"I confess that have been read this report and this report is acceptable from the scope and the quality for the awarded Bachelor of Mechanical Engineering (Automotive)"

Supervisor I

Signature : ....

Name : Hamzah Bin Mohd Dom

Date : 12/5/2009

STUDY AND PRELIMINARY DESIGN OF HIGH SPEED IMPACT TEST MACHINE USING HOPKINSON BAR TEST PRINCIPLE

ALYAA IZZATI BINTI HASHIM

This report is submitted in fulfillment the requirements for the award of degree of Bachelor of Mechanical Engineering (Automotive)

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

MAY 2009

"I hereby declare that I'm the author of this report and it as a result of my own work, except a few sections which were extracted from other resources as being mentioned"

Student's Signature	:	…………………….
Name	:	Alyaa Izzati Hashim
Date	:	13 May 2009

ACKNOWLEDGEMENT

I would like to express my deepest thanks to En. Hamzah who is my supervisor that always guides me in completing this final project report. I'm also wanted to extend my appreciation to En. Ahmad Rivai who also helps and guides me.

To my family members also I would to say thank you for their continual support and encouragement has been unending and unconditional, as is my love for them. All of my friends who are supporting me, I also want to extend my appreciation to them.

Lastly, thank to all of you who helping me directly or indirectly during my hard time in completing this final project report.

ABSTRACT

There are many type of test for materials to determine material properties at high strain rate. The most commonly used method is the split Hopkinson bar test and it is also known as Kolsky bar. The high strain rate is approximately in ranges 10^4 in/in/sec. The design of this device is presented in research, design, and measurement.

The overview of the split Hopkinson bar test are it is consists of two steel bar that sandwich a cylindrical specimen between them. One of the bars is striked by the striker bar, a compressive stress wave is generated that immediately begins to transverse towards the specimen. When it arrives at the specimen, the wave partially reflects back towards the impact bar end. The other part of the wave will transmit through the specimen and into the second bar causing the plastic deformation in the specimen. It is shown that the reflected and transmitted waves are proportional to the specimen's strain rate and stress. Specimen strain can be determined by integrating the strain rate.

A lot of research has been done because most of the data about the split Hopkinson bar test is protected. Many engineers make a research about this method and they come out with several design of split Hopkinson bar test.

ABSTRAK

Dari dulu hingga kini juruterkajian untuk menghasil suatu cara yang terbaik untuk menentukan kadar ketegangan yang tinggi pada sesuatu bahan. Split Hopkinson Bar Test merupakan suatu cara yang biasa digunakan untuk menentukan kadar ketinggian ketegangan sesuatu bahan. Kadar ketinggian ketegangan sesuatu bahan biasanya dalam angaran 10^4 in/in/sec. Dalam proses mereka bentuk split Hopkinson bar test ini kajian menyeluruh mengenainya perlu dilakuakan.

Gambaran sebenar split Hopkinson bar test ini adalah dua bar yang di tengah-tengahnya terdapat satu bahan contoh. Salah satu daripada bar tersebut iaitu dikenali juga sebagai input bar di langgar dengan kuatnya oleh satu bar lain. Semasa perlanggaran berlaku satu gelombang tekanan terhasil dalam input bar atau impact bar. Apabila gelombang ini menyentuh permukaan bahan contoh tersebut sebahagian daripada gelombang tersebut terpantul kembali ke dalam input bar dan sebahagian lagi akan merentasi bahan contoh dan bar yang satu lagi atau output bar. Ini menunjukan bahawa gelombang yang merentasi dan memantul adalah berkadar terus dengan kadar tekanan bahan contoh itu.

Banyak kajian yang perlu dibuat untuk mendapatkan maklumat yang lebih terperinci mengenai split Hopkinson bar test ini kerana maklumat mengenainya sangat terhad dan dilindungi. Namun begitu semakin banyak kajian yang dibuat dan semakin banyak rekabentuk split Hopkinson bar test.

