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by
M.N. Bassim

UNIVERSITY of MANITOBA
105 Administration Building
Winnipeg, Manitoba, Canada
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CONTRACTOR REPORT

Prepared for

Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

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Scientific Authority James R. Matthews

March 1996

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Abstract

This report describes results of fracture toughness studies performed on compact tension specimens of 350 WT steel with eight different notch configurations. The tests were performed at very high strain rates obtained by using a specially designed swing arm split Hopkinson Bar (SHB) system. The study compared between the effects of the notch acuity on the fracture toughness which was measured in terms of shear lip and stretch zone width. The program, which lasted nine months, involved the following tasks: (i) fabrication of specimens with different notch configurations (ii) fatigue precracking of some of the specimens (iii) testing at high strain rates at room temperature (15° C) and at -30° C and (iv) measurement of the stretch zone using scanning electron microscopy and the shear lip on the broken specimens. The results indicate that notch acuity has an important effect on the fracture toughness of this steel and has to be taken into consideration in fracture design.

Résumé

Le présent rapport décrit les résultats des essais de résistance à la rupture réalisés sur des éprouvettes d'acier 350 WT ayant fait l'objet d'essais de traction et renfermant huit types de contraintes différents. Les essais ont été effectués à une vitesse de déformation très élevée atteinte au moyen d'un système à barre fendue Hopkinson à pendule conçu spécialement pour ces essais. Dans le cadre de cette étude, nous avons comparé les effets de l'intensité de contrainte sur la résistance à la rupture de l'éprouvette dont nous avons mesuré la cassure de cisaillement et la largeur de la zone d'étirement. Les essais du programme, d'une durée de neuf mois, comprenaient les activités suivantes : fabrication d'éprouvettes comportant des contraintes de configuration différente, préfissuration par fatigue de certaines éprouvettes à contraintes de configuration différente, essais à très grande vitesse à la température ambiante (15 °C) et à - 30 °C et mesure de la zone d'étirement au moyen d'un microscope électronique à balayage et de la cassure de cisaillement de l'éprouvette cassée. D'après les résultats, nous avons conclu que l'intensité de contrainte a une incidence importante sur la résistance à la rupture de cette nuance d'acier et qu'il faut en tenir compte dans la conception de pièces résistantes à la rupture.

Table of Contents

1. Introduction

This project involves a study on the effect of notch acuity on the fracture toughness of 350 WT Plate steel, measured using shear lip and stretch zone width. The fracture toughness was measured at high strain rates by using a custom designed Split Hopkinson Bar which shoots a projectile at a speed of up to 50 m/s. Various notch configurations were machined into 12.7 mm (0.5 in) thick compact tension specimens which included saw cuts at 60°, saw cut at 60 then press, saw cut at 60° followed by fatigue precrack, EDM notch, notch cut at 45° notch at 45° followed by fatigue precrack and fatigue crack. Testing temperatures were 15° C °and -30° C. The project, which lasted from July '95 to March '96 was carried out with Dr. M. Nabil Bassim as principal investigator. He was assisted by a research associate and a technician.

2. Program

The objectives of the program were as follows:

Task 1: fabrication of specimens with various notch configurations followed by fatigue precracking of some of the specimens.

Task 2: Evaluation of the fracture toughness at very high loading rates.

Task 3: Measurement of the shearlip and the stretch zone width.

The testing program involved the following:

Preparation and machining of over 25 compact tension specimens of 350 WT Steel (thickness 12.7 mm) with the notch configurations as specified in the work statement and listed later in this report.

Some of the notched specimens were fatigue precracked. Fracture at 15°C and -30°C was performed at high strain rates using a Split Hopkinson Bar (SHB). Detailed descriptions of this system were presented in an earlier report (1) as well as several publications (2 - 4).

Following fracture, all the specimens which did not break entirely were broken and shear lip and stretch zone width measurements were performed. Scanning electron microscopy was used for stretch zone width determinations.

3. Experimental Procedure

Task 1 Specimen coupons were cut from the 350 WT plate supplied by DREA. Compact tension specimens were machined. The specimen dimensions are shown in Fig. 1.

The notches were obtained as follows:

1. Saw cut with 60° angle as per ASTM E604
2. Saw cut with 60° angle as per ASTM E604 then press to 0.01 inch as per ASTM E604.
3. Saw cut with 60° angle per ASTM E604 followed by additional fatigue precrack for 1 mm crack length.
4. EDM notch to $a/w = 0.5$
5. Saw cut with 45° angle as per ASTM E23
6. Saw cut with 45° angle as per ASTM E23 followed by fatigue precrack for an additional 1 mm.
7. Fatigue precrack to $a/w = 0.5$

