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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/679

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Ballistic and Metallurgical Investigation of Helmets Edge-Annealed in a "Tocco" Induction Heating Unit

BY

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DATE 18 July 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Final Report on Problem B-7.4

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ABSTRACT

The edge annealing of the entire circumference of the M1 helmet in a "Tocco" induction heating unit was found to satisfactorily stress relieve the edge. Ballistic testing of the edge annealed zone and the transition zone show ballistic characteristics identical to those of un-annealed helmets. No tendency towards crack formation exists. Ninety degree (90°) bend tests reveal the improved ductility of the annealed zone. Hardness surveys and metallographic examination indicate a zone of completely recrystallized, dead-soft metal at the edge of the helmets.

1. At the request of the Office, Chief of Ordnance[1], a group of ten (10) helmets was forwarded from the St. Louis Ordnance District to this arsenal for metallurgical investigation. These helmets had been edge annealed in a "Tocco" induction heating unit for the purpose of preventing delayed visor cracking. This type of defect has been occurring to a considerable extent at the Schlueter Manufacturing Company of St. Louis, Missouri, the producer of the subject helmets. The details of the induction hardening cycle are contained in a teletype from the St. Louis Ordnance dated 5 July 1944, Appendix A.

2. The Schlueter Manufacturing Company had previously submitted helmets which had been edge annealed in a seam welding machine. Metallurgical examination of these helmets[2] indicated that the edge annealing process applied to the visor provided a high degree of ductility and satisfactorily stress-relieved a zone very susceptible to delayed cracking.

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1. Teletype of 30 June and 4 July 1944, Appendix A.

2. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/612, "A Study of the Seam Welding Process Applied to Prevent Stress Cracking of the Visor of the M1 Helmet", 13 April 1944.

3. As a result of the tests performed upon samples selected from the ten helmets which had been edge-annealed in an induction heating unit it is concluded that:

a. The edge annealing process causes no decrease in the ballistic efficiency of the portion of the helmet to which the process is applied.

b. 90° bend tests conducted upon vertical sections cut from the visors of the "Tocco" edge annealed helmets indicate a high degree of ductility in the annealed zone extending to approximately 1/2" up from the edge.

c. The subject edge annealing process produces a soft, recrystallized zone for a distance of approximately 1/4" up from the edge. Between the recrystallized zone and the cold worked base metal lies a transition zone approximately 1/2" wide in which partial recrystallization has occurred.

d. Immersion of a "Tocco" edge annealed helmet in a dilute acid solution until a weight loss of approximately 50% resulted failed to develop any cracks whatsoever in the helmet shell.

4. The ten (10) submitted helmets were from Schlueter Lots 213B4 and 213B7. Six (6) helmets were selected for the various tests listed below:

W.A. No.	Schlueter Lot No.	Test Performed Upon Helmet
S1	213B7	Ballistic Test of Annealed Zone
S2	213B4	Ballistic Test of Annealed Zone
S3	213B7	Ballistic Test of Annealed Zone
S4	213B4	90° Bend Tests, Hardness Surveys, Microscopic Examination
S5	213B7	90° Bend Tests, Hardness Surveys, Microscopic Examination
S6	213B7	Acid Etching Test

5. Details of the ballistic and metallurgical tests follow:

a. Ballistic tests. To determine the effect, if any, of the edge-annealing treatment upon the ballistic properties of helmets, three edge-annealed and two normal production helmets, one from McCord lot 608A and the second from McCord lot 854C were subjected to ballistic tests using the caliber .45 steel-jacketed, 230 grain, ball projectile.