TABLE OF CONTENT

CHAPTER	DESCRIPTION		PAGES
	DECLARATION		ii
	AKNOWLEDGEMENT		iii
	ABSTRACT		iv
	ABSTRAK		v
	TABLE OF CONTENT		vi
	LIST OF TABLE		ix
	LIST OF FIGURE		x
	LIST OF SYMBOL		xii
	LIST OF APPENDICES		xi
CHAPTER 1	**INTRODUCTION**		
	1.1	Problem Statement	1
	1.2	Objectives	1
	1.3	Scope of Project	2
	1.4	Overview of Split Hopkinson Bar Test	2
CHAPTER 2	**LITERATURE REVIEW**		
	2.1	Introduction	3
	2.2	History Perspective	4
	2.3	Strain	4
	2.4	Stress-Strain Rate	5
	2.5	Wave Propagation	8

CHAPTER	DESCRIPTION		PAGES

	2.6	An Experiment Using Plasticine to Show The Wave Generate in Bar	9
	2.7	Theory of Split Hopkinson Bar	11
	2.8	Equation of Motion of Striker Bar	14
	2.9	Design of SHBT	15
	2.9.1	The Design from Southwest Research Institute	15
	2.9.2	The Design from University of Maine	17
	2.9.3	Function of Each Component	18
CHAPTER 3	**METHODOLOGY**		
	3.1	Introduction	19
	3.2	Concept Design	19
	3.3	Design Description	20
	3.4	Design Flow Chart	21
CHAPTER 4	**RESULTS**		
	4.1	Introduction	23
	4.2	Gas Tank	23
	4.3	Regulator	24
	4.4	Solenoid Valve	24
	4.5	Launching Tube	25
	4.6	Incident and Transmitter Bar	26
	4.7	Rod Interface Support	27

CHAPTER	DESCRIPTION		PAGES
	4.8	Stand	27
	4.9	Strain Gauges	28
	4.10	Summary of Overall Part and Component	30
	4.11	Final Design of SHBT	31
	4.12	Theoretical Calculation of Motion of Striker Bar	32
CHAPTER 5	**DISCUSSION**		
	5.1	Introduction	33
	5.2	Strain Gauges Measurements	33
	5.3	Testing Procedures	34
	5.4	Data Processing Procedures	37
	5.5	How SHBT Work	38
CHAPTER 6	**CONCLUSION**		
	6.1	Introduction	40
	6.2	Conclusion	40
	6.3	Recommendation	41
	REFERENCES		42
	BIBLIOGRAPHY		44
	APPENDIX A		45
	APPENDIX B		48

LIST OF TABLES

NO.	TITLE	PAGES
2.1	Testing Technique According to Strain Rate	6
2.2	Apparatus of SHBT in early 1960 in SwRI	15
2.3	The improvement of SHBT apparatus in early 1970 in SwRI	15
2.4	Function of each component of SHBT	17
4.1	Dimension of I-beam	28
4.2	Summary of apparatus in SHBT	30
4.3	Summary of component in SHBT	30
5.1	Test parameter calculates by MATLAB interface	36

LIST OF FIGURES

NO.	TITLE	PAGES
2.1	Definition of strain	5
2.2	Shows propagation waves on left and strain on right	8
2.3	Shows the reflection and absorption of the wave propagation wave	9
2.4	a) Plot of stress pulse profile recorded by the strain gauges on transmitter bar, b) calculated displacement history at the bar plasticine and c) cross-sectional view of the recovered plasticine after being subjected to the displacement history	10
2.5	Schematic drawing of SHBT	11
2.6	Free body diagram of striker bar	14
2.7	Shows a diagram of the apparatus	17
3.1	Flow diagram of the design	21
4.1	2 way high pressure solenoid valve	25

4.2	Launching tube	26
4.3	Figure of I beam	28
4.4	Stand	28
4.5	Schematic of SHBT	29
4.6	Results of SHBT design	31
5.1	Block diagram of SHBT scheme	35
5.2	Block diagram of typical data processing procedure	37
5.3	Expected incident wave	37
5.4	Expected transmitter bar wave	38

LIST OF SYMBOL

a_x	=	acceleration
P	=	initial pressure of compressed air tank
A	=	area of the projectile
L	=	travel distance (barrel length)
m	=	mass of the projectile
x	=	displacement of the projectile
V_x	=	velocity of the projectile

CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

High speed impact is not so easy to reproduce in testing and therefore usually use bullet impact is used for high speed test. Nowadays in a few development country the split Hopkinson bar apparatus has quickly become the most widely used device to test materials at high strain rates. The purpose of this study is to improve the current testing techniques and to design our own high speed impact test machine using Hopkinson bar principle.

1.2 OBJECTIVES:

1. To study the Hopkinson bar test development
2. To study the technique of high speed impact measurement system
3. To design of high speed impact test machine using Hopkinson bar principle.