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

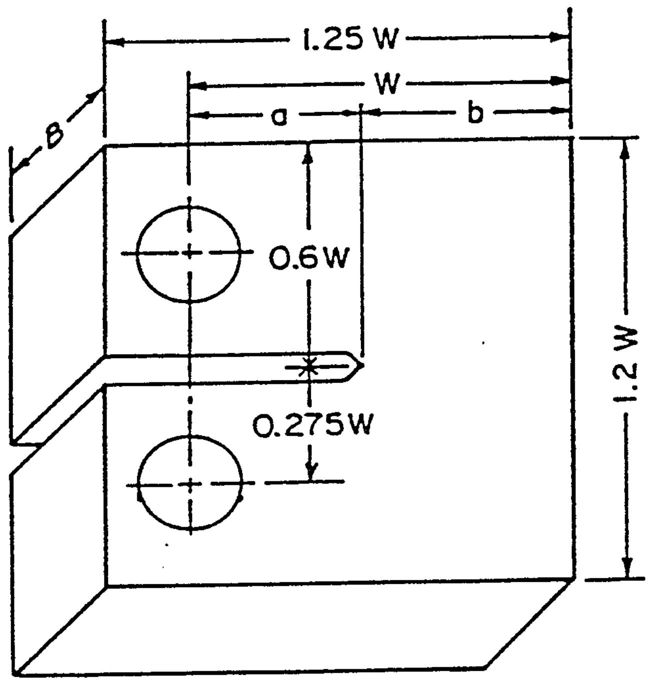

Fig. 1: Specimen dimensions

Some of the specimens were fatigue precracked using a servo hydraulic testing machine. The set point was 1800 kg, the amplitude of the sine wave form was 2000 kg and the frequency was 40 Hz. A travelling optical microscope was used to measure the fatigue crack as it developed in the material.

Task 2: The testing at high strain rates was performed at temperatures of -30°C and 15°C. Specimens tested at low temperature were immersed in a methanol bath and liquid nitrogen was poured onto the methanol until the temperature stabilized at -30°C. The specimens were then quickly mounted on the bar and impacted at speeds in excess of 30 m/s to fracture.

During the test, a two channel digital oscilloscope recorded the outputs of the strain gages on the SHB system. The oscilloscope was connected to a data acquisition and analysis computer system.

Task 3: Following the testing, the specimens were photographed, then they were opened up using the servohydraulic machine at strain rates of about 200 s^{-1}. Shear lip measurements were performed and some of the specimens were cut up for examination of the stretch zone width using the scanning electron microscopy.

Table 1: Summary of Results

NO	Specimen	Description	a/w	Temperature °C	Shear lip, mm	max load kg	remarks
1	B60R	Saw cut with included angle of 60 degrees per ASTM E604	0.5	15	(5.35)	6580	
2	B60LT		0.5	-30	2.35	5340	
3	B60PR	Saw cut with included angle of 60 degrees and press to 0.25 mm as per ASTM E604	0.5	15	(4.85)	7220	press to 0.2-0.3 mm
4	B60PLT		0.5	-30	1.35	5330	
5	B60FP	Saw cut with included angle of 60 degrees per ASTM E604 and fatigue precrack an additional 1 mm	0.5	15	(4.0)	6090	fatigue precrack an additional 0.9-1.1 mm
6	B60FPLT		0.5	-30	1.5	6290	
7	BEDM	Saw cut with included angle of 90 degrees and EDM notch an additional 5 mm	0.5	15	(4.35)	6320	EDM notch an additional 4.9-5.1 mm
8	BEDMLT		0.5	-30	(4.0)	6300	
9	B45R	Saw cut with included angle of 45 degrees per ASTM E23	0.5	15	(4.85)	6760	
10	B45LT		0.5	-30	(4.0)	6300	
11	BFP45	Saw cut with included angle of 45 degrees per ASTM E23 - fatigue precrack an additional 1 mm	0.5	15	(4.5)	6060	fatigue precrack an additional 0.9-1.1 mm
12	BFP45LT		0.5	-30	1.0	6300	
13	BEFP	Saw cut with included angle of 90 degrees, EDM notch an additional 1 mm and fatigue precrack an additional 4 mm	0.5	15	(4.5)	8680	EDM to 0.9-1.1 mm and fatigue precrack an additional 3.9-4.1 mm
14	BFPLT		0.5	-30	1.0	4920	

( ) post test crack opening shear lip, not test shear lip.

4. Results and Discussion

The difference in fracture toughness measurements, expressed in terms of shear lip, and maximum load to fracture are given in Table 1 for both temperatures (15 and -30°C).

Photographs of the specimens after undergoing high strain rate testing using the Split Hopkinson Bar are shown in Appendix I.

The results in Table 1 indicate that at 15°C, for all notch configurations, samples did not tear. At low temperature (-30°C), most notch configurations produced a tear and a shear lip between 1.00 and 2.35 mm except in the case of the notch produced by EDM which did not tear and that produced by a saw cut at 45° angle which also did not tear.

Notches which were followed by fatigue precracking or pressing and tested at -30C produced shear lips below 1.50 mm, while the E604 unpressed was 2.35 mm. This latter was clearly due to the Hopkinson bar slowing down more.