Each of the five helmets was impacted with three projectiles approximately one inch up from the edge; one was fired at the 0° position (middle of the visor), one at the 90° position (middle right hand side), and one at the 270° position (middle left hand side). Velocities in the range of 650-700 feet/second were employed since this range represents approximately the ballistic limit of this portion of the helmet. Normally, when firing to determine the ballistic limits of helmets, the impacts are placed on the vertical section of the helmet lying between 1-1/2" and 4" up from the rim, in which zone the ballistic limit is approximately 50 to 100 feet/second higher than in the zone lying between the rim and 1-1/2" up from the rim. This is believed attributable to the inward curvature of the zone just above the rim which prevents the cushioning effect obtained when the projectile strikes a convex surface such as exists in the areas normally impacted.

Typical results of the ballistic tests are shown in Figures 1A through E. Examination of these photographs reveals that the edge-annealing process produces no noticeable change in the ballistic characteristics of the zone lying within 1" of the edge. There is no tendency for crack propagation through either the annealed or the transition zone. Figure 1E is a photograph of an edge-annealed helmet which was struck by a projectile exactly on the edge of the rim, which was pushed inwards 0.7". No cracks resulted and the helmet displayed excellent ductility.

b. Hardness Surveys. Three vertical sections approximately 2" long were cut from the visors of helmets S4 and S5. These sections extended from 330° to 350°, 350° to 10°, and 10° to 30° respectively. Three Rockwell "C" hardness surveys were made upon each section, starting at 1/8" from the rim and at every 1/8" station perpendicularly up from the edge for a distance of two inches.

Hardness surveys at 340°, 0° and 20° on helmet No. S5 are plotted in Figure 2. All the other hardness surveys made upon both this helmet and helmet No. S4 coincide with these curves. For a distance of approximately 1/4" the hardness is that of the material in the dead soft condition, Rockwell C 5.5 - 14 (Rockwell B 89 - 95). The unaffected cold worked base metal has a hardness of Rockwell C 47 - 49.5, and between this region and the dead soft zone is a transition zone approximately 1/2" in width.

c. 90° Bend Tests. Bend tests were conducted upon the sections lying between 350° and 0° cut from helmets S4 and S5. Photographs of the bent sections are shown in Figure 3D. The region lying between the edge and 1/2" up from the edge developed no cracking upon being bent through 90°. The cold worked zone broke apart in one case and cracked severely in the other. Previous tests at this arsenal[2] upon helmets that were not edge annealed resulted in complete breakage of the sections. This test reveals the excellent ductility produced by the annealing of the helmet edge.

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2. See Footnote 2, page 1.

d. Acid Etching Test. Helmet No. S6 was immersed for 40 hours in a 10% hydrochloric acid solution and decreased in weight from 965 grams to 533 grams, a loss of 44.8%. Careful examination failed to reveal any cracks formed upon etching. It has been determined at this arsenal that immersion of helmets in dilute acid solutions for periods of time between 20 and 40 hours is capable of causing the formation of cracks in regions of highest residual stresses when these stresses are of the order of magnitude capable of causing draw breakage and service cracking. When the residual stresses are below the danger point, helmets will not crack even after a loss in weight of 50%. Further experimentation is being conducted along these lines and will be reported in the future.

e. Microscopic examination. Specimens for microscopic examination were cut from helmets Nos. S4 and S5. For a distance of approximately 0.25" from the edge the microstructure consisted of a completely recrystallized structure with undissolved carbides at the grain boundaries, Figure 3A. The 1/2" wide transition zone consisted of a partially recrystallized structure with a large amount of carbides precipitated along slip lines and at grain boundaries, Figure 3B. Figure 3C shows the cold worked structure of the unaffected base metal.

6. This laboratory suggests the advisability of applying the "Tocco" annealing cycle after the deep drawing operation and prior to trimming. It has been established that the notches produced in the edges of the helmets result from nicks in the trimming dies which operate under the very severe service of shearing metal which has been cold worked to a hardness of Rockwell C 45 - 55. If the annealing were performed prior to the trimming operation, the die life would be greatly extended and notches in the edges of the helmets could be avoided. It is possible that the necessity for the edge grinding operation might be eliminated by this procedure. The visor spanking operation should be easily applicable to the visor in the annealed condition without creating excessively high residual stresses. It is believed that this method could be tested very readily with the cooperation of the Ohio Crankshaft Company, Cleveland, Ohio.

