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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/673

HELMETS

Determination of Residual Stresses in M1 Helmets

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Watertown Arsenal Laboratory
Memorandum Report No. WAL 710/673
Problem No. L-3.3

1 July 1944

HELMETS

Determination of Residual Stresses in M1 Helmets

OBJECT

To describe (1) experimental methods of measuring strain changes due to residual stress, (2) analytical procedures of analyzing residual stresses, (3) preliminary residual stress determinations on M1 helmets, and (4) some factors influencing cracking and residual stress.

REFERENCES

The basic correspondence and material pertaining to this report are contained in Appendix A.

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CONCLUSIONS

1. The experimental technique of sectioning, etching, measuring curvature changes, measuring strain by resistance strain gages, protecting strain gages during etching, etc., is briefly described.

2. Methods are described for determining residual stresses from strain and curvature changes observed during sectioning and etching.

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3. The macroscopic stresses in the few M1 helmets tested varied considerably from helmet to helmet and in different positions on the same helmet but averaged about 70,000 p.s.i. compression on the inside surface and less than 10,000 p.s.i. compression on the outside surface.

4. The stresses in the helmets were favorably distributed to resist failure by projectile impact.

5. There was insufficient evidence to correlate the residual stresses with cracking, but in general the highest stresses observed were in the regions where cracking has been observed.

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NOTATION

Tension and extension are positive.

T = Original thickness of test specimen.

t = Thickness expressed as a fraction of the original thickness, T.

S_x, S_y = Original stresses in X, Y directions at a distance t from the surface which is not to be etched.

e_x, e_y = Unit elongations in X, Y directions when the remaining thickness is t.

e = Unit elongation when the thickness is t, measured by strain gages glued to unetched surfaces when curvature changes are prevented. (With combined strain e is the effective strain, e.g., $e = e_x + \mu e_y$ or $= e_y + \mu e_x$ when curvature changes are prevented).

e_s = Unit elongation from start of test when the thickness is t, measured by strain gages glued to unetched surface, curvature changes not prevented.

e_c = Unit elongation in fibre at unetched surface from start of test when the thickness is t, measured by curvature gage, assuming e_c is produced by a uniform bending moment corresponding to the curvature change.

S = Original (uniaxial) stress at a distance t from the surface which is not to be etched.

$\frac{d}{dt}$ = Differential coefficient.

E, μ = Young's Modulus, Poisson's Ratio, respectively.

L = Span length of curvature gage.

Δ = Deflection by curvature gage in span length, L, of uniform curvature.

R_o, R = Initial and instantaneous radii of curvature of test area.

INTRODUCTION

Exploratory tests were undertaken at the request of the Armor and Projectile Section of the Watertown Arsenal Laboratory in a preliminary effort to correlate the cracking that occurs in M1 helmets with average residual stress patterns produced in the helmet during the forming operation.

In this report these tests and new experimental and analytical methods used in the determination of residual stresses are briefly described. The test methods necessitate the destruction of the structure being examined. They deal with macroscopic stress on a rather large scale and not with the superposed variations associated with wrinkles.

This report does not deal with the necessity or advisability of detailed residual stress analysis in helmets, although it does point out special circumstances under which residual stress may significantly influence the ballistic limit of a helmet as well as cracking.

Information contained in this report was informally reported to the Armor and Projectile Section as it became available.

TEST PROCEDURE

A. General

Residual stress investigations were made on three (3) M1 helmets, Lot 62A-S, manufactured by the Schlueter Manufacturing Company. There were no apparent cracks present in the helmets used in making these studies.

The specimens to be cut out were located symmetrically on each side of the center of the helmet and were specified by means of a layout graph divided into "clock positions". Strain gages were cemented in these positions on the inside surface of the helmet on one side and on the outside surface on the other half of the helmet. After the gage cement had thoroughly dried, rubberized "Tygon"[1] paint was applied to protect the gage and lead wires while sectioning, i.e., cutting out the specimens.

The work hardening characteristics of the type of steel used in the M1 helmet necessitated the use of a grinding cut-off wheel in this sectioning operation. A standard mixture of soluble oil and water was used as a coolant. After sectioning, the specimens were carefully trimmed by means of a hand grinder, care being taken to avoid burning the metal.

Strain gage measurements were taken on each specimen before and after cutting it out of the helmet.

Both strain and curvature measurements were taken before and after etching. The specimens were suspended into the agitated acid solution by their rubber covered lead wires for successive equal lengths of time, the brown coating which formed during etching being scrubbed off prior to each measurement. The remaining thickness, tT, after each etch was usually determined from the final thickness by assuming the thickness removed was proportional to the time in solution.

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[1] Tygon Temp-tec, manufactured by U. S. Stoneware, Akron, Ohio.

B. Details

Electrical strain gages (Baldwin-Southwark SR-4 Gages) of types A-1 and R-1 were used to measure the change in strain in one surface of the specimen while sectioning and during the subsequent removal of material from the surface opposite to that upon which the gages were mounted. The type R-1 gage is a 45° rosette consisting of three type A-1 gages.

Figure 1 shows a type R-1 gage cemented with "Duco Household Cement" to a specimen. The gage as well as the entire surface to which the gage is attached has been protected from the action of the acid used to remove material by very carefully painting with "Tygon" rubberized paint. The lead wires were covered by "Biraco"[2] rubberized tubing and sealed to the specimen with "Tygon" paint.

Two of the one-quarter inch type gages on each specimen used would have been more satisfactory than the single larger A-1 gage. Not only would it have been desirable to check gages against each other when acid penetration into the gage was feared, but the difference in residual stresses in slightly different locations could have been easily compared.

A Baldwin-Southwark SR-4 Wheatstone Bridge Control Box was used to measure the strains picked up by the type A-1 and R-1 resistance strain gages.

A more convenient instrument for this purpose is the Baldwin-Southwark SR-4 Portable Strain Indicator, which, although less sensitive than the control box used, is satisfactory for the purpose.

The gages were and should always be measured within a very few degrees of a convenient standard temperature.

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[2] Manufactured by Birnbach Radio Company

A gage cemented to a piece of steel was used as a standard when measurements were taken. That is, a reading on the measuring box was always taken of this gage to make certain that the measuring box always read the same as it did initially.

Curvature changes were measured by means of a dial indicator graduated in 0.0001 inches mounted between three gaging supports as shown in Figure 4. The etched surface of the specimen rested on the gaging supports which were electrically insulated from the indicator stem. The point of contact of the indicator stem with the specimen was indicated by means of a "Carson Electronic Micrometer".[3] Fixed stops on two sides of the gage assured proper location of the gaging points after each etch. A fine thread screw adjustment on the indicator stem, Figure 5, protruding from the non-contact side of the indicator facilitated the taking of curvature measurements.

It was later found that radii of curvature could be directly measured by means of the convergence of beams of light reflected from small galvanometer mirrors attached to the specimen at fixed points by simply wetting the surface of the test specimen and putting the backs of the mirrors against the surface. A parallel source of light was used and a paper target for the reflected beams of light.

The average size of the specimens used with type A-1 resistance strain gages was 2½ inches by 1 inch. This was as small as could conveniently be used with these gages, although a somewhat shorter and narrower specimen could have been used more satisfactorily with the curvature gage. With one-quarter inch type A-7 strain gages a smaller specimen could and would have been used.

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[3] Manufactured by Instrument Specialties Company, Little Falls, New Jersey. Model E-D-2-2.

The rosette gage used is considered to have been too large. A rosette made up of smaller gages would have been more desirable. The size of the specimens having the rosette gages was approximately three inches square.

The acid solution used for etching consisted by volume of:

50% H_3PO_4 (85%--Spec. grav. at 15° C = 1.41)
20% HNO_3 (Spec. grav. = 1.42)
30% H_2O

The acid was kept at an elevated temperature of about 45° Centigrade by means of a temperature controlled[4] water bath. Vigorous agitation of the acid during etching was secured with a power operated glass stirring rod. Figures 2 and 3 show the smooth type of surface to be expected from the action of this etchant[5] which proved better than the usual 20% (by volume) water solution of HNO_3 (Sp. gr. 1.42).

A cooler and, hence, slower etching solution, to enable the taking of frequent readings, is desirable for determination of surface stresses.

Measurements of the amount of material removed were determined in three ways: (a) from length of time in acid, (b) by micrometer calipers, and (c) from change in weight of the specimen. In Figure 6 is seen a plot of the etching time versus material removed for a

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[4] Rotax Temperature Controller, The Foxboro Company, Foxboro, Mass.

[5] The above proportions represent the result of only a few trials, no attempt having been made to determine the best type of solution.

particular freshly mixed acid solution and a small specimen. It was found that the amount of material removed was directly proportional to the etching time.

ANALYSIS

The total residual stress in the intact helmet is made up of (a) that released by sectioning (cutting out) the test area from the helmet—resulting in a change of shape of the specimen and (b) that remaining after sectioning and which is progressively released by etching away material from one surface of the specimen—resulting in progressive changes in the shape of the remaining specimen to compensate for the realignment of the remaining stresses. These changes in the shape of the specimen, i.e., curvature and/or strain changes, are utilized in determining the total residual stress.

A. Residual Stress Released by Sectioning

The residual stress released by sectioning is distributed rectilinearly across the thickness, is zero at the center, and has the same magnitude on each surface. It is tension on the side of the specimen towards which the specimen curves as the result of sectioning and is compression on the other side.

The absolute magnitude of the surface stress (a), released by sectioning, is given by multiplying E by the absolute[6] value of strain;

$$\left|\frac{T}{2}\left(\frac{1}{R_o} - \frac{1}{R}\right)\right|$$

in terms of curvature change; or approximately by

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[6] i.e., magnitude only; sign taken as positive.

$$\left|\frac{4T\Delta}{L^2}\right|$$

in terms of deflection, Δ, given by the curvature gage over a span length, L, or

$$|e|$$

in terms of resistance strain gage change, e.

B. Residual Stresses Remaining after Sectioning

The determination of the residual stresses after sectioning, (b), from strain gage and curvature gage readings may be made by carrying out the operations indicated in any of the following formulae[7]:

Case 1. Original curvature maintained

Plot -Ete against t, take the slope of this curve to get the stress, i.e.,

$$S = -E\frac{d(te)}{dt},$$

using resistance strain gages and holding the specimens to its original curvatures (neglecting radial displacement) by means of a mold[8] which might conceivably be made of wood, Wood's metal, or plaster of Paris to fit the curvature, shape of strain gages, etc., if strain changes, e, were not prevented.

The initial slope is the value of the surface stress which thus requires but little etching for its determination.

Case 2. Using both Strain Gage and Curvature Measurements

Plot -Ete against t, and take the slope of this curve to get the stress, i.e.,

$$S = -E\frac{d(te)}{dt},$$

taking e to be resistance strain gage readings, e_s, $\left\{\begin{matrix}\text{reduced by}\\\text{added to}\end{matrix}\right\}$

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[7] The derivation of these formulae will be given in another report.

[8] The whole helmet might be covered with gages, if only moments are released by slitting, as may be approximately the case.

the absolute magnitude of the curvature strain e_c

$$\left|\frac{tT}{2}\left(\frac{1}{R_o}-\frac{1}{R}\right)\right|$$

or approximately

$$\left|4\,\frac{tT\Delta}{L^2}\right|$$

when the specimen curves $\left\{\begin{matrix}\text{away from}\\ \text{towards}\end{matrix}\right.$ the strain gage. Here Δ and the difference in curvatures refer to changes from the sectioned condition, not the original state.

