Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 509572
UNCLASSIFIED	

TITLE

HIGH ENERGY DYNAMIC SYSTEM FOR NOTCH ACUITY STUDIES

System Number:

Patron Number:

Requester:

Notes:

DSIS Use only:

Deliver to:

National Defence
Research and Development Branch

Défense nationale
Bureau de recherche et développement

DREA CR 98/431
July 1998

HIGH ENERGY DYNAMIC SYSTEM FOR NOTCH ACUITY STUDIES

M.N. Bassim

UNIVERSITY OF MANITOBA
311 Administration Building
Winnipeg, Manitoba, Canada
R3T 2N2

CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

DEFENSIO PER SCIENTIAM

Canada

PLEASE DIRECT ENQUIRIES TO:

THE DIRECTOR GENERAL
DEFENCE RESEARCH ESTABLISHMENT ATLANTIC
P.O. BOX 1012
DARTMOUTH, NOVA SCOTIA, CANADA
B2Y 3Z7

National Defence
Research and Development Branch

Défense nationale
Bureau de recherche et développement

DREA CR 98/431

HIGH ENERGY DYNAMIC SYSTEM FOR NOTCH ACUITY STUDIES

M.N. Bassim

UNIVERSITY OF MANITOBA
311 Administration Building
Winnipeg, Manitoba, Canada
R3T 2N2

Scientific Authority J. R. Matthews

W7707-7-4997
Contract Number

July 1998

CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

DEFENSIO PER SCIENTIAM

Canada

Abstract

This report describes a process for increasing the capacity of a specially designed Split Hopkinson BAR (SHB) system in order to fracture 12.7 mm thick compact tension specimens of 350 WT steel in both L-T and T-L orientations at temperatures of 0°C and 15°C. The change in design of the SHB resulted in significant increase in the impact energy applied on the specimens. Following the modification of the SHB, tests were conducted on compact tension specimens with different notch configurations. The results show that the energy capacity of the redesigned SHB increased. Due to this increased capacity, it was possible to effect complete fracture on all the specimens tested.

Résumé

Le présent rapport décrit un procédé visant à augmenter la capacité d'une barre de conception spéciale, le système Split Hopkinson Bar (SHB), afin de briser des éprouvettes de traction compactes de 12,7 mm d'épaisseur en acier de 350 WT dans les orientations L-T et T-L à des températures de 0°C et 15°C. Le changement dans la conception du SHB a entraîne une augmentation importante de l'énergie de rupture appliquée aux éprouvettes. Suite à la modification du SHB, des essais ont été menés sur des éprouvettes de traction compactes avec différentes configurations d'encoches. Les résultats indiquent que la capacité d'énergie du SHB modifié a augmenté. Grâce à cette augmentation de capacité, il a été possible de briser complètement toutes les éprouvettes lors des essais.

Table of Contents

1. Introduction

This project involves a study of notch acuity on the fracture toughness of 350 WT plate steel. The measurements are conducted at high strain rates using a custom designed Split Hopkinson Bar (SHB) with a swing arm mechanism. Compact tension specimens with thickness of 12.7 mm are used. Earlier tests on this material had shown that the existing SHB did not have sufficient impact energy to break the specimens, particularly at relatively high temperatures of 0°C and 15°C (1-4). In the current study, significant modifications of the SHB in terms of redesigning of the swing arm mechanism and increasing the speed and weight of the projectile were implemented. This was followed by testing more than 10 CT specimens with the following specifications:

(a) saw cut with included angle of 60 degrees per ASTM E604 and pressed to 0.01 inch as per ASTM E604;

(b) saw cut with included angle of 60 degrees per ASTM E604 and pressed to 0.01 in., followed by fatigue precracking to a/W = 0.55, and;

(c) a saw cut with included angle of 60 degrees per ASTM E604 and fatigue precracked to a/W of 0.55.

Both L-T and T-L orientations were tested at 0°C and 15°C. Also tested were a few added specimens with an EDM cut and a/W = 0.5.

The project lasted from November 97 to February 98. It was carried out by Dr. M. Nabil Bassim as principal investigator. He was assisted by a research associate and two technicians.

2. Program

The objectives of the program were as follows:

Task 1: modification of the Split Hopkinson Bar (SHB) system to increase its impact energy capacity.

Task 2: fabrication of specimens with various notch configurations from coupons cut in the T-L and L-T orientations followed by press and/or fatigue precracking of some of the specimens.

Task 3: conduct ten representative tests on 350 WT steel at high loading rates and at temperatures of 0 and 15°C to evaluate the capacity of the redesigned and rebuilt SHB system.

The testing program involved the following: Redesigning the SHB by changing the swing arm mechanism and by increasing the weight and speed of the projectile.

This was followed by preparation of coupons for 16 specimens of 12.7 mm (0.5 in) compact tension specimens of 350 WT steel with two crack orientations (T-L and L-T). The notches were next machined, pressed and/or fatigue precracked. Some specimens were tested containing an EDM notch. This was followed by testing at high strain rates using the modified SHB system. Following fracture, all specimens were photographed before they were entirely broken apart. Also, the fracture surfaces were photographed.

3. Experimental Procedures

Task 1: Modification of the SHB system.

In order to increase the impact energy capacity of the SHB existing system to enable fracturing of the 12.7 mm 350 WT compact tension specimens, three steps were undertaken:

(a) use of a heavier projectile weighing 2.8 kg

(b) use of higher gas pressure to produce higher projectile speeds in excess of 50 m/s at the impact point, and

(c) modification of the swing arm mechanism to avoid the excessive energy dissipation which was associated with the initial design.

In the initial design, the specimen holder was connected to the swing arm. This produced excessive energy dissipation. In the redesigned SHB system, the target block is mounted vertically to the horizontal I-beam test bed and the specimen is mounted at the center of the actual target block by a removable pin. When the projectile hits the upper end of the target block, the target block will swing to the right. It is estimated that the force on the specimen is twice that of the impact force applied on the target block. A drawing of the specimen holder is shown in Fig. 1. Figure 2 shows a photograph of the new swing arm mechanism and Appendix I shows more photographs of the new swing arm.

