Proceedings of International Conference on Applications and Design in Mechanical Engineering (ICADME)
11 – 13 October 2009, Batu Ferringhi, Penang, MALAYSIA

The Effect of High Loading Rate to Tensile Strength for Mild Steel by Using Hopkinson Bar Technique.

[1]Mohd Shahiddin Suhadi, [1]Rakhmad Arief Siregar, [1]Shah Fenner Khan,
[2]Ahmad Yusri, [1] Abd Hamid Adom
1) School of Mechatronic Engineering
University Malaysia Perlis
Jalan kangar arau 02600 Jejawi Perlis Malaysia
2) Fakulti Kejuruteraan Mekanikal
Universiti Teknologi Mara, Shah Alam
Email: rakhmad@unimap.edu.my

***Abstract*- This paper presents the effect of high strain rate loading to tensile strength for mild steel by using Hopkinson bar technique. The behavior of material at high strain rates is important for application such as structural impact, automotive safety engineering and metalworking. In automotive industries, mild steel has been used as material in some of component. Due to dynamic condition occurrence during vehicle crash it is important to analyze the strength of component.**

Split Hopkinson Pressure Bar (SPHB) is the most common method for determining material properties at high strain rates, it consist of two long slender bar that sandwich a short cylindrical specimen between them. A striker bar impacts the incident bar, producing in it elastic wave pulse that travels through the incident bar and then reaches specimen. Upon arrival at the specimen, the wave partially reflects back towards the impact end and the remainder of the wave transmits through the specimen into the second bar. By capturing the wave pulse at the Hopkinson Bar apparatus a stress-strain relationship on the specimen can be calculated. It is found that the tensile strength on the stress-strain diagram increase significantly compared to a static test.

I. INTRODUCTION

For the past decade, study of mechanical properties on metal under quasi-static condition and dynamic condition has been the interest of researchers. Therefore, metals are usually tested to obtain the strength data under long term condition (hours to day) or static condition using Universal testing machine (minutes). The maximum deformation of metal tested on these machines is at very low strain rate at $10^{-1}s^{-1}$. One of the most widely used experimental configurations for dynamic condition on material is the Split Hopkinson Pressure Bar (SHPB) or Kolsky apparatus. Split Hopkinson Pressure Bar has been a wide acceptance for researchers as the instrument to measure intermediate strain rate testing at $10^{2}s^{-1}$ until $10^{4}s^{-1}$ [1]. Behavior of material properties at high strain rates is important for application such as structural impact, automotive industries, aerospace and metalworking.

Mild steel are widely used for automotive industries as material to develop component in vehicle. Therefore the dynamic properties for this material are increasingly needed from the impact crashworthiness view point [2]. The performance assessment of a component or structure requires accurate knowledge on the strength properties of the material involved. The objective of this paper is to determine the tensile stress-strain characteristic of mild steel at high strain rate. The impact tension tests are conducted using the tensile version of the Split Hopkinson Pressure Bar. Split Hopkinson Pressure Bar tensile apparatus consist of incident bar, transmitted bar, specimen and a striker. A striker bar impacts the stopper at incident bar, producing in it a pulse. The amplitude of elastic wave travels through the incident bar, then reach the specimen and through to the transmitted bar. By attaching strain gauges at incident bar and transmitted bar the wave that travels through can be measured directly [3].

II. EXPERIMENTAL SET UP

Tensile Split Hopkinson Bar Apparatus consists a striker tube cylinder, incident bar, transmitted bar, tower impact, specimen, and stopper. Figure 1 shows the design of Tensile Split Hopkinson Bar Apparatus.

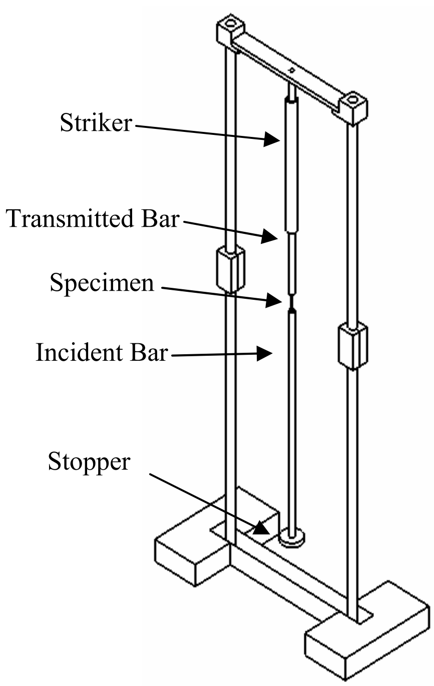

Fig. 1. Split Hopkinson Pressure Bar Apparatus.

All the bars and striker tube cylinder are made from mild steel. The diameter of both incident and transmitted bars is 20mm and their lengths are 2100mm. For striker tube cylinder diameter is 30mm and the length is 1000mm.

