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Aircraft Structures Report 449

**DAMAGE TOLERANCE ASSESSMENT OF BORON/EPOXY
REPAIRS TO FUSELAGE LAP JOINTS**

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by

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SUMMARY

This report describes an experimental program into the damage tolerance of boron/epoxy repairs to multi-site damage in a typical aircraft fuselage lap joint. Repaired lap joint specimens containing adhesive disbonds and impact damage were evaluated using both fatigue and static tension tests. It was demonstrated that such damage had no significant effect on the performance of the repairs.



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1. INTRODUCTION

In a series of previous reports [1,2] the authors have presented the results of an experimental test program into the fatigue performance of fuselage lap joints. Particular attention has been paid to joints containing multi-site damage, and both repaired and unrepaired specimens have been tested. In these investigations the test configuration was optimised so as to produce crack growth rates in good agreement with fleet data, see [2].

Before implementing any repair it is necessary to understand the load transfer mechanisms. This was achieved through the use of thermal emission techniques, see [3]. As a result of this work it was determined that the provision of an alternative load path with the load bypassing the critical region, as in the F111 repair [4], would be a viable repair option. This concept forms the basis of the externally bonded repair described in [1,2]. It was subsequently shown, [2], that this repair was not significantly degraded by exposure to a hot, wet, salt environment. In this paper it is shown that the fatigue performance of the repair is not degraded by either low velocity impact damage or by the presence of adhesive disbonds. It is also shown that the static strength of a damaged repair exceeds that of an undamaged specimen.

2. SPECIMEN DESCRIPTION

The lap joint specimens consisted of two 1.016mm thick 2024-T3 aluminium sheets fastened with three rows of 3.97mm diameter BACR15CE-5 100° shear head counter sink rivets. Specimen dimensions are shown in Figure 1. To reproduce crack growth rates in agreement with fleet measurements [2], the specimens were assembled in pairs by bonding back to back on a 12.5mm thick honeycomb core. Multiple cracks in the upper row of rivets were initiated and grown under a tensile fatigue loading. The specimens were then repaired using a 203mm long by 203mm wide unidirectional boron/epoxy doubler. Details of specimen manufacture, crack initiation, crack growth rates and further details of the repair can be found in previous reports [1,2].

Six specimens were used to investigate the damage tolerance of the proposed repair scheme. A summary of the specimen histories, prior to damage tolerance testing, is given in Table 1. Specimens A3,A4 and A5 had experienced a large number of fatigue cycles prior to the application of the impact damage.

Specimens A3,A4 and A5 only contained impact damage, whilst specimen A6 contained both impact damage and adhesive disbonds, and specimens A9 and A10 contained adhesive disbonds, see Figures 2-4.

2.1 Adhesive Disbonds

In specimen A6 the adhesive disbonds were simulated by inserting teflon release film between the aluminium sheet and adhesive during bonding of the doubler (repair). The size and the location of these inserts is shown in Figure 2.

For specimens A9 and A10 a deliberate attempt was made to produce a poor quality bond. In this case the low temperature curing adhesive Flexon 241 which has an inferior durability performance [5], was used. These specimens also contained areas in which the patch was not bonded. The extent of these disonds was not known until the patches were removed after testing had been completed. The debonded area in specimen A9 was approximately five percent of the total patch area, see Figure 3, whilst for specimen A10 approximately twenty percent of the patch area was debonded, see Figure 4. The adhesive thickness was also very uneven, varying from "zero" to approximately 1mm.

2.2 Impact Damage

Specimens A3,A4,A5 and A6 were subjected to low velocity impact damage using a 9.5mm diameter impactor, of varying mass, dropped from a height of 1.3m. A special impact test rig was used to record the absorbed impact energy. The rig consisted of a laser which was triggered by the impactor both before and after impact, producing initial and rebound pulses which were recorded on a digital oscilloscope (NICOLET 2090 MODEL 207) and analysed on a HP9816 computer. From these results the kinetic energy of the impactor before and after impact was determined.

A typical impact test result is shown in Figure 5. The impact site locations are shown in Figure 6, and the impact energies are summarised in Table 2.