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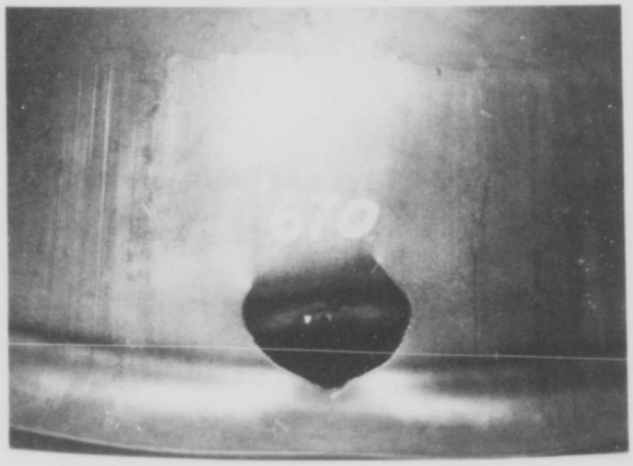
APPROVED:

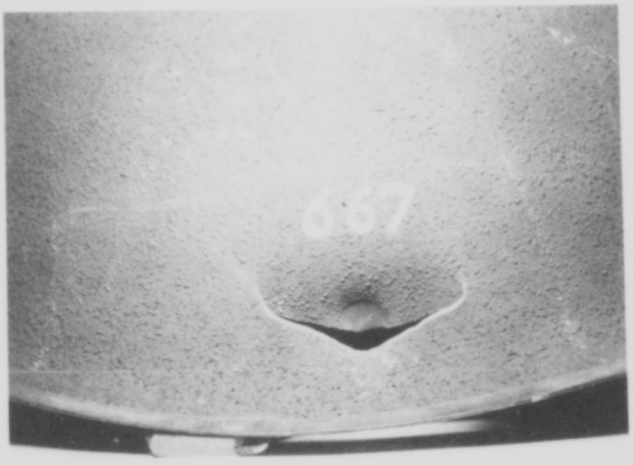
N. A. Matthews

N. A. MATTHEWS
Major, Ordnance Dept.
Chief, Armor Section

Magnification X 2/3

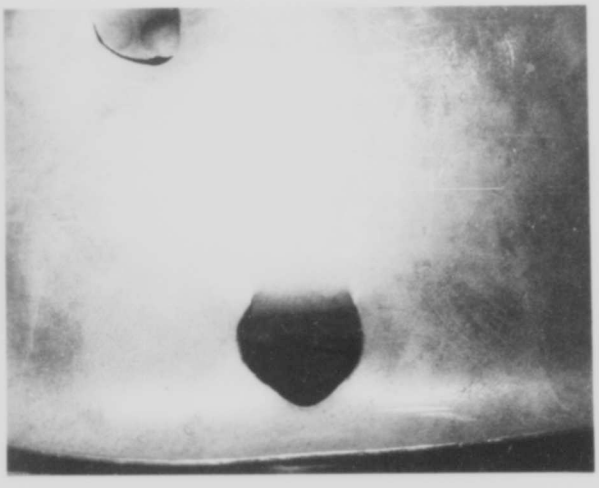


Helmet S3. Schlueter 213B7. -A-
Edge Annealed. Impact 1.0" up from rim at 265°.



Helmet 14. McCord 608A. -B-
Normal Helmet. Impact 0.9" up from rim at 250°.

Helmet S1. Schlueter 213B7. -C-
Edge Annealed. Impact 1.2" up from rim at 255°.7



Helmet 16R. McCord 854C. -D-
Normal Helmet. Impact 0.7" up from rim at 83°.

FIGURE 1.