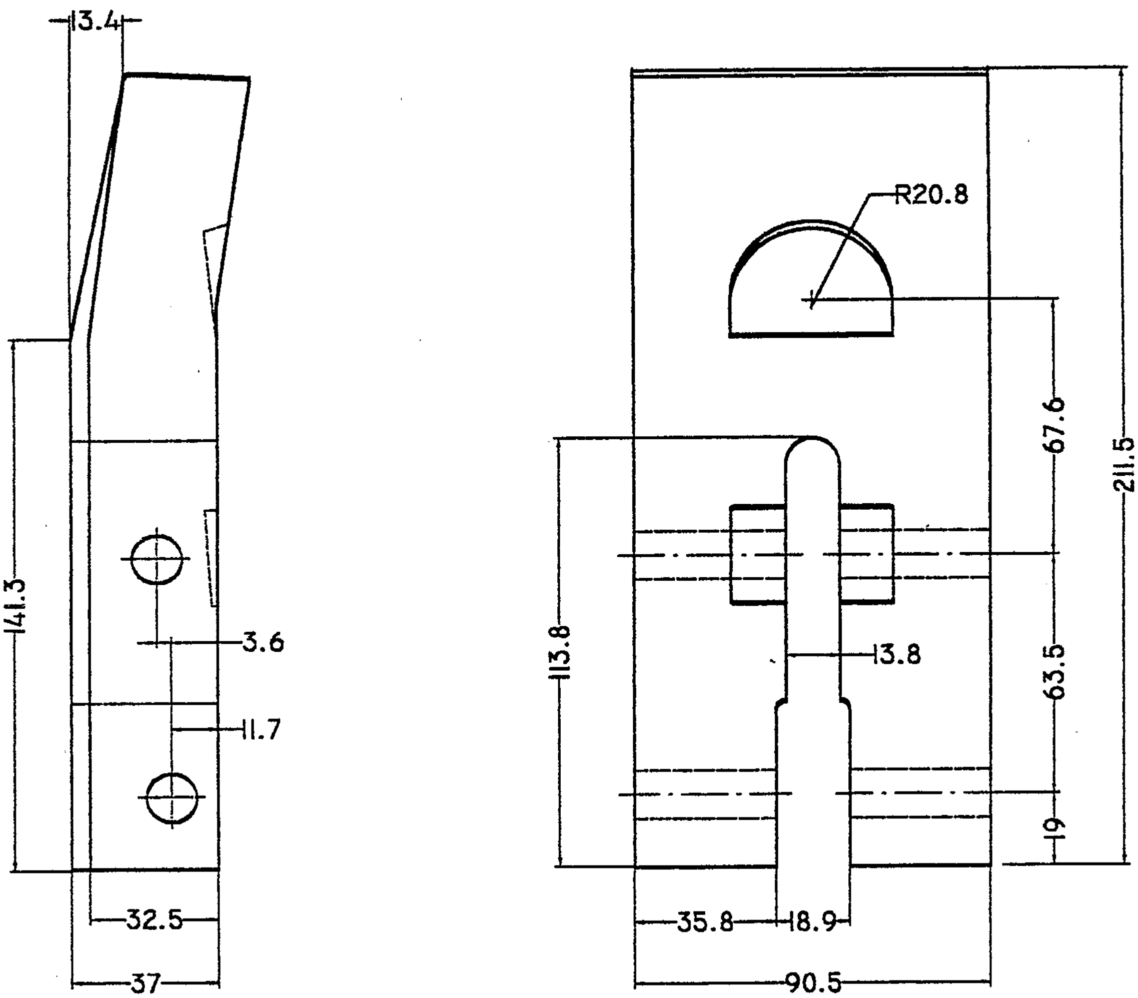
The combination of using a heavier projectile, higher pressure and a modified specimen holder mechanism has significantly increased the capacity of the SHB system, as reflected by its ability to fracture the 350 WT compact tension specimens tested in this program. A quantitative estimation of the increase in energy which takes into account the wave propagation into the swing arm mechanism was not performed due to its complexity.

Task 2: Preparation of the Specimens

Specimen coupons were first produced. Compact tension specimens with notches either in the T-L or the L-T direction, with the dimensions shown in Fig. 3 were machined. The specimen notches were prepared and tested according to Table 1.

Task 3: Fracture Testing using SHB System

The specimens were tested using the testing arrangement described earlier. Also tested were specimens containing an EDM notch at 15°C. Most of the specimens almost broke. All were photographed following fracture. Some were broken apart with a servo hydraulic machine (to break the last small remaining ligament). In all tests, the specimens opened over 90 degree and some were close to 180 degrees.



All dimensions are in mm

Figure 1: Swing Arm Assembly Mechanism

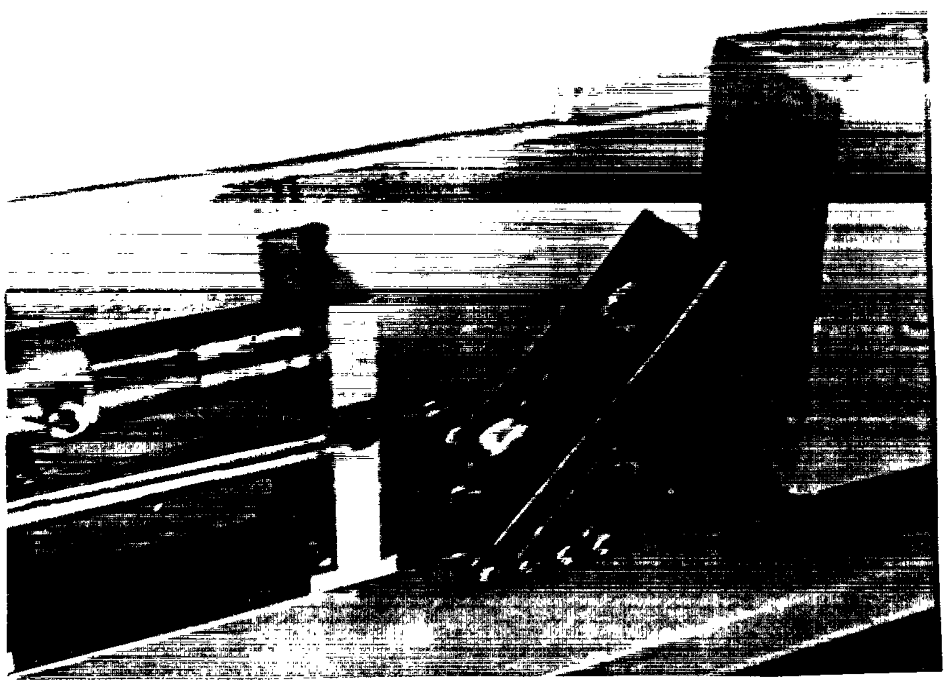
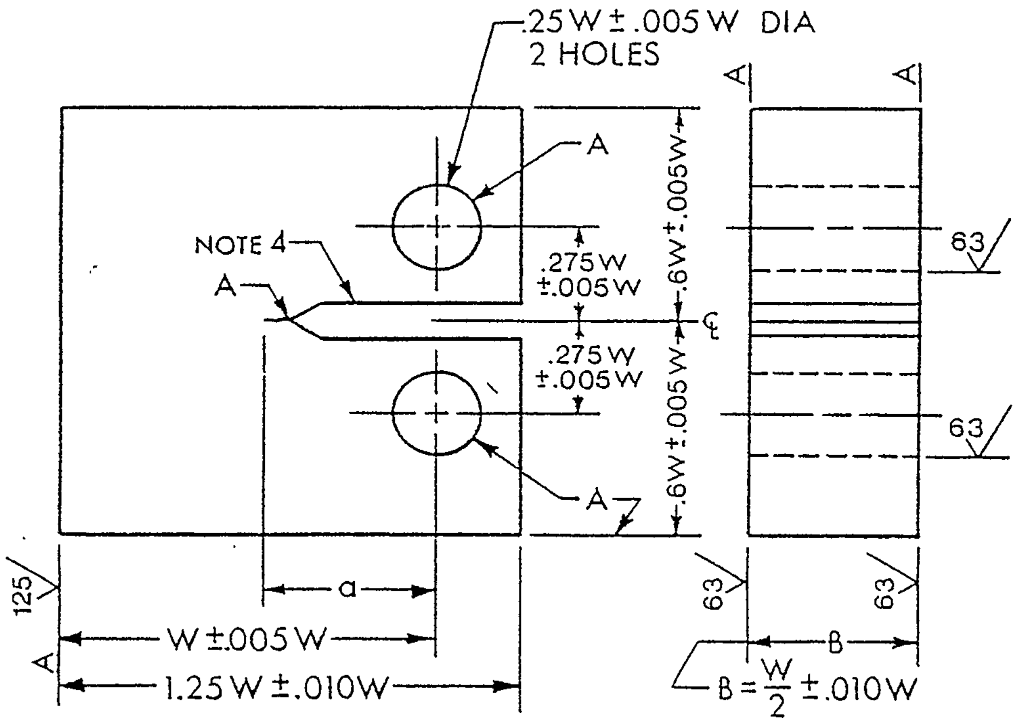


