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HELMETS

Metallurgical and Ballistic Investigation of Fifty Captured German Helmets

OBJECT

To study the ballistic, metallurgical, and strain characteristics of the steel used in constructing the helmets, and to analyse various physical and chemical characteristics for comparison with the American M1 Helmet.

SUMMARY OF RESULTS

1. The subject German helmets were fabricated from two principal types of steel; the ones manufactured prior to 1940 being made from a medium carbon nickel-silicon steel, and those produced after that date from a medium carbon silico-manganese steel. The change-over was probably dictated by the scarcity of nickel.

2. Ballistic tests conducted upon German and American helmets with three different projectiles indicate that the German helmets offer from 8% to 25% superior protection. This superiority is traceable to the fact that the German helmets averaged 20% greater in thickness in the ballistically tested zones than the M1 helmet.

3. German infantry helmets have an average weight of 47.3 ± 1.7 ounces, or approximately one ounce more than the M1 helmet and liner. The one German paratrooper helmet included in the subject group of helmets weighs 59.6 ounces.

4. The German helmets are heat treated to a hardness of Rockwell C 49-54, but several were found to be considerably softer in the region lying within 4-5 inches of the rim. This soft zone is believed to be of accidental origin, resulting from variations in heat treating practice.

5. The headband components manufactured prior to 1940 were produced from manganese-aluminum, and manganese-silicon-magnesium-aluminum cold rolled strip. Those subsequently produced were made from ferrous metals; the outer headband from hot rolled rimmed steel, and the inner headband from hardened high carbon steel.

6. The German helmet shells are believed to have been hot formed and subsequently heat treated. Qualitative tests indicate very low residual stresses in German helmets as compared to the American M1 helmet, which is produced by severe cold forming operations.

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INTRODUCTION

In accordance with instructions from the Office, Chief of Ordnance, Technical Division, Small Arms Branch,[1] 50 captured German helmets, presumably from the North African theatre of operations, were forwarded to this Arsenal for investigation.

A single German helmet, previously examined at this Arsenal,[2] was found to be formed from a chromium steel similar in analysis to SAE 5140 averaging 0.040" in thickness and uniformly heat treated to a hardness of approximately Rockwell C 50. The weight of this helmet, including the lining and chin straps, was 1176 grams (41.4 ounces) and the weight of the stripped helmet shell was 1082 grams (38.2 ounces).

TEST PROCEDURE

The helmets were examined visually and all serial numbers and markings were noted. Only those helmets which were completely assembled and contained leather linings, metal headbands, and chin straps were weighed in the as-received condition. All helmet shells were weighed after removal of the interior components. The various serial numbers and manufacturers' identification markings on the lining components were noted.

Ballistic tests were conducted upon several helmets selected at random, using steel jacketed caliber .45 ball ammunition, and specially developed caliber .30 soft steel projectiles, one weighing 34 and the other 150 grains, which simulate flak and high explosive shell fragments.[3] For purposes of comparison, similar ballistic tests were conducted upon regular production M1 helmets.

Chemical analyses were obtained of a sufficient number of helmet shells and headband components to insure adequate sampling. Several helmets and headband components were sectioned for hardness surveys and thickness measurements. Specimens for microscopic examination were cut from numerous helmets in an effort to determine the nature of the heat treatment employed. Some of the characteristics of the paint coatings on several of the helmets were also investigated.

A qualitative comparison of the residual stress conditions in German and American helmets was attempted by means of a simple test involving the measurement of dimensional changes resulting from the partial sectioning of helmets.

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[1] O.O. 386.3/690 - W.A. 386.3/52, See Appendix E.

[2] WAL Report No. 710/418, "Helmets - Metallurgical Examination of Helmets from Germany, the Netherlands, France, and the Irish Free State" - 26 March 1942.

[3] WAL Memorandum Report No. 762/247(c), "Development of Projectiles to Be Used in Testing Body Armor to Simulate Flak and 20 mm. H.E. Fragments" - 17 December 1943.

DATA AND DISCUSSION

1. Visual Examination

Fifty-one helmets were received at this Arsenal, but two were, upon request, returned to the Office, Chief of Ordnance. The remaining helmets were assigned numbers 1 through 49. All but three of the helmets appeared to be very similar to each other as regards size, shape, and construction. One of the three, helmet No. 1, is presumed to be a paratrooper helmet because of the Air Corps insignia on its left side, its rugged, shock resistant construction, and because it is rimless, see Figure 1. The flaring rim common to the German infantry helmet is absent in this helmet because otherwise severe air drag would result as the parachutist decends. The helmet was originally painted a greenish black color, and was subsequently repainted a light brown color.

Helmet No. 2 had a flaring rim the edge of which was not doubled over as were the rims of all the other helmets, see Figure 2. The leather lining and the chin straps were missing from this helmet, but the metal headband was present. The inside view of the helmet, Figure 2, shows the assembly of the headband components. The outer headband consists of a band of metal strip riveted together at the ends and contains five series of slots equidistantly spaced around the circumference. The inner headband consists of a thinner strip of metal to which are riveted five 8"x½" strips of spring steel. The inner headband is attached to the outer headband by means of the five spring steel strips which fit into the slots in the outer headband. Small aluminum fasteners are employed to attach the leather lining to the inner headband. The headband assembly is attached to the helmet shell by means of three metal fasteners which fit through holes in the helmet shell and the outer headband. The chin strap loops are riveted to the outer headband. The headband assembly provides a fairly flexible and comfortable fit on the head.

Helmet No. 3, see Figure 3, is typical of 46 of the helmets examined at this Arsenal. The helmet was painted a sandy yellow color, undoubtedly for camouflage purposes in desert regions. Figure 3 also shows the disassembly of the headband components previously described. The headband components of some helmets of this type were made of steel strip, while others were made of aluminum alloy strip. The fasteners attaching the helmets to the headbands were made of steel when the headband components were of steel strip, and made of brass when the headband components were of aluminum alloy strip. It was noted that there was considerable variation in the size of the helmet shells.

Helmet No. 4, see Figure 4, differed from helmet No. 3 in that the helmet shell was very much larger than any of type No. 3 and was also covered with a coat of greenish-black paint over which was spread a coat of dark colored paint in which straw-like fibres are mixed, giving the helmet a very rough exterior surface. The headband components of this helmet are made from aluminum alloy strip.

Dimensional drawings of helmets Nos. 1, 2, 3, and 4 are contained in Figures 5 through 8.

2. Markings on Helmet Shells and Headband Components

Every helmet shell has two sets of numbers stamped on the inside approximately one-half inch up from the rim, one at the back and one at the left side of the helmet. These numbers are listed in Appendix A. The outer headbands are stamped with a manufacturer's symbol and a serial number on the right and left side of the headband respectively. Typical markings are shown in Figure 9 and are listed in detail in Appendix A. These markings indicate that the headband components were produced by five facilities in the years 1937 through 1942.

Markings were also found upon both the brass and steel fasteners used to attach the headbands to the helmet shells and one listed in Appendix A. The fact that the dates of manufacture of the fasteners are not in all cases the same as those stamped on the outer headbands makes it impossible to definitely ascertain the dates of manufacture of the helmet shells. Neither can it be determined whether or not the helmet shells were fabricated by the same facilities which produced the headband components. The haphazard distribution of serial numbers and manufacturers' markings on the helmet shells, headbands, and fasteners indicate that the helmets are most probably indiscriminately assembled from components produced by a variety of facilities, each of which may produce but one of the components.

3. Chemical Analysis

a. Helmet Shells

To insure adequate sampling, eleven helmets containing headbands indicating manufacturing dates ranging from 1937 to 1942 were selected for chemical analysis. The chemical analyses of these helmets are listed in Table I.

Three of the helmets were produced from essentially nickel-silicon steels containing a small amount of chromium. Helmets Nos. 10 and 36 have almost exactly the same analysis as a Dutch helmet examined at this Arsenal in 1942.[2] A Czechoslovak helmet examined in 1940[4] was also found to be of similar analysis. The chemical analyses of these helmets are as follows:

	C	Mn	Si	S	P	Ni	Cr	Cu	Zr
Czechoslovak Helmet	.34	.62	1.84	.016	.005	2.03	.17	.12	.04
Dutch Helmet	.36	.50	1.70	.014	.010	2.05	.33	.25	nil
German Helmet #10	.34	.55	1.86	.018	.014	2.03	.34	.30	nil
German Helmet #36	.33	.57	1.77	.015	.008	2.19	.32	.26	nil

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[2] See Footnote No. 2, page 1.

[4] WAL Memorandum Report No. 320/12 - "Armor Plate for Helmets", H. C. Mann and R. E. Peterson, 12 December 1940.

The former Czechoslovakian Government specification[5] covering steel helmets for the Czechoslovak army includes the following specification of the chemical analysis of the steel to be employed for helmets:

carbon	.30/.45%
manganese	.50/.65%
silicon	1.65/2.05%
nickel	not less than 1.90%
chromium	not less than 0.20%
phosphorus	not more than 0.025%
sulfur	not more than 0.025%

The specification also requires that the helmets be hot formed and heat treated to a hardness of Rockwell C 47-51.

The Skoda plant in Czechoslovakia was the big European producer of helmet steels and helmets, supplying them not only to the Czech government but to foreign countries. It is highly probable that both the Dutch and the subject German nickel-silicon steel helmets, produced in 1938 and 1939, were manufactured in Czechoslovakia.

The third nickel-silicon steel helmet contains approximately half as much nickel as the other two helmets, but has 0.31% molybdenum. The remaining eight helmets were fabricated from silico-manganese steels, with the manganese ranging from 0.98 to 1.52%, the silicon from 1.26 to 1.67%, and the carbon from 0.29 to 0.40%.

If the dates stamped on the headbands may be taken as an indication of when the helmet shells were produced, it appears that the nickel-silicon steel was employed up to 1939, in which year a changeover, probably dictated by the strategic position occupied by nickel, was made to the silico-manganese type of steel.

The chemical analyses indicate that all the steels were aluminum killed, see Table I.

b. Outer Headbands

(1) Steel Headbands

The chemical analyses of five outer headbands produced from steel strip are contained in Table I. The very low carbon and manganese contents and the complete absence of silicon suggest the employment of rimmed steel for this headband component.

(2) Aluminum Alloy Headbands

The chemical analyses of four aluminum alloy outer headband components are listed in Table I. The analyses of these four items, produced in 1938, 1939, and 1940 indicate the use of one type of alloy whose principle alloying agent is from 1.0 to 1.5% manganese. This alloy appears to be very similar to the 3S wrought aluminum alloy produced domestically by the Aluminum Company of America. The 3S alloy is a non-heat treatable product which may be hardened by cold rolling.

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[5] Inclosure O.O. 421/1867, W.A. 421/109, Appendix I of WAL Memorandum Rpt. No. 320/12.

The dates stamped upon the outer headbands indicate the occurrence of a change-over in the year 1940 from the aluminum alloy to a cheaper, less strategic ferrous material.

c. Inner Headbands

(1) Steel Headbands

The chemical analyses of five steel inner headband components, see Table I, show them to be fabricated from unalloyed high carbon steels (0.78-0.97% C).

(2) Aluminum Alloy Headbands

The analyses of the aluminum alloy inner headband components differ considerably from those of the outer headbands. Whereas the latter consisted of 1.0-1.5% manganese alloys, the former contain .70-1.0% manganese, .80-.85% silicon, and .50-.75% magnesium, see Table I. This alloy, except for the fact that it contains no copper, is very similar to duralumin and is undoubtedly hardenable by a quenching and aging treatment.

d. Springs

The chemical analyses of eight sets of springs used to attach the inner headbands to the outer ones are listed in Table I. These springs are fabricated from high carbon steels (.75-.95 C) containing residual amounts of nickel and chromium.

e. Aluminum Alloy Fasteners

The chemical analyses of various aluminum alloy fasteners are contained in Table I. These fasteners attach the leather lining around the circumference of the inner head band. The majority of the fasteners are made of a complex alloy containing approximately 0.80-1.0% manganese, 1.0-1.25% silicon, and .30-1.30% magnesium, being somewhat similar in analysis to the inner headbands from helmets containing aluminum alloy components.