The stretch zone width was measured for the specimens which were fatigue precracked before fracture. The values are given in Table 2:

Table 2: Stretch zone measurements

Specimens	Stretch Zone Width	Test temperature °C
B60FP	200-500	15
BEFP	350-550	15
B60 FPLT	20 - 45	-30
B60 PLT	25 - 40	-30
BFPLT	too small	-30

Calculation of J_{ic} from the stretch zone width yielded values ranging from

60 kJ/m^2 for B60/FPLT

to 700 k J/m^2 for B60FP

and 900 k J/m^2 for BEFP specimens which appear to be in agreement with testing conducted at DREA.

5. Conclusions

The research described deals with the effect of notch acuity on the fracture toughness of 350 WT steel plate tested at very high strain rates using a Split Hopkinson Bar device. Several notch configurations were studied and in some cases, fatigue precracking was also produced. Generally, specimens tested at low temperature (-30°) exhibited shear lips independent of notch type. SZW and shear lips decreased with temperature which indicated normal transition behavior.

6. References

1. M. Nabil Bassim, "High-Strain Rate Impact Study of Submarine Pressure Hull Weldments" submitted to DREA, Halifax 1989.

2. D. Shum, M.Sc. Thesis, University of Manitoba 1985.

3. M. R. Bayoumi, J. R. Klepaczko and M. N. Bassim, J. Testing and Evaluation 12 (1984) pp. 316-323.

4. M. N. Bassim, M. R. Bayoumi, T.R. Hsu and J. R. Matthews, J. of Testing and Evaluation (1986) pp. 229-235.

Acknowledgment

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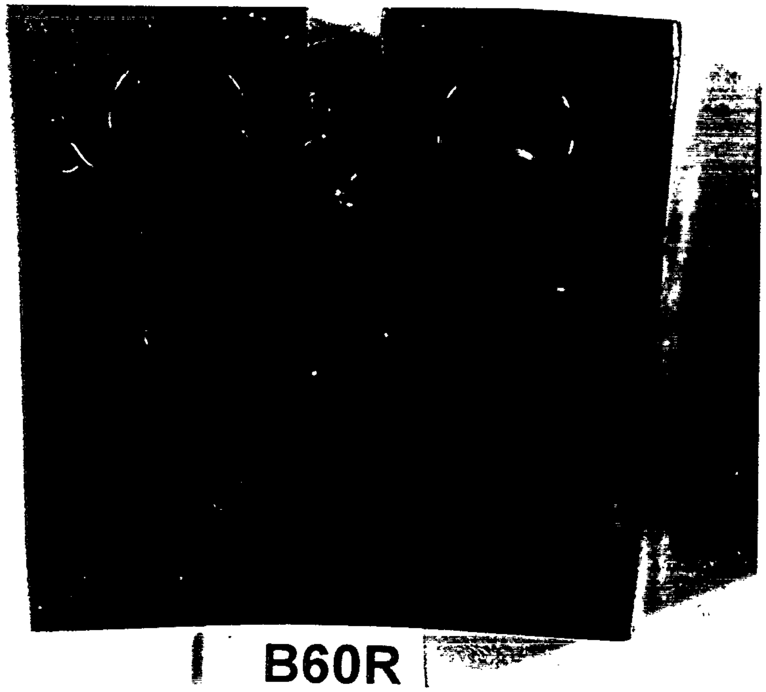
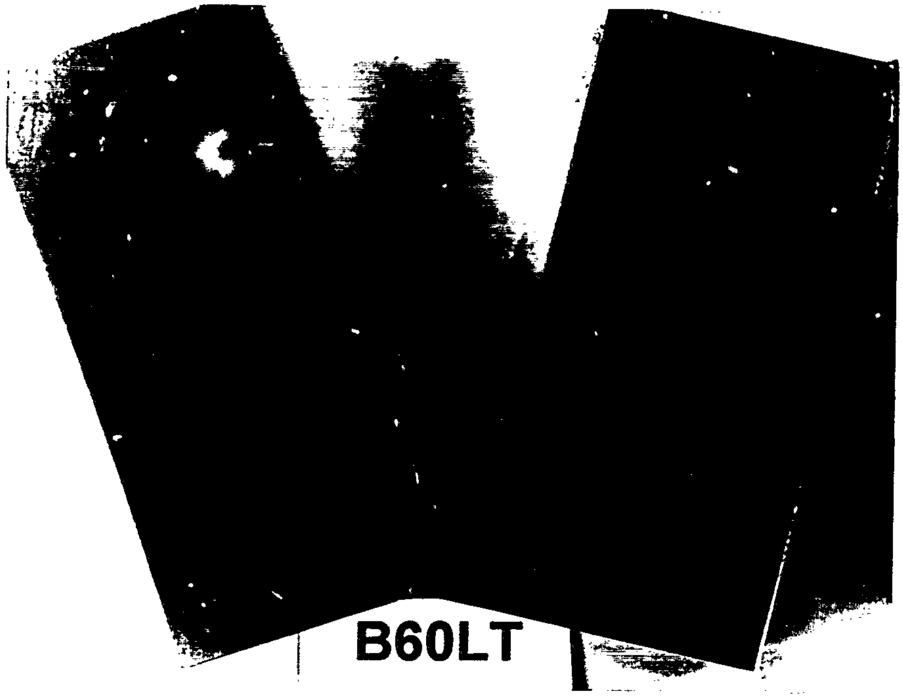


b)