The initial slope, which can be determined by a few test points, of the curve -Ete vs. t gives the surface stress.

Case 3. Using Curvature Change Only

Plot $1/t^2$ vs. t^2e_c, integrate (by planimeter) from $t = 1$ to the various values of t multiplying each integral (area) by Et/3, plot the products vs. t, and the differentiate to get the stress, i.e.,

$$-teE = \frac{Et}{3}\int_{t=1}^{t=t}\frac{d(t^2e_c)}{t^2}$$

$$S = \frac{d(-teE)}{dt}\,.$$

Here[9] the magnitude of e_c is determined by the curvature gage or curvature changes from

$$\left|\frac{tT}{2}\left(\frac{1}{R_o}-\frac{1}{R}\right)\right|$$

or approximately

$$\left|4\,\frac{tT\Delta}{L^2}\right|$$

and is positive if the specimen has curved toward the etched side as a result of etching to tT.

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[9] An expression given by Sachs ("A New Method for Determination of Stress Distribution in Thin-walled Tubing", AIME, October 1941) for residual stress, which contains the unknown stress both under and outside an integral sign, was solved to get the above formulae after first finding the above solution by two other independent methods.

One-third of the product of (-E) and the initial slope (at $t = 1$) of t^2e_c or e_c plotted against $1-t$ is the surface stress at $t = 1$, which can thus be determined from a few readings taken with very little removal of material.

Case 4. Using Strain Gage Measurements[10] Only

Plot $1/t^3$ vs. t^2e_s, integrate (by planimeter) from $t = 1$ to various values of t multiplying each integral (area) by $(Et^2)/2$, plot the products vs. t and differentiate to get the stress, i.e.,

$$-teE = \frac{Et^2}{2} \int_{t=1}^{t=t} \frac{d(t^2e_s)}{t^3}$$

$$S = \frac{d(-teE)}{dt} .$$

Here e_s is the strain change, from beginning of etching, of a resistance strain gage glued to the test area, with curvature changes unrestrained.

One-half of the product of (-E) and the initial slope (at $t = 1$) of t^2e_s or e_s plotted against $1-t$ is the surface stress at $t = 1$. This stress can thus be determined from a few readings taken at short intervals of time.

C. General Considerations

The formulae are written above as though the test pieces were narrow (in proportion to their thickness) bars[11] instead of wide strips, and as though the stress had only one component (uniaxial stress). Actually the principal residual stresses, S_x and S_y, relieved in the principal (assumed constant) X and Y directions should be taken into account.

In order to do so in the above formulae in the X direction S_x is substituted for S and $e_x+\mu e_y$ for e in Cases 1 and 2, e_c in Case 3, and e_s in Case 4; similarly, in the Y direction S_y is substituted for S and $e_y+\mu e_x$ for e, e_c, or e_x; while in each case $E/(1-\mu^2)$ is substituted for E. e_x and e_y are determined from strain or curvature changes as the case may be. This substitution

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[10] Strain gage measurements can be made equivalent to X-ray measurements when the latter are obtainable.

[11] Not necessarily small bars.

is to be made in determining the stresses relieved by sectioning - if done - as well as those relieved by etching. Cases 3 and 4 only apply to flat plates which, however, need not be small.

In making these substitutions[12], it is assumed on the theoretical side that the strip does not buckle locally, that the test strip is sufficiently large so that the gage length and width is sufficiently removed from the edges of the strip - two thicknesses to any edge - where equilibrium of stresses takes place by a different mechanism than in the middle of the strip, and, in Cases 3 and 4, that the deflections are small compared with the thickness of the plate, and that the strip is large enough so that any curling of the edges (due to the above edge effect) does not appreciably affect the stiffness in bending as a flat plate as stresses are relieved.

When, in Cases 3 and 4, appreciable bending is allowed to take place, or the strip is not flat initially, it is assumed that the strip is sufficiently narrow to be sensibly flat in one direction, Y, i.e., it is assumed to have the stiffness against bending of a flat strip in one direction and to be infinitely stiff in the other direction. Here, in e_s or e_e, e_y is determined from strain gages and e_x from curvature or strain gages depending on which case is to be used to determine e (from the integral) and S_x. Case 1[13] is then used with

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[12] For the narrow beam $e_y = -\mu e_x$, since there is no restriction to lateral strain. This value of e_y gives the formulae, as stated, in Cases 1 - 4.

[13] The equilibrium condition $\left[S = -E \dfrac{d(te)}{dt}\right]$ on which all four cases are based is independent of curvature and holds even for a thin cylinder in both circumferential and axial directions.

$e_y + \mu e_x = e_y (1-\mu^2) + \mu e$ to determine S_y.

On the test side, it is assumed that the stresses and change in material properties associated with the saw cut do not affect an unreasonably large percentage of the material being investigated, and that the cement on the strain gages does not unduly influence the bending of the strip during the amount of etching done; on the other hand, it is assumed that the test piece is sufficiently small so that the character of the stress does not vary appreciably over its area. Thus, even in the narrow direction of a rectangular test strip, the gage is kept away from the region of the edge effect and thus in a uniform field of surface stress which, except for that relieved by sectioning (if done) and etching, is the same as it was before the strip was sectioned from the helmet.

It is thought that the formula of Case 1 with the above substitutions for S and e may be satisfactorily used where the test area is etched, while incorporated in a helmet whose curvatures are everywhere maintained at their original values. This thought is based on the belief that the net average (over the entire thickness) stress over any section of the helmet is likely to be very small although the moment of the stresses is not small.

The initial slope from which a surface stress component is found can be determined easily from a log log paper plot which is sometimes more convenient than the ordinary plot for this purpose. Several test points are plotted and extrapolated into a forty-five degree line to correspond to going through zero on ordinary paper. The ordinate corresponding to the intersection of this forty-five degree line with the vertical where the abscissa is unity is the required value, as is ten times the ordinate where the abscissa is one tenth, etc.

In three cases—where the rosette strain gage was used—the strain was actually measured in two directions for the preliminary tests of this report. In these cases the gage was so large that the specimen was appreciably dome shaped. Thus these specimens could not be analyzed by curvature changes. It was arbitrarily assumed that Case 1 holds and that any curvature changes that occurred in one direction were compensated for in strain change by those occurring at right angles to this direction.

In the other cases, it was assumed that the strain was undirectional, that is, that the test strips were wide in comparison with their thicknesses and bent as though they were flat beams subjected to external bending moments. This means that lateral (to the bending direction) strains, e_y, do not occur (except at the edges). Thus, simply, e_x and $E/(1-\mu^2)$ are to be substituted for e and E in Cases 1 - 4.

Even though the above assumption does not represent the actual state of affairs, the error in stress is unlikely to be sufficient to change the order of magnitude of the determination since the e_y strain is only added to the e_x strain after being multiplied by Poisson's ratio[14,15]. Figures 7, 8, and 9 and Tables 2, 3, and 4 each show the details of the calculations for Cases 3 and 4.

The lower curves contain plots of the gage readings. From the smooth curves readings were written down at selected fractions, t, of wall thickness shown on the middle curves and converted, by multiplying

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[14] If $e_y = +\mu e_x$ then $e_x - \mu e_y \approx 0.9\ e_x$; If $e_y = e_x$, $e_x - \mu e_y \approx 0.7\ e_x$.

[15] The method adopted was used, however, in these preliminary experiments for (a) simplicity, (b) comparison purposes, and (c) order of magnitude of stresses.

by constants[16], into strains. These strains were multiplied by t^2 and plotted against $1/t^3$ or $1/t^2$, according to the method of gaging. These plots were then integrated by a planimeter <u>from</u> the previously selected values of t shown beside the curves <u>to</u> $t = 1$. Since the planimeter read areas in square inches, these areas were corrected by multiplying by the product of the vertical scale reading in one inch and the horizontal scale reading in one inch. Each corrected area was multiplied by $E_1 t^2/2$ or $E_1 t/3$, again corresponding to the type of measurement made, Case 3 or 4, where $E_1 = 30 \cdot 10^6 = E/(1-\mu^2)$.

These values were plotted against t to form the M_1te curves at the top of the curve sheets. The negative derivative of these curves, with respect to t, gave the stress curves shown in the same place. These derivatives were very easily and rapidly formed with the aid of a drafting machine[17] as shown on Figure 10, where R has been used as a variable in place of t. It is to be noted that it is unnecessary to do any computing or reading of angles in this operation.

In Figures 7 and 9 close agreement between the strain gage and curvature gage determinations is not to be expected with, among the variables, the size of specimens used and the different effective gage lengths of curvature and strain gages.

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[16] For strain gages a sensitivity factor for gages and gage measuring box given by the manufacturer ($2.586 \times 10^{-4}/2.04$); for curvature gages $\frac{4tT\Delta}{L^2}$

[17] Paragon Drafting Machine #1370, Keuffel & Esser Co., New York

DISCUSSION

A. Test Results

As stated under analysis, the entire initial residual stress consists of the sum of (a) the part released by sectioning the test sample from the helmet (b) the part released by etching the sample.

Figures 7, 8, and 9 show the distribution of the stresses left after sectioning. These are seen to be high at the surface and to fall off rapidly with depth below the surface. The surface stresses were compression in all cases measured.

Figures 11, 12, and 13 show particular examples of the character of the complete initial stress distribution obtained when the stress released by etching is added to the rectilinearly distributed stress released by slitting. The stress on the outside surface of the helmet is reduced while the compressive stress on the inside surface is considerably increased.

Table 1 gives the values of surface stress relieved by sectioning as well as the surface stress relieved by etching and the total initial residual stress at the surface when these are available. For purposes of comparison it is assumed in some cases that the stress distribution remaining after sectioning is symmetrical. That relieved by sectioning is of course anti-symmetrical[18].

From the limited results of Table 1, it is tentatively concluded

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[18] i.e., symmetrical about the middle thickness points but opposite in sign.

that the:

Surface Stresses Relieved by Sectioning

(a) Have widely different values at different locations on the same helmet; those on the outside surface vary from -5000 p.s.i.(compression) in the top specimens to 46,300 p.s.i. (tension) in the F(L)[19] horizontal specimen, helmet A.

(b) In specimens cut from different helmets but in the same locations and direction [F(L and R) horizontal and B(L and R)horizontal] show considerable variation in magnitude (17,800 to 66,900 p.s.i.), but in all cases are of the same sign (tension on the outside surface).

(c) In specimens cut from the sides of the helmets [S(L and R) vertical and horizontal] are in general of lesser magnitude than, but of the same sign as, the stresses in specimens mentioned in (b) above.

(d) In the outside surface of the top of the helmet are of small magnitude and are compressive in all directions.

(e) Have principle stress directions which are approximately circumferential and vertical in the body of the helmet since stresses measured by the oblique gages, helmet B, are small in comparison to the stresses measured in the other two directions.

(f) Have their highest values, in general, at the F(L and R) and B(L and R) locations in the regions where cracking has been observed.

Surface Residual Stresses after Sectioning

(a) Are compressive on both the inside and outside surfaces.

(b) Have widely different values on different specimens cut from the same helmet.

(c) Are of comparable magnitude in the vertical and circumferential directions.

Total Stresses in Helmets

(a) On the inside and outside surface are compressive and average roughly 70,000 p.s.i. and 10,000 p.s.i., respectively.