4. Ballistic Tests

Six German helmets and six regular production M1 helmets were selected at random for ballistic testing. Ballistic limits were obtained on three helmets of each type using the caliber .30 soft steel fragment simulating projectile weighing 34 grains, projectile No. G-1-S,[3] at a range of 8 feet. Ballistic limits were obtained on the remaining three helmets of each type with the caliber .30 soft steel fragment simulating projectile weighing 150 grains, projectile No. G-1-A.[3] The projectiles were fired from a caliber .30 Mann barrel in a fixed rest and velocities were measured with a Remington Arms Chronoscope. All firing with the fragment simulating projectiles was restricted to the vertical portions of the backs and sides of the helmets, in the zone between two and four inches up from the rim.

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[3] See Footnote No. 3, page 1.

All six helmets of both types were subjected to ballistic testing with caliber .45 ball copper coated steel jacketed projectiles weighing 230 grains. The caliber .45 ball projectiles were fired from a Thompson submachine gun barrel fitted with a caliber .30 Springfield bolt and receiver. The range was 25 feet, and velocities were measured with an Aberdeen chronograph.

The ballistic limits of the two groups of helmets when tested with the various projectiles are contained in Table II. Detailed results of the ballistic testing may be found in Appendix B. From the results in Table II it is apparent that the German helmet offers superior protection to the projectiles used than does the M1 helmet; having approximately a 75 ft/sec. higher limit against caliber .45 ball projectiles, a 230 ft/sec. higher limit against the small fragment projectile, and a 25 ft/sec. higher limit against the large fragment projectile. This superiority is due, as will be subsequently shown in detail, to the greater thickness of the German helmet shell.

Photographs of some of the German and American helmets after ballistic testing are shown in Figures 10 and 11. Figure 10 illustrates the ductile behavior of the M1 helmet. Complete penetrations of caliber .45 ball projectiles cause a circular tear in the metal and the bending inward of the torn flap. Partial penetrations produce relatively large indentations and very rarely cause cracking, either near or through the impacted zone.

Complete penetrations of caliber .45 ball projectiles through German helmets are accomplished by the breaking out, in a brittle manner, of pieces several times larger than the caliber of the projectile, see the top photograph of Figure 11. The brittle behavior of German helmets is also illustrated in the two lower photographs.

5. Weights of Helmets

Twenty-one helmets similar in type to helmet No. 3 were found to be complete with leather linings, headbands, and chinstraps. These helmets have an average weight of 1340 ± 49 grams (47.3 ± 1.7 ounces). The average weight of the 49 stripped helmet shells is 1088 ± 58 grams (38.4 ± 2 ounces). The weights of the individual helmets are tabulated in Appendix C.

Seven regular production M1 helmet shells complete with chinstrap loops and chinstraps were found to have an average weight of 1061 ± 8 grams (37.4 ± 0.3 grams). The only liner from the M1 helmet available at this Arsenal weighs 255 grams (9 ounces). The M1 helmet is, therefore, approximately one ounce lighter in weight than the average German helmet.

The paratrooper helmet weighs 1692 grams (59.6 ounces) complete, and the stripped shell weighs 1029 grams (36.3 ounces).

6. Thickness Measurements

Four German helmets were selected at random and sectioned for thickness measurements. A one inch wide strip was cut from the midsection of each helmet, two longitudinally and two transversely, and the thicknesses were measured every inch along the lengths of the strips. Similar data had previously been obtained from a number of M1 helmets. Figure 12 contains graphs showing the variation in gage along longitudinal and transverse sections of German and American helmets.

The average M1 helmet suffers a 25-30% reduction in gage in the crown during the cold forming operation, whereas the four German helmets which were sectioned and measured showed a reduction of gage in the crown varying between 15 and 25%.

In the ballistically tested vertical regions lying between 2 and 4 inches up from the rim, the thickness of the M1 helmet is generally between 0.041" and 0.043". The thickness of the German helmets in the same region varies from 0.048" to 0.052", being roughly 20% greater in thickness than comparable zones on the M1 helmet. The increased ballistic protection afforded by the German helmets is solely a function of the increased thickness of the helmet shells. Numerous different types of heat treated magnetic steels have been ballistically tested at this Arsenal with projectiles varying in caliber from .22 to .45 and, in the thickness range 0.040"-0.045", no heat treatable steel has yet been found superior to or even equal to austenitic manganese steel in ballistic properties.

The thicknesses of the various headband components may be found in Appendix D.

7. Hardness Surveys

a. Helmet Shells

Rockwell C hardness readings were taken every inch along the strips cut from the longitudinal sections of helmets Nos. 34 and 38 and on the transverse strips from helmets Nos. 35 and 44. The results of the hardness surveys are included in Table III.

Helmets Nos. 35 and 38 have relatively uniform hardnesses varying between Rockwell C 51 and 54.5. Helmet No. 34 was found to vary from a hardness of Rockwell C 32 near the rim to Rockwell C 49.5 at the top of the crown, and helmet No. 44 from Rockwell C 16 at the rim to Rockwell C 53.5 at the top of the crown. Two inch long strips were cut from the sides and crown of four additional helmets and hardness readings were taken on them to check the wide variations in hardness patterns found on the first four helmets. Helmet No. 10 was found to have a hardness of Rockwell C 44-45.5 in the region between 1 and 2 inches up from the rim, helmet No. 12 a hardness of Rockwell C 50.5-52, helmet No. 22 a hardness of Rockwell C 49-50, and helmet No. 28 a hardness of Rockwell C 11-14 in the same region. At the top of the crown, however, all four helmets have approximately the same hardness, within the range of Rockwell C 48.5-53.5.

b. Headband Components

(1) Steel Components

Due to the thinness of the headband components, hardness surveys were made using the 15T and 15N scales of the Rockwell Superficial Hardness Tester. The outer headbands, which were made of rimmed steel, have hardnesses in the range of Rockwell 15T 78-86 (100-144 Brinell). The inner headbands, which were made of high carbon steel, have hardnesses in the range of Rockwell 15N 84.5-87.5 (477-578 Brinell). The springs, also made of high carbon steel, are in the fully hardened condition, having hardnesses in the range of Rockwell 15N 85.0-89.5 (514-664 Brinell), see Table III.

(2) Aluminum Alloy Components

The hardness of the 1.0-1.5% manganese aluminum alloy, similar to the 3S alloy of the Aluminum Company of America, which was used for the outer headbands is in the range of Rockwell 15T 54-61 (48-53 Brinell), see Table III. These hardnesses correspond to between the 3/4 and fully hardened tempers, and since this alloy is hardenable only by cold working, fabrication by cold rolling is indicated.

The inner headbands, made of the manganese-silicon-magnesium-aluminum alloy were found to have hardnesses in the range of Rockwell 15T 78-80.5 (100-108 Brinell). To obtain this high hardness, it is believed that the strip from which the inner headbands were made was cold rolled after being heat treated.

8. Microstructure and Heat Treatment

a. Helmet Shells

Specimens for microscopic examination were cut from the strips taken from helmets Nos. 34, 35, 38, and 44 from positions corresponding to 1" up from the rim, halfway between the rim and the top of the crown, and at the top of the crown. In addition to this, specimens were cut from helmets 8, 10, 12, 22, and 28 from positions approximately 1" up from the rim at the left sides of the helmets.

Figure 13 illustrates the variation in the microstructure from rim to crown of helmet No. 34. At 1" up from the rim, the microstructure consists of martensite, ferrite and carbides, Figure 13C. Fairly extensive surface decarburization was found, particularly in the region nearest the rim, Figure 13B. Halfway between the rim and crown the microstructure is the same as that closer to the rim, but at the crown a completely martensitic microstructure is found.

Helmets Nos. 35 and 38 have completely martensitic microstructures throughout. Helmet No. 44 displays a wide variation in microstructure, being almost completely ferritic 1" up from the rim, and almost completely martensitic in the crown, Figures 14A, B, and C. An extreme variation in microstructure, correlating with the large variation in hardness, was found in the specimens cut from positions approximately 1" up from the rim at the left sides of helmets 8, 10, 12, 22, and 28. A completely spheroidized annealed structure was found in helmet No. 28, Figure 14D, and a fully hardened martensitic structure was found in helmet No. 8, Figure 14G.

The combination of martensite, carbides, and ferrite found in several of the helmets must result from either one or both of the following treatments:

(1) heating to a temperature between the Ac_1 and the Ac_3 temperatures to form austenite and ferrite and then quenching to transform the austenite to martensite.

(2) heating for a very short time at a temperature above the Ac_3 point, allowing insufficient time for complete austenitization and carbide solution, resulting in sufficient decrease in hardenability to cause ferrite rejection upon quenching.

Undoubtedly it was intended to heat treat all the helmets to obtain fully hardened martensitic structures, and this aim was attained in several instances. In heat treating very thin sections, it is extremely important to take precautions to avoid decarburization during heating since thin stock will decarburize extremely rapidly to such a degree that the effective hardenability is seriously impaired. In fact, no more than a few minutes at the austenitizing temperature should be employed for 0.050" sections even if attempts are made to control the furnace atmosphere.

It is believed that the subject helmets were most likely heat treated by traversing, rim down, through a continuous furnace, and were oil quenched upon emerging from the furnace. Being rim down on the furnace hearth, the crowns were completely exposed to the heat and came up to temperature very rapidly, whereas the sides of the helmet shells, being cut off from receiving heat by radiation because of interference from the adjacent helmet shells, heated at a very much lower rate than the crowns. The rate of traverse through the furnace was such that the sides of all helmets did not come up to the austenitizing temperature, or were not at the austenitizing temperature for a sufficient length of time to completely harden upon quenching. In addition, slight variations in furnace temperature and rate of travel through the furnace would be responsible for relatively large variations in microstructure and hardness obtained in the helmets. The time factor is very important when the entire heat treatment consumes but a few minutes.

The microstructure near the rim of helmet #28, Figure 14D, indicate that the helmet shells are in the spheroidized annealed condition prior to the final heat treatment.

In order to verify the theory that the helmets were hardened by quenching, two helmets, #10 (nickel-silicon steel) and #34 (silico-manganese steel), were cut into two pieces and heat treated. One piece of each helmet was heated in a furnace at 1600°F. for a total time in the furnace of 5 minutes and air cooled. The remaining pieces were similarly heated and oil quenched. It was noted that the helmet sections came up to the furnace temperature in approximately 1½ minutes. Two inch square pieces were cut from the heat treated sections, ground free of scale and decarburization and tested for hardness with the following results:

	Rockwell C Hardness after Following Heat Treatment (Ave. of 3 readings)	
Helmet No.	1600°F, 5 min. Oil Quenched	1600°F, 5 min. Air Cooled
10 (Ni-Si)	52.0	43.0
34 (Si-Mn)	53.0	26.5

The hardenability of the Ni-Si composition is greater than that of the Si-Mn steel as evidenced by the greater hardness developed upon air cooling. Since the hardness after oil quenching is approximately the same as that of the majority of the helmets, it is evident that if any tempering was performed, the tempering temperature was below that at which any softening occurs, or below approximately 300-400°F.

b. Headband Components

(1) Steel Components

The outer headbands have a microstructure consisting of equi-axed ferrite grains with occasional carbides, indicating that the strip from which the headbands were formed was hot rolled.