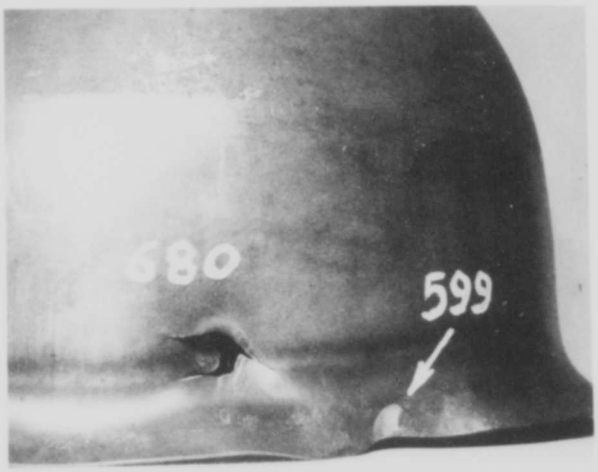
BALLISTIC TESTS CONDUCTED WITH

CAL. .45 STEEL-JACKETED EXPANDING

BALL PROJECTILES

Numbers Painted on Helmets Are Striking Velocities in Feet Per Second.

Impacts Are Located by Rotating Clockwise, Starting From Middle of Visor as 0°.



Helmet S1. Schlueter 213B7. -E-
Edge Annealed. 680 ft./sec. - 1.1" up from rim at 83°. 599 ft./sec. - edge of rim at 60°, rim pushed in 0.7".