3. FATIGUE TESTING

3.1 Fatigue Test Procedure

Fatigue testing was conducted in a 1MN Instron servo-hydraulic test machine. The damaged specimens were subjected to a constant amplitude tensile fatigue loading with $R \approx 0.05$, a load amplitude of 38kN, and a frequency of 2.5 Hz. This loading represents the hoop stress in the fuselage skin due to pressurization, refer [1]. Testing was continued until failure of the specimen occurred, or a sufficient number of cycles had been accumulated to demonstrate the effectiveness of the repair.

The condition of the impacted specimens was monitored throughout the test using the shadow moiré technique. A detailed description of this technique and its application to monitoring damage growth is given in [6]. The patches were coated with a white matte paint and two 100mm by 125mm glass plates with 1/1000 inch grid lines were placed directly over the area containing the damage. A collimated light source was then directed at the specimen at an angle of approximately 45° to the surface. The resulting moiré fringe pattern was monitored visually and also photographed at various stages during the test, thus enabling a qualitative assessment of patch debonding to be made.

3.2 Fatigue Test Results

The number of fatigue cycles applied to each of the specimens is shown in Table 3. None of the repairs showed any significant sign of failure or degradation during the tests. This contrasts with an average life of 75,000 cycles for the unrepaired specimens, refer [1].

More than 1,000,000 cycles were applied to specimens A9 and A10 without failure of the repairs. It should be noted that for these specimens, prior to repair, the cracks at the first row of rivets had propagated across the entire width of the specimen (i.e. the specimen had failed). Despite the deliberate poor quality of these repairs and in particular the large disbond area in specimen A10, the composite doubler was able to carry the load without further degradation.

Specimen A6 withstood more than 1,400,000 cycles without failure or apparent disbond growth.

After impacting, specimens A3 and A4 were subjected to in excess of 450,000 cycles. These failed by fatigue crack growth in the aluminium sheet outside the repair, see Figure 7. It should be noted that these specimens had accumulated a total of more than 3,000,000 load cycles during previous testing. There was no sign of degradation or failure of the repair. An eddy current inspection of the specimens was conducted to determine the extent of crack growth since impacting. It was found that no further crack growth had occurred during this test program.

Specimens A5 and A6 withstood 180,000 cycles after impacting, again with no apparent degradation or failure. The Moiré fringe pattern for these specimens, i.e. A3 - A6, revealed that there had been no delamination growth, see Figures 8 and 9.

4. TENSION TESTING

On completion of these fatigue tests four specimens, namely A3/A4 and A9/A10, were loaded to failure in tension in order to determine the strength of the damaged repair. For the purpose of comparison an undamaged and unrepaired, i.e. "as new", lap joint specimen pair was also tested. In each case load was applied at a rate of 37.5kN/min.

The specimen pair A3/A4, which had previously failed outside of the patched region, was repaired to enable the tensile test to be conducted. A new grip fitting was bonded and bolted to the end of the specimen, see Figure 10. The tension test results are shown in Table 4. The repaired specimens exceeded the strength of the "as new" lap joint specimen. Specimens A3/A4 failed in the aluminium sheet outside the repair area, while specimens A9/A10 failed by debonding and tearing of the composite doublers. The significantly lower strength of specimens A9/A10 was expected due to the poor quality of the bond. Despite this, the strength of these fatigued specimens still exceeded the strength of the standard, "as new" lap joint.

5. CONCLUSION

This test program has demonstrated that the presence of adhesive disbands and damage due to low velocity impacts does not degrade the boron/epoxy repairs. This was shown by demonstrating that the fatigue life of the repaired specimens, containing damage, far exceeds that of an unrepaired lap joint specimen. Inspection of the specimens during and after testing revealed no damage growth and that the multi-site damage beneath the repair does not grow. It was also shown that the static strength of the damaged repairs exceeds that of an uncracked lap joint specimen.

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TABLE 1. SPECIMEN HISTORY

Specimen No.	Fatigue Cycles			
	Precracking	Unrepaired	Repaired	Environmental
A3	178,400	-	2,155,550	1,062,400
A4	178,400	-	2,155,550	1,062,400
A5	5,000	41,400	1,300,070	-
A6	5,000	25,000	-	-
A9	19,210	110,030	-	-
A10	19,210	105,700	-	-