The inner headbands have either dark etching martensitic or bainitic microstructures with the hypereutectoid carbides occurring as fine globules. The inner headbands were heat treated either by an austempering or a quench and tempering operation. The microstructure of the springs is exactly similar to that of the inner headbands.

All of the steel components with the exception of the springs were zinc coated. The thickness of the zinc coatings as measured by means of a Magne-gage varied between .0004" and .0008". Due to the absence of spangles and a Fe-Zn alloy layer between the zinc coating and the steel base it is concluded that the zinc was electrodeposited. The high hardness of the inner headband precludes the use of hot dip galvanizing.

(2) Aluminum Alloy Components

The microstructure of the outer headbands consists of grains elongated by cold working and globules which etch dark in 0.5% hydrofluoric acid. These globules are believed to be the Al-Fe-Mn intermetallic compound.

The microstructure of the inner headbands also shows evidence of cold rolling. The intermetallic compounds are generally small and well distributed.

9. Method of Manufacture of Helmet Shell

It is believed that the helmets were hot formed because the variation in gage is much less than would be expected from a cold forming operation, and because some of the curvatures are too extreme to allow for successful cold drawing. The folding inward of the edge of the rim must of necessity have been done while the metal was hot.

10. Residual Stress Analysis

Qualitative and quantitative measurements of the residual stresses in the M1 helmet have been made at this Arsenal. The stresses on the outside surface of the M1 helmet are generally tensile in character and are compressive on the inside surfaces, and the magnitude of the highest stresses are in the order of 80,000-90,000 p.s.i. These stresses are induced by the very severe cold forming operations employed in the production of the helmet shells.

Since the German helmets are heat treated after forming, the only residual stresses are those resulting from quenching and transformation to martensite. These latter stresses would be expected to be very small compared to those resulting from cold forming the M1 helmet.

Since the quantitative determination of residual stresses in non-symmetrical thin walled sections is extremely difficult and laborious, a simple qualitative method was chosen which would dramatically reveal large variations in residual stresses. This method consisted of making a vertical cut extending from the rim to the top of the crown, and measuring the displacement at the rim. Small crosses were scratched at the rim approximately one inch apart and the distance measured to an accuracy of ± .001 by means of a cathetometer. The vertical cut was made midway between the two crosses, after which the distance between them was again measured. The magnitude of the change in the distance between the crosses is a rough measure of the stress condition in the vicinity of the cut. An opening up at the cut; i.e., a tendency to return to the prior flat condition of the helmet blank, indicates the existence of tensile stresses on the outer surface of the helmet. Very little change in dimensions indicates low residual stresses.

Three German and three American helmets were selected for this test. One of each was sectioned vertically from the middle of the visor to the midpoint of the crown, one from the middle of the right side to the midpoint of the crown, and one from the middle of the back to the midpoint of the crown. The results of the measurements of the dimensional changes are contained in Table IV, and photographs of four of the helmets are shown in Figure 15.

The three German helmets underwent dimensional changes in the order of 0.10" and less, while the three American helmets suffered changes in the order of 0.80 to 1.0". It may be concluded from this test that the German helmets have low residual stresses and that the service cracking and production breakage occurring as a result of the cold forming of austenitic steel helmets presents no serious problem in the hot forming of ferritic steel helmets.

11. Paint Analysis

The paint coatings on helmets Nos. 1, 2, 3, and 4 were subjected to some physical and chemical tests, the results of which are summarized in Table V. Several of the helmets were found to be painted a greenish-black color, and then repainted a sandy yellow or tan color, presumably for camouflage purposes in desert terrain.

12. General Considerations

Although the German helmet shells weigh on the average but one ounce more than the M1 helmet shells, they have, nevertheless, a wall thickness approximately 20% greater. This is made possible by a much smaller surface area; i.e., a closer fit to the head. The M1 helmet fits over a large liner which covers the head as completely as does the helmet shell. The liner contains an inner adjustable suspension to fit the head. The German helmet, on the other hand, contains a simple adjustable leather cap which allows for a close fit of the helmet shell to the head.

The M1 helmet is fabricated from austenitic manganese steel which is ductile and deforms considerably upon impact of large projectiles or fragments whereas the German helmets are produced from a ferritic steel which is heat treated to a relatively high hardness. The steel is brittle and relatively nondeformable, indenting very much less than the M1 helmet upon the partial penetration of caliber .45 ball projectiles, but cracking and allowing pieces to be broken out upon complete penetration. The M1 helmet, because of its deforming characteristics, should, for maximum protection, be kept some distance away from the head. This is accomplished admirably by the liner.

A considerable amount of experimental work has been done during the last twenty-five years, both in this country and abroad, on the use of nickel-silicon steels for personal armor, and several nations have standardized on this type analysis for helmet steel. The silico-manganese steel employed by the Germans after 1940 represents the replacing of the 2.0% nickel content of the nickel-silicon steel by approximately 1.0% of manganese. It is known that this proportion of manganese to nickel produces approximately the same effect upon the transformation characteristics upon quenching, and should produce similar mechanical properties. The silico-manganese steel appears, therefore, the best strategic substitute for the nickel-silicon composition.

Likewise, the replacement of the aluminum alloy headband components by zinc plated steel seems to indicate another strategic substitution.

TABLE I

Chemical Analysis of German Helmet Components

Analysis of Helmet Shells

A. Nickel-Silicon Steel

Helmet No.	Date of Mfg. of Headband	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	Al
10	1938	.34	.55	1.86	.018	.014	2.03	.34	nil	.30	.015
36	1939	.33	.57	1.77	.015	.008	2.19	.32	trace	.26	.02
42	1937	.27	.58	1.85	.016	.008	1.16	.37	.31	.16	.01

B. Silico-Manganese Steel

Helmet No.	Date of Mfg. of Headband	C	Mn	Si	S	P	Ni	Cr	Mo	Cu	Al
21	1940	.31	.98	1.34	.018	.011	.14	.12	trace	.15	.01
28	1942	.33	1.19	1.26	.014	.017	trace	.05	nil	.03	.015
31	1939	.29	1.15	1.34	.017	.006	trace	.08	trace	.16	.01
34	1940	.40	1.19	1.45	.033	.017	.11	.105	trace	-	.005
35	1942	.36	1.52	1.30	.014	.016	nil	.01	trace	-	.008
38	1940	.39	1.22	1.33	.020	.014	.11	.115	trace	-	.005
44	1940	.36	1.25	1.30	.017	.019	nil	.035	trace	-	.007
45	1940	.36	1.03	1.67	.015	.008	.14	.01	trace	.16	.01

TABLE I (Continued)

Analysis of Outer Headbands

A. Steel Headbands

Helmet No.	Mfgr.	Date of Mfg.	C	Mn	Si	S	P	Ni	Cr
3	Schuberth-Werk	1940	.07	.35	trace	.021	.008	trace	.02
14	"	1940	.05	.34	nil	.045	.042	"	.02
17	"	1940	.08	.26	trace	.029	.036	"	.01
23	"	1940	.04	.27	trace	.043	.040	"	.02
35	B&C, Litzmannstadt	1942	.05	.28	trace	.030	.053	"	.11

B. Aluminum Alloy Headbands

Helmet No.	Mfgr.	Date of Mfg.	Mn	Si	Cu	Fe	Mg	Cr	Al
4	Schuberth-Werk	1938	1.48	trace	trace	.21	trace	trace	remainder
6	Metall- Lederverarbeitung	1940	1.34	.21	.01	.39	trace	-	remainder
29	B&C, Berlin	1940	1.33	.35	.08	.53	.02	-	remainder
32	B&C, Berlin	1939	1.06	.35	.08	.44	.15	-	remainder

TABLE I (Continued)

Analysis of Inner Headbands

A. Steel Headbands

Helmet No.	Mfgr.	Date of Mfg.	C	Mn	Si	S	P	Ni	Cr
3	Schuberth-Werk	1940	.78	.65	.23	.024	.030	trace	.10
14	"	1940	.86	.60	.21	.041	.020	"	.05
17	"	1940	.97	.54	.31	.030	.047	"	.02
23	"	1940	.88	.53	.33	.030	.018	"	.11
35	B&C, Litzmannstadt	1942	.89	.58	.17	.046	.028	"	.05

B. Aluminum Alloy Headbands

Helmet No.	Mfgr.	Date of Mfg.	Mn	Si	Cu	Fe	Mg	Cr	Al
4	Schuberth-Werk	1938	.97	.81	.03	.29	.52	trace	remainder
6	Metall- Lederverarbeitung	1940	.73	.84	.01	.36	.65	-	remainder
29	B&C, Berlin	1940	.68	.84	.20	.37	.71	-	remainder
32	B&C, Berlin	1939	.72	.84	.05	.36	.77	-	remainder

TABLE I (Continued)

Analysis of Springs

Helmet No.	Year of Mfg.	Metal from Which Headband Is Made	C	Mn	Si	S	P	Ni	Cr	Mo
3	1940	Steel	.80	.42	.31	.032	.008	.19	.29	nil
6	1940	Aluminum	.77	.63	.57	.032	.020	trace	.12	nil
14	1940	Steel	.79	.32	.27	.033	.009	.12	.15	nil
17	1940	Steel	.75	.46	.17	.026	.010	.15	.02	.04
23	1940	Steel	.88	.43	.35	.029	.009	.17	.24	nil
29	1940	Aluminum	.94	.32	.19	.019	.017	trace	.03	nil
32	1939	Aluminum	.78	.60	.29	.035	.038	.05	.16	trace
35	1942	Steel	.84	.60	.27	.037	.008	.09	.12	trace

Analysis of Aluminum Alloy Fasteners Which Attach Leather Lining to Inner Headband

Helmet No.	Date of Mfg. of Headband	Mn	Si	Cu	Fe	Mg	Aluminum
6	1940	Insufficient Sample	1.27	.16	.42	.52	remainder
14	1940	.95	1.31	.15	.35	.81	remainder
17	1940	.85	1.12	.10	.42	1.34	remainder
23	1940	.85	1.12	.21	.42	.35	remainder
29	1940	.81	1.03	.31	.48	.28	remainder
32	1939	.48	.56	.73	.64	.27	remainder

TABLE II

Ballistic Tests of German and American Helmets

Helmet No.	Date of Mfg. of Headband	Ballistic Limit – Feet Per Second Caliber .45 Ball (Steel Jacketed Projectile)	*Caliber .30 Soft Steel Small Fragment G-1-S (34 Grains)	*Caliber .30 Soft Steel Large Fragment G-1-A (150 Grains)
A. German Helmets				
7	obliterated	1066	1220	-
8	1940	1007	-	388
9	1942	1025	-	508
10	1938	878	1033	-
12	1941	1024	-	453
22	1941	933	1150	-
		Average - 989	1134	450
B. American Helmets				
#I1 (McCord Lot 584C)		835	918	-
I2 (McCord Lot 589A)		905	905	-
I3 (McCord Lot 594A)		921	885	-
I4 (McCord Lot 594B)		927	-	445
I5 (McCord Lot 595E)		948	-	428
I6 (McCord Lot 595A)		952	-	400
		Average - 915	903	424

*WAL Memorandum Report No. 762/247(c) - "Development of Projectiles to Be Used in Testing Body Armor to Simulate Flak and 20 mm H.E. Fragments." 17 December 1943.

