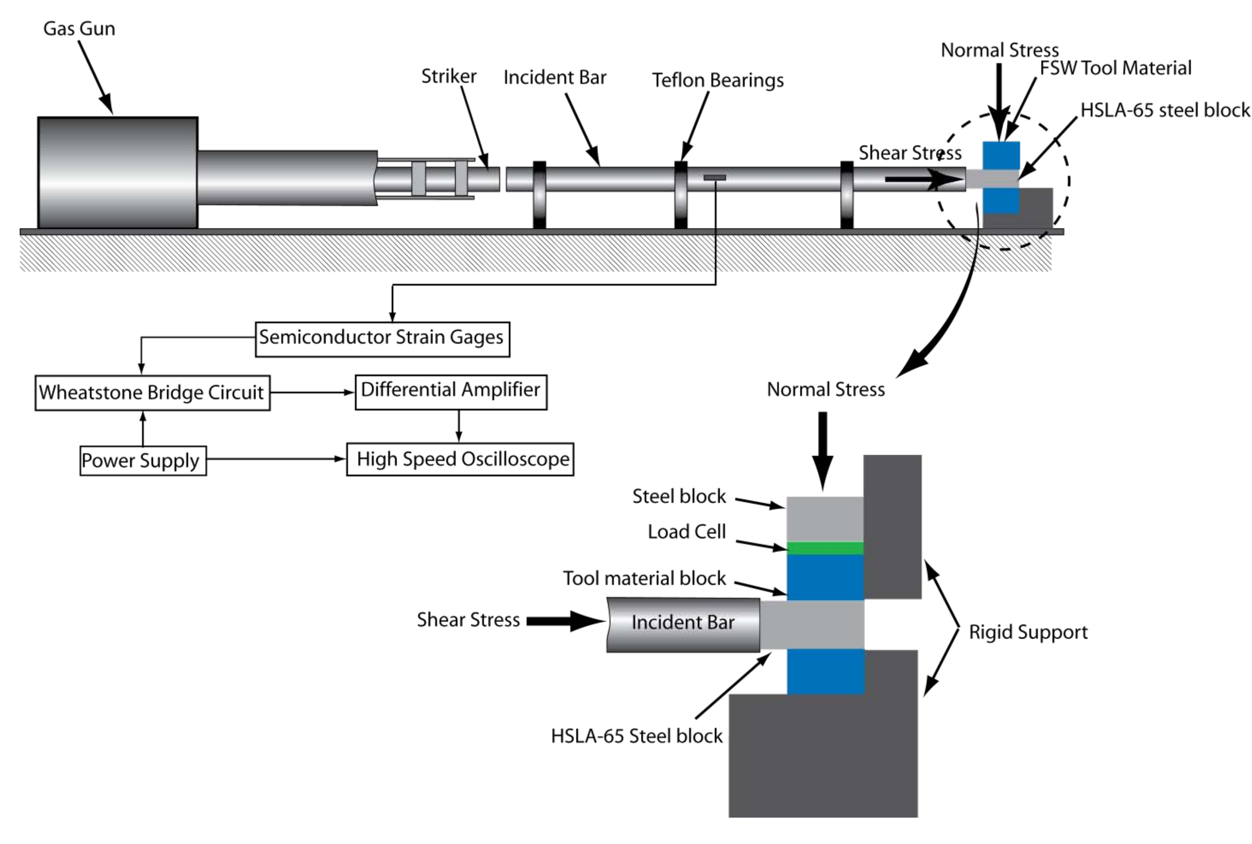


Figure 17: Schematic of friction bar

- The striker is propelled by the gas gun to strike the incident bar generating a longitudinal compressive wave
- HSLA-65 steel sample shears against the FSW tool material
- Difference between incident and reflected wave gives shear stress
- The normal stress is measured by the load cell
- Friction coefficient is calculated from the shear stress/normal stress combination

Summary

- Mechanical behavior of HSLA-65 at high strain rates and high temperatures differs considerably from that observed at quasi-static strain rates
- Flow stress decreases with increase in temperature except at 600°C
- Future work will measure dynamic friction between HSLA-65/FSW tool material pairs

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