TABLE 2. IMPACT RESULTS

Specimen No.	Impact Mass (g)	Impact Site	Impact Energy (J)
A3	200	1	1.6
		2	1.7
		3	1.2
A4	200	1	1.7
		2	2.0
		3 ^a	-
A5	400	4	1.4
		1	4.0
A6	400	2	3.7
		1	4.0
A6	400	2	4.2
		1	4.0

a - impact energy not recorded

TABLE 3. FATIGUE TEST RESULTS

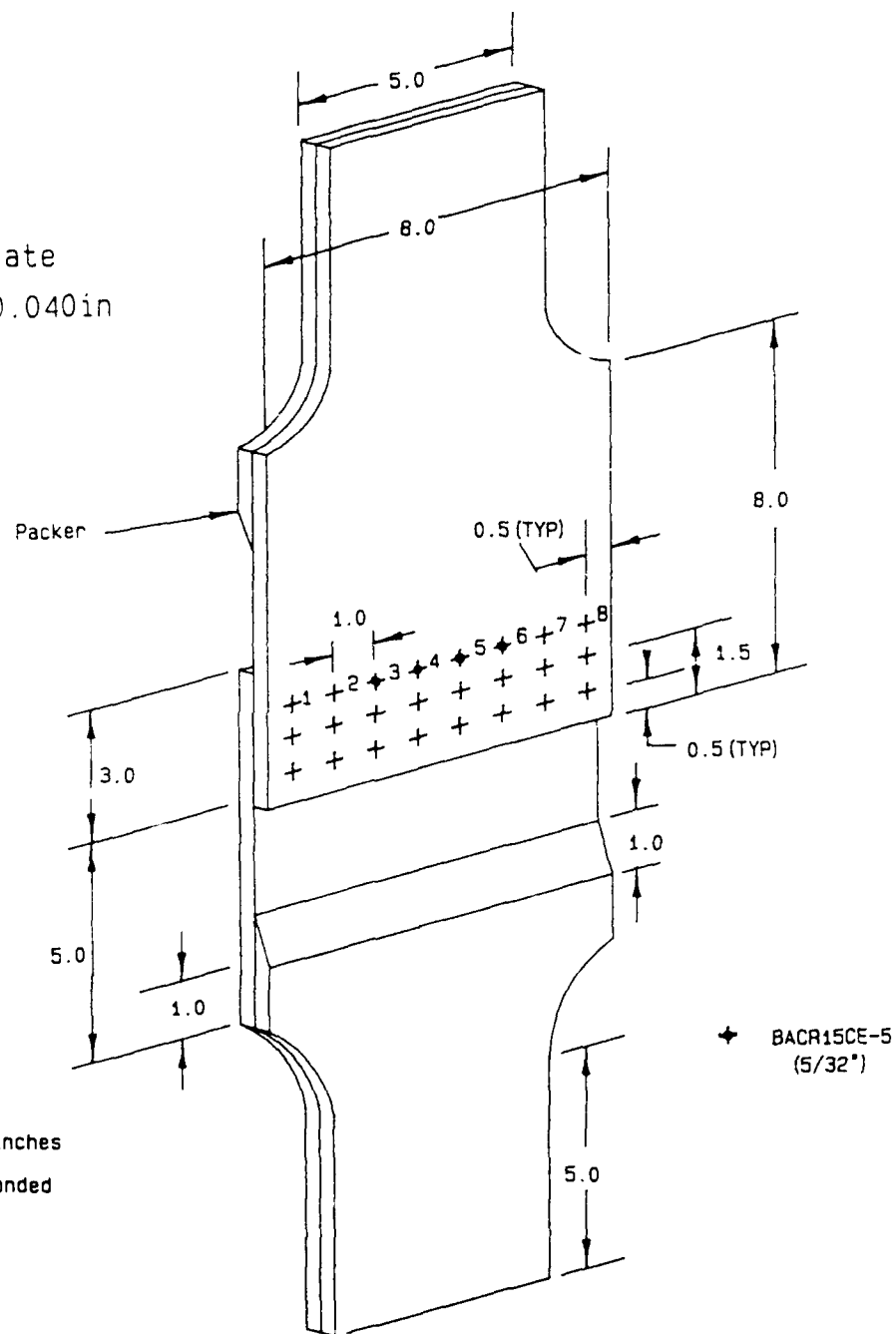
Specimen No.	Type of Damage	Fatigue Cycles
A3 ^a	impact	454,670
A4 ^a	impact	454,670
A5	impact	180,000
A6	disbond	1,316,470
	impact	180,000
A9	disbond	1,000,000
A10	disbond	1,004,330

a - specimen failed by fatigue in aluminium sheet outside repair area

TABLE 4. TENSILE TEST RESULTS

Specimen	Total Fatigue Cycles	Static Failure Load (kN)
Undamaged Lap Joint	0	116
A3/A4	3,672,570	161
A9/A10	1,110,030	121