TABLE III

Hardness Surveys of German Helmets and Headband Components

Helmet Shells

Distance from Origin at Rim - Inches	Hardness - Rockwell C							
	[1]Helmet No. 34	[2]Helmet No. 35	[1]Helmet No. 38	[2]Helmet No. 44	Helmet No. 10	Helmet No. 12	Helmet No. 22	Helmet No. 28
1	38	51.5	54.5	16	45.5	50.5	49	11.0
2	38	54.5	52.5	26	44	52	50	14.0
3	38	53.5	53.5	37				
4	40.5	53.5	54.5	42				
5	40.5	52.5	52.5	48				
6	40.5	53.5	53	53.5				
7	44.5	53.5	53.5	53.5				
8	48.5	54.5	53.5	52.5	51	52	48.5	53
9	49.5	54.5	54.5	53.5	53	53.5	51	52.5
10	49.5	53.5	50.5	51.5				
11	46.5	53.5	52.5	53.5				
12	40.5	52.5	52	47				
13	40	52	51	44				
14	38	51.5	51.5	38				
15	32	52.5	54	32				
16	32	52	53	24				
17	34	53.5	54.5	18				

1 - Longitudinal Sections - Readings are from Front to Back of Helmet

2 - Transverse Sections - Readings are from left side to right side.

TABLE III (Continued)

Outer Headbands

(Steel Components)

Helmet No.	Hardness	
	*Rockwell 15T	Brinell Equivalent
3	78	100
14	86	144
17	85	139
23	86	144
35	84.5	137

Outer Headbands

(Aluminum Alloy Components)

Helmet No.	Hardness	
	*Rockwell 15T	Brinell Equivalent
4	54	48
32	61	53

Inner Headbands

(Steel Components)

Helmet No.	Hardness	
	Rockwell 15N	Brinell Equivalent
3	85	514
14	87.5	578
17	85	514
23	85.5	525
35	84.5	477

Inner Headbands

(Aluminum Alloy Components)

Helmet No.	Hardness	
	Rockwell 15T	Brinell Equivalent
4	78	100
32	80.5	108

---

*Average of three hardness readings.

Springs

Springs

Helmet No.	Hardness	
	Rockwell 15N	Brinell Equivalent
3	85.5	525
14	87.5	578
17	87.0	566
23	85.0	514
32	87.5	578
35	86.5	664

TABLE IV

Residual Stress Analyses of German and American Helmets

Helmet No.	Location of Vertical Cut	Original Distance Between Scratches Inches	Distance Between Scratches after Vertical Cut Was Made – Inches	Dimensional Change Produced by Cutting – Inches
German Helmet #23	Middle of Visor	0.984	0.927	-0.057
American Helmet I8 (McCord Lot 596C)	Middle of Visor	1.042	1.991	+0.949
German Helmet #28	Middle of Right Side	1.035	1.130	+0.095
American Helmet #H (McCord Lot 618B)	Middle of Right Side	1.059	1.867	+0.808
German Helmet #41	Middle of Back	0.998	0.988	-0.010
American Helmet #F (Schlueter Lot 62As)	Middle of Back	1.000	1.976	+0.976

TABLE V

d Chemical Characteristics of Paint Coatings on German Helmets

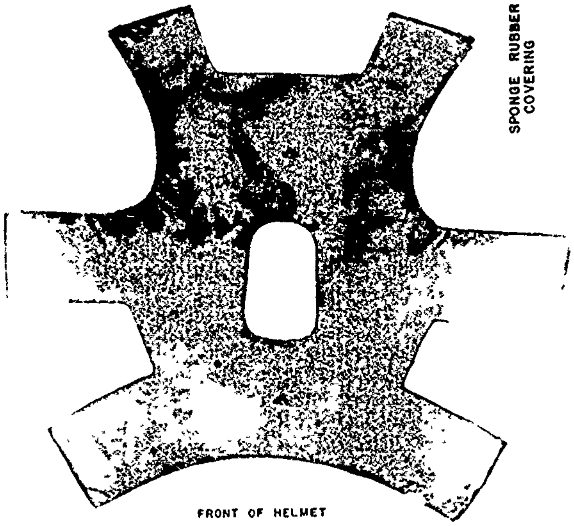
			Helmet No. 4	
oat	Helmot No. 2	Helmet No. 3	Under Coat	Top Coat
rown	Green-black	Tan	Green-black	Burnt Ochre(1)
3"	.0038"	.0031"	.0005"	.0063"
r	Good	Good	Good	Poor
, Pb, Ti	Fe, Ti, Zn	Ti, Fe	Zn, Fe, Ti, Sn	Zn, Sn, Pb
, Cr, Ag	Cu, Ni, Pb, Cr, Mg, Al	Zn, Cu, Si	Si, Cr, Cu, Pb, Ag, Mg	Cu, Si, Mg, Cr
4%	75.6%	40.9%	55.8%	42.5%
7%	2.8%	19.1%	—	10.0%
7%	14.5%	14.7%	—	14.6%

e fibers while still wet.