Fig. 2: Photograph of Swing Arm Mechanism



W = 50 mm
B = 12.7 mm
a/W = 0.5

Figure 3: Compact Tension Specimen Dimensions

Table 1: Summary of Specimens Tested and Shear Lip Measured

Specimen II-1 to II-4: A saw cut with included angle of 60 degree per ASTM E604 and pressed to 0.010 inches as per ASTM E604 with a/W of 0.55

Specimen	Notch	Orientation	Temperature	Shear Lip, mm
II-1	pressed	L-T	15°C	6.1
II-2	pressed	T-L	15°C	6.0
II-3	pressed	L-T	0°C	6.1
II-4	pressed	T-L	0°C	6.0

Specimen II-5 to II-6: A saw cut with included angle of 60 degree per ASTM E604 and pressed to 0.010 inches as per ASTM E604 with a/W of 0.55 and fatigue precracked an additional 1 mm.

Specimen	Notch	Orientation	Temperature	Shear Lip, mm
II-5	pressed and fatigue precracked	L-T	15°C	6.00
II-6	pressed and fatigue precracked	L-T	0°C	6.00

Specimen II-7 to II-10: A saw cut with included angle of 60 degree per ASTM E604 and fatigue precracked to a/W of 0.55

Specimen	Notch	Orientation	Temperature	Shear Lip, mm
II-7	fatigue precracked	L-T	15°C	5.5
II-8	fatigue precracked	T-L	15°C	6.0
II-9	fatigue precracked	L-T	0°C	3.0
II-10	fatigue precracked	T-L	0°C	3.8

4. Results and Discussion

The earlier results using the SHB with the initial swing arm mechanism [1] showed that, except for those specimens which had fatigue precracks, the SHB was not able to fracture the specimens totally and, as a consequence, much lower values of shear lips, ranging from about 0.5 to 3 mm were reported. Those with a value of 3 mm occurred at 15°C. (see Figure 4)

In this current study, the main objective was to modify the SHB to be able to impact the specimens with sufficient energy to produce ductile fracture. This was followed by the fracturing of ten specimens containing various notches as outlined in Table 1.

The shear lip measurements from these specimens are also given in Table 1, while photographs of the specimens after testing as well as the fracture surfaces are given in Appendix II. The shear lips observed in these specimens have much higher values than in the previous study [1] (see Figure 4). Except for specimens II-9 and II-10 (fatigue precracked, L-T and T-L, at 0°C) which had values of 3.0 and 3.8 mm respectively, all other specimens had shear lips from 5.5 to 6.1 mm, which basically indicates complete ductile fracture.

5. Conclusions

A major modification to the swing-arm Split Hopkinson Bar System was carried out which results in increasing significantly the impact energy of the projectile. This allows fracturing of 350 WT steel compact tension specimens with thickness of 12.7 mm in the transition range of 0°C to 15°C which was not possible in earlier tests.

Observation of larger shear lips with the modified system as opposed to results with the lower capacity energy system indicates a strong rate effect of tearing resistance.