In view of these test results, a satisfactory method of comparing

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[19] F,B,S,T,L,R refer to front, back, side, top, left, right respectively.

residual stresses might be to section, without etching, a sufficient number of helmets to establish a definite average behavior while curvature and dimensional measurements, only, were made in very carefully specified locations. From the helmets measured in this way, a number of specimens would then be etched and analyzed in detail as extreme or typical cases, because they had shown a cracking tendency, because they had unusually high ballistic limits, etc. This procedure would eliminate from the initial investigation, at least, the inherent difficulties and time consumption of the etching procedure along with the care needed to protect strain gages from the etchant.

In carrying out this program, care should be taken to use helmets of the same age and history. Other factors that should be considered are contained in the following section.

B. Factors Influencing Cracking and Residual Stress

It is presumed in the following that purely metallurgical factors responsible for or affecting cracking such as surface decarburization and the presence of undissolved carbides have been adequately taken care of by metallurgists.

The residual stresses are put into the helmet when it is made, the forming operations being so severe that residual stresses in the blank sheet can probably do no more than alter the forming load at which yielding takes place in the forming operation. In this operation important factors that affect residual stress, cracking, and the ballistic limit are:

(a) The material, its mechanical history, hardness, etc., and heat treatment.

(b) Shape of dies, character of draws, aging of the material, stress relieving heat treatments used in forming helmets.

(c) Metallurgical changes in the material during cold working, e.g., decomposition of austenitic steel.

(d) Direction of rolling of sheet material relative to the position of visor in the helmet.

(e) Gage thickness.

(f) Trimming.

(g) Condition of dies: roughness, alignment, etc.

(h) Lubrication of dies.

(i) Temperature while forming.

(j) Hold down force and its distribution.

The material used in the M1 helmet is 1.30 C, 13 Mn, 0.40 Si Hadfield manganese steel. It is cross-rolled into sheet form from its ingot with whatever heating is necessary and is finally water quenched from about 1800°F to produce a uniform austenitic structure. The sheet is then punched into circles.

The helmets are made from the circular sheet stock by a single deep draw, a spanking operation to make the visor, a trimming operation, a spot welding operation to add an edge protector, a cleaning operation (dilute phosphoric acid), and painting. Since no stress relieving treatment is used, the residual stresses can be expected to be high as shown by the average test results. It must, of course, be limited by the yield strength of the steel under the most severe combined stress and temperature conditions encountered under the forming load or without the forming load. This limiting condition might be inferred from tensile tests of the material along with the fracture stresses and reductions of area.

All of the factors from (c) to (j), inclusive, can have a serious bearing on the character of residual stresses and cracking although it is understood that appreciable decomposition of the austenite has not been observed[20] and is therefore not to be expected except under unusual coldworking conditions. The fracture stress and work hardening characteristics of the steel may be different in different directions and with the time consumed in and after the draw (aging), the forming pressures will vary with gage thickness, the trimming operation will leave notches causing local intensification of the residual stress, the condition of the dies will affect forming pressures and extent of cold working, proper lubrication will eliminate shearing stresses and galling. Temperature[21] of forming will influence the crack sensitivity, the stress-strain relation of the material and the tendency to decompose into hard brittle martensite with volume, and consequent stress altering strain changes, and an uneven hold down force will cause wrinkles which mean local overwork hardening or embrittlement of the material and stress concentration.

Cracking may also be due to stress corrosion, as well as single and repeated external loading stresses acting in conjunction with the residual stresses. Such cracking will be influenced by the temperature, time of loading (impact and creep), type of loading, the history of over-straining of the piece, and especially the complete strain,

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[20] On the other hand, it has been considered (Ref: Studies of Hadfield's Manganese Steel with the High-power Microscope - John Howe Hall - Iron and Steel, 1929) that a large part of the strain hardening of Hadfield's manganese steel is due to the formation of martensite, i.e., the slip layers are or become martensitic with time.

[21] A temperature of 550°F is sufficient to effect some decomposition of the helmet steel into martensite in a short time. (Ref: WAL Rpt. No. 710/609 - "Metallurgical and Ballistic Investigation of a $3\frac{1}{2}\%$ Nickel Modified Hadfield Manganese Steel Proposed for Use in the M1 Helmet").

or hardness, of the helmet, Figure 14. A brittle helmet requires but little residual stress energy to propagate a crack. Acids[22], perhaps the cleaning acid, stacking helmets in huge piles, banging helmets into and out of shape all can be causative factors in cracking.

It should be emphasized, however, that the ordinary characteristics of Hadfield manganese steel are excellent against shock loading and repeated loading where there are notches or cracks. This resistance, of course, becomes less, the deeper the draw of the material.

Residual stresses can be very desirable and are at times intentionally put into a structure in such a direction that the sum of the residual stress and the loading stress are algebraically less than the stress due to loading alone. Such is the case with built-up and autofrettaged guns where a preliminary compressive stress is locked into the bore material--the most highly stressed part of a simple gun tube when firing--by the tendency of the outside material to contract.

In just the same way it is possible that residual stresses add to the ballistic limit of the helmet. The 0.45 caliber ball ammunition used against the helmet causes the helmet wall to bend and to stretch radially towards the impact zone where the wall bends sharply over the flattened ball where fracture occurs. In this region external load put on the helmet by the ball must be sufficient to overcome the compressive residual stress of the inside surface of the helmet before yielding can occur at that surface, assuming yielding does not occur elsewhere first.

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[22] It would be interesting to determine the time required to cause cracking, while under load, in tensile specimens of helmet steel permanently stretched assigned amounts and immersed in acid.

In general, the test results show that the residual stress distribution is a good one against bending produced by external loads, since, roughly, the inside half of the wall is under compression and the outside half under tension.

If the work necessary to cause yielding is an appreciable fraction of the energy of the ball at the ballistic limit, then the residual stresses will appreciably augment the ballistic limit. A bullet fired from the inside of the helmet would lead to a correspondingly lower limit. Such lowering has been observed[23].

These effects on the ballistic limit should be more pronounced the harder and more brittle (under firing and fixed temperature conditions) the material is, for then a large part of the work of deformation will be elastic. Figure 14 shows the hardness distribution in the helmet. It seems likely from this figure that the material actually is in a brittle state, especially in the regions most subject to cracking.

Shot blasting is a method by which both favorable and unfavorable residual stress distributions may be established. By this means it has been observed that the highest ballistic limit is associated with what is expected to be the most desirable residual stress distribution. For example, shot blasting internally raises the ballistic limit against a shot fired against the outside surface of a helmet while it lowers the resistance to penetration of a shot fired against the inside surface. Shot blasting also works the material severely

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[23] Memorandum Rpt. WAL No. 710/476 - "A Preliminary Study of the Effect of Shot Blasting upon the Ballistic Characteristics of the M1 Steel Helmet".

causing decomposition of the austenite and making the helmet hard. Shot blasting may possibly favorably influence the ballistic limit by bending and folding the material in such a way as to favorably alter the path of yielding and rupture.

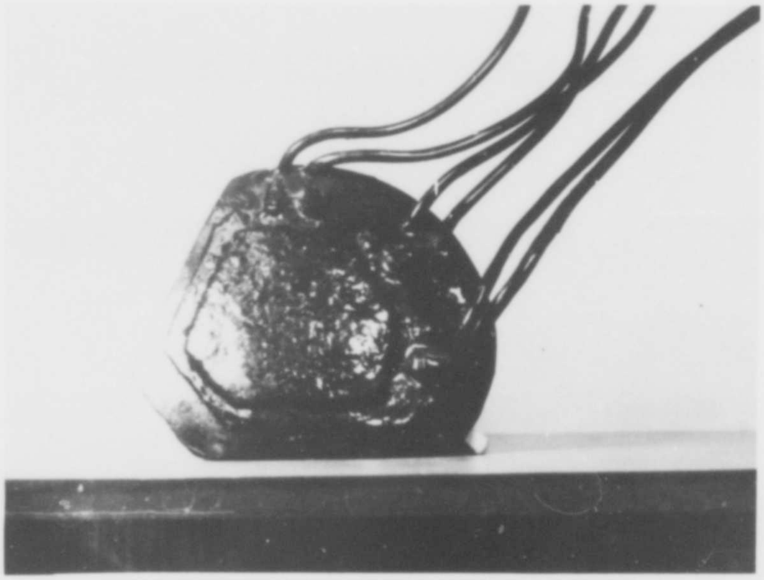
The above remarks are not modified, on the average, by the presence of notches or serrations. The variations in residual stress produced by such irregularities are simply superimposed on the average residual stresses. Nor are they modified by the dome-shaped structure of the helmet. With or without such stresses that shape will be favorable if sufficient material deforms.

The residual stresses shown by the few test results herein reported are generally favorable towards prevention of corrosion cracking because they tend to be compression on both surfaces.

It should be evident from the above remarks that elimination of cracking is not the same as elimination of residual stresses.