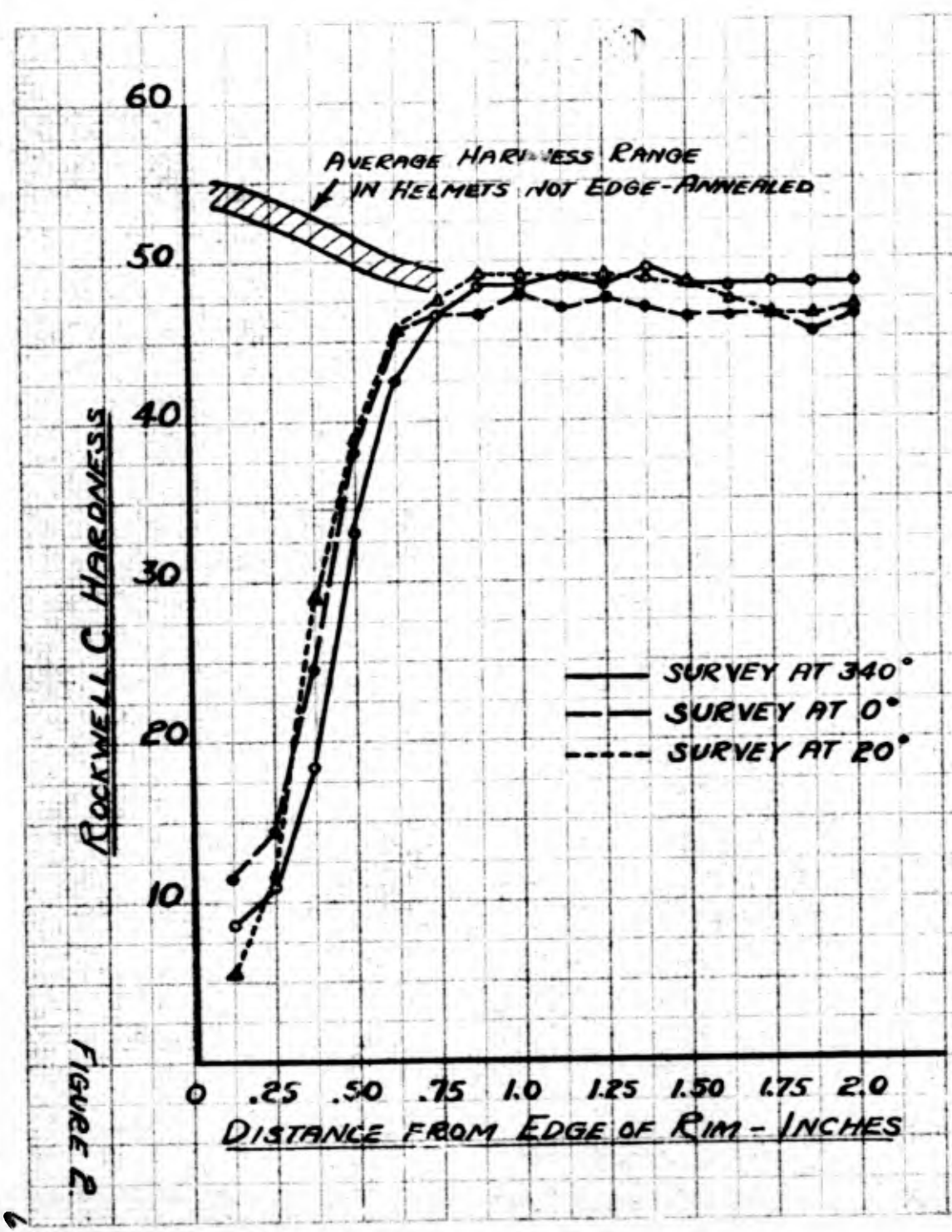


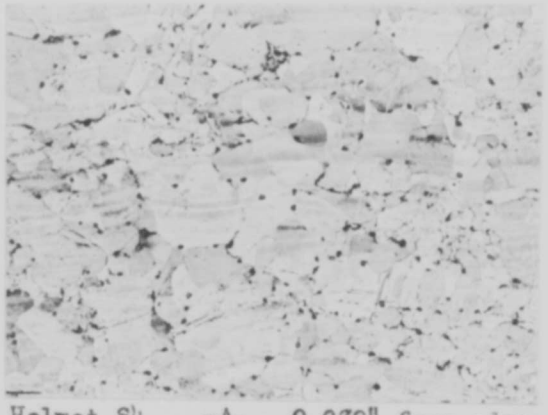
FIGURE 2.

ROCKWELL C HARDNESS SURVEYS TAKEN PERPENDICULARLY UP FROM EDGE OF "TOCCO" ANNEALED RIM OF M1 HELMET.

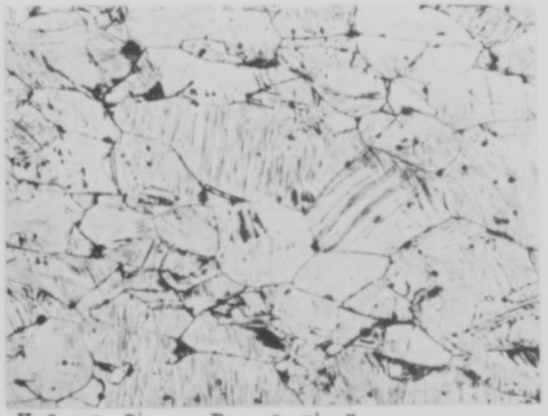
SCHLUETER MFG. CO.
LOT 213B7

Microstructure Along Edge-Annealed Zone

Nital Etch. Mag. X250



Helmet S4. -A- 0.030" from edge. Recrystallized austenitic grains. Some undissolved carbides at grain boundaries. Hardness, Rockwell C 10.



Helmet S4. -B- 0.540" from edge. Partially recrystallized zone. Some grains show evidence of cold working. Extensive carbide precipitation. Rockwell C 35.

Helmet S4. -C- 0.750" from edge. Unaffected cold worked region. Severely deformed grains. Rockwell C 47.

-D- Mag. X 2/3

90° bend tests on sections cut from visors of edge annealed helmets. Similar tests on helmets without edge-annealing resulted in complete breakage.

FIGURE 3.