1.3 SCOPE OF PROJECT:

1 Literature research to understand high speed impact and measurement system
2 Collect the data of Hopkinson bar test development
3 Design of impact test machine, consist of:
   - Rig design: impacter and specimen holder
   - Measurement system
4 Measurement system calibration
5 Report writing

1.4 OVERVIEW OF SPLIT HOPKINSON BAR TEST

The materials are stronger at higher strain rates, which are caused by an impact. The behaviour of the materials attract the engineer to do more research about this problem and to come out with the design that can test and measure the strain rates of the materials. One of the devices that is most widely used to test materials at high strain rates is Split Hopkinson Bar Test (SHBT) and it is also the most commonly used method for determining material properties at high rates of strain.

SHBT also known as Kolsky apparatus (Adam Kaiser,Michael. Virginia Polytechnic Institue), which is a short cylindrical specimen is sandwiched between two long elastic bars. It start with a projectile is fired into one of the end of the input bar, and resulting the bar to generate a compressive stress pulse. The pulse will travels along the input bar and partially transmitted through the specimen and into the output bar. The reflected pulse is reflected as a wave in tension, whereas the transmitted pulse remains in compression. Constant strain rate test can be performed at strain rate approaching 10^4 s^{-1}.

The specimen strain rate can be calculated from the strain histories. Under certain deformation conditions, only two important strain pulses need be identified. These are the reflected pulse and the pulse transmitted through the specimen.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Materials are stronger at high strain rate that caused by an impact. The behaviour of structure to impacts attracts the engineers for purpose of design the constitutive models of materials tested. The SHBT has become widely and commonly used method for testing high strain rate. Constant strain rate tests can be performed at strain rates approaching 10^4 s^{-1} relative easily.

The SHBT is composed of a striker bar, an incident bar, and the test specimen and output bar. When the incident bar is impacted by striker bar, the compressive wave is generating in incident bar. Once this wave is reaches the test specimen the part of it transmits through it and part of it is reflected back through incident bar. From one dimensional wave propagation analysis, the high strain rate stress-strain curves can be determine from the measurements of strain gauges which is installed in the incident and output bars. In order to obtain correct wave propagation the striker bar must reach necessary velocity before it hits the incident bar. Kolsky developed the relation for calculating the specimen stress which is I include it in the theory. In this chapter focuses on the research and the data I got about the SHBT.

2.2 HISTORY PERSPECTIVE

a) Betram Hopkinson(1913) was the one who found out and introduces a technique for determining the pressure-time relations due to an impact. Hopkinson's idea was that as by impacting one end of the rod, a compressive pressure wave is generate inside the rod and as the compressive wave traversed through the bar, it will reflected back as a pulse of tension at the free end.

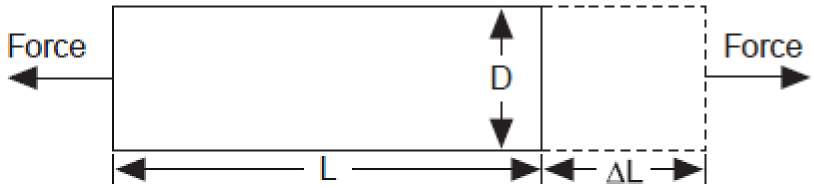
b) Davies(1948) was the one who improving the accuracy of Hopkinson's original apparatus by using condensers to measure strains. He was develops a technique using condensers to measure the strains existing in the pressure bar.

c) Kolsky an Investigation of the Mechanical Properties of Materials at Very High Rates of Loading, Proc. Phys. Soc. London (1949). adds a second bar to Hopkinson's original apparatus and he name it as split Hopkinson bar which is Kolsky sandwiched a specimen between two bars. He expressions the calculation of the specimen based on the strain histories and the strain were measured using the condenser used by Davies. The Kolsky's idea has become the most widely used testing for high rate test today and the split Hopkinson bar also referred by Kolsky bar.

d) Hauser(1970) add strain gauges to the split Hopkinson bar to measure surface displacements.

2.3 STRAIN

Strain is amount of deformation of a body due to an applied force. More specifically, strain (ε) is defined as the fractional length, as shown in Figure 2.1 below.



$$\varepsilon = \frac{\Delta L}{L}$$

Figure 2.1: Definition of Strain

(Source from www.strain.com)