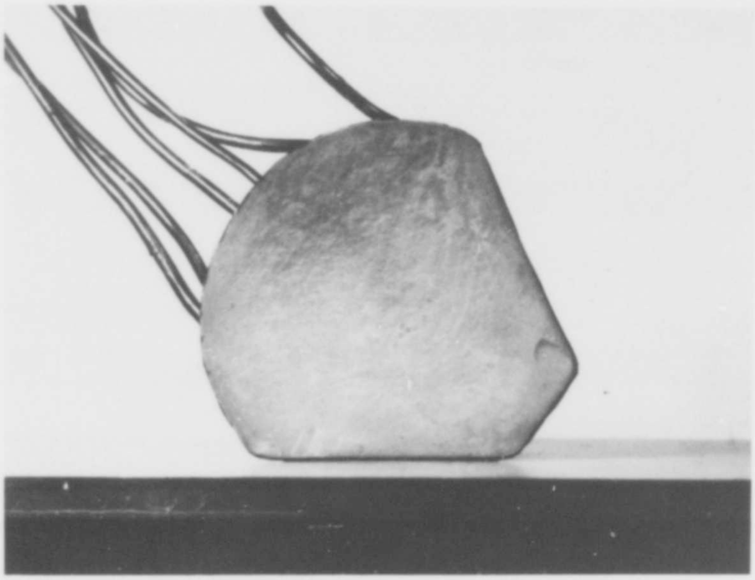
LIST OF FIGURES

LIST OF TABLES



OUTSIDE SURFACE OF SPECIMEN SHOWING
ROSETTE STRAIN GAGE

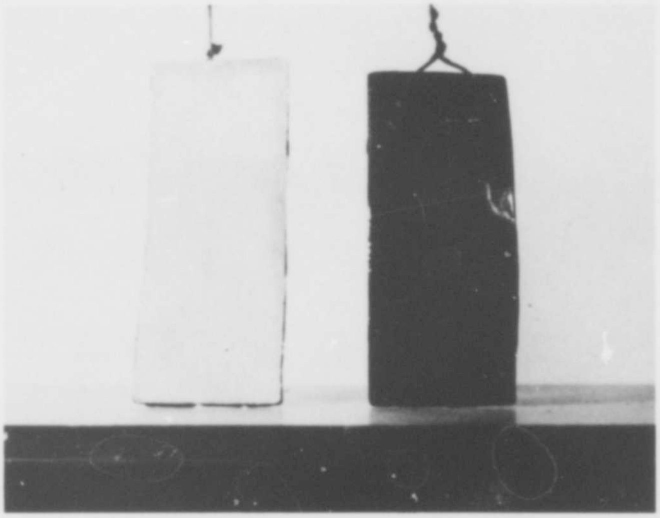
FIG. 1



INSIDE SURFACE OF SPECIMEN AFTER ETCHING

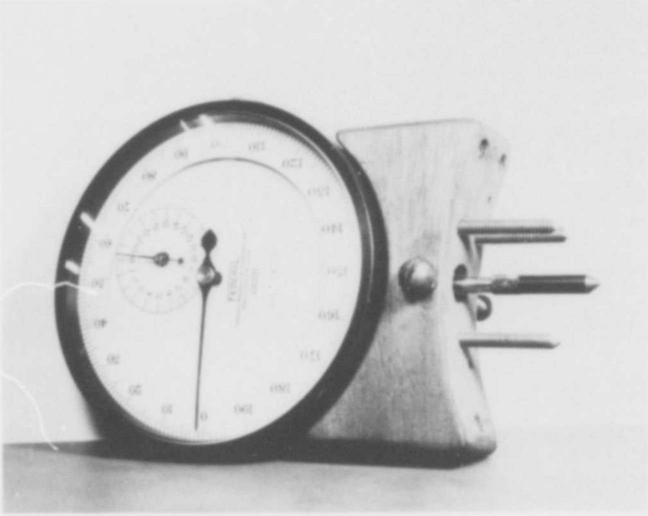
FIG. 2

WTN.639-6925



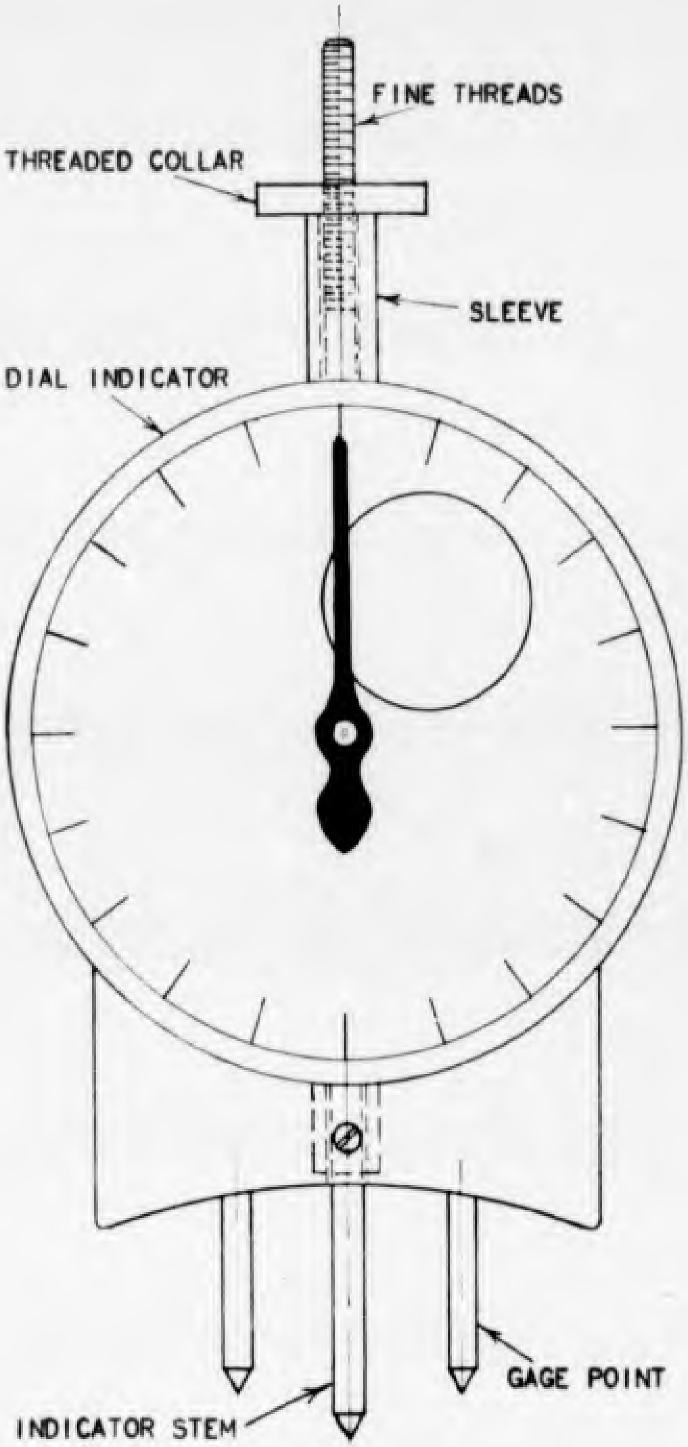
ETCHED (L) AND PROTECTED (R) SURFACES OF SPECIMENS

FIG. 3



CURVATURE GAGE

FIG. 4



CURVATURE GAGE
SHOWING
CONTACT ADJUSTMENT MECHANISM

FIG. 5

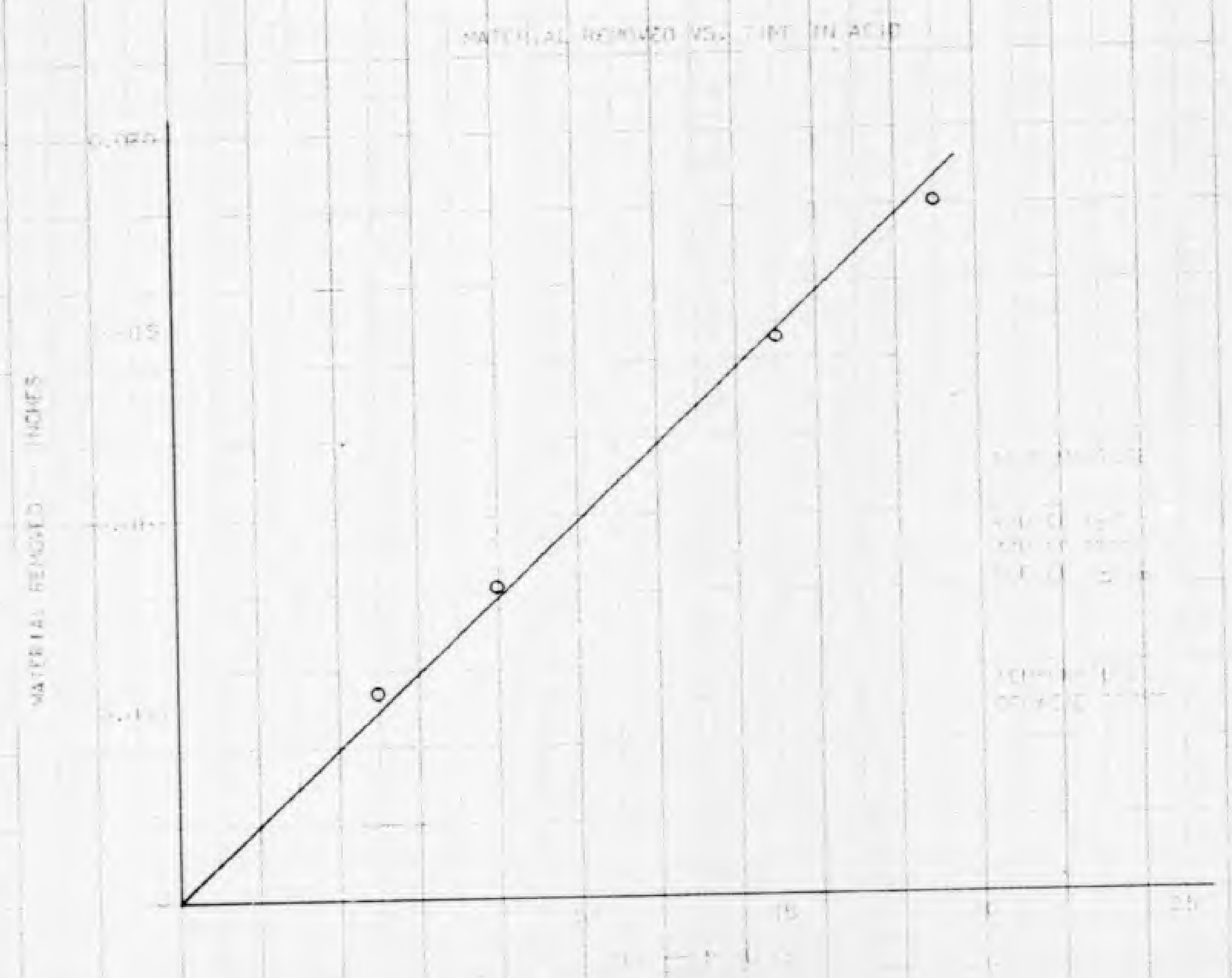
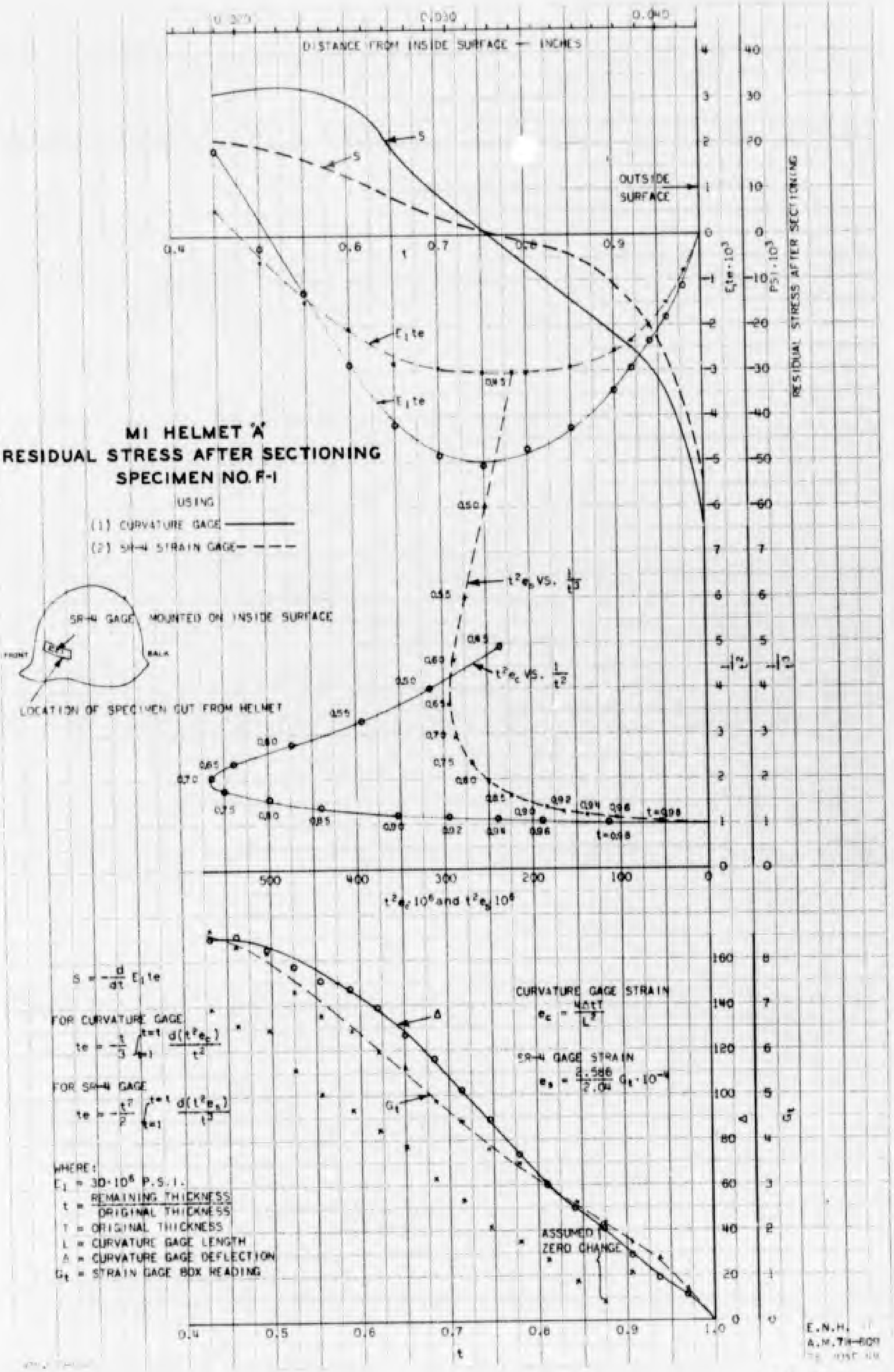