Fig.1-a,b. B60R

a)



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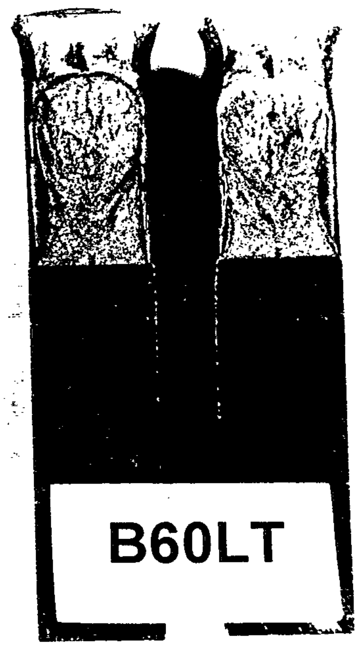
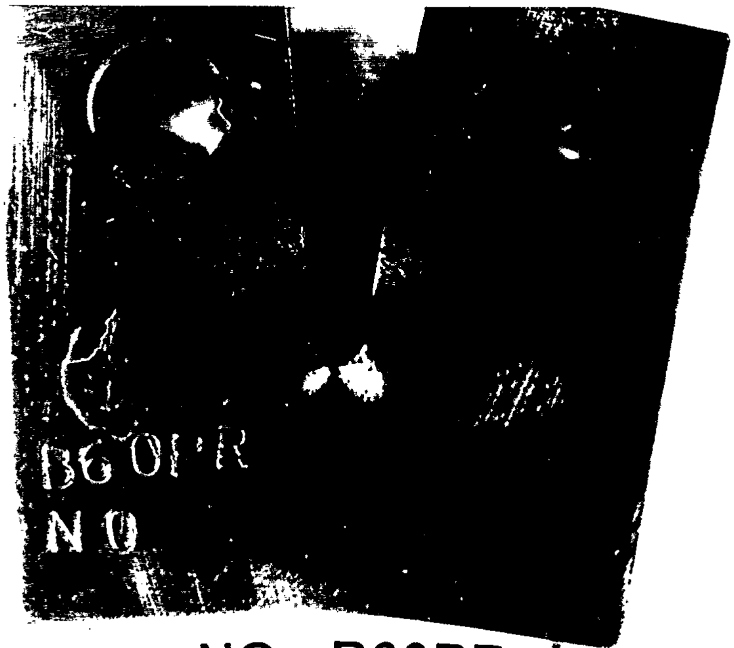


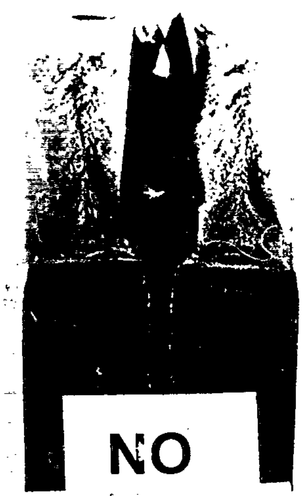
Fig.2-a,b. B60LT

a)



NO B60PR

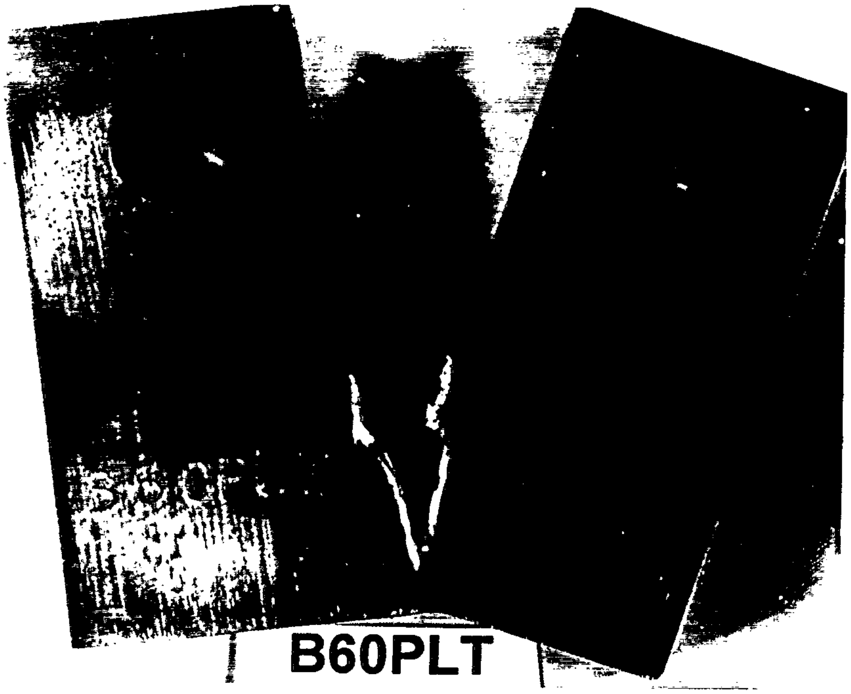
b)