2024-T3 Plate
Thickness=0.040in



Dimensions in inches
Packer to be bonded

Figure 1. Fuselage Lap Joint Specimen

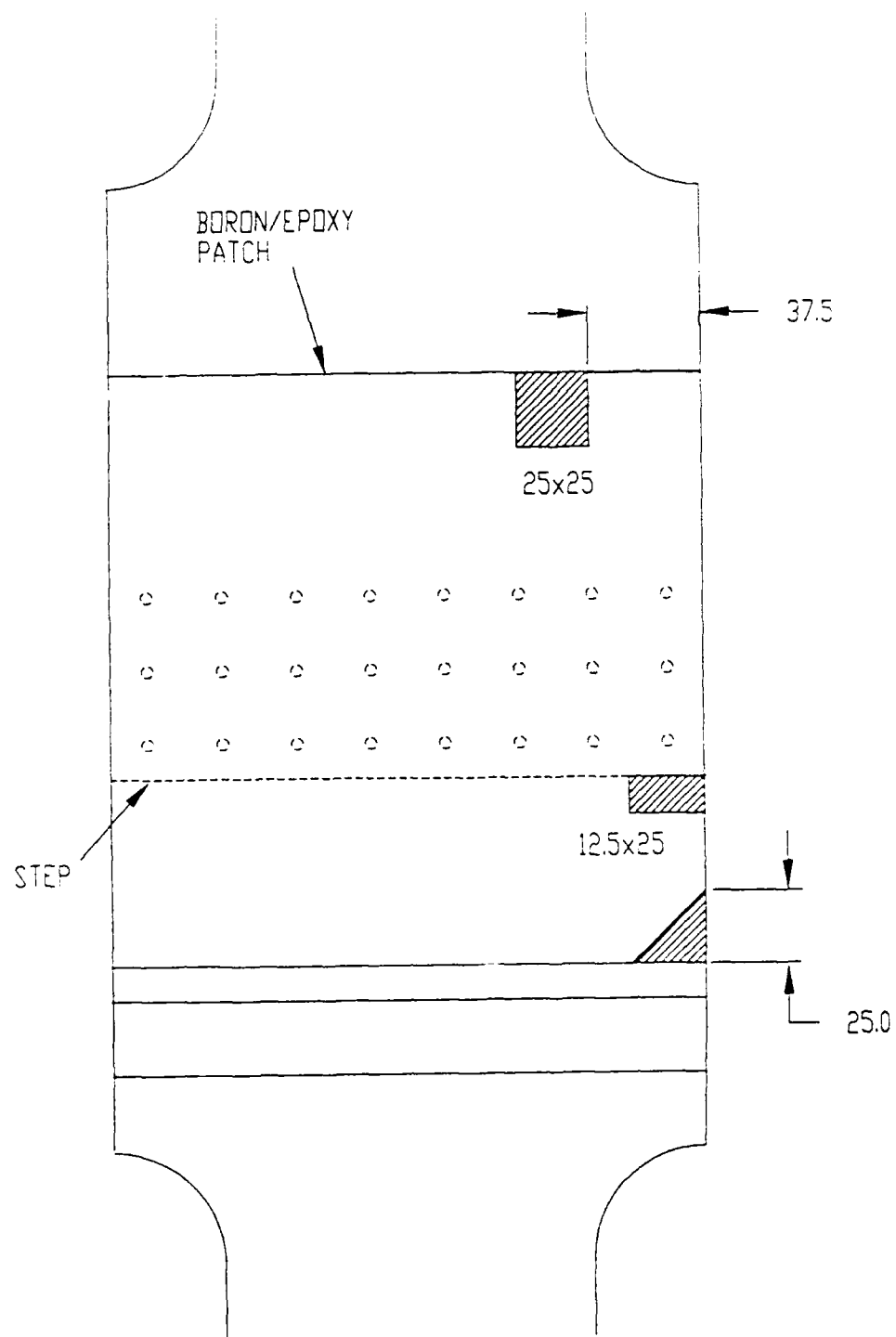


Figure 2. Insert Detail for Specimen A6

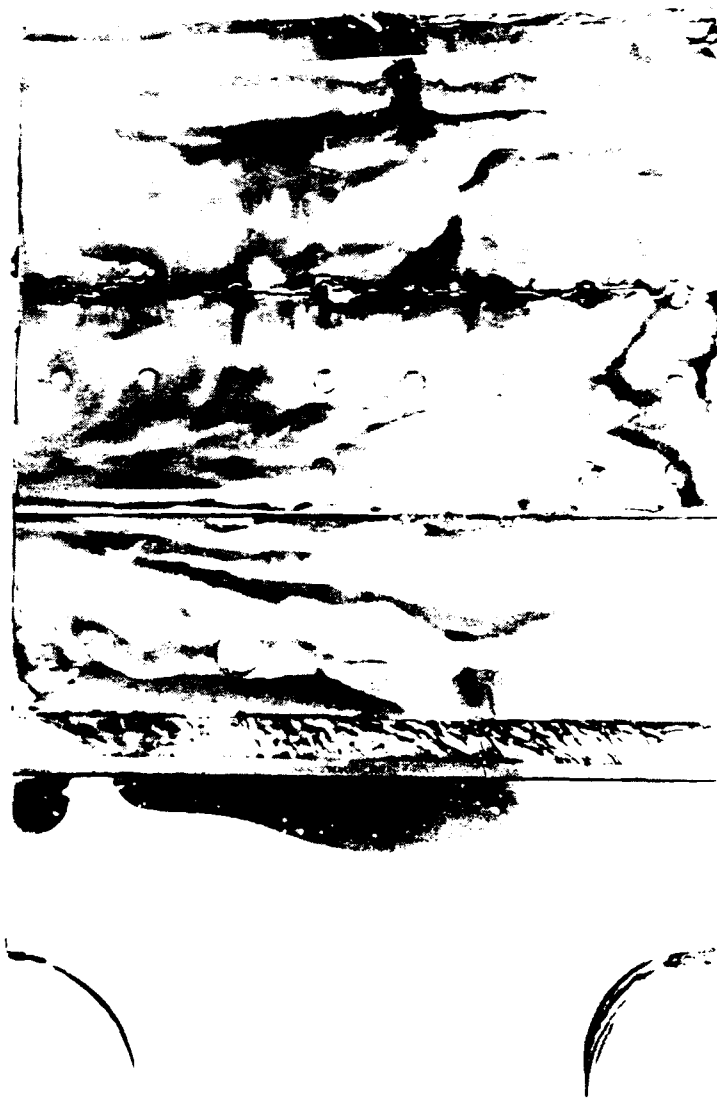


