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Dynamic Characterization of a 316 Stainless Steel at Elevated Temperatures

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ABSTRACT
316 stainless steel is a promising material for the nuclear power industry due to its corrosion resistance, machinability, and mechanical properties at elevated temperatures. Nuclear facilities such as fission and fusion reactors are routinely exposed to elevated temperatures as a result of startups and shutdowns [1, 2]. They are also required to maintain sufficient strength against accidental drop, impact, and crashes at these elevated temperatures. Therefore, it is important to study the thermo-mechanical behavior of 316 stainless steel to understand the sensitivities of strength and ductility to strain rate and temperature. A comprehensive study of the mechanical response of a 316 stainless steel under dynamic loading is presented. Using the split-Hopkinson bar technique coupled with different environmental chambers, tension and compression experiments were performed at strain rates of 500 s^{-1}, 1500 s^{-1}, and 3000 s^{-1} and at temperatures of 300°C and 600°C.

The 316 stainless steel used in this study was obtained from Marco Steel & Aluminum, and the chemical composition from the supplier is listed in Table 1. The tension and compression specimens were obtained from a cold-drawn round bar with a diameter of 25.4 mm. The tension specimens had a diameter of 3.18 mm and gage length of 6.35 mm, for a L/D ratio of 2. The compression specimens had a diameter of 6.35 mm and length of 3.18 mm, for a L/D ratio of 0.5. The specimen is designed to ensure uniform deformation and to reduce the longitudinal and radial inertia effects during a dynamic experiment.

Figure 1 shows a schematic view of the tension split-Hopkinson pressure bar with the thermal chamber that is used to perform tension experiments at 300°C. Figure 2 shows a schematic view of the split-Hopkinson tension bar with the induction heater that is used to perform tension experiments at 600°C [3]. The induction heater consists of a control box, coil box, and water chiller. The coil box contains the induction coils that are used to heat the specimen. The induction coils are wrapped around the specimen, and a pair of thermocouples are placed near the shoulders of the specimen to measure the temperature and to ensure even heating across the gage section. The water chiller is a cooling system developed to cool the bars and is shown in Figure 2. The water chiller is connected to two hollow water-cooled pillow blocks that are placed at the incident and transmitted bar ends to cool the bars and to ensure only the specimen was heated.

Figure 3 shows a schematic view of the automated high-temperature split-Hopkinson pressure-bar system that is used to perform compression experiments at 300°C and 600°C. This automated system consists of an electrical tube furnace and pneumatic sliders to move the transmission bar as well as to hold and move the specimen into and out of the furnace [4]. A pair of clamps are also installed onto the incident and transmission bars to ensure the transmission bar moves forward and the incident bar stays in place when the specimen comes in contact with it. The timing for the sequence of steps, which includes loading the specimen and opening the fire valve on the gas gun to initiate the experiment, must be precise to have the cold contact time (CCT) as short as possible. CCT is the time during which the heated specimen stays in contact with the cold bars until it is deformed, and a short CCT is desired to prevent a temperature reduction in the specimen before impact.

Using the split-Hopkinson bar technique, a 316 stainless steel was characterized in compression and tension at three different strain rates of 500 s^{-1}, 1500 s^{-1}, and 3000 s^{-1} and at two temperatures of 300°C and 600°C. The strain rate and temperature effects on the compression and tension stress-strain response of the 316 stainless steel were determined.

The experimental data obtained from this study provides a solid foundation for high-fidelity analysis of 316 stainless steel on the component and system design levels over a broad range of extreme and abnormal environments.

Keywords: Stainless steel, Mechanical characterization, Strain rate sensitivity, Temperature sensitivity

Table 1
Reported chemical composition of 316 stainless steel

C	Co	Cr	Cu	Mn	Mo	N	Ni	P	S	Si	Fe
0.015	0.41	16.53	0.36	1.29	2.024	0.030	10.51	0.031	0.026	0.27	Remainder