APPENDIX A

Correspondence

COPY

GA35 GA38

BWA V CSO NR251 WD R

FROM GARDNER ST LOUIS ORD DIST ST LOUIS MO 30 JUNE 44 2144Z

TO COMMANDING OFFICER WATERTOWN ARSENAL WATERTOWN MASS

GR NC

PER INSTRUCTIONS OFFICE CHIEF OF ORDNANCE 10 HELMETS STEEL M1 WITH EDGES ANNEALED IN INDUCTION HEATING UNIT SHIPPED FROM SCHLUETER MFG CO 30 JUNE 1944 TO HIS ARSENAL ATTENTION MAJOR N A MATTHEWS FOR TESTING SIMILAR TO TESTS PREVIOUSLY CONDUCTED ON HELMETS ANNEALED ON SEAM WELDER REPORT NO. WAL 710/612. REQUEST YOU ADVISE BY TT DATE RECEIVED AND EARLIEST DATE TESTS CAN BE COMPLETED. END CITE SEYMOUR SMALL ARMS BR TT 37553.

WTN 421/434 3022572

B15

WA163

BWA V WAOC NR13 WD

FROM KIRK C OF ORD ASF WASHINGTON DC 042210Z JUL 44

TO CO WATERTOWN ARS WATERTOWN MASS

GRNC

ST LOUIS ORD DISTRICT FORWARDED YOUR ARSENAL ON 6/30/44 BY EXPRESS B/L WT 5453135 TEN HELMETS WHICH HAVE BEEN EDGE ANNEALED BY MEANS OF TOCCO HEATER UNITS INSTEAD OF BY MEANS OF A SEAM WELD REQUEST THAT THESE TEN HELMETS BE GIVEN A COMPLETE ANALYSIS SIMILAR TO THAT GIVEN THE HELMETS IN WATER REPORT NO. WAL 710/612 DATED 4/16/44 REQUEST THIS OFFICE BE SUPPLIED WITH A REPORT IN LETTER FORM PRIOR TO THE SUBMISSION OF A MEMORANDUM REPORT THIS PROJECT SHOULD BE EXPEDITED. END CITE SPOIS HEWITT

WTN 421/437 2500272

COPY

COPY

B17

GA294 MWNA197 JV

BWA V CSO NR 25 WD P

FROM GARDNER ST LOUIS ORD DIST ST LOUIS MO 5 JULY 44 1637Z

TO C.O. WATERTOWN ARSENAL WATERTOWN 72 MASS.

GR NC

10 HELMETS STEEL M1 FORWARDED FROM SCHLUETER MFG CO ATTN-- MAJOR N. A. MATTHEWS HAD EDGES ANNEALED IN AN INDUCTION HEATING UNIT BY OHIO CRANKSHAFT CO. CLEVELAND OHIO. OHIO CRANKSHAFT WILLING TO RUN FURTHER TESTS IF CONSIDERED NECESSARY. TEST RESULTS AS FOLLOWS--

OHIO CRANKSHAFT PROJECT NO. 5-2474-1 TEST NO. 4744

APPARATUS 150 KW - 9600 CYCLES

POWER 24 KW /START/

HEAT TIME 4.0 SEC

DELAY TIME 2.0 SEC

QUENCH TIME 5.0 SEC /74 DEGREES F. WATER SPRAY/

HARDNESS - EDGE GRADES FROM 53/61 RA FRO ABOUT 1/4 INCH TO 76-78 RA IN THE UNHEATED AREA.

COMMENTS-- HIGHER POWER COULD NOT BE USED SINCE HEATING BECOMES LESS UNIFORM THAN AT LOW POWER.

END CITE SMALL ARMS BR. SEYMOUR/NT TT 38402

1814Z

IN EIGHTH LINE SHOULD READ HEAT TIME 5.0 SEC ST OF 4.0 SEC. RPT 5.0 SEC SHUD BE 5.0 SEC

WTN 1.21/43

COPY