Figure 3. Specimen A9 with Doubler Removed

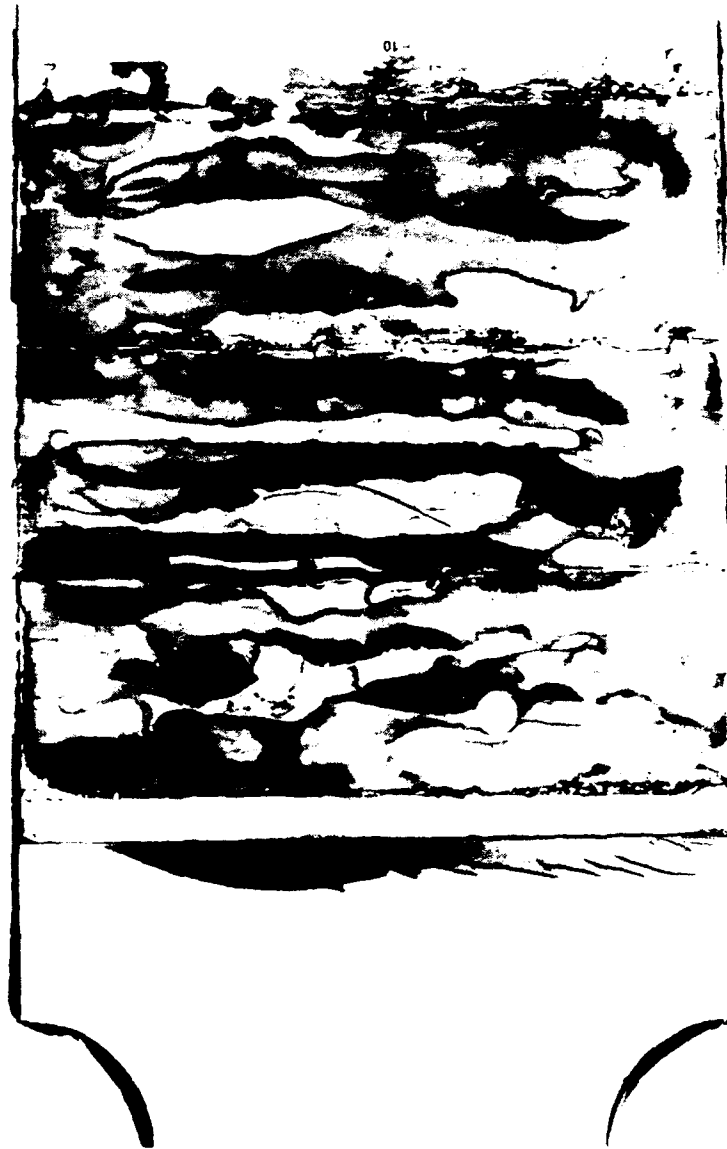
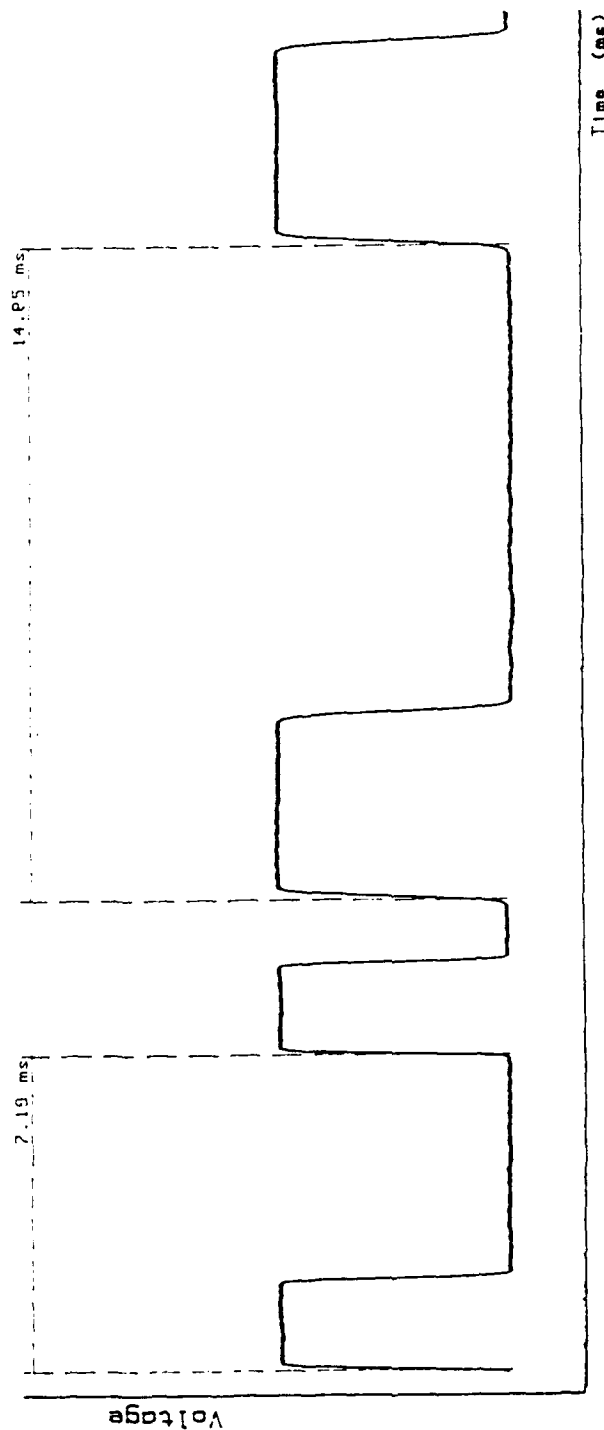


Figure 4. Specimen A10 with Doubler Removed

IMPACT TEST PLOT



D REES

LNP JOINT SPEC # RS-2

35/34/91

14: 54: 24 05 APR 91

Mass of Impactor = .4020 kg.
 Initial time = 7.1920 ms.
 Initial displac. = 35.1903 mm.
 Initial velocity = 4.8943 m/s.
 Initial Energy = 4.2502 Joules.
 Rebound time = 14.8500 ms.
 Rebound displac. = 35.4660 mm.
 Rebound velocity = 2.3829 m/s.
 Rebound Energy = 1.1404 Joules.