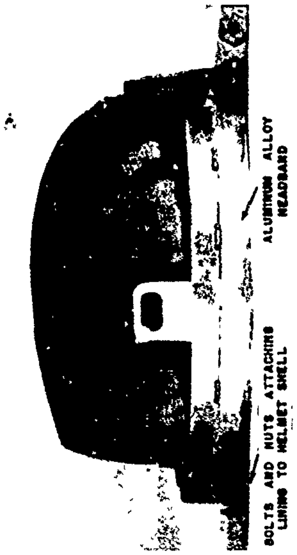
the coating could be

GERMAN HELMET NO. 1 – PARATROOPER HELMET

BACK VIEW OF LINING
SPONGE RUBBER COVERING REMOVED



SPONGE RUBBER COVERING



LEFT SIDE VIEW OF LINING

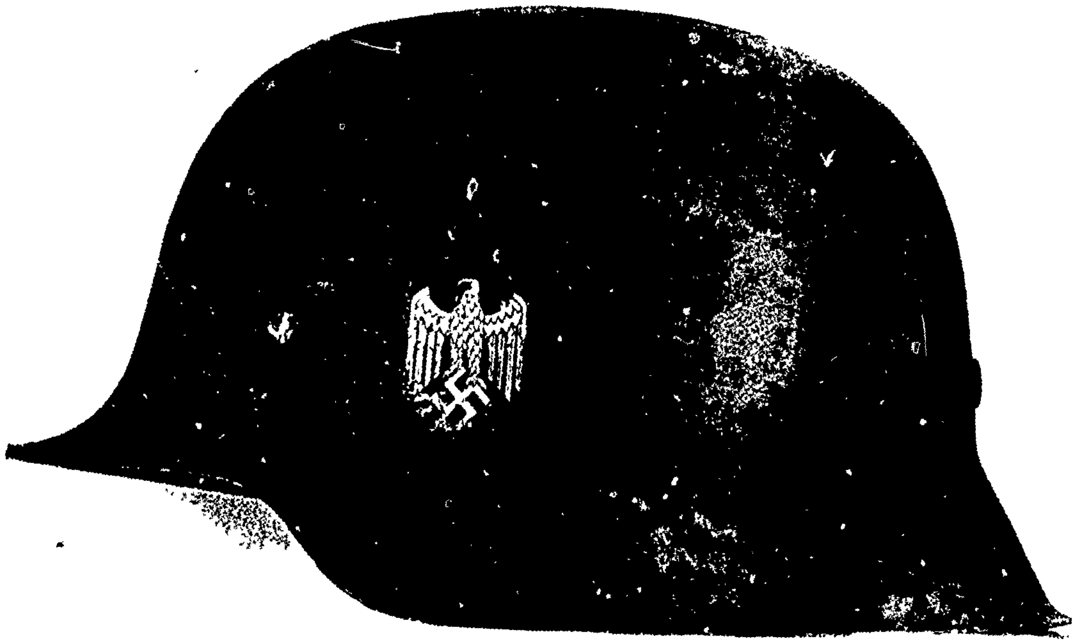
LEFT SIDE VIEW

INSIDE VIEW

WTN.639-6056

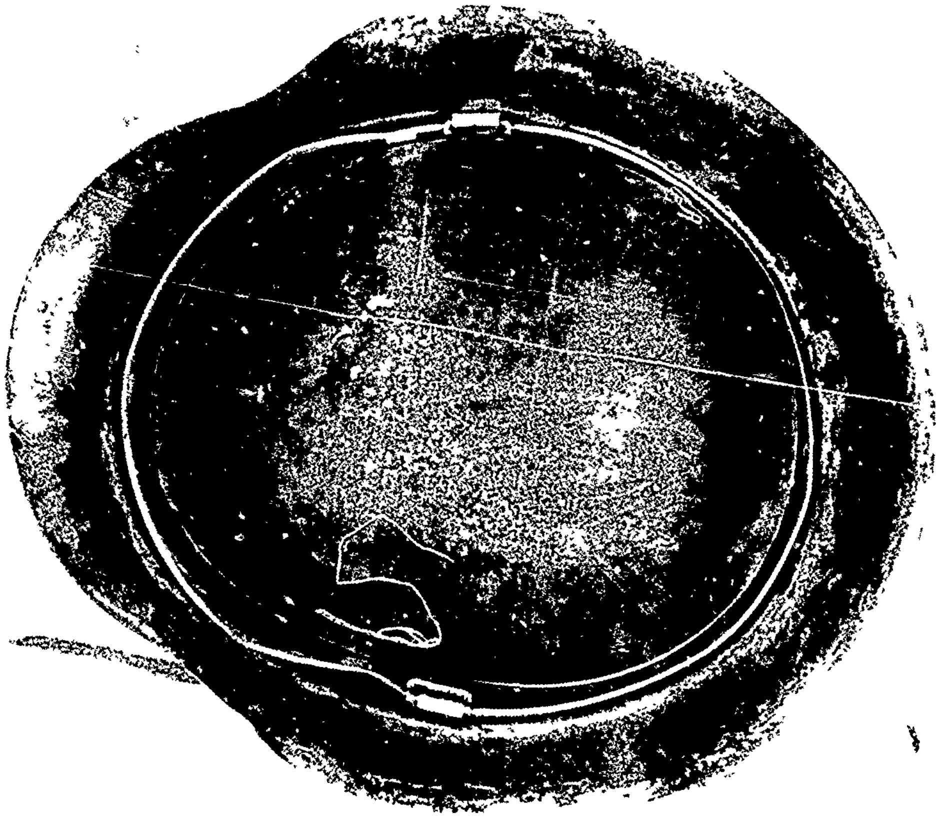
FIGURE 1

GERMAN HELMET NO. 2 - INFANTRY HELMET



LEFT SIDE VIEW

FLARING RIM
NOT BENT IN

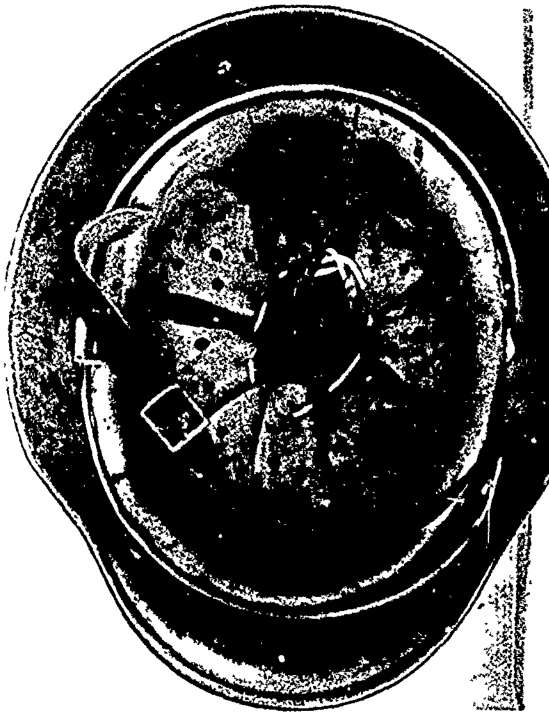


WTN.639-6057

INSIDE VIEW

FIGURE 2

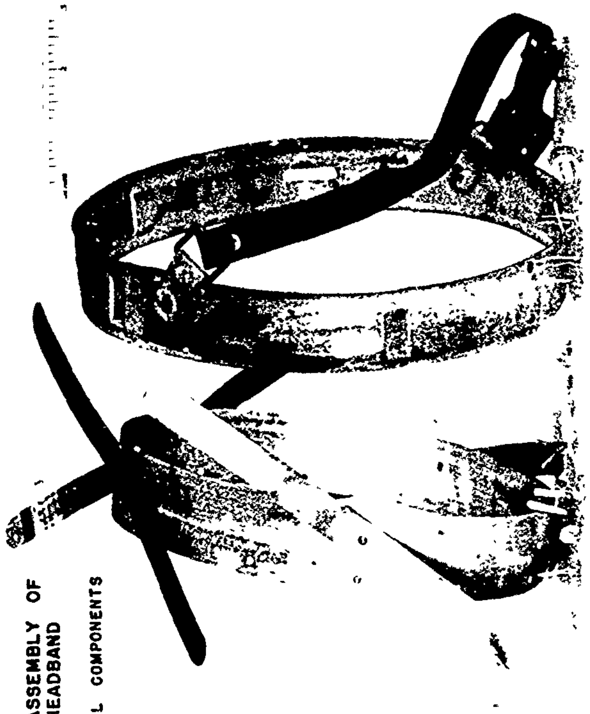
GERMAN HELMET NO. 3 - INFANTRY HELMET



INSIDE VIEW

LINING

LEFT SIDE VIEW



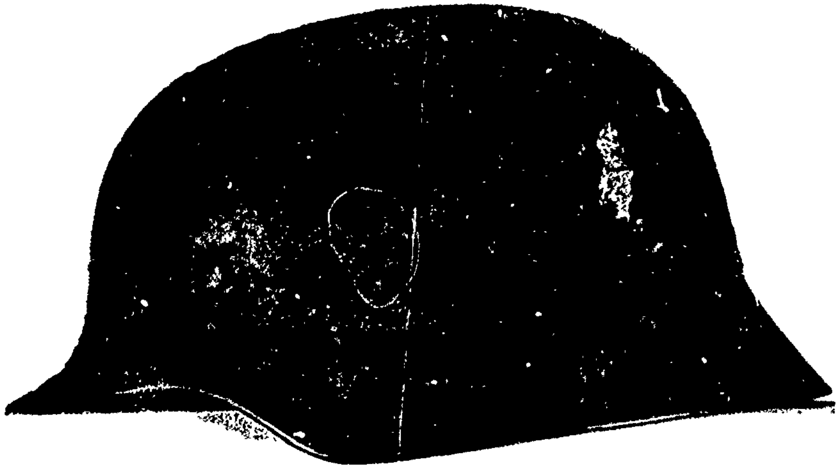
DISASSEMBLY OF HEADBAND

STEEL COMPONENTS

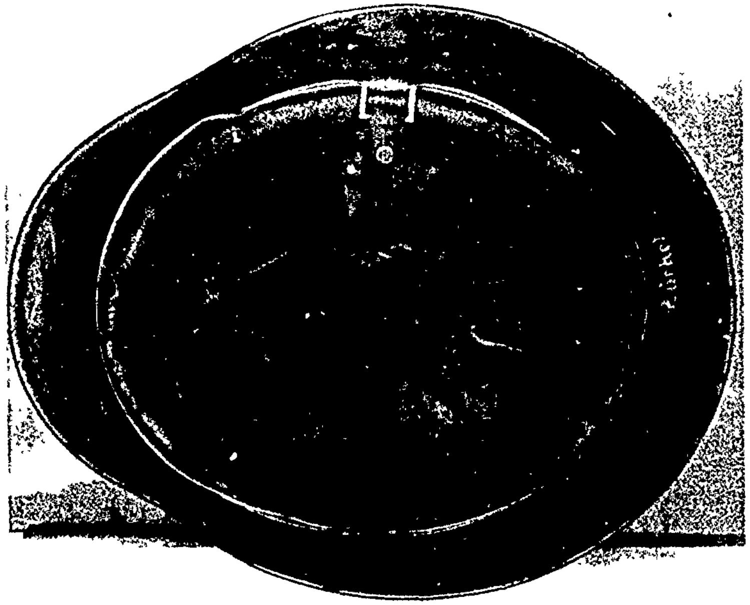
WTN.639-6058

FIGUR

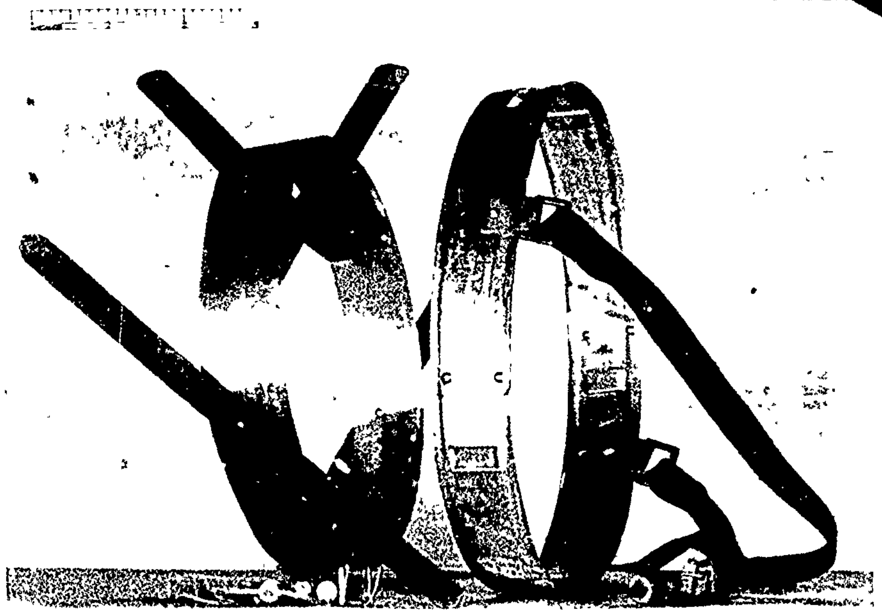
GERMAN HELMET NO. 4 - INFANTRY HELMET



LEFT SIDE VIEW



INSIDE VIEW

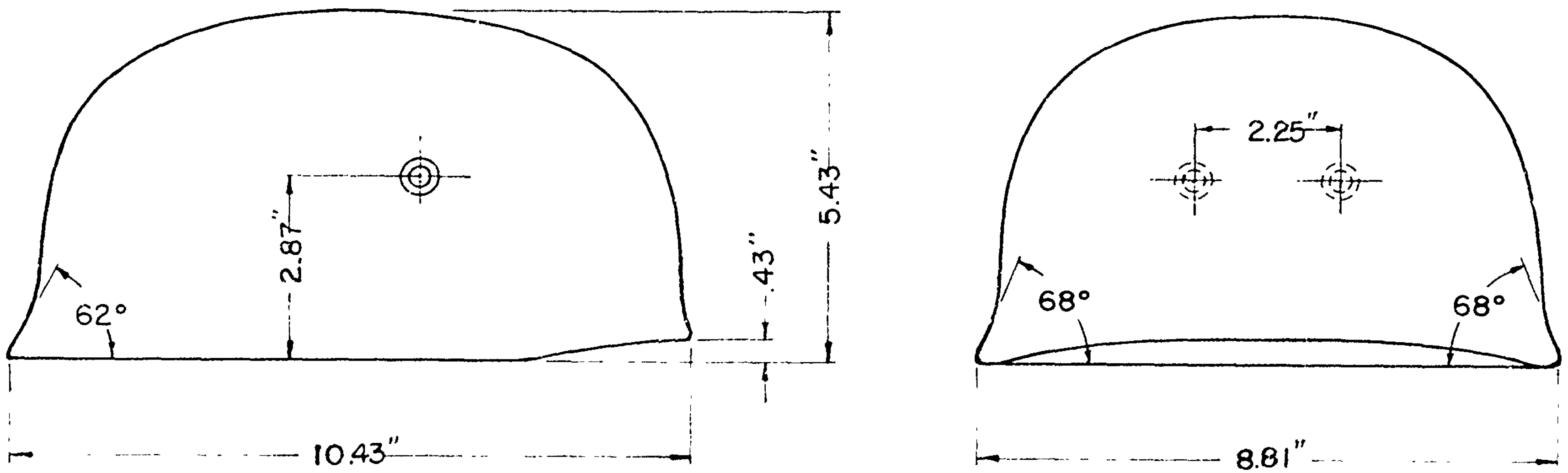


DISASSEMBLY OF HEADBAND

STEEL SPRINGS - ALUMINUM ALLOY COMPONENTS

WTN.639-6059

FIG.