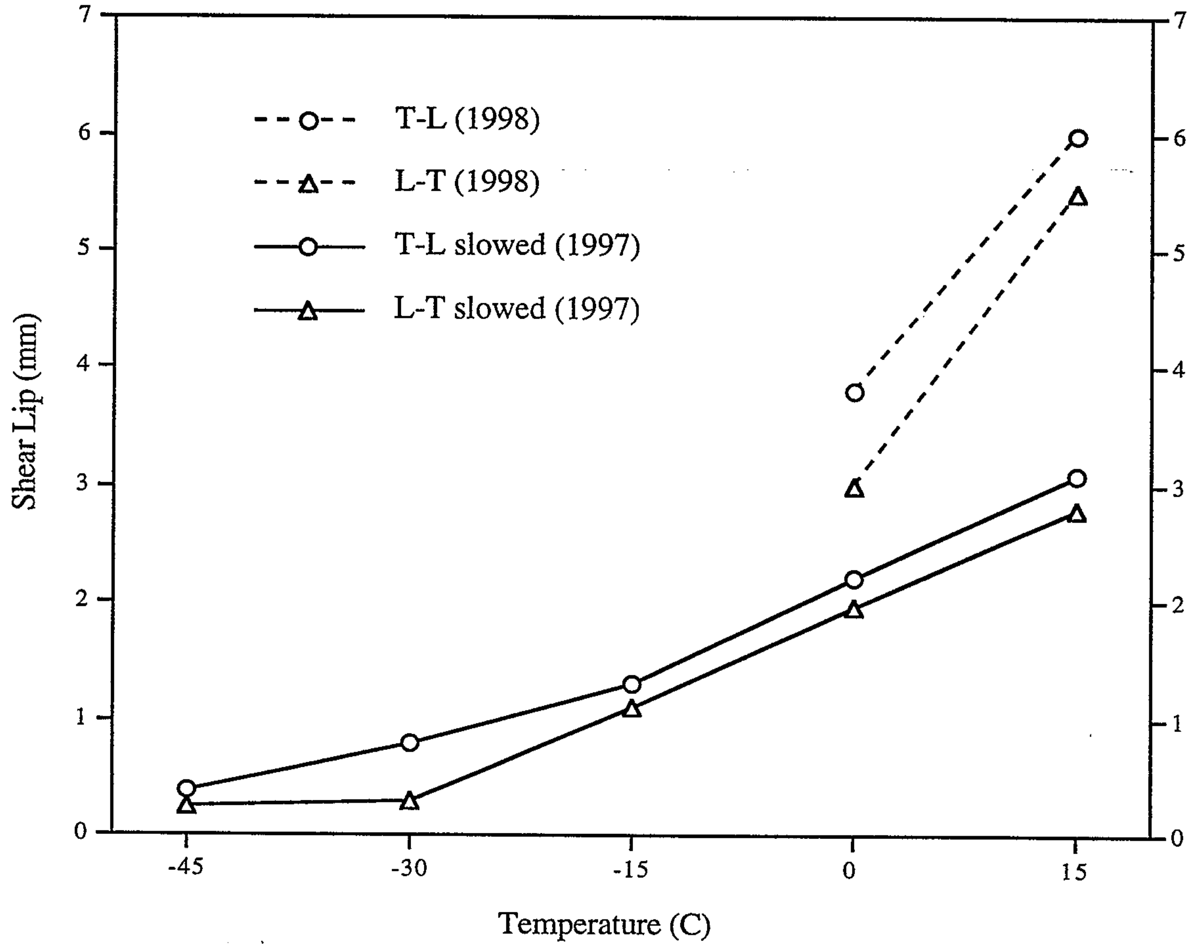


Figure 4: Comparison of Results for the unmodified Split Hopkinson Bar (1997) which slowed considerably during the test and actually stopped at 0 and 15°C and results with the modified Split Hopkinson Bar (1998). Graph shows variation of Shear Lip with Temperature for Fatigue Pre-Cracked Specimens.

6. References

(1) M.Nabil Bassim "Notch Effect of 350 WT Plate Steel at High Strain Rates", DREA CR/97/424.

(2) J.R. Matthews "Prediction of Ductile Behavior in Welded Structures" in Recent Advances in Fracture Proceedings of TMS Conference, 1997, pp. 159-170.

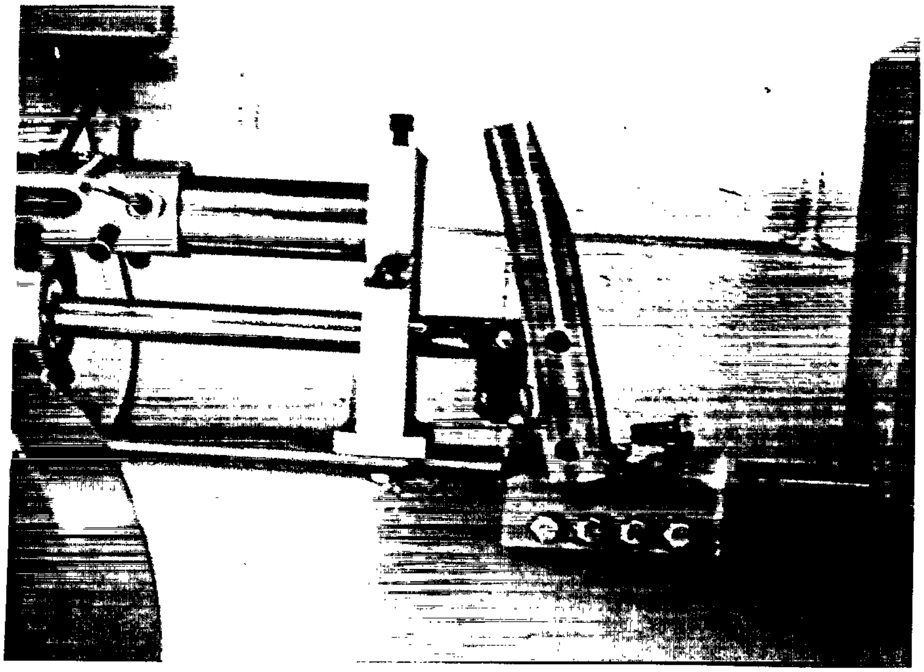
(3) M.N. Bassim and J.R. Matthews "Ductile Fracture Toughness Evaluation at High Strain Rates Using Stretch Zones and Shear Lips", in Recent Advances in Fracture, Proceedings of TMS Conference, 1997, pp. 205-212.

(4) D.Shum, M.Sc. Thesis, University of Manitoba, 1985.

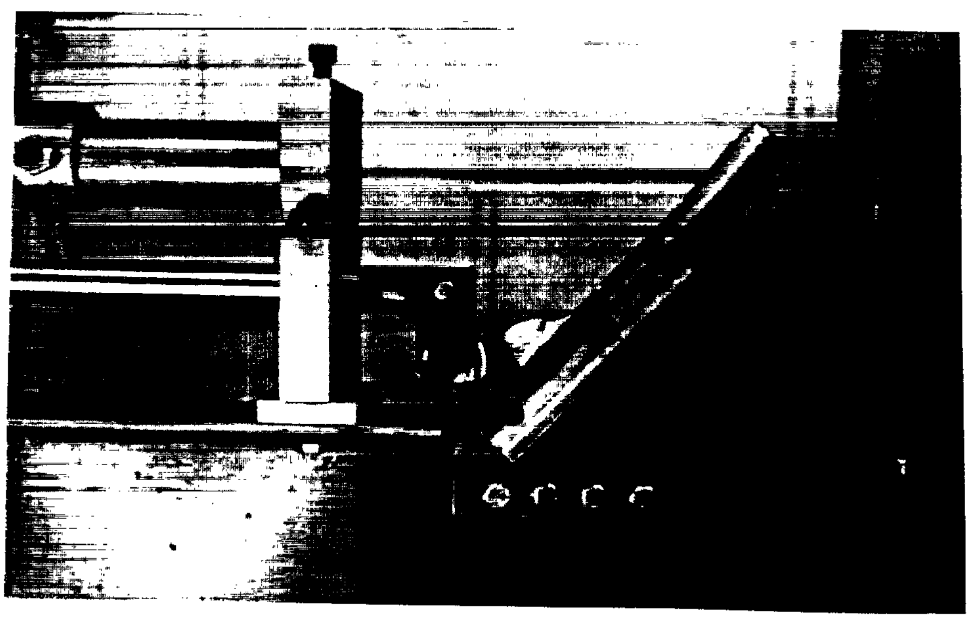
Acknowledgments

The support of the Department of National Defence, Defence Research Establishment Atlantic and of the Scientific Authority, Dr. J.R. Matthews, are gratefully acknowledged.