MATERIAL REMOVED VS. TIME IN ACID
MATERIAL REMOVED — INCHES
0.020
.015
.010
.005
5
15
25

FIG. 6



MI HELMET 'A'
RESIDUAL STRESS AFTER SECTIONING
SPECIMEN NO. F-1

USING
(1) CURVATURE GAGE ———
(2) SR-4 STRAIN GAGE — — —

$$S = -\frac{d}{dt} E_1 te$$

FOR CURVATURE GAGE

$$te = -\frac{t}{3}\int_{t=1}^{t=t} \frac{d(t^2 e_c)}{t^2}$$

FOR SR-4 GAGE

$$te = -\frac{t^2}{2}\int_{t=1}^{t=t} \frac{d(t^2 e_s)}{t^3}$$

CURVATURE GAGE STRAIN

$$e_c = \frac{4\Delta tT}{L^2}$$

SR-4 GAGE STRAIN

$$e_s = \frac{2.586}{2.04} G_t \cdot 10^{-4}$$

WHERE:
$E_1 = 30 \cdot 10^6$ P.S.I.
$t = \frac{\text{REMAINING THICKNESS}}{\text{ORIGINAL THICKNESS}}$
T = ORIGINAL THICKNESS
L = CURVATURE GAGE LENGTH
Δ = CURVATURE GAGE DEFLECTION
G_t = STRAIN GAGE BOX READING

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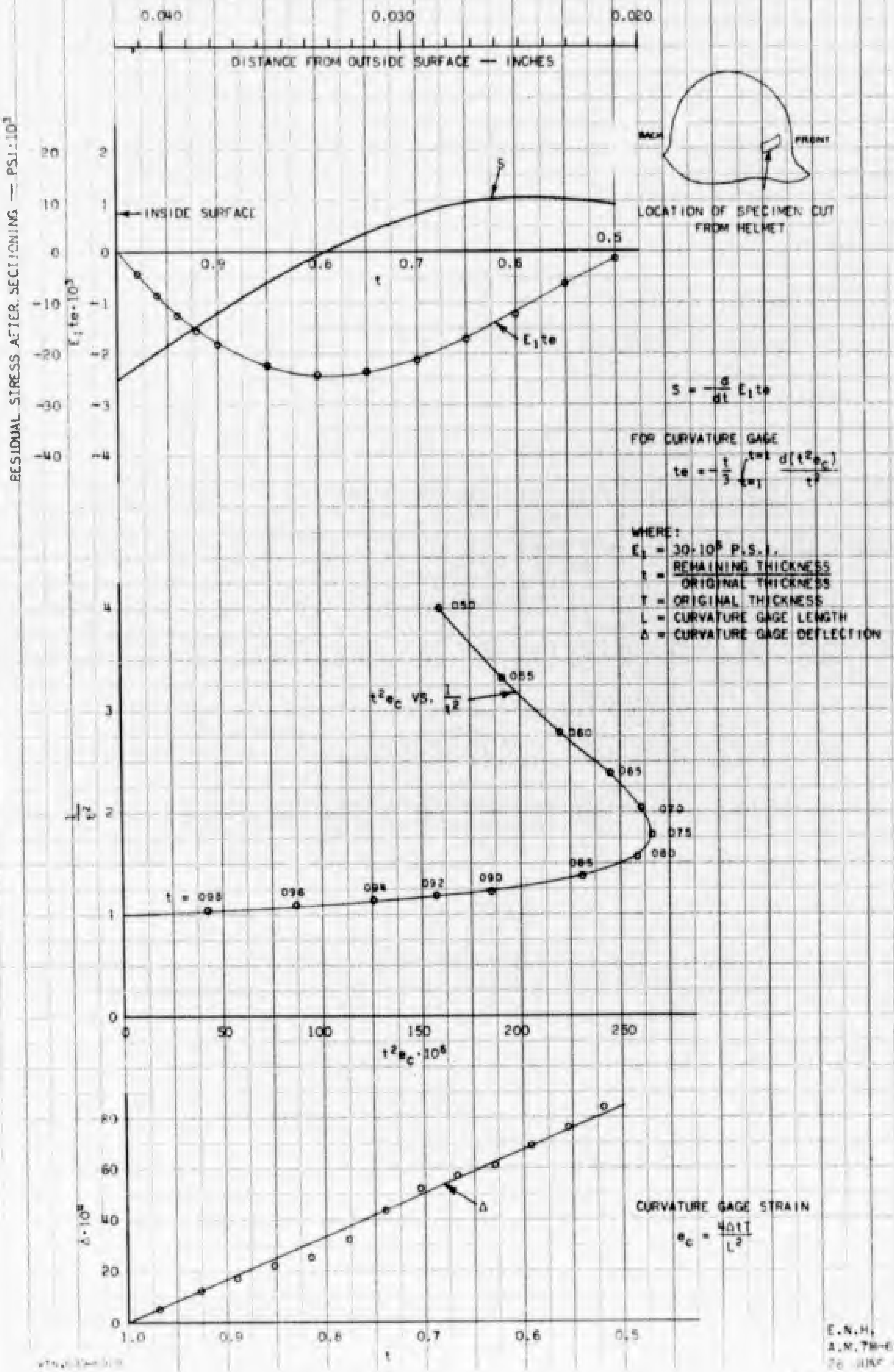
FIGURE 7

MI HELMET 'A'
RESIDUAL STRESS AFTER SECTIONING
SPECIMEN NO. F-2

USING

CURVATURE GAGE



$$S = -\frac{d}{dt} E_1 te$$

FOR CURVATURE GAGE

$$te = -\frac{t}{3}\int_{t=1}^{t=t} \frac{d(t^2 e_c)}{t^2}$$

WHERE:

E_1 = $30 \cdot 10^6$ P.S.I.

t = $\frac{\text{REMAINING THICKNESS}}{\text{ORIGINAL THICKNESS}}$

T = ORIGINAL THICKNESS

L = CURVATURE GAGE LENGTH

Δ = CURVATURE GAGE DEFLECTION

CURVATURE GAGE STRAIN

$$e_c = \frac{4\Delta tT}{L^2}$$

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FIGURE 8

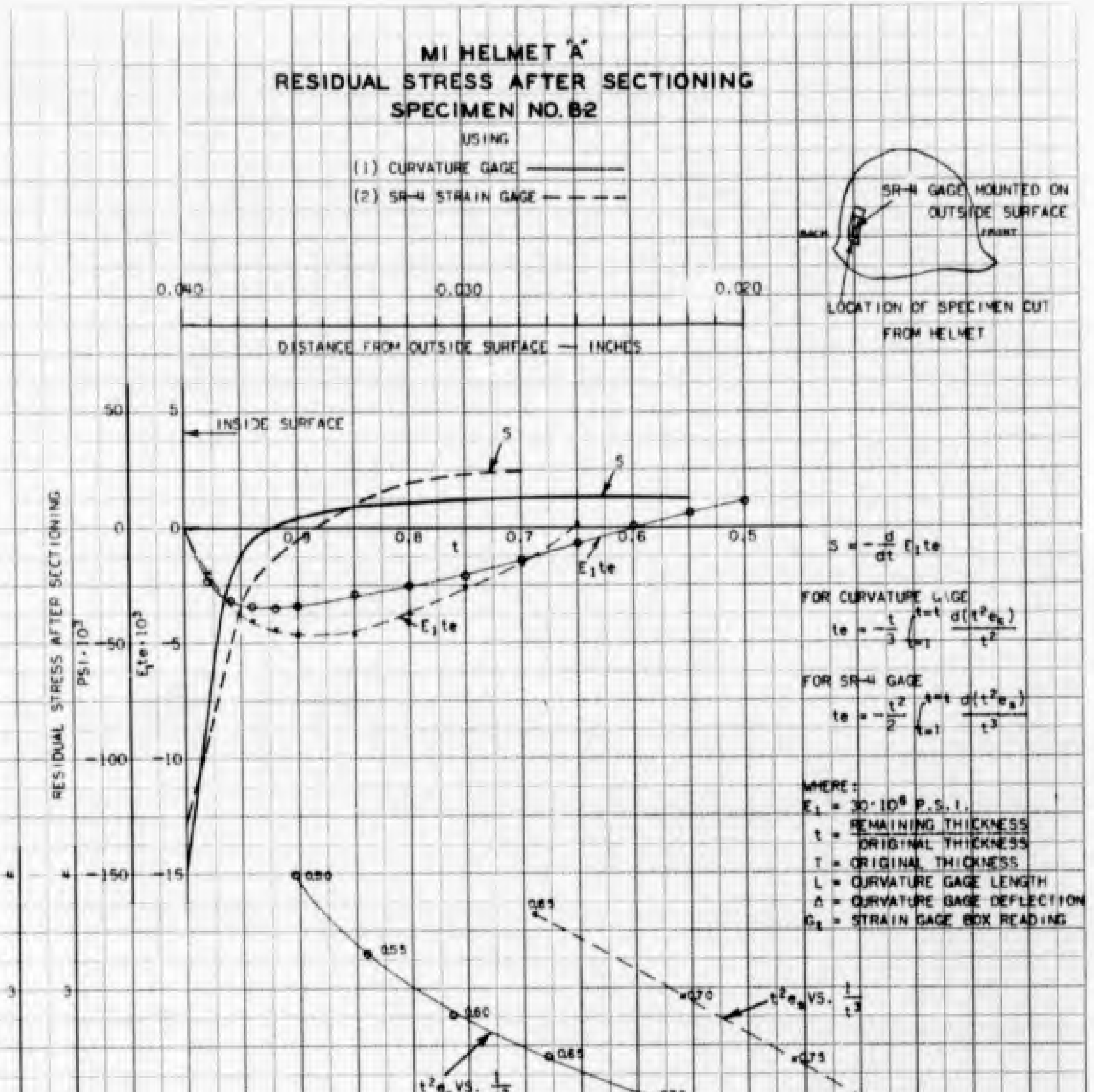
MI HELMET "A"
RESIDUAL STRESS AFTER SECTIONING
SPECIMEN NO. B2
USING
(1) CURVATURE GAGE
(2) SR-4 STRAIN GAGE
SR-4 GAGE MOUNTED ON OUTSIDE SURFACE
BACK
FRONT
LOCATION OF SPECIMEN CUT FROM HELMET
0.040
0.030
0.020
DISTANCE FROM OUTSIDE SURFACE — INCHES
INSIDE SURFACE
S
S
E_1te
E_1te
t
RESIDUAL STRESS AFTER SECTIONING PSI·10^3
$E_1te \cdot 10^3$
$S = -\frac{d}{dt} E_1 te$
FOR CURVATURE GAGE
$te = -\frac{t}{3} \int_{t=1}^{t=t} \frac{d(t^2 e_c)}{t^2}$
FOR SR-4 GAGE
$te = -\frac{t^2}{2} \int_{t=1}^{t=t} \frac{d(t^2 e_s)}{t^3}$
WHERE:
E_1 = 30·10^6 P.S.I.
t = REMAINING THICKNESS / ORIGINAL THICKNESS
T = ORIGINAL THICKNESS
L = CURVATURE GAGE LENGTH
Δ = CURVATURE GAGE DEFLECTION
G_t = STRAIN GAGE BOX READING
t^2e_c VS. $\frac{1}{t^2}$
t^2e_s VS. $\frac{1}{t^3}$
t = 0.98
t = 0.98
$\frac{1}{t^2}$
$\frac{1}{t^3}$
$t^2e_s \cdot 10^6$ and $t^2e_c \cdot 10^6$
G_t
Δ
G_t
Δ·10^3
t
CURVATURE GAGE STRAIN
$e_c = \frac{4\Delta tT}{L^2}$
SR-4 GAGE STRAIN
$e_s = \frac{2.566}{2.04} G_t \cdot 10^{-6}$
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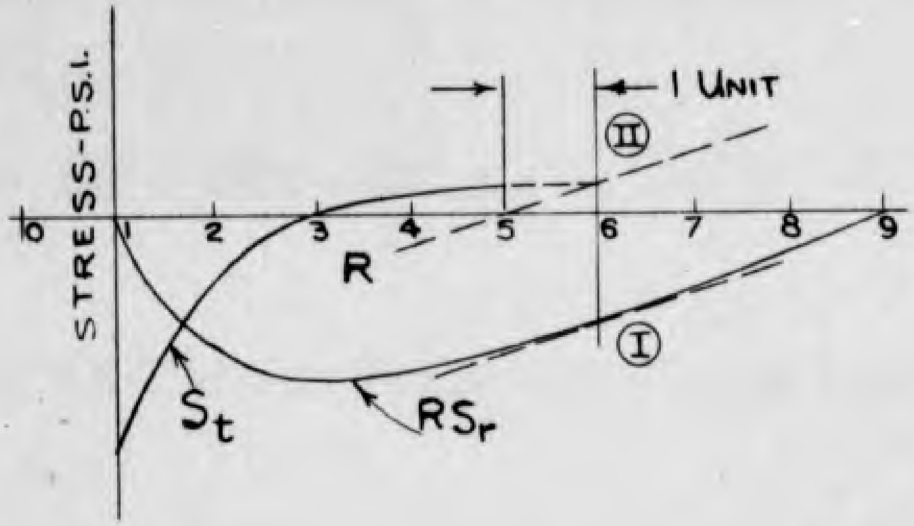
FIGURE 9