B60PR

Fig.3-a,b. B60PR

a)



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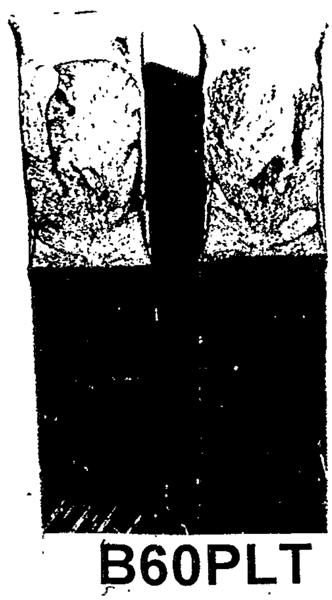

Fig.4-a,b. B60PLT

a)

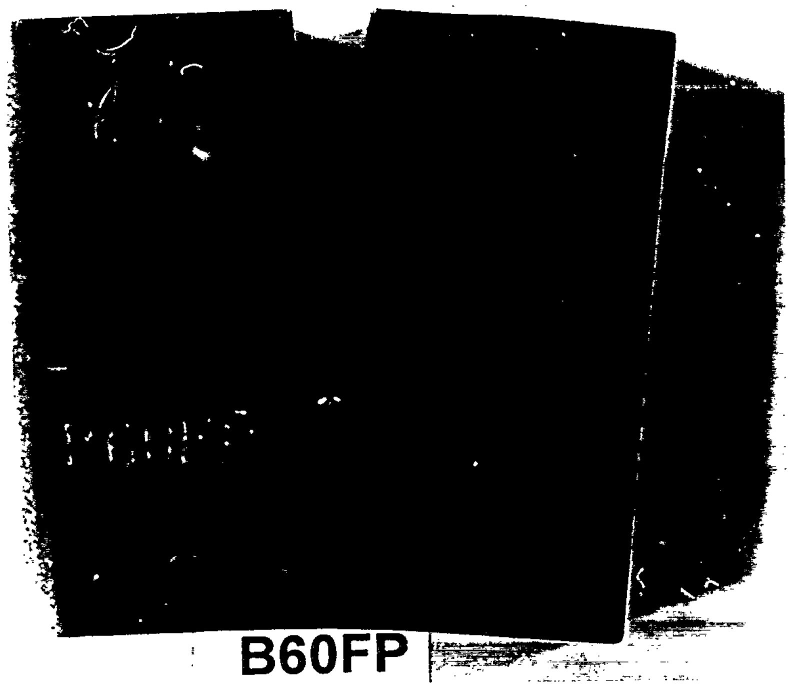

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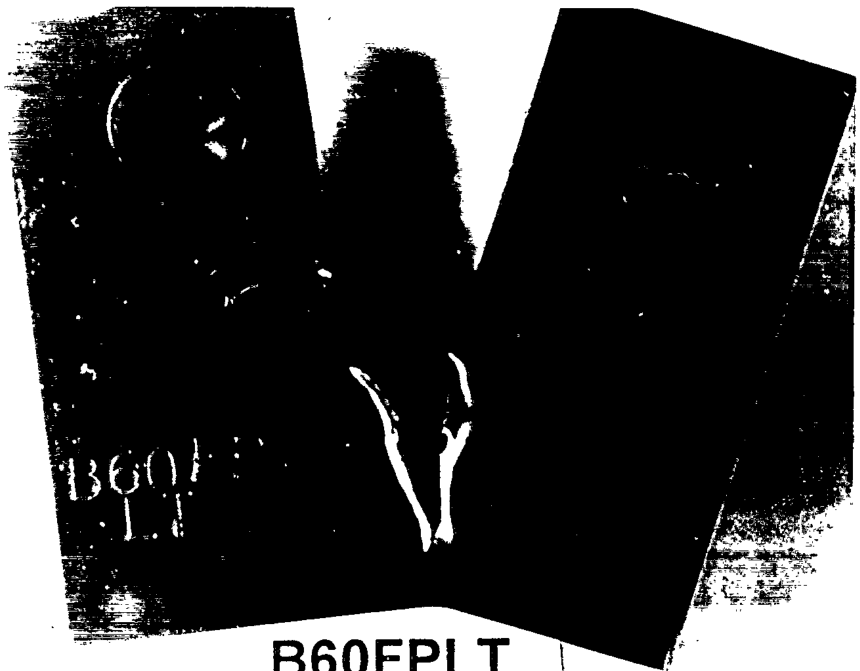
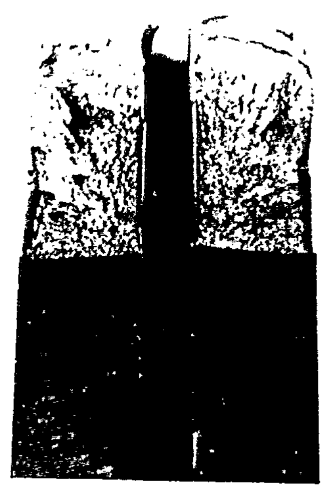
Fig.5-a,b. B60FP