APPENDIX I: Photographs of Swing Arm Mechanism



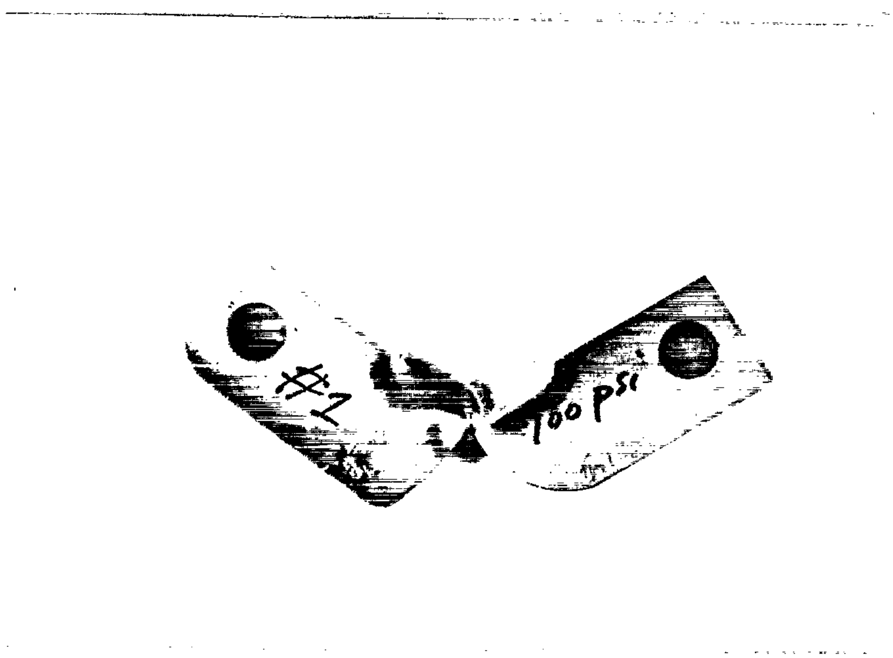
(a)



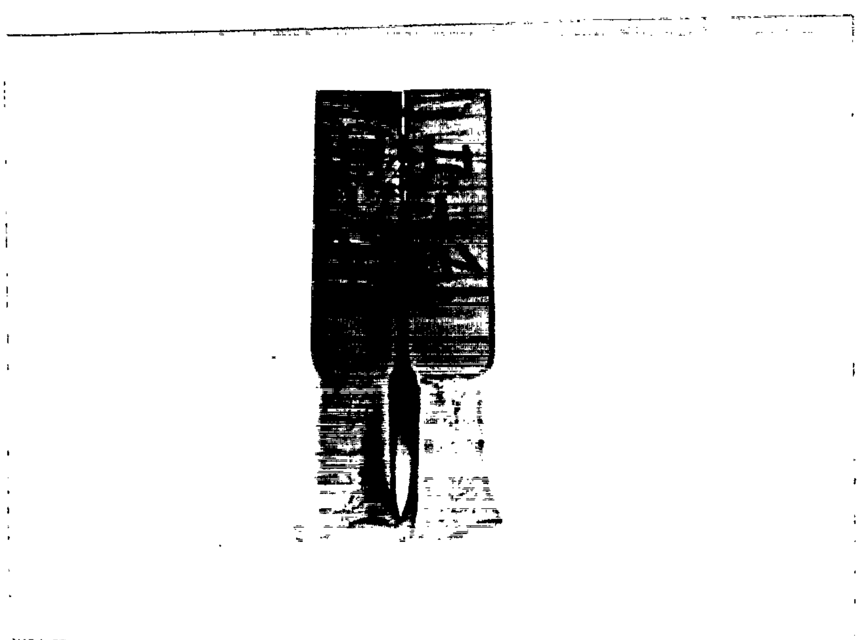
(b)

Figure 1: Swing arm mechanism (a) at the beginning of specimen fracture and (b) at the end of specimen fracture

APPENDIX II: Photographs of broken specimens and fracture surfaces

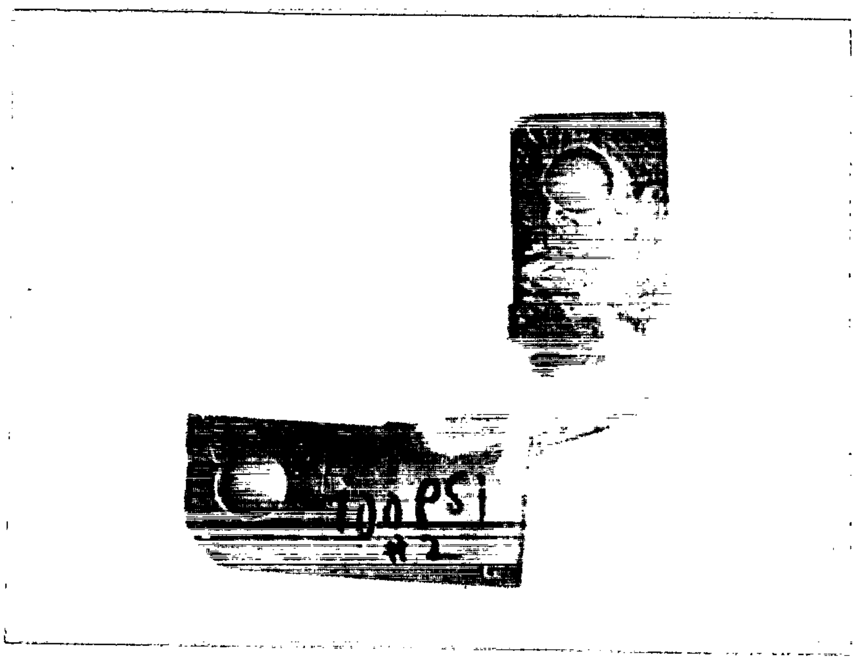


(a)