For experiment setup the striker tube cylinder need to be pulled up at certain height and release. There are two waves produced upon striker arrival at stopper one is tensile wave that has been produced and measured using strain gauges mounted bi-axially. The other is compressive wave that partially reflect back once reach at the specimen and partially through to the transmitted bar as tensile wave.

The incident wave (I), reflected wave (R), and transmitted wave (T) are recorded by the strain gauge mounted onto the incident and transmitted bar. Figure 2 shows set of oscilloscope traces from tensile Hopkinson bar test.

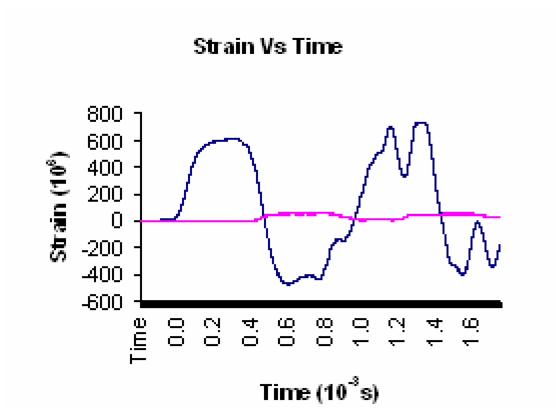

Fig. 2. Oscilloscope traces from Hopkinson bar test.

1. Split Hopkinson Technique.

The equation that has been use for data analysis in Tensile Split Hopkinson Pressure Bar is almost identical to that of the compression test. Change in sign of the tensile are the only major differences.

For this study, the incident and transmitted bars were made from the same material with equal cross-sectional areas. In this experiment we need to focuses on the stress, strain and strain rate in a specimen when we know the strain in the bar (from strain gauges recordings). By using Hopkinson Pressure bar or Kolsky bar theory shows below the stress (σ), strain (ε) and strain rate ($\dot{\varepsilon}$) on the specimen can be obtained.

$$\sigma(t) = E_0 \frac{A_0}{A} \varepsilon_T(t) \quad (1)$$

$E_\circ$ is the elastic modulus of the bar, and $A_\circ$ is their cross-sectional area

$$\dot{\varepsilon}(t) = \frac{C_\circ}{L}(\varepsilon_I - \varepsilon_R - \varepsilon_T) \quad (2)$$

$$C_\circ = \sqrt{\frac{E_\circ}{\rho}} \quad (3)$$

$C_\circ$ is the velocity of the elastic wave in the bar.

$$\varepsilon(t) = -\frac{2C_\circ}{L}\int_0^t \varepsilon_R dt \quad (4)$$

Thus, the stress-strain behavior of specimen is determined simply by measurement made on the elastic wave in tensile Split Hopkinson Bar. The above equation relate strain gauges measurement to stress-strain behavior in the deforming specimen and require that the wave within the pressure bar must be one dimensional and the specimen must deform uniformly.

2. Material and Specimen Preparation.

Mild Steel has been used for tested in this Split Hopkinson Pressure Bar experiment. The geometries design for the specimen with threaded end is shown in Figure 3 below. The threaded end is used to hold the specimen between the incident bar and transmitted bar.

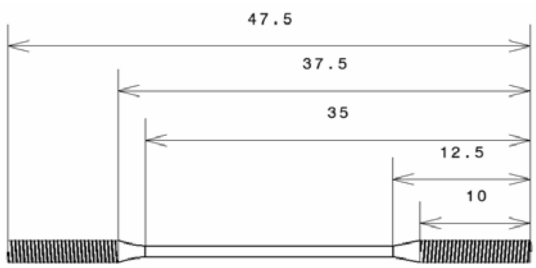

Fig. 4. Dimension of impact tension specimen with threaded (mm).

III. RESULTS

A static test has been performed at different value of cross-sectional speed using Autograph Universal Testing machine using a load cell of 10kN. The cross-sectional speed that has been used is 0.5mm/min, 5 mm/min and 50 mm/min. Figure 5 shows stress-strain diagram on static test.

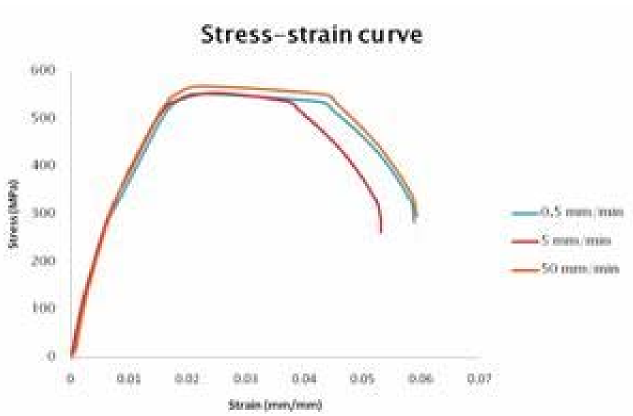

Fig. 5. Stress Vs Strain on static test.