Strain can be positive (tensile) or negative (compressive). Although dimensionless, strain is sometimes expressed in units such as in./in. or mm/mm. in practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as micro strain ($\mu\varepsilon$), which is $\varepsilon \times 10^{-6}$. When a bar is strained with a uniaxial force, as in Figure 2.1, a phenomenon known as Poisson Strain causes the girth of the bar, D, to contract in the transverse, or perpendicular, direction. The magnitude of this transverse contraction is a material property indicated by its Poisson's Ratio. The Poisson's Ratio v□ of a material is defined as the negative ratio of the strain in the transverse direction (perpendicular to the force) to the strain in the axial direction (parallel to the force), or $v = -\varepsilon_T/\varepsilon$. Poisson's Ratio for steel, for example, ranges from 0.25 to 0.3.
(reference: www.strain.com)

2.4 STRESS-STRAIN RATE

Strain rate test is widely used to provide the information on the strength of materials and as an acceptance test for the specification of materials. The material also is stronger at the higher strain rate. From my research of stress-strain rate, the parameters, which are used to describe the stress-strain curve of a metal, are tensile strength, yield strength, percent elongation and reduction area.

In the elastic region stress is proportional to strain. Initially the strain hardening more than compensates for this decrease in area and the engineering stress continues to rise with increasing strain.
(Reference: http://en.wikipedia.org/wiki/Stress-strain_curve)

Table 2.1 : Testing Technique According to Strain Rate
(Source from thesis of spectral analysis of wave propagation through a polymeric Hopkinson bar, University of Waterloo).

STRAIN RATE	TESTING METHOD	CATEGORY
10^7 10^6 10^5	-Explosives -Gun systems -Pulsed laser -Plate impact	Ultrahigh Strain Rate
10^4 10^3	-Taylor Anvil Tests -Hopkinson Bar Test -Expanding Ring	High Strain Rate
10^2 10^1	-High-velocity hydraulic or pneumatic machines; cam plastomer	Low Strain Rate

a) Taylor Anvil Test

This method propels a cylindrical into a target which is rigid or symmetric. The process of deformation results from a sequence of elastic and plastic waves propagating in the cylinder. From initial and final measurements, the initial velocity of the projectile and the velocity of the target, the material behavior can be deduced through the application of conservation equations (source from thesis of spectral analysis of wave propagation through a polymeric Hopkinson bar, University of Waterloo).

b) Expanding Ring

This method uses a hollow cylinder with an explosive core as a method of initiating a shock wave. The material to be tested is placed in a ring around the hollow cylinder. As the explosive is detonated, the shock wave expands radially, which in turn causes the cylinder and specimen to expand. In order to determine the stress strain curve for the material, the velocity history of the ring is recorded. This method uses varying amounts of explosive to select the strain rate desired (source from thesis of spectral analysis of wave propagation through a polymeric Hopkinson bar, University of Waterloo).

c) Split Hopkinson Bar Test

The Split Hopkinson Bar comprised of three separate bars known as the striker bar, incident and the transmitter bar. The striker bar is propelled towards the incident bar at a desired velocity. A compressive wave is imparted into the incident bar as the striker impacts. Some of the wave in the incident bar is transmitted through the sample into the transmitter bar and the rest of the wave is reflected in the incident bar. In order to determine the strain within the sample, strain gauges are mounted on both the incident and transmitter bars (source from thesis of spectral analysis of wave propagation through a polymeric Hopkinson bar, University of Waterloo).
(reference for a),b),c): Christopher Calisbury (2001). “Spectral Analysis of Wave Propagation Through A Polymeric Hopkinson Bar”. University of Waterloo: Thesis Master.)