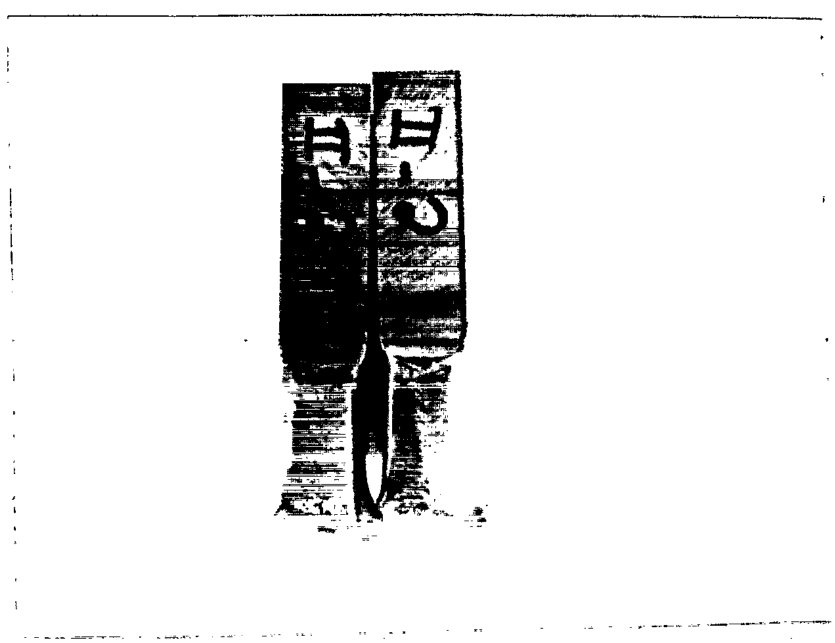


(b)

Fig. 1: (a) Broken specimen #1 and (b) Fracture surface of specimen #1 (See Table 1, Page 7)

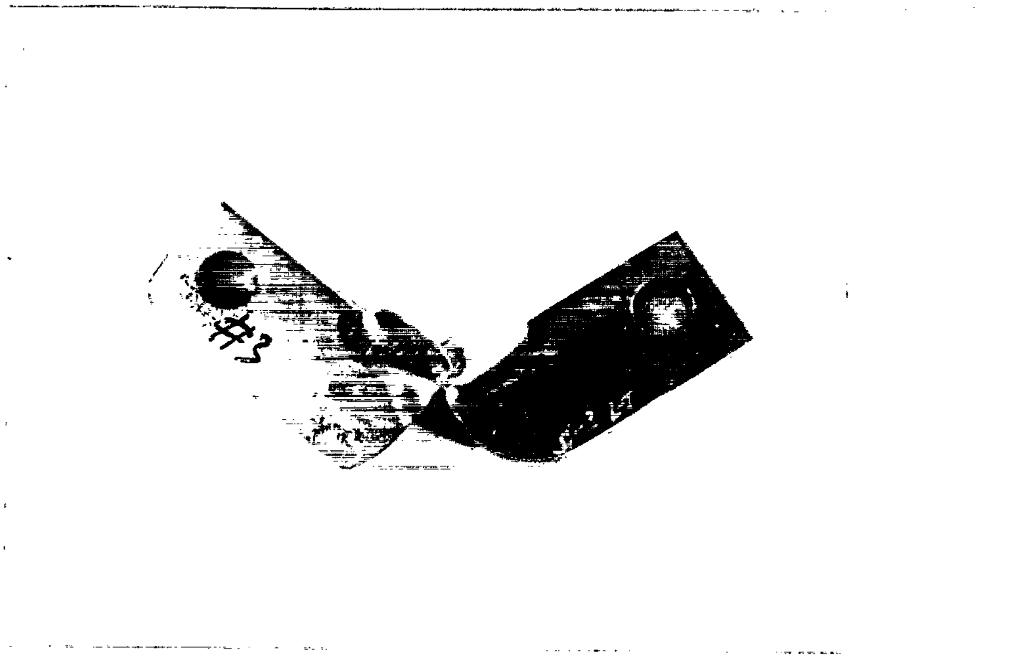


(a)

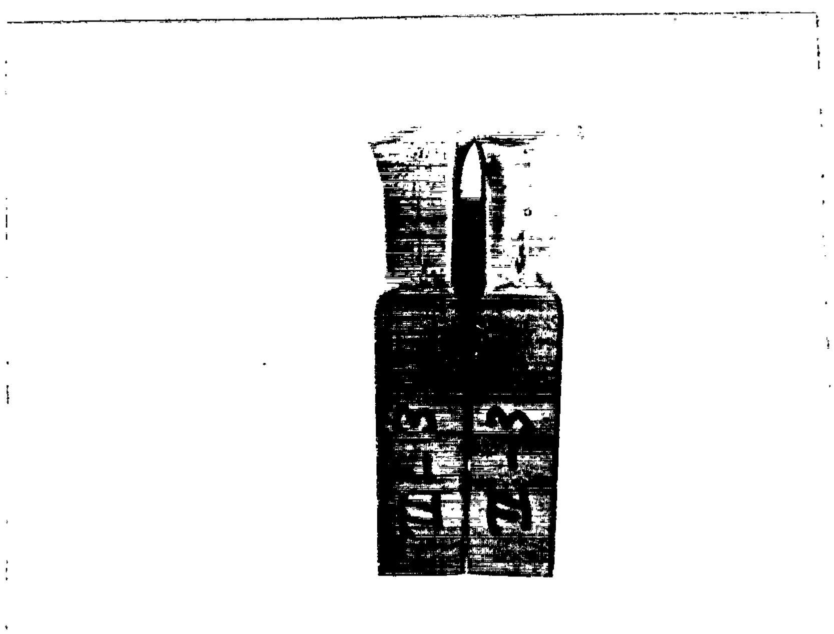


(b)

Fig. 2: (a) Broken specimen #2 and (b) Fracture surface of specimen #2 (See Table 1, Page 7)



(a)



(b)

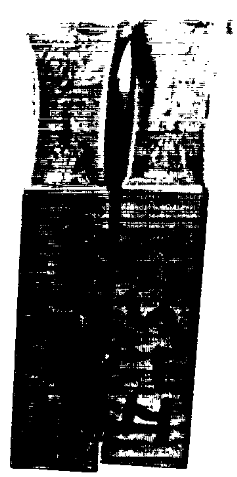
Fig. 3: (a) Broken specimen #3 and (b) Fracture surface of specimen #3 (See Table 1, Page 7)