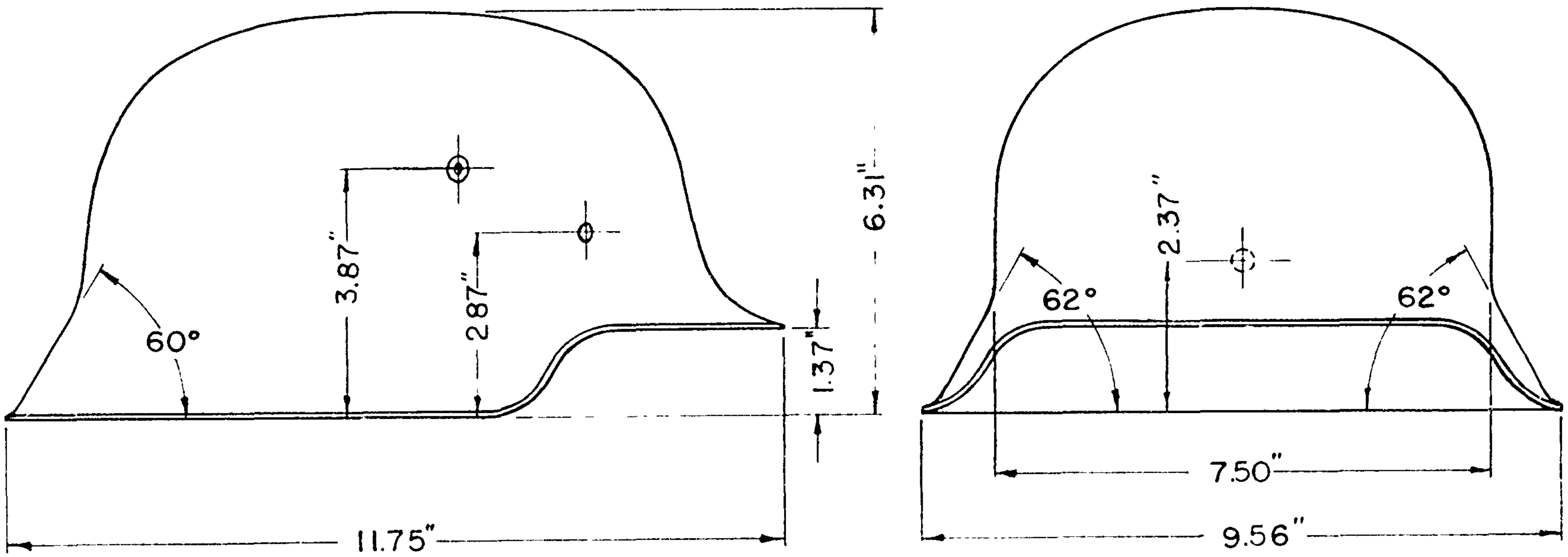
RIGHT SIDE VIEW

FRONT VIEW

GERMAN HELMET NO. 1 – PARATROOPER HELMET

SCALE $\frac{3}{8}$

Figure 5



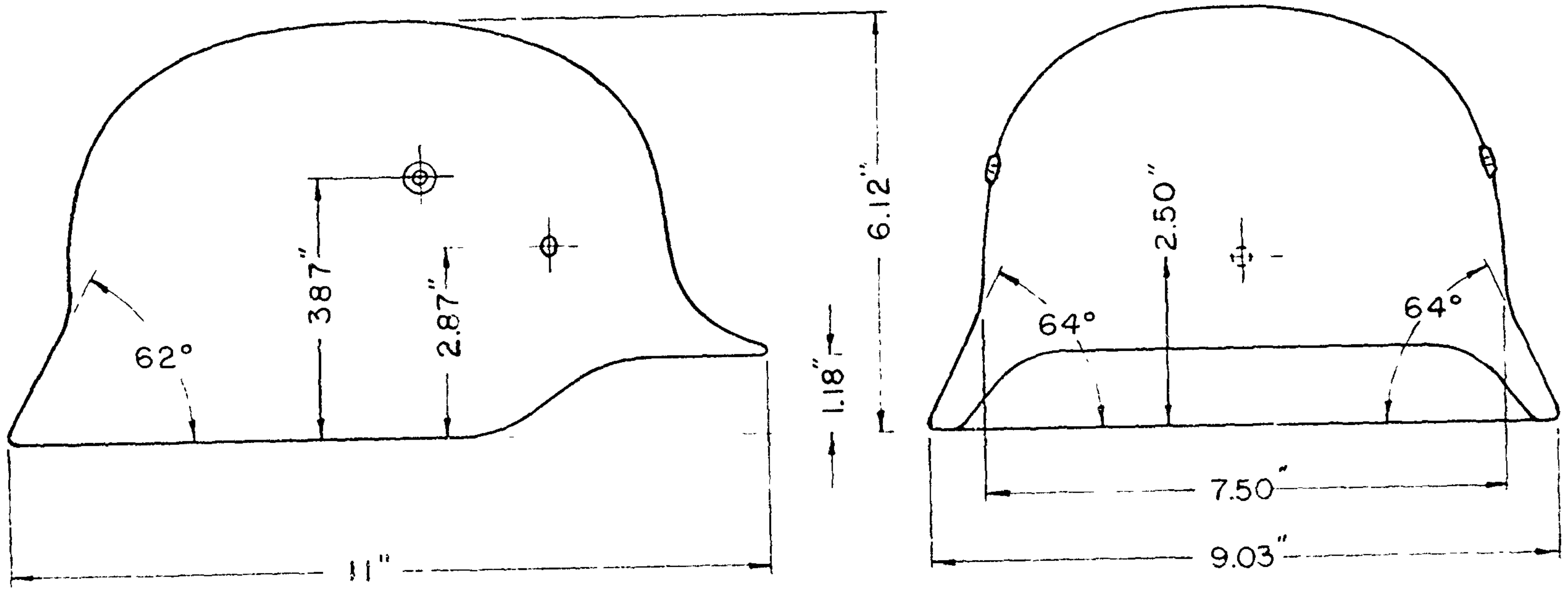
RIGHT SIDE VIEW

FRONT VIEW

GERMAN HELMET NO.2 – INFANTRY HELMET

SCALE $\frac{3}{8}$

FIGURE 6



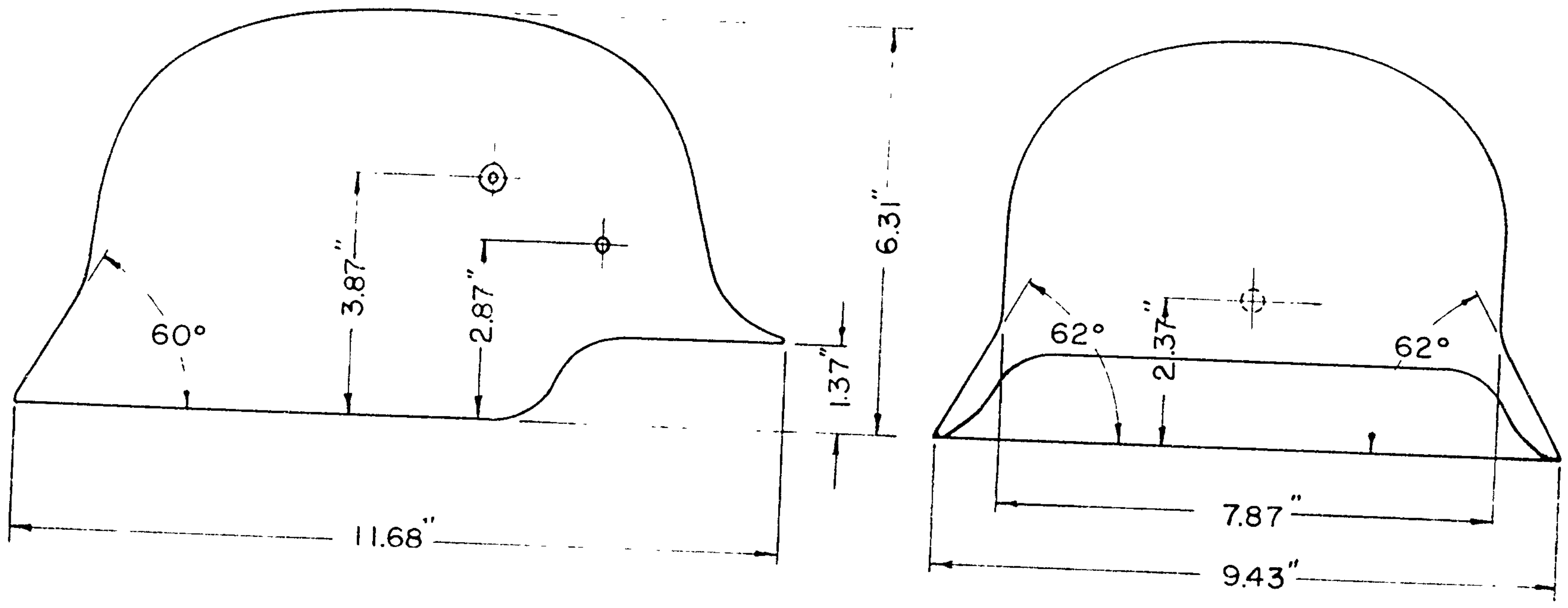
RIGHT SIDE VIEW

FRONT VIEW

GERMAN HELMET NO. 3 — INFANTRY HELMET

SCALE $\frac{3}{8}$

FIGURE 7



RIGHT SIDE VIEW

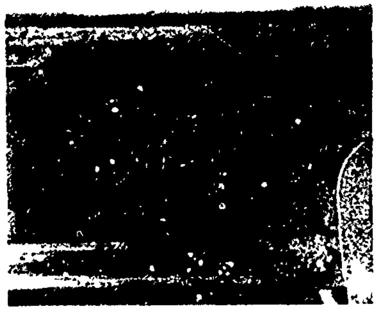
FRONT VIEW

GERMAN HELMET NO. 4 — INFANTRY HELMET

Figure 8

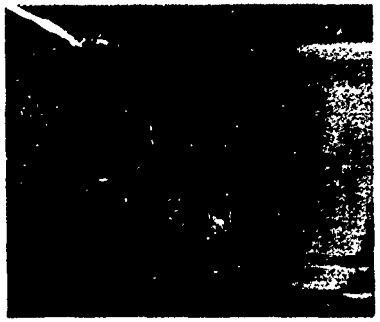
SCALE $\frac{3}{8}$

Manufacturer's Stampings on Metal Headbands of German Helmets

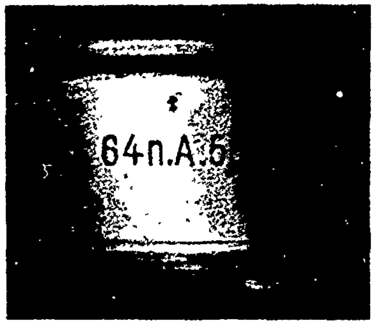


Helmet No. 43 -A-
Stamping on right side of steel headband.

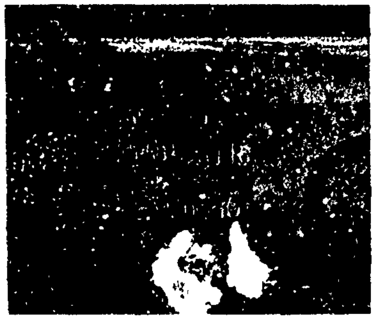
Helmet No. 43 -B-
Stamping on left side of steel headband.



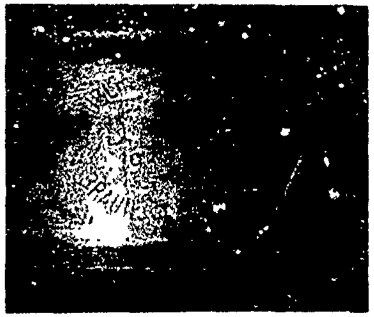
Helmet No. 10 -C-
Stamping on right side of aluminum alloy headband.



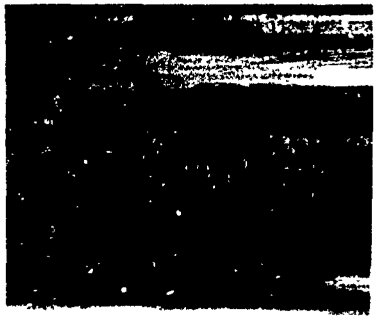
Helmet No. 10 -D-
Stamping on left side of aluminum alloy headband.



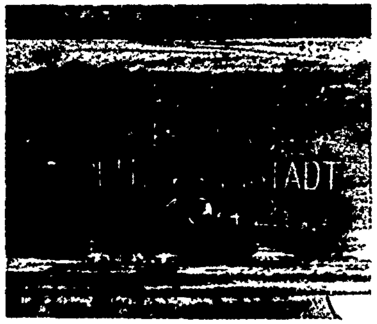
Helmet No. 4 -E-
Stamping on right side of aluminum alloy headband.



Helmet No. 31 -F-
Stamping on right side of aluminum alloy headband.



Helmet No. 28 -G-
Stamping on right side of steel headband.

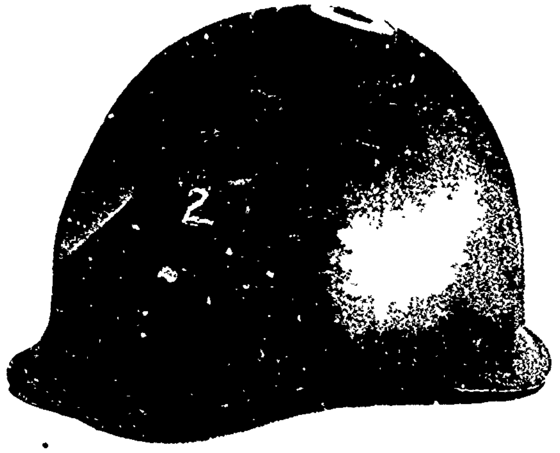


Helmet No. 19 -H-
Stamping on right side of steel headband.

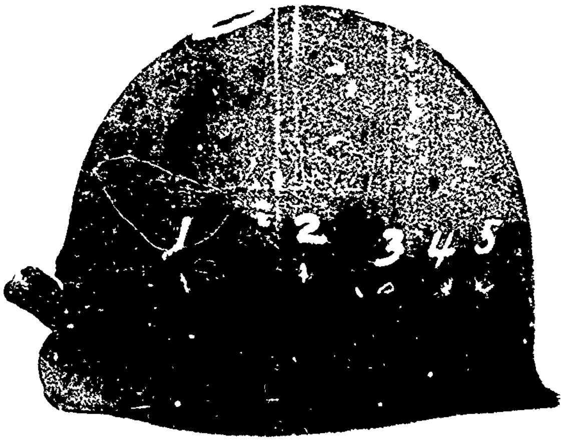
FIGURE 9

AMERICAN HELMETS AFTER BALLISTIC TESTING

American helmet No. I1. McCord Lot 5840. Tested with caliber .45 ball ammunition. Ballistic limit - 918 ft./sec. Complete penetrations result from the folding back of petals.



