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# High Temperature Dynamic Tension Behavior of Titanium Tested with Two Different Methods

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**Abstract**

In this work, the dynamic response of Ti6Al4V alloy at high temperature was studied using the Split Hopkinson Pressure Bar –SHPB- apparatus with two different heating systems. The first device uses direct electric current to heat the sample to the testing temperature in a fraction of a second, whereas the second device uses a furnace to heat the sample and as a consequence, short sections of the bars, in few minutes. Tension tests were carried out at strain rates up to 1500 $s^{-1}$ and at temperatures ranging from room temperature up to 700 °C. The conventional strain gauge measurements from the pressure bars were used to obtain the stress–strain curves and the Johnson-Cook material model was used to fit the results of the tests. High speed photography and digital image correlation were used to quantify the total strain during the test. The plasticity of the titanium alloy clearly increases as the temperature is increased. The maximum strains, obtained from the stress-strain curves, also increase when the temperature is increased from room temperature. DIC results, however, show clear differences in the maximum strain before failure with respect to the values obtained from strain gauges measurements. The maximum strain in the gauge section of the sample prior to failure increases steadily as the testing temperature is increased. At 60 °C, the strains within the gauge section reach values almost 50% just before failure. At 300 °C, the maximum strains are close to 65%, and at 700 °C the maximum strains extend close to 80%.


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*Keywords:* Titanium; high strain rate; high temperature.


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## 1. Introduction

Various industrial and military applications involve dynamic material behavior at high temperatures. Optimal design and development of components requires in-depth understanding of the plastic deformation and failure of materials at these conditions. Nowadays, the most commonly used testing method to study the mechanical behavior of metal alloys at high strain rates is the Split Hopkinson Pressure Bar (SHPB) device. It consists of two long and aligned bars with the specimen sandwiched (compression version) or held (tensile version) between them, and a propulsion device for accelerating a projectile. The striking projectile impacts at the end of one of the bars producing a stress wave which travels along the bars. Strain gauges, amplifiers and oscilloscopes are used to measure the strain wave propagation in the bars and by applying the principles of one-dimensional elastic wave propagation; it is possible to obtain the stress-strain curves of the material, as well as the test strain rate. Moreover, the use of Digital Image Correlation (DIC) technique provides in-depth understanding of the deformation and failure of the specimen by tracking the movement of a surface pattern during testing. Previous research on the dynamic behavior of Ti6Al4V with SHPB devices have been reported [1], including tensile loading [2] and compression loading at high temperatures [3]. However, none has been found involving dynamic tensile loading at high temperatures.

High temperature testing by using the tensile version of the SHPB device is complicated by the fact that the specimen must be firmly fixed to the bars before heating the specimen up to the desired temperature. Because of this, mechanical manipulation of the specimen and the bars is restricted after positioning the specimen. Furthermore, SHPB testing at high temperature presents other difficulties [4]. Due to the length of both bars and the supporting system for keeping bar alignment, it is operationally impossible to heat the entire bar assembly, so a temperature gradient may appear, changing elastic properties of the bars along its length. Consequently, a study of the temperature-gradient effect on the elastic modulus and the longitudinal sound speed should be performed to take into account the corresponding corrections.

High temperature tension tests with the SHPB device can be carried out basically by two ways: heating up the specimen and short sections of the bars to the desired temperature using a furnace [5] [6] [7], or heating up just the sample using, for example, infra-red radiation or direct electric current [8]. Both methods have their advantages, drawbacks, and limitations with respect to the temperature ranges, control of temperature, etc. In fact, no detailed studies have been carried out in the past about the exact effect of the heating method on the obtained final results.

The first method, from now on called furnace method, uses a furnace to slowly heat the sample and inevitably, short sections of the bars, causing some temperature gradient in them. Incident and transmitted bars should be made of a material with a low variation of the elastic properties with temperature to avoid the need for corrections. This method usually implies mechanical clamping since bars are heated up and adhesive degrade its properties at high temperatures. This mechanical clamping could produce disturbances or oscillations in the obtained strain curves.

The second method, which uses direct electric current and called electric method, enables the use of adhesive fixing since the sample is heated up rapidly, so the temperature of the adhesive joint does not increase significantly. Therefore, it would enable to obtain higher quality results. Unfortunately, temperature control of the system becomes difficult since the heating is achieved in less than a second by means of electric current.

There is a third method, which would imply using mechanical devices that brings the room-temperature pressure bars into contact with the heated sample in a fraction of a second before the stress pulse arrives at the end of the incident bar [9] [10]. Regrettably, it is only practical in the case of a compression SHPB test because in tensile SHPB testing the sample needs to be mechanically coupled or adhesively fixed to the pressure bar.

In this paper, the furnace and the electric method are presented and applied to Ti6Al4V alloy.

## 2. Furnace heating method

The furnace method was employed by using the SHPB tensile system of the Department of Material Science at Technical University of Madrid [5]. In this laboratory, the incident and transmitted bars have 4.05 m and 3.85 m length respectively, 19.3 mm diameter, and they are made of the René 41 alloy, a nickel-based super-alloy with optimal high-temperature properties and low dependence of its elastic properties on temperature. The bars have