(a)

(b)

Fig. 4: (a) Broken specimen #4 and (b) Fracture surface of specimen #4 (See Table 1, Page 7)

(a)



(b)

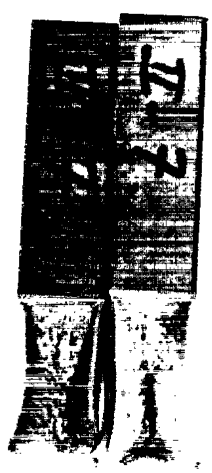
Fig. 5: (a) Broken specimen #5 and (b) Fracture surface of specimen #5 (See Table 1, Page 7)

(a)

(b)

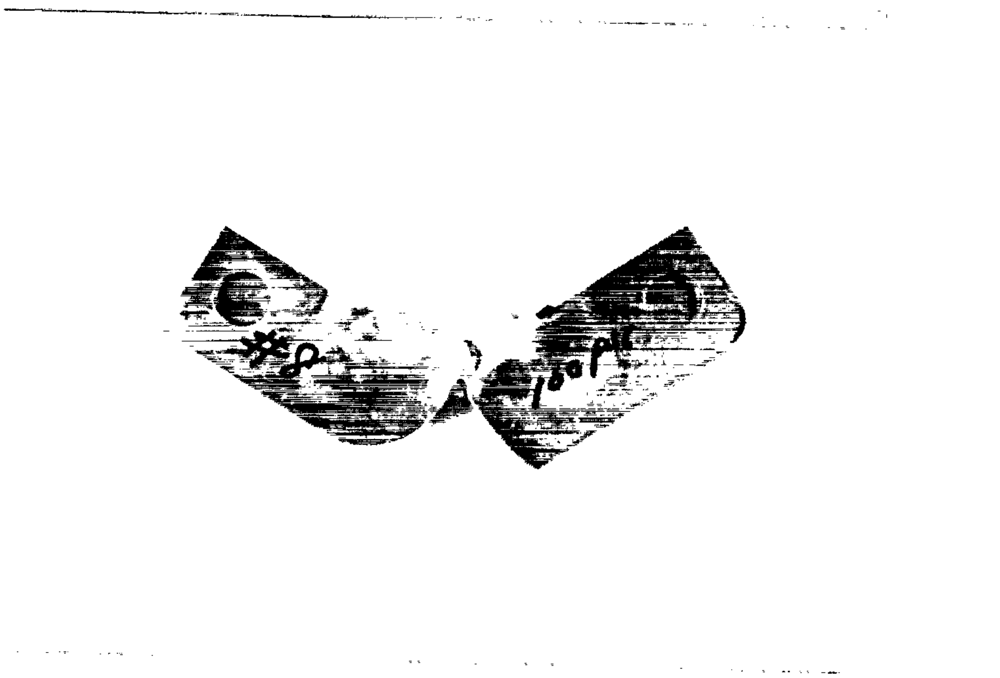
Fig. 6: (a) Broken specimen #6 and (b) Fracture surface of specimen #6 (See Table 1, Page 7)

(a)

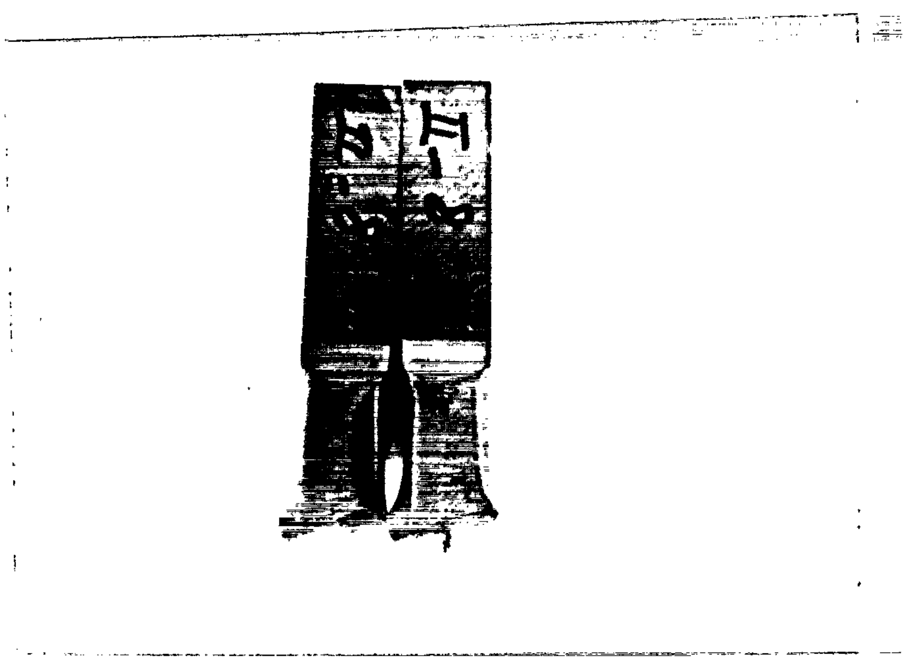


(b)

Fig. 7: (a) Broken specimen #7 and (b) Fracture surface of specimen #7 (See Table 1, Page 7)

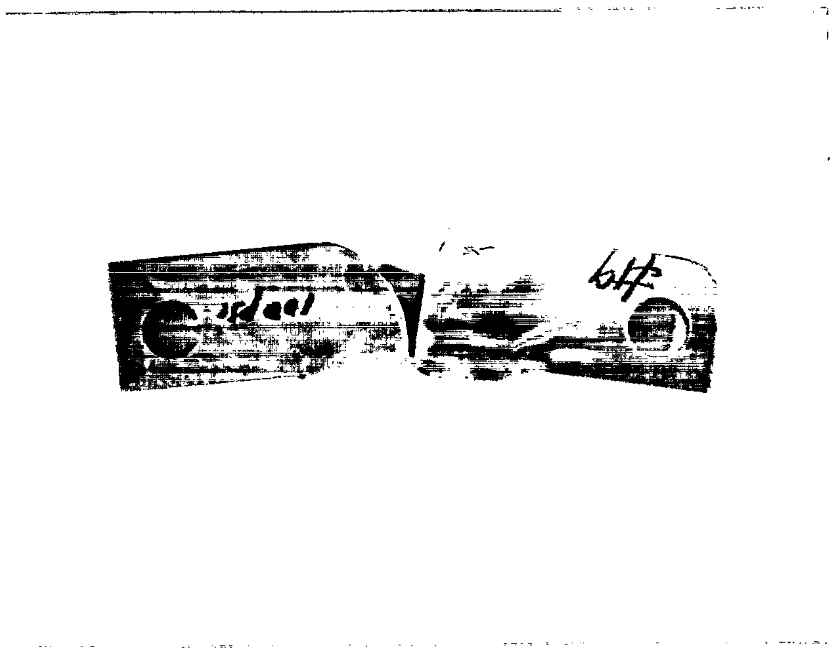


(a)