a)



B60FPLT

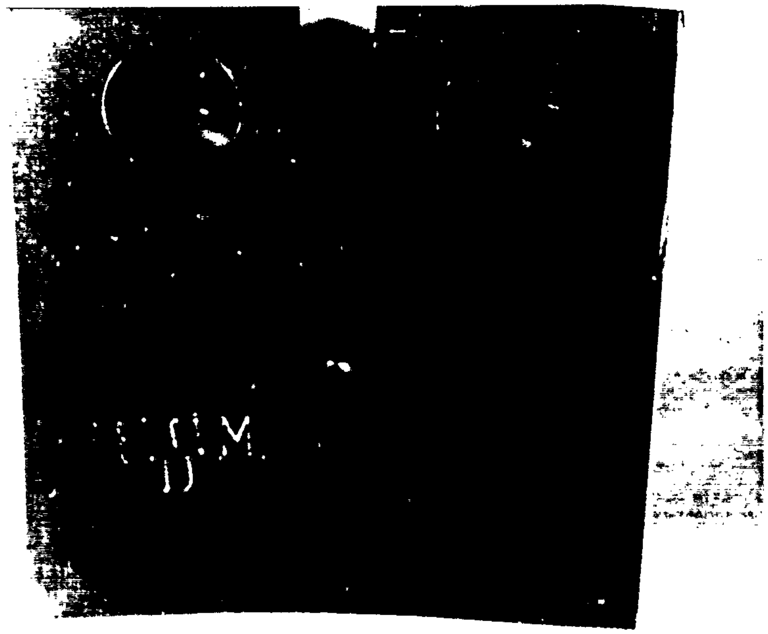
b)



B60FPLT

Fig.6-a,b. B60FPLT

a)



BEDM

b)

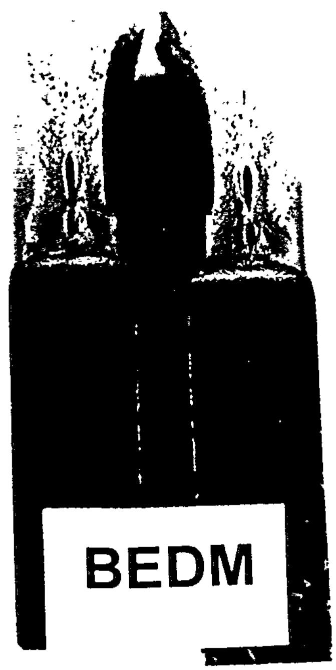
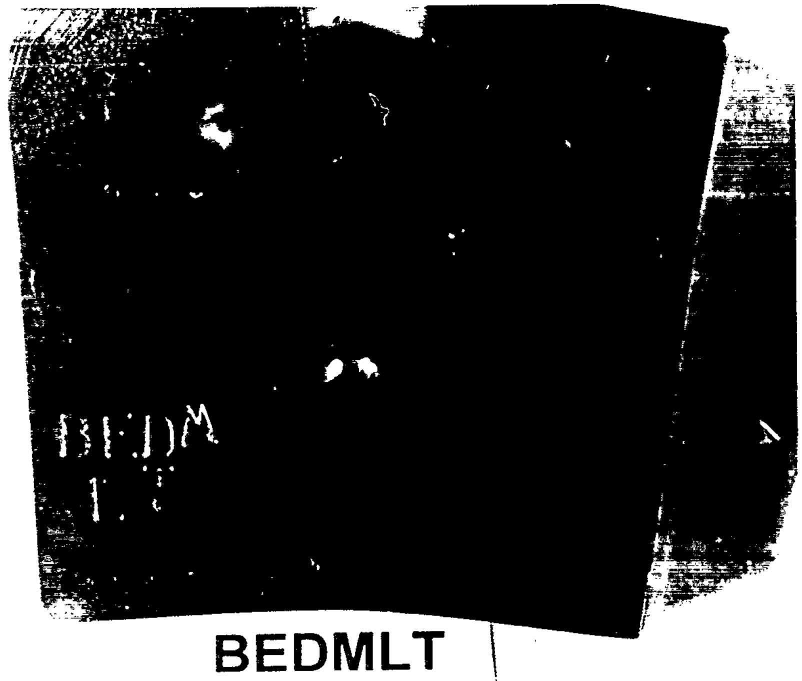