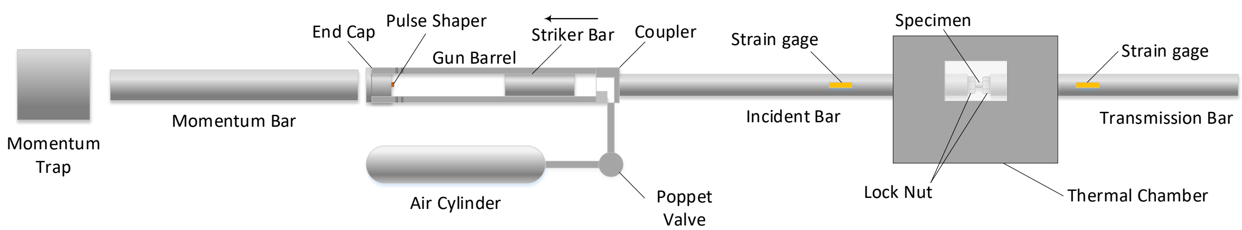

Figure 1: Schematic view of the split-Hopkinson tension bar with thermal chamber for experiments at 300°C.

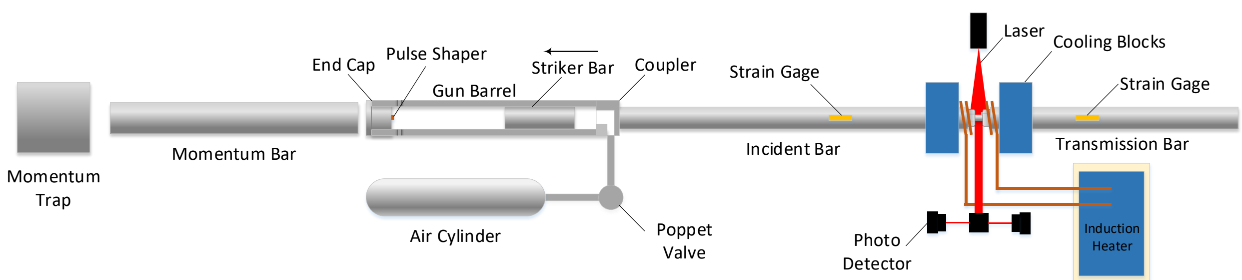

Figure 2: Schematic view of the split-Hopkinson tension bar with induction heater for experiments at 600°C.

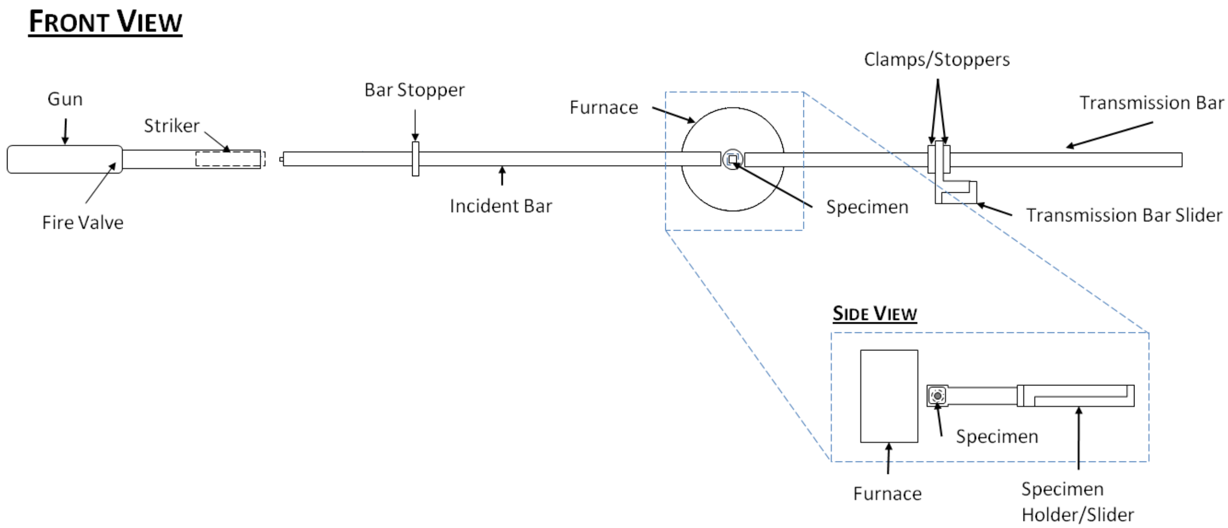

Figure 3: Schematic view of the automated high temperature split-Hopkinson pressure bar system for compression experiments at 300°C and 600°C.

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