GRAPHICAL DETERMINATION OF S_t

$$S_t = \frac{d}{dR}(RS_r)$$



Ⓘ LAY STRAIGHT EDGE TANGENT TO RS_r CURVE AT POINT WHERE S_t IS TO BE DETERMINED, R=6.

Ⓘⓘ TRANSFER TANGENT TO GO THROUGH POINT 1 UNIT, IN R, R=5, BEHIND THE PLACE WHERE S_t IS BEING DETERMINED. THE VALUE OF S_t IS FOUND AT THE INTERSECTION OF THE TRANSFERRED TANGENT AND THE ORDINATE, R=6.

NOTE: IN SOME CASES, AS WHEN RS_r IS SMALL OR THE TOTAL CHANGE IN R IS SMALL, IT IS EXPEDIENT TO PLOT RS_r TO 10 TIMES SCALE AND TO THEN TRANSFER THE TANGENT TO A POINT 1/10 UNIT INSTEAD OF 1 UNIT BEHIND THE PLACE WHERE S_t IS DESIRED.

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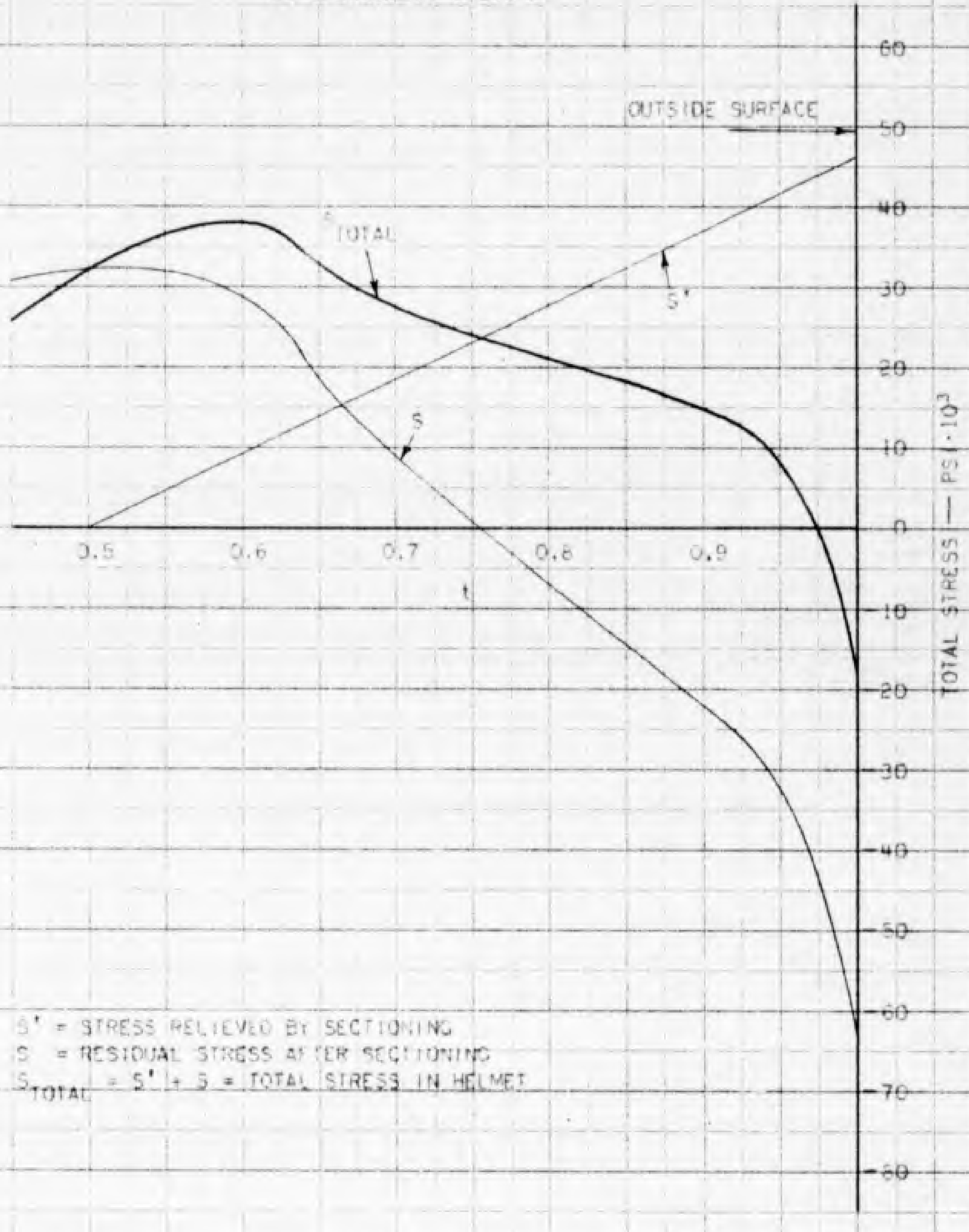
TOTAL STRESS IN HELMET "A"
SPECIMEN NO. F-1



S' = STRESS RELIEVED BY SECTIONING
S = RESIDUAL STRESS AFTER SECTIONING
S_{TOTAL} = S' + S = TOTAL STRESS IN HELMET

FIG. 11

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TOTAL STRESS IN HELMET "A"
SPECIMEN NO. F-2