Fig.7-a,b. BEDM

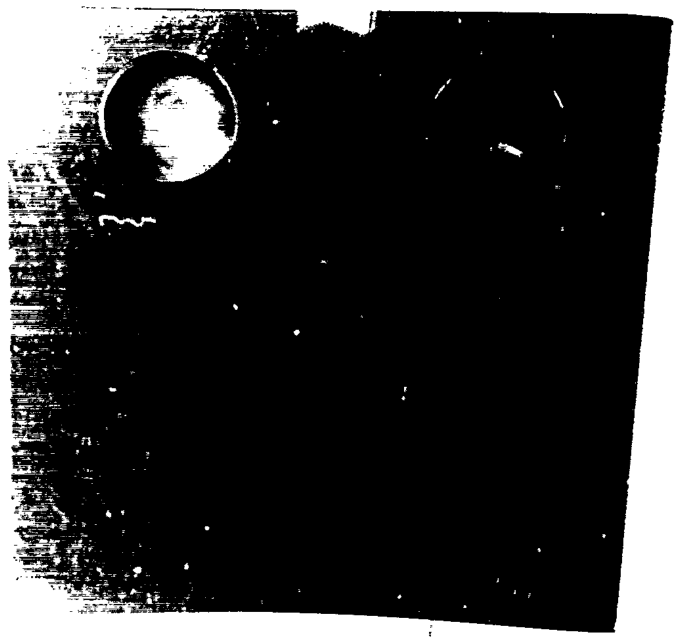
a)



b)

Fig.8-a,b. BEDMLT

a)

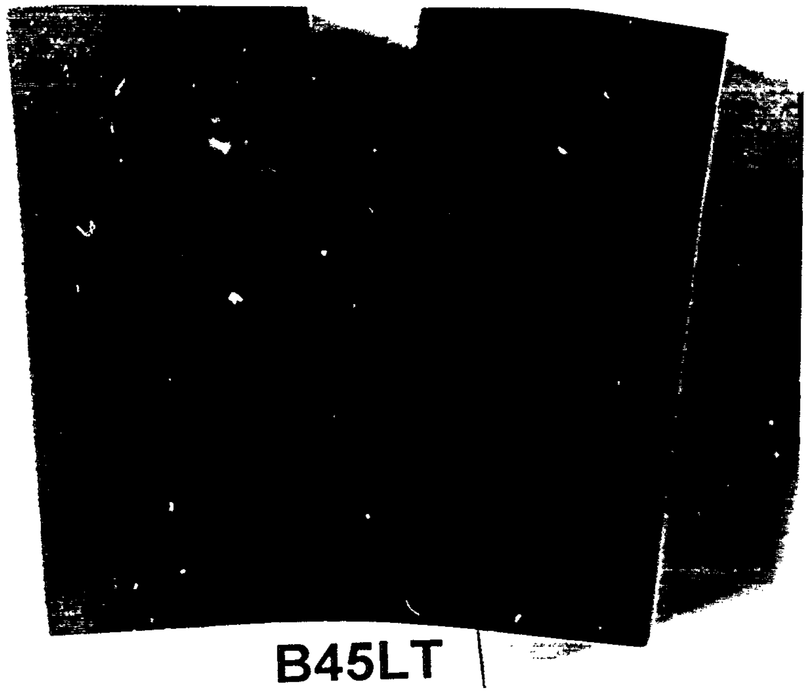


B45R

b)

Fig.9-a,b. B45R

a)



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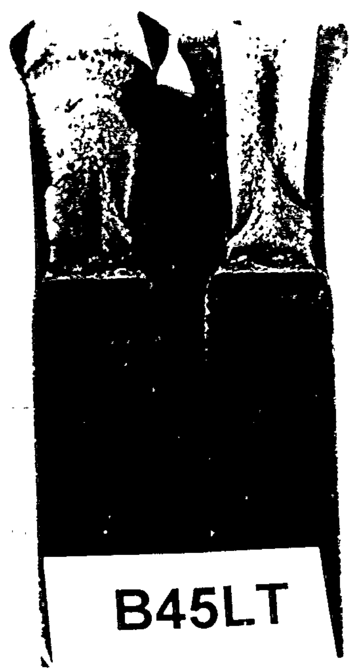