2.5 WAVE PROPAGATION

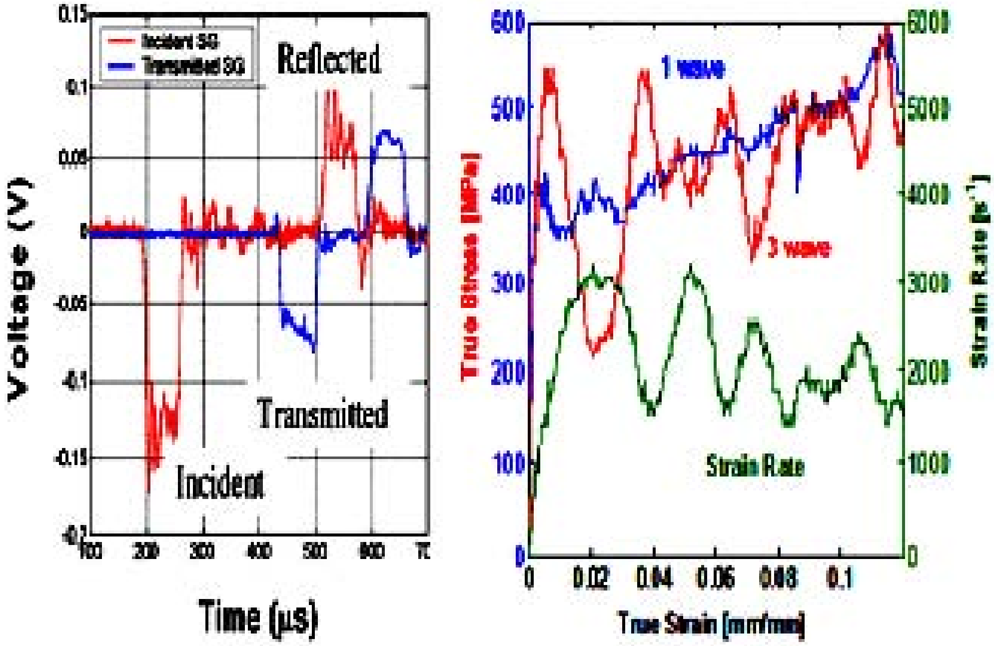


Figure 2.2: Shows propagation waves on left and strain on right
(source: University of Maine)

The figure 2.2 show the graph results from the experiments. At the left is the graph of voltage versus time, it show how the wave propagate in the bar. The red line show the wave in incident bar and the blue color is representing the wave in transmitter bar. In incident bar it shown that the wave propagate at time 200 microsecond and when the wave hit the specimen the wave is reflected at time 500 microsecond. At transmitter bar the wave propagate in that bar is only one wave. At the right show the graph true stress versus true strain which is there are wave and strain rate.

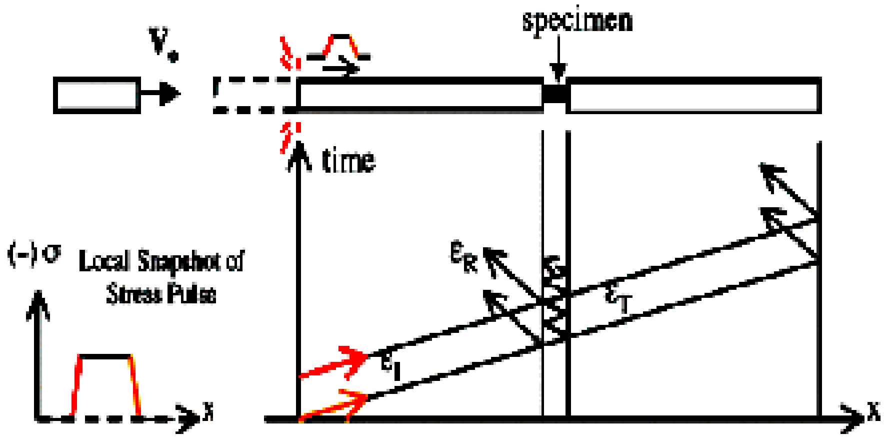


Figure 2.3: Shows the refraction and absorption of the wave propagation waves.
(Source: University of Maine)

Using one dimensional wave propagation analysis we can determine high strain rate stress-strain curves from the measurements of strain in the incident and output bars. In order to obtain correct wave propagation the striker bar must reach necessary velocity before it hits the incident bar.

2.6 AN EXPERIMENT USING PLASTICINE TO SHOW THE WAVE GENERATE IN BAR

There are many research and experiment done to study the wave pulse in SHBT and one of the experiments is using plasticine. Plasticine is added at the end of transmitter bar. Supposedly the end of transmitter bar must be free end but the acoustic impedance of plasticine is very small in comparison to that of the steel bar, so we can assume that is justified purposes to have free surface. The plasticine in the figure 2.4 shown that the wave is propagated in the bar after the experiments.