From the stress strain diagram the yields stress and ultimate tensile strength for the static test has been calculated to be compared the effect of tensile strength on static test and dynamic test. It is found that the ultimate tensile stress at static test is almost the same at each cross-sectional speed.

Series of dynamic tension test was conducted using the tensile Hopkinson Bar. The raw data obtained using oscilloscope is processed using equation (1), (2) , (3) and (4) as mention on split hopkinson technique section. The dynamic tensile test was conduct four times, where the striker tube cylinder was release at different height level, at 2.5m and 2.9m. Figure 6 shows the dynamic stress-strain diagram. By changing the height of striker release form 2.5m to 2.9m a significantly increment in tensile stress occur to the material. By incrementing the height for striker has been release it also increase the strain rate for the material. Comparison on static and dynamic stress-strain is shown at Figure 7. From the graph, at higher strain rates it shows that the strength of material increases. This shows that at dynamic condition the material has become stiffer compared to static condition test.

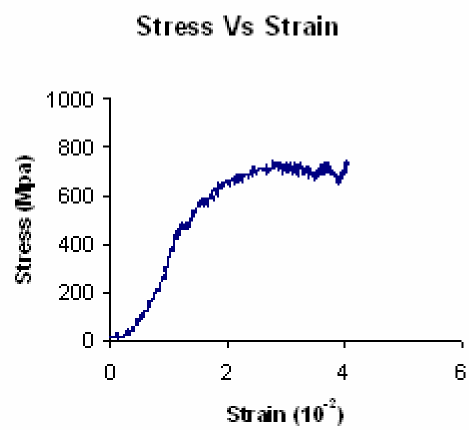

Fig. 6. Dynamic Stress-Strain diagram

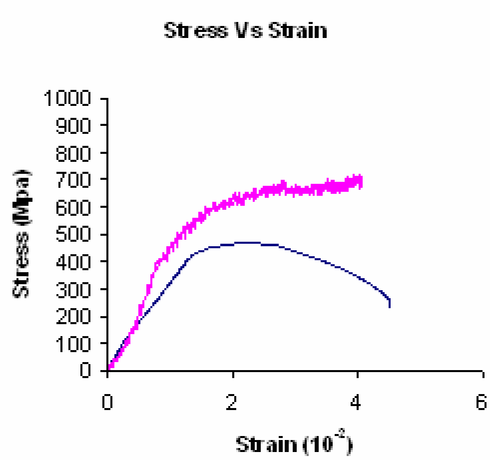

Fig. 7. Comparison Static and Dynamic stress-strain diagram

To see the effect of strain rate the points of ultimate tensile stress versus strain rate were plotted to show comparison between static and dynamic condition of strain rate Figure 8 show comparison on ultimate tensile strength Vs strain rate. The comparison can be seen where as the strain rate increase the ultimate stress of material also increase.

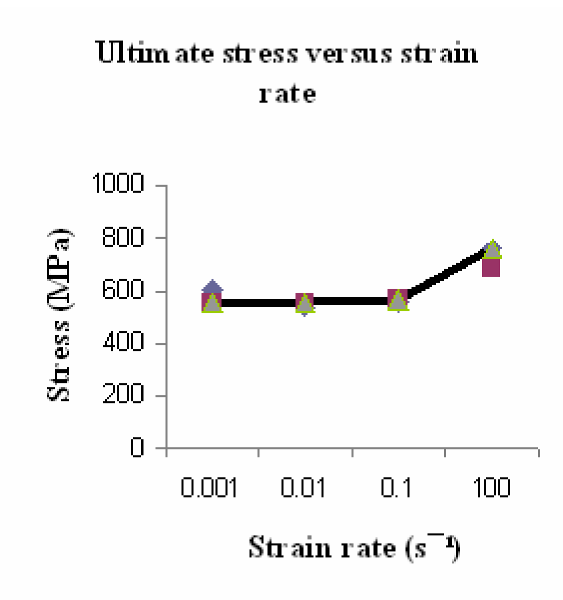

Fig. 8. Ultimate Tensile Test Vs Strain rate.

III. CONCLUSION

Mild steel specimen has been impacted at series of 2.5m and 2.9m height to using Tensile Split Hopkinson Pressure Bar apparatus. From the experiment at height of 2.5m the ultimate tensile stress is 683.2 MPa and at 2.9m the ultimate tensile stresses obtain is 702.09 MPa. Both series of height gives the strain rate almost at $10^2 s^{-1}$ where it is within the intermediate dynamic loading rate. The comparison between the static loading rate and dynamic has been made and it is found that the higher loading rate, it increase the tensile strength of material.

IV.REFERENCES

[1] Marc A. Meyers “Dynamic Behavior of Materials” University of California, 1994
[2] Dong Wei Shu “Tensile Mechanical Properties of AM50A alloy by Hopkinson Bar” Nanyang Technological University, 2007
[3] Zhan Xing Ming “ Dynamic Property Evaluation of alluminium alloy 2519A by Split Hopkinson Bar” Central South University of China, 2007.