Fig.10-a,b. B45LT

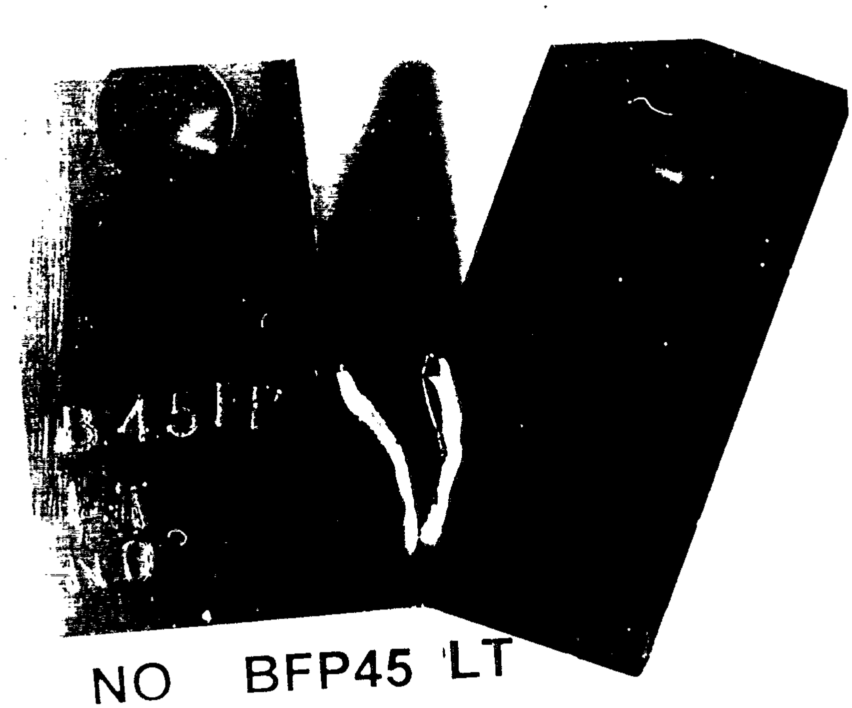
a)

BFP45

b)

Fig.11-a,b. BFP45

a)



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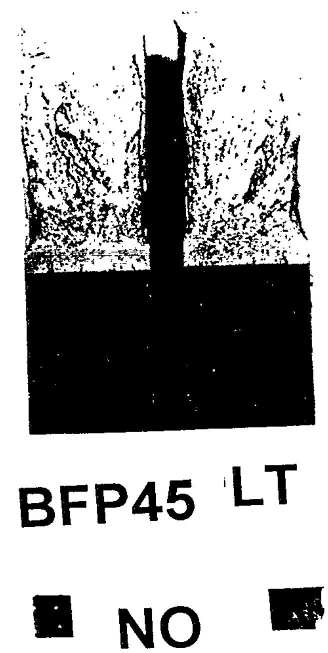
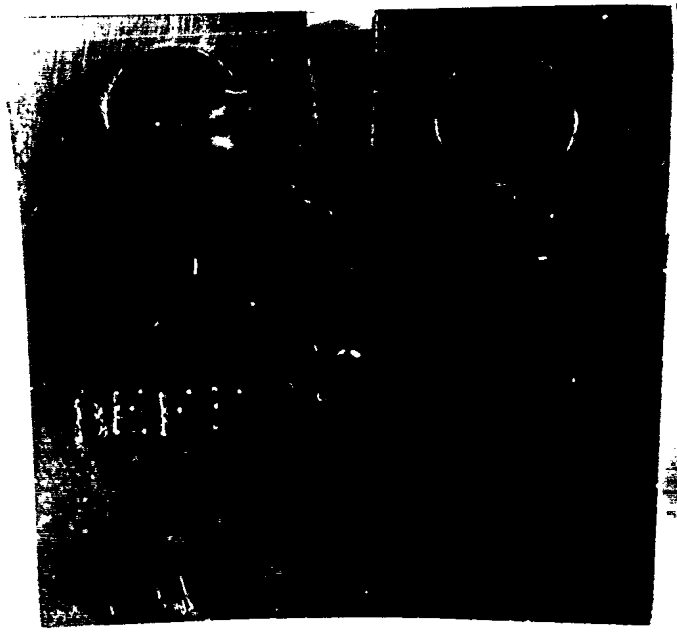


Fig.12-a,b. BFP45LT

a)



BEFP

b)

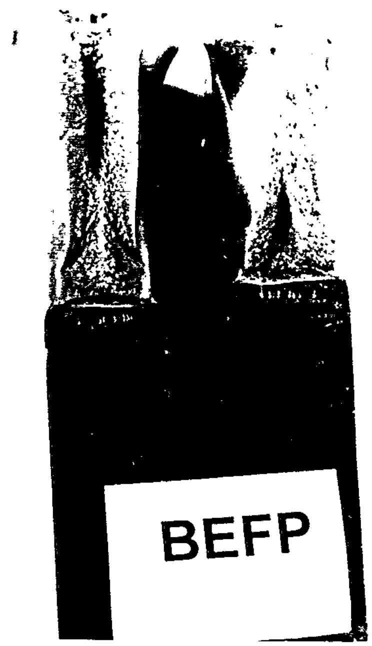


Fig.13a,b. BEFP

a)

BFPLT

b)

BFPLT

Fig.14-a,b. BFPLT

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