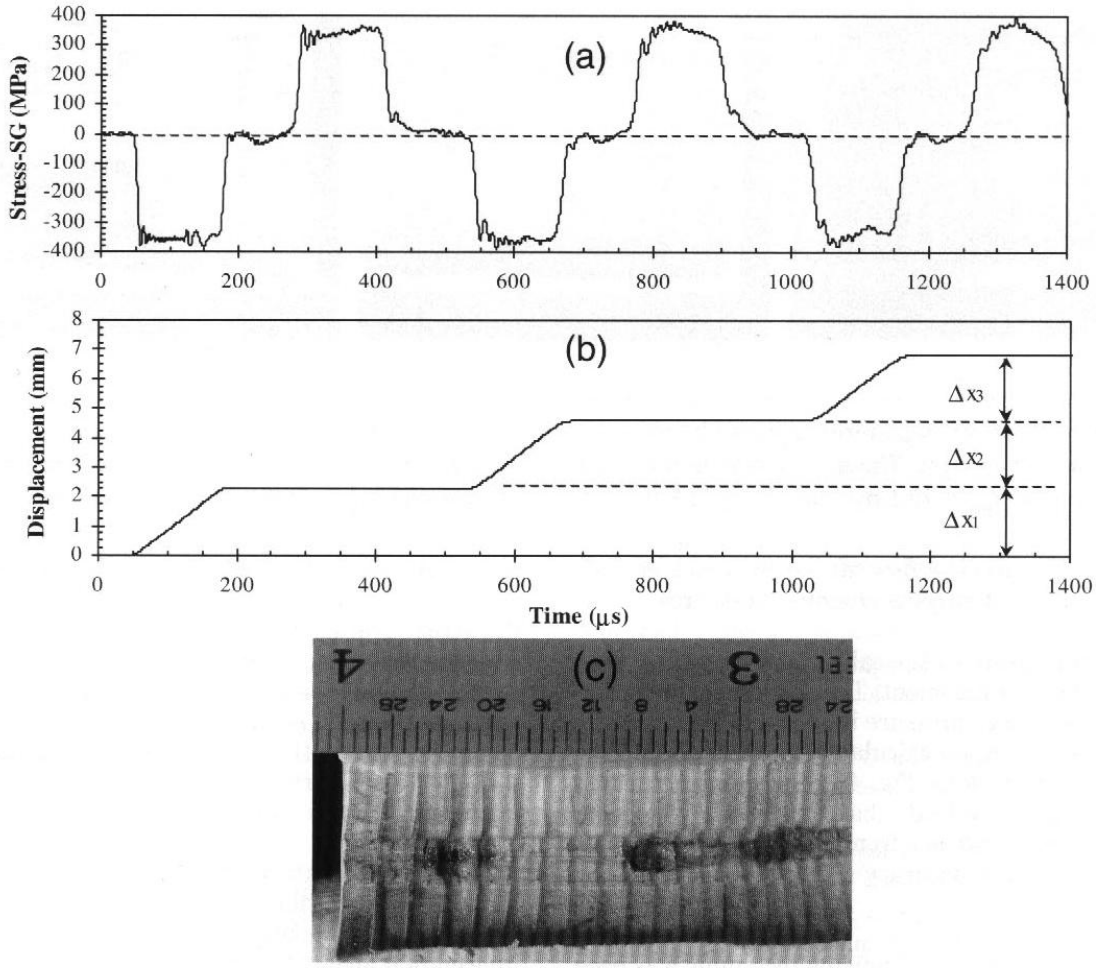


Figure 2.4: a) Plot of stress pulse profile recorded by the strain gauges on transmitter bar, b) calculated displacement history at the bar-plasticine and c) cross-sectional view of the recovered plasticine after being subjected to the displacement history.

(Reference: Vural, M. and Rittel, D. "An Educational Visualization Technique for Kolsky (Split Hopkinson Bar)".)

2.7 THEORY OF SPLIT HOPKINSON BAR

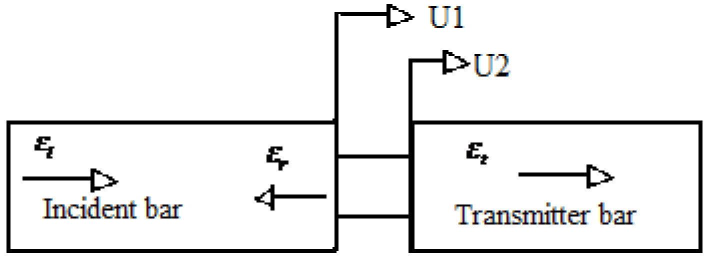


Figure 2.5 : schematic drawing of SHBT

(Source from theory of split Hopkinson bar)

SHBT is consists of a striker bar, an incident bar, specimen under test and output bar. Wave equation:

$$\frac{\partial^2 u}{\partial x^2} - \frac{1\partial^2 u}{c^2 \partial t^2} \qquad (1)$$

Which has the solution:

$$u = f(x - ct) + g(x + ct) = u_i + u_r \qquad (2)$$

Where u_i= incident wave

u_r = reflected wave

Assuming a one-dimensional system, the strain in the incident rod is, by definition,

$$\varepsilon = \frac{\partial u}{\partial x} \qquad (3)$$

Therefore strain in the incident bar can be determining by differentiating equation (2):