American helmet No. I5. McCord Lot 595E. Tested with caliber .45 ball ammunition. Ballistic limit - 948 ft./sec. Note ductile behavior.

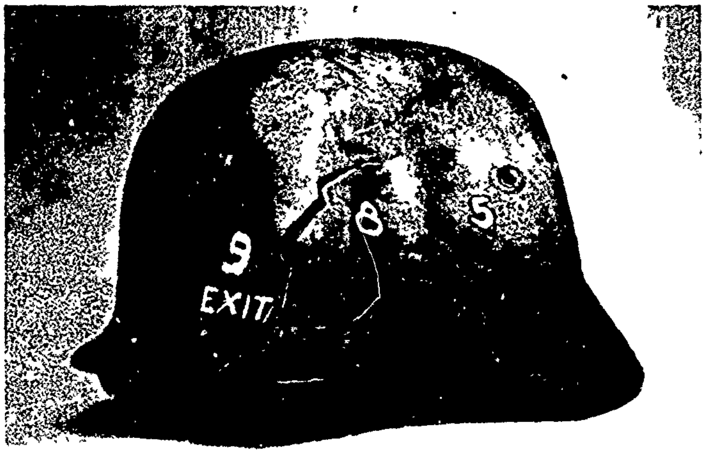


WTN.539-6.53

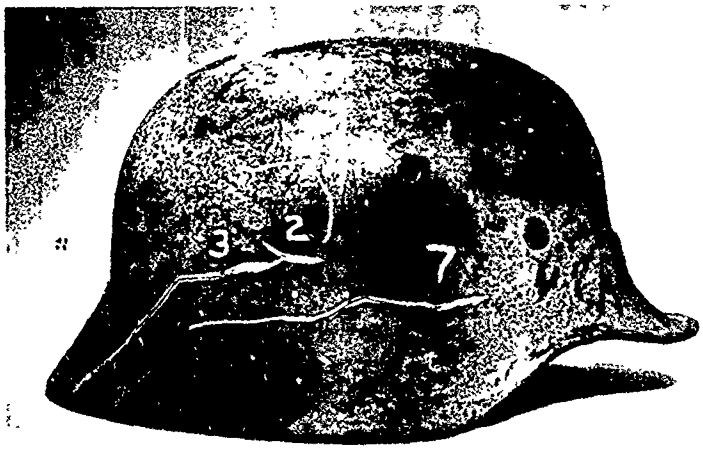
American helmet No. I2. McCord Lot 589A. Tested with 24 grain caliber .30 fragment-simulating projectile No. G-1-S. Ballistic limit-905 ft./sec. Ductile behavior typical of austenitic manganese steel.

GERMAN HELMETS AFTER BALLISTIC TESTING

German helmet No. 22. Tested with caliber .45 ball ammunition. Ballistic limit - 933 ft./sec. Complete penetrations break out pieces of the helmet in a brittle manner.



German helmet No. 12. Tested with caliber .45 ball ammunition. Ballistic limit - 1024 ft./sec. Crack caused by bullet entering through the back of the helmet and impacting the inside near the visor.



German helmet No. 8. Tested with 150 grain caliber .30 fragment-simulating projectile No. G-1-A. Ballistic limit - 388 ft./sec. Extensive cracking resulting from impacts producing partial penetrations.

FIGURE

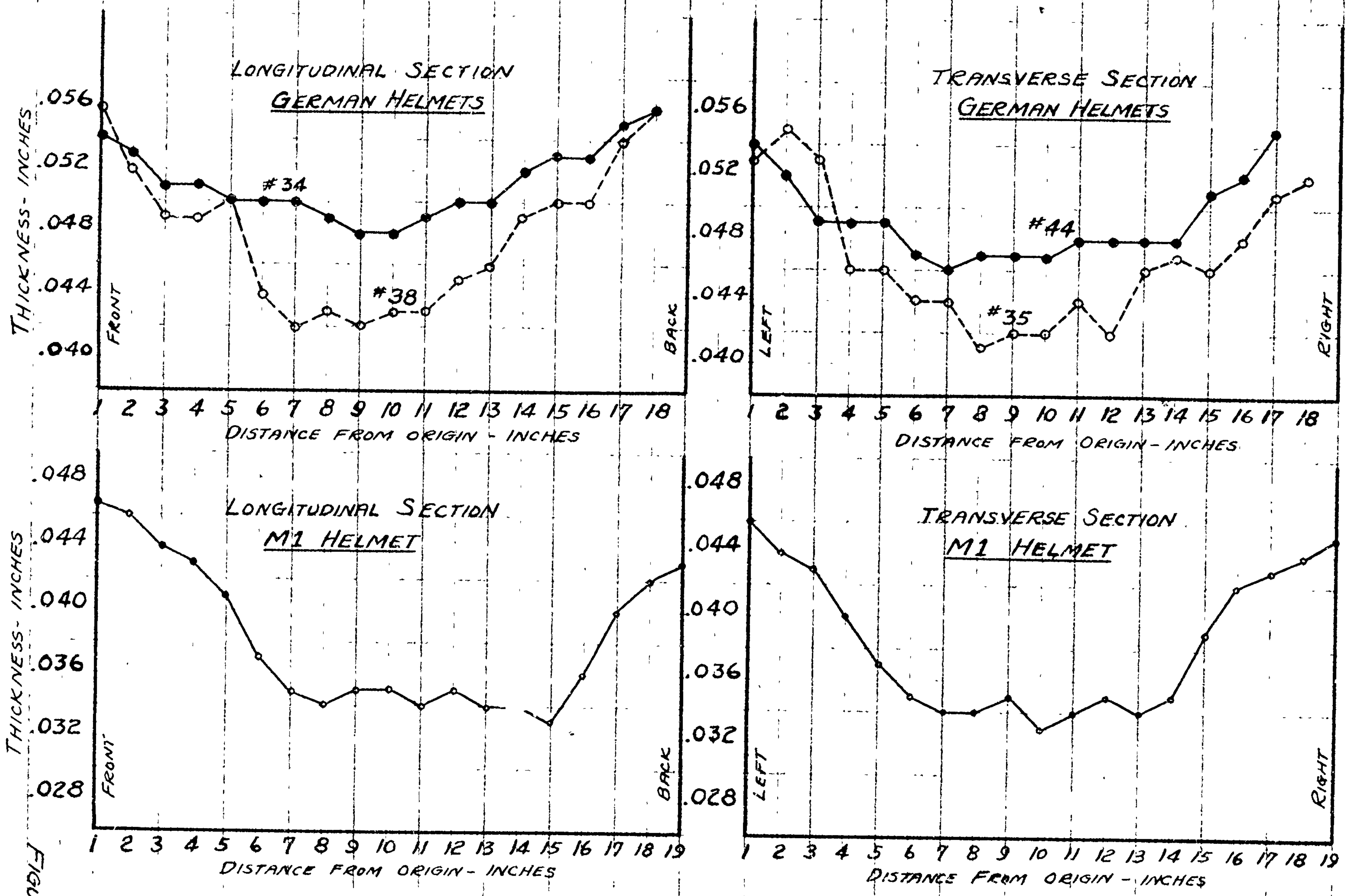
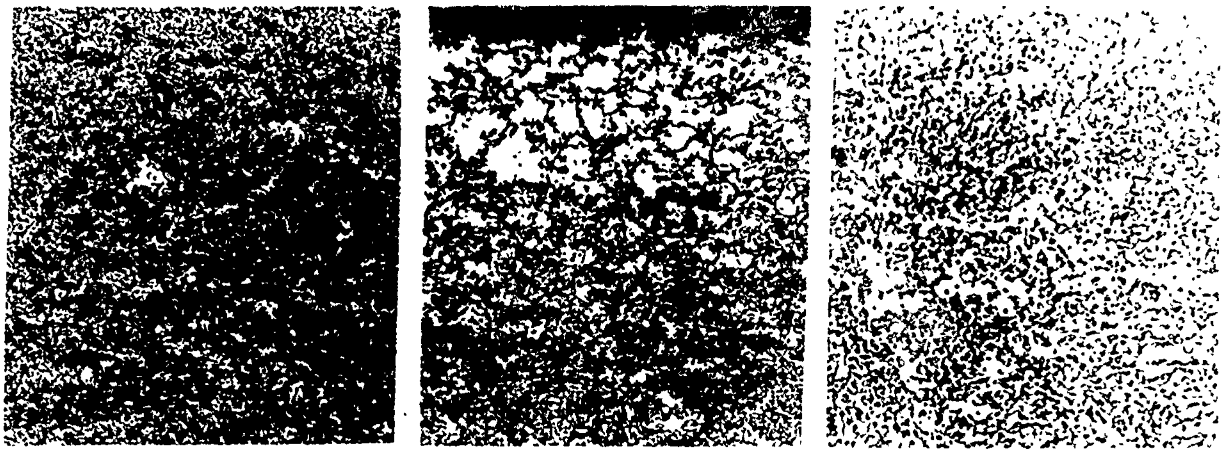


FIGURE 12

THICKNESS MEASUREMENTS OF SECTIONS OF GERMAN AND AMERICAN HELMETS

Microstructure of German Helmet No. 34

Picral Etch



-A- X200

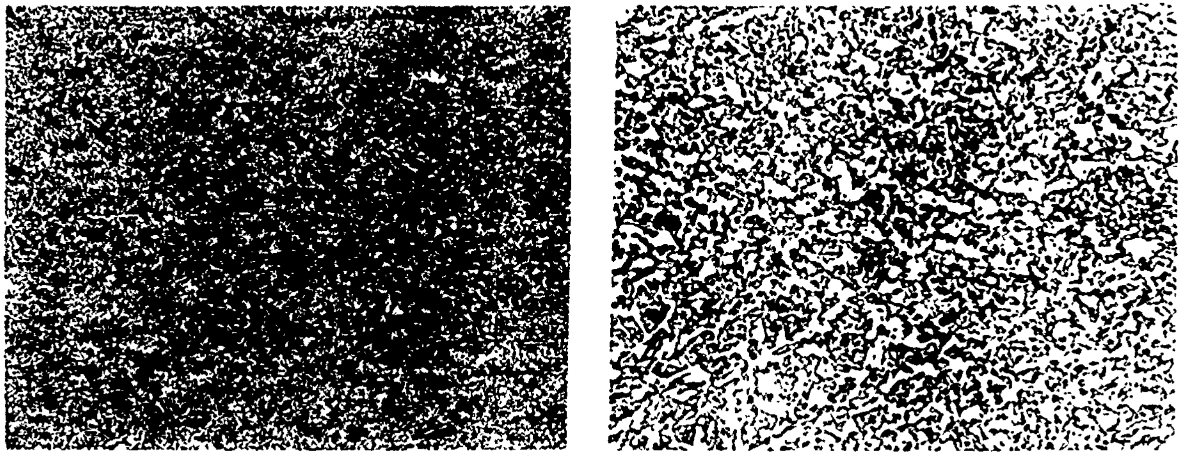
1" up from rim.

-B- X200

Decarburized surface.
Average depth - 0.007"
Hardness (on decarb. layer) - Rc 32.

-C- X1000

Martensite, undissolved carbides and ferrite.