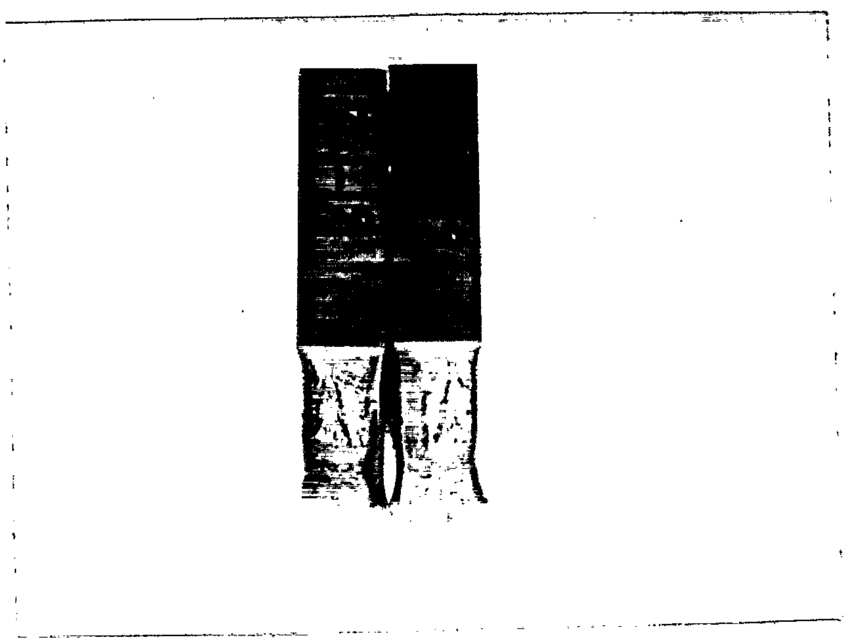


(b)

Fig. 8: (a) Broken specimen #8 and (b) Fracture surface of specimen #8 (See Table 1, Page 7)

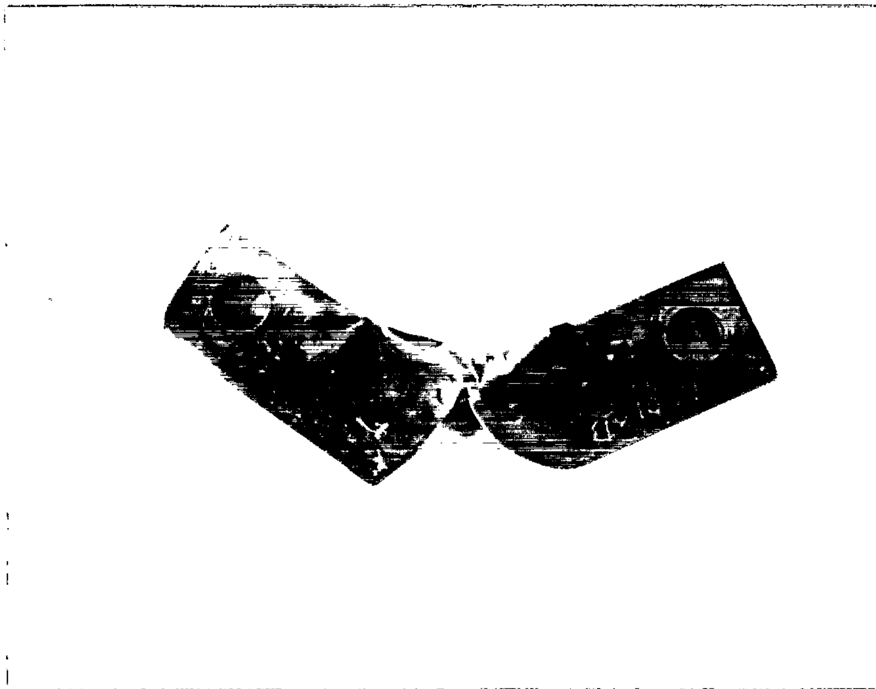


(a)



(b)

Fig. 9: (a) Broken specimen #9 and (b) Fracture surface of specimen #9 (See Table 1, Page 7)



(a)

(b)

Fig. 10: (a) Broken specimen #10 and (b) Fracture surface of specimen #10 (See Table 1, Page 7)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document.. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

University of Manitoba
311 Administration Building
Winnipeg, Manitoba, Canada, R3T 2N2

2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable).

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title).

High Energy Dynamic System for Notch Acuity Studies

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

M.N. Bassim

5. DATE OF PUBLICATION (month and year of publication of document)	6a. NO .OF PAGES (total containing information Include Annexes, Appendices, etc).	6b. NO. OF REFS (total cited in document)
July 1998	27 (approx.)	4

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).

CONTRACTOR REPORT

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address).

Defence Research Establishment Atlantic
PO Box 1012, Dartmouth, NS, Canada B2Y 3Z7

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant).	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written).
Project 1gh	W7707-7-4997

10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
	DREA CR/98/431

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
(   ) Defence departments and defence contractors; further distribution only as approved
(   ) Defence departments and Canadian defence contractors; further distribution only as approved
(   ) Government departments and agencies; further distribution only as approved
(   ) Defence departments; further distribution only as approved
(   ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected).

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

This report describes a process for increasing the capacity of a specially designed Split Hopkinson Bar (SHB) system in order to fracture 12.7 mm thick compact tension specimens of 350 WT steel in both L-T and T-L orientations at temperatures of 0°C and 15°C. The change in design of the SHB resulted in significant increase in the impact energy applied on the specimens. Following the modification of the SHB, tests were conducted on compact tension specimens with different notch configurations. The results show that the energy capacity of the redesigned SHB increased. Due to this increased capacity, it was possible to effect complete fracture on all the specimens tested.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

Split Hopkinson Bar
High Strain Rate Fracture
Shear Lips

DREA

DEFENSIO PER SCIENTIAM

CRDA

#509572