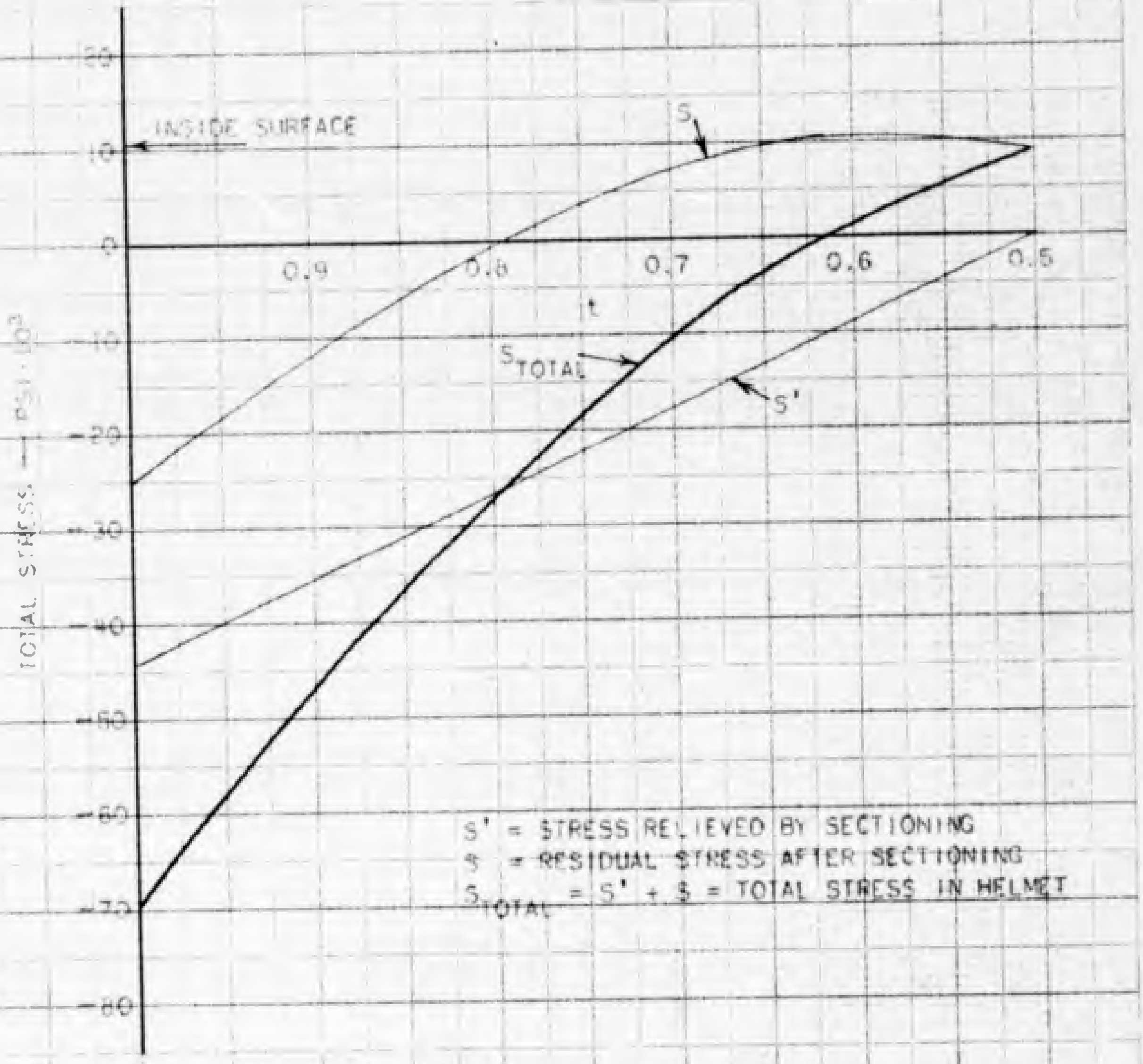

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FIG. 12

TOTAL STRESS IN HELMET "A"
SPECIMEN NO. B-2

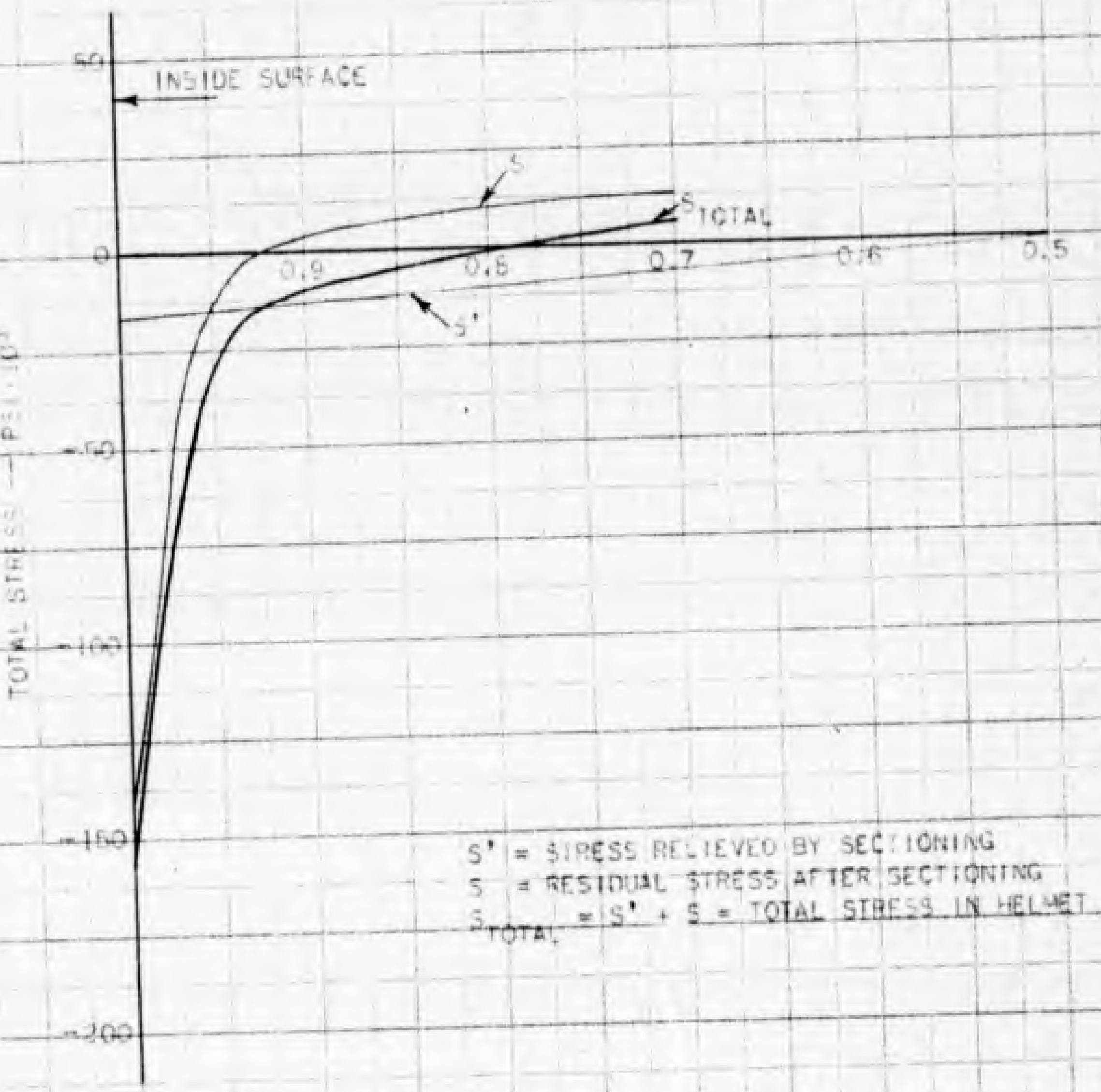

FIG. 13

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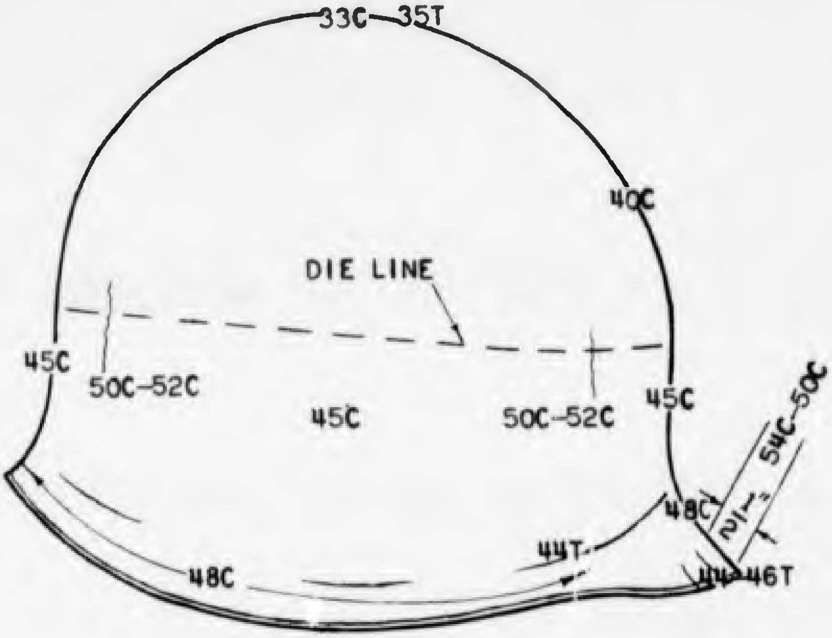
SIDE VIEW



TYPICAL CHARACTERISTICS OF M1 HELMETS
(VERBAL DATA FROM A. HURLICH)

–C = ROCKWELL C HARDNESS

–T = APPROXIMATE THICKNESS
IN THOUSANDS

HARDNESS REQUIRED FOR CRACKING = 50 OR ABOVE

ORIGINAL THICKNESS = 44–46T

BALLISTIC LIMIT* = 835 TO 950 FT./SEC.

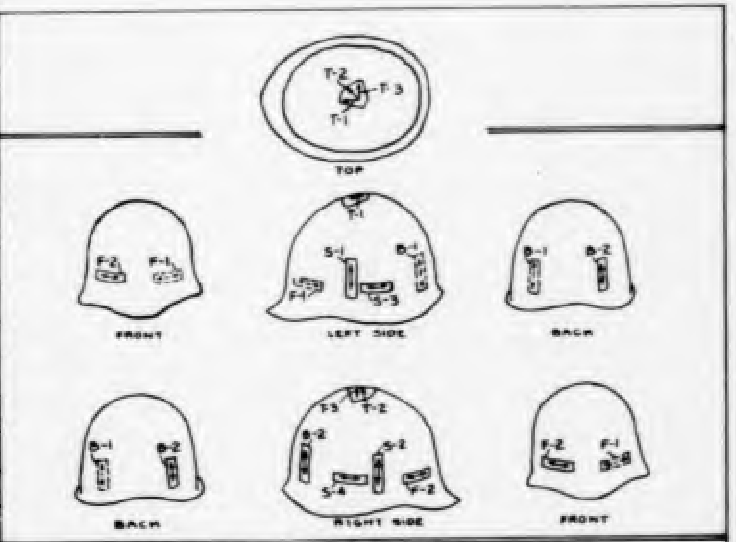
⌇⌇⌇⌇ = POSITION OF CRACKING

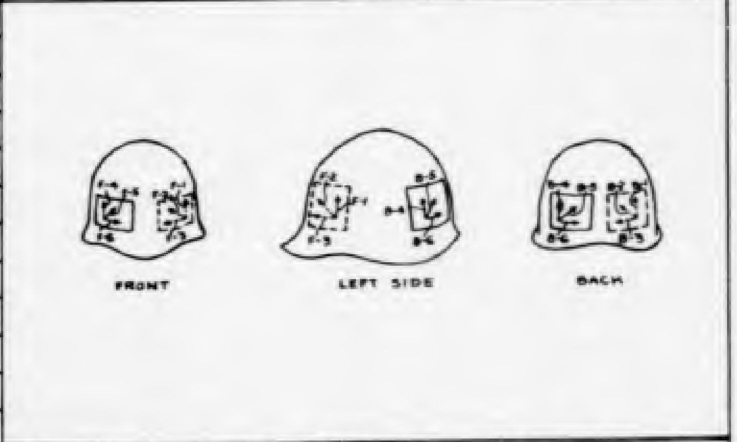
---

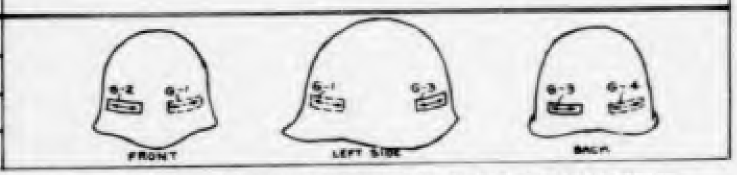
* 1/2 X [HIGHEST VELOCITY REQUIRED FOR PARTIAL PENETRATION + LOWEST VELOCITY REQUIRED FOR COMPLETE PENETRATION]; WITH SUFFICIENT FIRING SO THAT THESE TWO VELOCITIES DO NOT DIFFER MORE THAN 50 FT./SEC.

TABLE I
SURFACE STRESSES IN MI HELMETS

HELMET	LOCATION OF SPECIMEN AND GAGING DIRECTION	GAGING SURFACE	SECTIONING MICROSTRAIN	SURFACE STRESS RELIEVED BY SECTIONING		SURFACE RESIDUAL STRESS[1] AFTER SECTIONING		TOTAL STRESS IN HELMET P.S.I.		SPECIMEN NUMBER
				INSIDE	OUTSIDE	INSIDE	OUTSIDE	INSIDE	OUTSIDE	
	F(L) HORIZ.[2]	IN	1,546	-46,300	(46,300)[3]	(-41,000)	-41,000	-87,300	5,300	F-1
A	F(R) HORIZ.	OUT	-1,470	(-44,100)	44,100	-24,500	(-24,500)	-68,600	19,600	F-2
	B(L) VERTICAL	IN	CRACKED	(AXIALLY) DURING SECTIONING						B-1
	B(R) VERTICAL	OUT	-654	(-19,600)	19,600	-115,000	(-115,000)	-134,600	-95,400	B-2
	S(L) VERTICAL	OUT	-553	(-16,600)	16,600	-26,000	(-26,000)	-42,600	-9,400	S-1
	S(R) VERTICAL	OUT	-2,890	(-86,700)	86,700	-41,000	(-41,000)	-127,700	45,700	S-2
	S(L) HORIZ.	OUT	-789	(-23,650)	23,650	-20,000	(-20,000)	-43,650	3,650	S-3
	S(R) HORIZ.	OUT	408	(12,250)	-12,250	-16,700	(-16,700)	-4,450	-28,950	S-4
	T - AXIAL	OUT	72	(2,200)	-2,200					T-1
	T - OBLIQUE	OUT	159	(4,800)	-4,800					T-2
	T - LATERAL	OUT	144	(4,300)	-4,300					T-3
B	F(L) VERTICAL	IN	-384	11,500	(-11,500)					F-1
	F(L) OBLIQUE	IN	34	-1,000	(1,000)					F-2
	F(L) HORIZ.	IN	881	-26,400	(26,400)					F-3
	F(R) VERTICAL	OUT	872	(26,160)	-26,160					F-4
	F(R) OBLIQUE	OUT	30	(900)	-900					F-5
	F(R) HORIZ.	OUT	-1,098	(-32,900)	32,900					F-6
	B(R) VERTICAL	IN	-169	5,070	(-5,070)					B-1
	B(R) OBLIQUE	IN	140	-4,200	(4,200)					B-2
	B(R) HORIZ.	IN	699	-20,970	(20,970)					B-3
	B(L) VERTICAL	OUT	519	(15,570)	-15,570					B-4
	B(L) OBLIQUE	OUT	-253	(-7,600)	7,600					B-5
	B(L) HORIZ.	OUT	-926	(-27,600)	27,600					B-6
C	F(L) HORIZ.	IN	794	-23,800	(23,800)					G-1
	F(R) HORIZ.	OUT	-2,214	(-66,900)	66,900					G-2
	B(L) HORIZ.	OUT	-594	-17,800	(17,800)					G-3
	B(R) HORIZ.	IN	1,350	-40,500	(40,500)					G-4







[1] CALCULATED FROM SLOPE OF INITIAL STRAIN CURVE.