Absorbed Energy = 3.6524 Joules.

Figure 5. Typical Impact Test Result

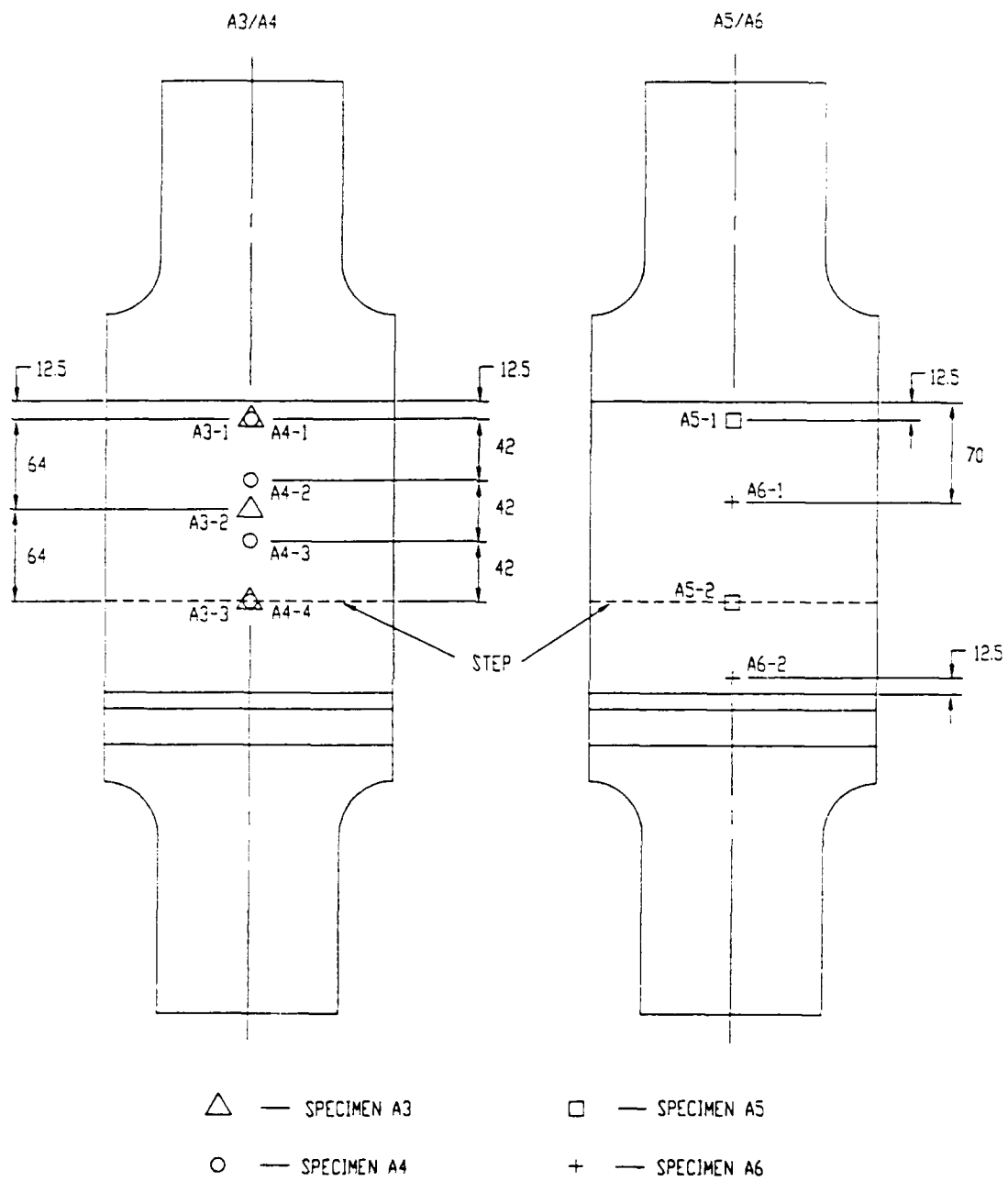


Figure 6. Impact Site Locations



Figure 7. Fatigue Failure of Specimen A3/A4

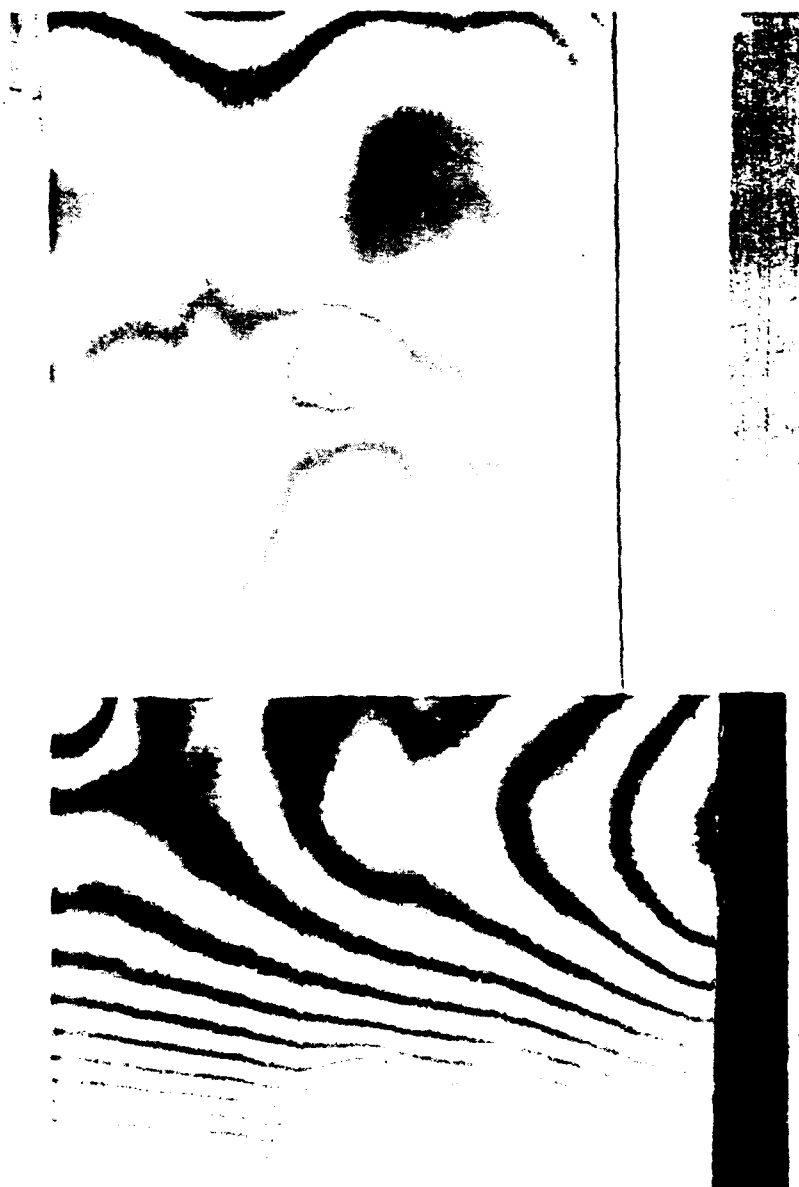


Figure 8. Moiré Fringe Pattern for A6 After Impacting



Figure 9. Moiré Fringe Pattern for A6 at 180,000 Additional Cycles

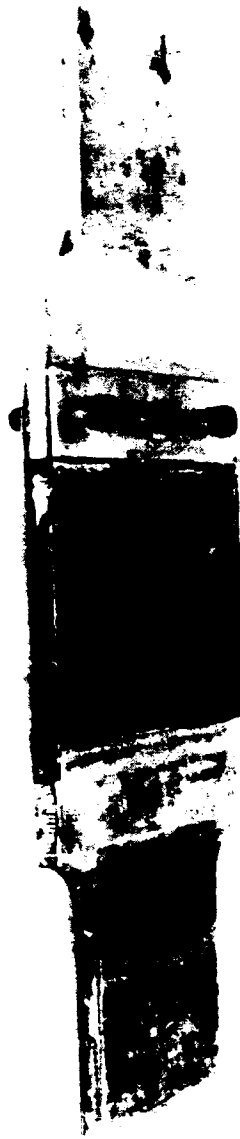


Figure 10. Repair of Specimen A3/A4 Prior to Tension Test

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