[2] F, B, S, T, L, R REFER TO FRONT, BACK, SIDE, TOP, LEFT, RIGHT OF HELMET, RESPECTIVELY.

[3] FIGURES IN PARENTHESES ARE VALUES OF STRESSES ON SIDE OPPOSITE TO THAT ON WHICH STRESS DETERMINATIONS WERE MADE AND ARE ASSUMED TO BE OF EQUAL MAGNITUDE BUT OF OPPOSITE SIGN WHEN RELIEVED BY SECTIONING AND TO BE OF EQUAL MAGNITUDE AND SIGN AFTER SECTIONING.

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CALCULATIONS—RESIDUAL STRESS AFTER SECTIONING
M1 HELMET A SPECIMEN F-1

EXPERIMENTAL DATA					CURVATURE GAGE						SR-4 GAGE				
TIME IN ACID MIN.	MATERIAL REMOVED INCHES	t	$\Delta \cdot 10^4$	G_t	t	Δ	$e_c \cdot 10^6$	$t^2 e_c \cdot 10^6$	$te \cdot 10^6$	$E_1 te$	G_t	$e_s \cdot 10^6$	$t^2 e_s \cdot 10^6$	$te \cdot 10^6$	$E_1 te$
0	0	1.000	0	0	1.00	0	0	0	0	0	0	0	0	0	0
5	0.00133	0.968	12	0.70	0.98	0.0008	119	114	−39	−1170	0.50	63	61	−27	−810
10	0.00267	0.936	19	1.37	0.96	0.0014	204	188	−61	−1830	0.90	113	104	−50	−1500
15	0.00400	0.905	29	1.04	0.94	0.0019	271	239	−78	−2340	1.25	158	140	−68	−2040
20	0.00533	0.873	41	0.45	0.92	0.0025	350	296	−98	−2940	1.55	195	165	−79	−2370
25	0.00667	0.841	50	0.82	0.90	0.0032	437	354	−114	−3420	1.80	227	184	−85	−2550
30	0.00800	0.810	60	1.34	0.85	0.0047	607	439	−142	−4260	2.45	309	223	−97	−2910
35	0.00933	0.778	74	1.71	0.80	0.0064	778	498	−157	−4710	3.10	391	250	−101	−3030
40	0.0107	0.745	89	2.02	0.75	0.0086	980	551	−170	−5100	3.80	479	269	−101	−3030
45	0.0120	0.714	105	2.67	0.70	0.0108	1149	563	−162	−4860	4.65	586	287	−98	−2940
50	0.0133	0.683	116	3.12	0.65	0.0129	1275	539	−140	−4200	5.50	693	293	−94	−2820
55	0.0147	0.650	127	3.87	0.60	0.0144	1313	473	−95	−2850	6.35	800	288	−69	−2070
60	0.0160	0.619	139	4.22	0.55	0.0156	1304	394	−42	−1260	7.20	907	274	−49	−1470
65	0.0173	0.588	147	4.67	0.50	0.0166	1262	316	+10	+300	7.95	1002	251	−20	−600
70	0.0187	0.555	151	5.01	0.45	0.0170	1163	236	+63	+1890	8.45	1065	216	+18	+540
75	0.0200	0.524	157	5.57											
80	0.0213	0.493	165	6.45											
85	0.0227	0.460	171	6.58											
90	0.0240	0.429	174	6.93											

TABLE 2

CALCULATIONS—RESIDUAL STRESS AFTER SECTIONING
M1 HELMET A SPECIMEN F-2

EXPERIMENTAL DATA				CURVATURE GAGE					
TIME IN ACID MIN.	MATERIAL REMOVED INCHES	t	$\Delta \cdot 10^4$	t	Δ	$e_c \cdot 10^6$	$t^2 e_c \cdot 10^6$	$te \cdot 10^6$	$E_1 te$
0	0	1.000	0	1.00	0	0	0	0	0
5	0.00156	0.968	5	0.98	0.00030	45	43	−14	−420
10	0.00311	0.926	14	0.96	0.00065	95	88	−29	−870
15	0.00467	0.889	17	0.94	0.00100	143	126	−42	−1260
20	0.00622	0.852	22	0.92	0.00132	185	157	−52	−1560
25	0.00778	0.815	25	0.90	0.00167	228	185	−61	−1830
30	0.00933	0.778	32	0.85	0.00248	320	231	−75	−2250
35	0.0109	0.740	43	0.80	0.00332	404	259	−81	−2430
40	0.0124	0.705	52	0.75	0.00415	473	266	−79	−2370
45	0.0140	0.667	57	0.70	0.00500	532	261	−71	−2130
50	0.0156	0.629	61	0.65	0.00588	581	245	−59	−1770
55	0.0171	0.593	69	0.60	0.00670	611	220	−41	−1230
60	0.0187	0.555	76	0.55	0.00755	631	191	−21	−630
65	0.0202	0.519	84	0.50	0.00840	638	160	−0.5	−15

TABLE 3

CALCULATIONS—RESIDUAL STRESS AFTER SECTIONING
M1 HELMET A SPECIMEN B-2

EXPERIMENTAL DATA					CURVATURE GAGE						SR-4 GAGE				
TIME IN ACID MIN.	MATERIAL REMOVED INCHES	t	$\Delta \cdot 10^4$	G_t	t	Δ	$e_c \cdot 10^6$	$t^2 e_c \cdot 10^6$	$te \cdot 10^6$	$E_1 te$	G_t	$e_s \cdot 10^6$	$t^2 e_s \cdot 10^6$	$te \cdot 10^6$	$E_1 te$
0	0	1.000	0	0	1.00	0	0	0	0	0	0	0	0	0	0
5	0.00178	0.956	27	2.22	0.98	0.00170	242	232	−77	−2310	1.10	139	134	−65	−1950
10	0.00356	0.912	33	3.20	0.96	0.00250	348	321	−107	−3210	2.00	254	234	−111	−3330
15	0.00533	0.868	36	3.83	0.94	0.00290	396	350	−115	−3450	2.57	326	288	−135	−4050
20	0.00712	0.822	40	4.05	0.92	0.00320	427	362	−117	−3510	3.00	380	322	−147	−4410
25	0.00889	0.777	46	4.92	0.90	0.00340	444	360	−113	−3390	3.40	431	349	−155	−4650
30	0.0107	0.733	50	4.42	0.85	0.00370	456	330	−96	−2880	4.10	520	376	−152	−4560
35	0.0124	0.690	52	4.27	0.80	0.00420	488	312	−83	−2490	4.40	558	357	−123	−3690
40	0.0142	0.645	52	3.88	0.75	0.00480	522	294	−70	−2100	4.50	570	321	−87	−2610
45	0.0160	0.600	54	—	0.70	0.00510	518	254	−48	−1440	4.35	551	270	−55	−1650
50	0.0178	0.555	54	—	0.65	0.00530	500	211	−24	−720	3.90	494	209	+78	+2340
55	0.0195	0.501	54	—	0.60	0.00535	466	168	+8	+240					
					0.55	0.00537	429	130	+21	+630					
					0.50	0.00540	392	98	+39	+1170					

TABLE 4

APPENDIX A

INTRAOFFICE MEMORANDUM UNCLASSIFIED

2 July 1943

A. Hurlich Armor & Projectile Section

Major N. A. Matthews Armor & Projectile Section

Subject: Investigation of Defective M1 Helmets

In accordance with the proposed program covering the study of the M1 helmet mfd. by the McCord Radiator and Mfg. Co., it is necessary to study the stress pattern produced in the helmet during the forming operation.

Examination of several hundred defective helmets discloses that cracks occur in the helmet body in four distinct zones:

Zone 1 35-60°
Zone 2 135-160°
Zone 3 190-235°
Zone 4 325-340°

starting from the middle of the visor as 0° and proceeding clockwise. These cracks occur in a region approximately $1\frac{1}{2}$-$2\frac{1}{2}$" up from the rim and extend vertically up and down.

It is proposed that the Applied Mechanics Section conduct tests on as many of the 10 uncracked helmets now at this Arsenal as necessary in an effort to correlate the cracking with areas of high stress concentrations.

It is desirable to have this information within four weeks.

A. HURLICH
Assistant Metallurgist

UNCLASSIFIED

TELETYPE

BI

WAOA NR202 WD /HEREWITH REPOKE OF OUR BWA A155

BWA A NR155 WD

FROM KIRK C OF ORD ASF WASHINGTON DC 201553Z MAY 44

TO C O WATERTOWN ARS WATERTOWN MASS

GRNC

RE HELMET STEEL M1 ST LOUIS ODO WOULD LIKE TO RECEIVED FROM YOUR ARSENAL A DESCRIPTION OF THE METHOD OF MEASURING THE STRESSES IN THE HELMET STEEL M1 BELIEVE THERE IS A FACILITY IN THE ST LOUIS DISTRICT WHO WILL RUN SOME STRESS ANALYSIS FOR THE ORD DEPT REQUEST IF POSSIBLE THAT YOUR ARSENAL FORWARD DIRECT TO THE ST LOUIS ODO A DESCRIPTION OF THE METHOD USED BY THE ARSENAL IN COMPUTING THE STRESSES IN THE HELMET ADVISE THIS OFFICE WITH A COPY OF YOUR LETTER OF TRANSMITTAL END CITE SPOIS HEWITT

2142Z

Wtn. 421/426

WATERTOWN ARSENAL LABORATORY

Problem Assignment

Problem No.
L-3.3

Subject: Measurement of Residual Stresses in Helmets July 1/43

Authority: Director of Laboratory Ex.O. 52

Specific Object of Problem:

To assist in explaining the high rate of cracking of M1 helmets in storage and service, and in cooperation with the Armor Section, study the distribution and intensity of stresses believed to result from the cold-drawing operation and suspected to be a cause of the cracking.

The problem will be completed by Memorandum Report, with a copy to the Armor Section.

Estimated Completion: 1 December, 1943

Problem No.		Assigned to:
L-3.3	Measurement of Residual Stresses in Helmets	Dr. Beeuwkes