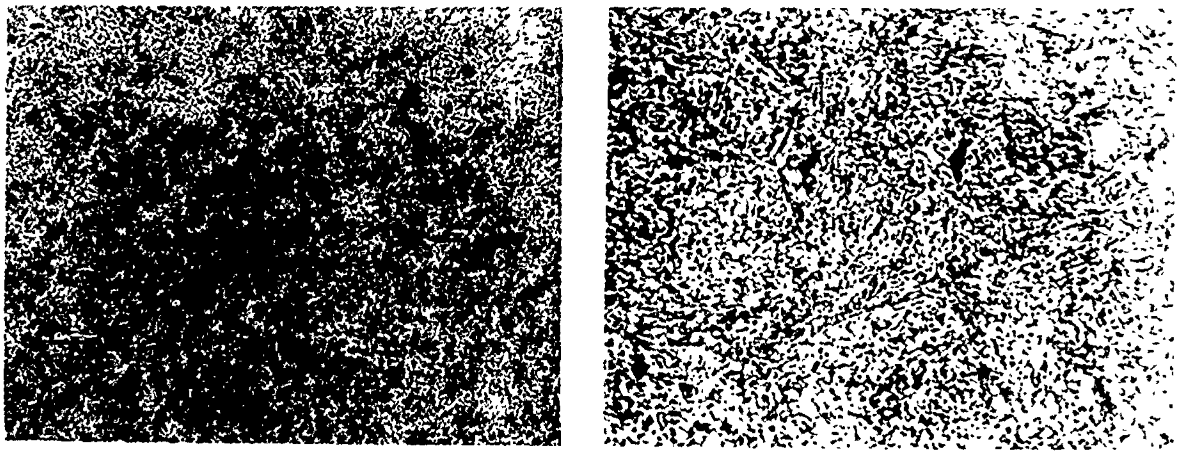


-D- X200

4½" up from rim.

-E- X1000

Martensite, undissolved carbides, and ferrite. Hardness - Rc 40.5.



-F- X200

9" up from rim. (top of crown)

-G- X1000

Completely martensitic microstructure.
Hardness - Rc 49.5

FIGURE 13

Microstructure of German Helmet No. 44

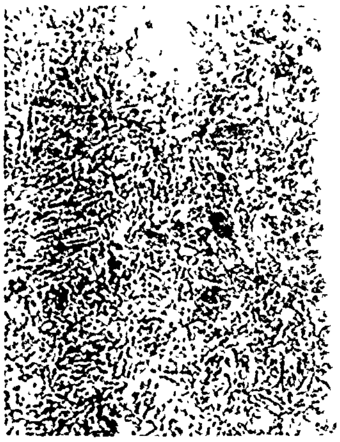
Picral

-A- X1000

1" up from rim.
Ferrite, carbides, and small amount of martensite. Hardness - Rc 16.

-B- X1000

4½" up from rim.
Ferrite, carbides, and martensite. Hardness - Rc 42.



-C- X

9" up from rim. (top of crown)
Martensite and ferrite. Hardness - Rc 53.5

-D- X1000

German Helmet No. 28. - 1" up from rim. Ferrite and carbides. Rc 11.0.

-E- X10C

German Helmet No. 10. - 1" up from ri
Ferrite, carbides and martensite. Rc 45.5.

-F- X1000

German Helmet No. 22. - 1" up from rim. Martensite, pearlite, and ferrite. Rc 49.

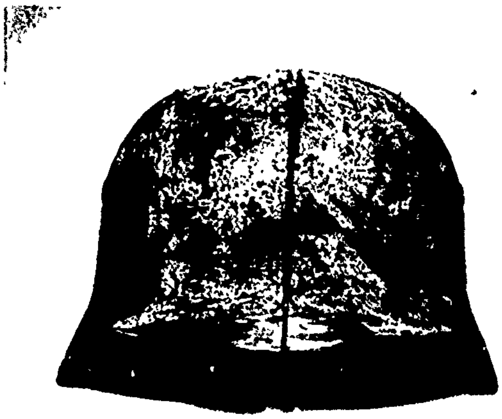
-G- X10C

German Helmet No. 8. - 1" up from rim. Martensite and carbides. Rc 51.

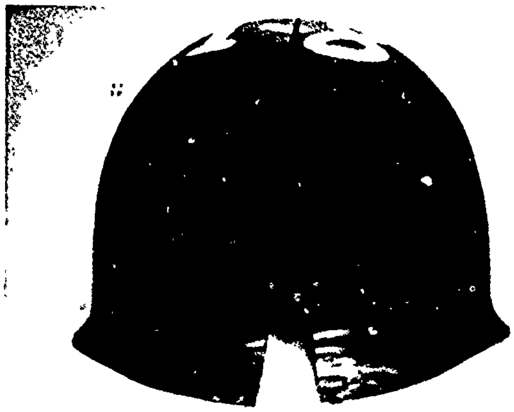
WTN.639-6912

FIGURE 14

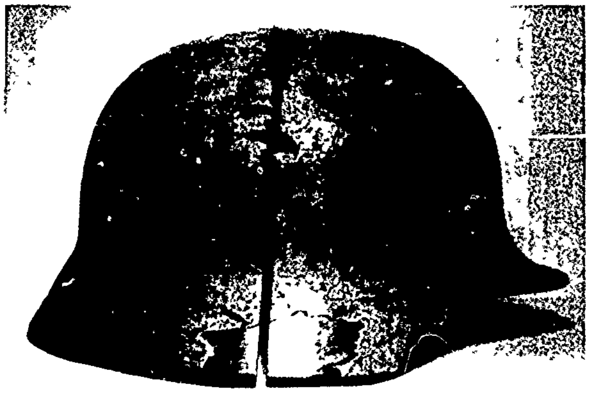
COMPARISON OF RESIDUAL STRESS CONDITIONS IN GERMAN AND AMERICAN HELMETS



German Helmet No. 23. Lateral displacement resulting from cutting from middle of visor to middle of crown is -0.057".

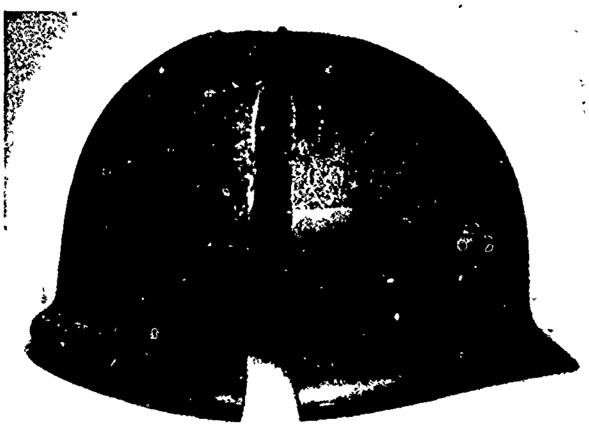


American Helmet. McCord Lot 596C. Lateral displacement resulting from cutting from middle of visor to middle of crown is +0.949".



German Helmet No. [illegible]. Lateral displacement resulting from cutting from middle of right side to middle of crown is +0.095".

WTN.639/1055



American Helmet. McCord Lot [illegible]. Lateral displacement resulting from cutting from middle of right side to middle of crown is +0.606".

FIGURE 15

APPENDIX A

Markings on Helmet Shells and Headband Components

Helmet No.	Stampings on Inside of Helmet Shell		Stamping on Headband		Date on Headband	Metal Used for Headband	Metal Used for Large Fasteners	Stamping on Large Fasteners
	Back	Left Side	*Right Side	Left Side				
1	5014	ET71	none	none	none	aluminum	steel	none
2	1710	ET66	*9F	$\frac{66n.A.}{58}$	1940	steel	steel	—
3	992	Q64	9F	$\frac{64n.A.}{58}$	1940	steel	brass	1KA 40
4	258	SE68	9E	$\frac{68n.A.}{60}$	1938	aluminum	brass	B.U.C. 38
5	1037	SE62	9F	$\frac{62n.A.}{55}$	obliterated	steel	steel	1KA 40
6	4756	ET64	9G	$\frac{64n.A.}{57}$	1940	aluminum	brass	D&C 1939
7	603	ET66	9E	$\frac{66n.A.}{58}$	obliterated	steel	steel	1KA 141
8	11633	EF64	9F	$\frac{64n.A.}{57}$	1940	steel	steel	-
9	1451	EF64	9G	$\frac{64n.A.}{56}$	1942	steel	steel	S↟C 1942
10	995	Q64	9C	64n.A.56	1938	aluminum	brass	B.U.C. 38
11	IN 179	C64	9F	$\frac{64n.A.}{56}$	1940	steel	steel	-

*The numbers refer to the figure numbers of the photographs of the various manufacturers' stampings shown in Figure 9.

Helmet No.	Stampings on Inside of Helmet Shell		Stamping on Headband		Date on Headband	Metal Used for Headband	Metal Used for Large Fasteners	Stamping on Large Fasteners
	Back	Left Side	Right Side	Left Side				
12	DN97	NS64	9G	$\frac{\text{64n.A.}}{57}$	1941	steel	steel	D&C 1941
13	DN194	Q64	9H	64n.A./56	1942	steel	steel	↟ S C 1942
14	IN172	062	9F	$\frac{\text{62n.A.}}{55}$	1940	steel	steel	↟ S C 1942
15	5085	EF66	9A	$\frac{\text{66n.A.}}{58}$	1941	steel	steel	↟ S C 1941
16	4711	EE62	9G	$\frac{\text{62n.A.}}{54}$	1941	steel	brass	—
17	22448	EF64	9F	$\frac{\text{64n.A.}}{56}$	1940	steel	steel	—
18	T473	Q62	9E	$\frac{\text{62n.A.}}{55}$	obliterated	steel	steel	—
19	5193	EF66	9H	66n.A./58	1942	steel	steel	D&C 1940
20	5920	NS64	9F	$\frac{\text{64n.A.}}{57}$	1940	steel	brass	—
21	21236	EF64	9C	64n.A./56	1940	steel	steel	D&C 1940
22	10019	SE62	9A	$\frac{\text{62n.A.}}{54}$	1941	steel	steel	1KA 41
23	3589	Q66	9F	$\frac{\text{66n.A.}}{59}$	1940	steel	brass	1KA 40

Helmet No.	Stampings on Inside of Helmet Shell		Stamping on Headband		Date on Headband	Metal Used for Headband	Metal Used for Large Fasteners	Stamping on Large Fasteners
	Back	Left Side	Right Side	Left Side				
24	159	Q66	9F	$\frac{66n.A.}{58}$	1940	steel	brass	1KA 40
25	5083	Q64	9F	$\frac{64n.A.}{57}$	1940	steel	steel	1KA 40
26	0089	EF64	9F	$\frac{64n.A.}{55}$	1940	steel	steel	—
27	3656	SF62	Headband Missing					
28	RC36	Q64	9G	$\frac{64n.A.}{56}$	1942	steel	steel	—
29	20762	EE64	9C	64n.A.57	1940	aluminum	brass	D&C 1939
30	722	EF62	9C	62n.A./55	1941	steel	steel	—
31	6146	NS66	9F	$\frac{66n.A.}{59}$	1939	aluminum	brass	WW 40
32	4290	SE66	9C	66n.A.59	1939	aluminum	brass	1KA 39
33	1402	SE62	9E	$\frac{62n.A.}{55}$	obliterated	steel	steel	↑ sc 1942
34	8218	NS64	9F	$\frac{64n.A.}{57}$	1940	steel	steel	WW 41
35	DN224	Q66	9H	66n.A./58	1942	steel	steel	—
36	1290	SE64	9C	64n.A.56	1939	aluminum	brass	1KA 39

Helmet No.	Stampings on Inside of Helmet Shell		Stamping on Headband		Date on Headband	Metal Used for Headband	Metal Used for Large Fasteners	Stamping on Large Fasteners
	Back	Left Side	Right Side	Left Side				
37	0067	EF62	9F	$\frac{62n.A.}{55}$	1940	steel	steel	—
38	932	Q64	9F	$\frac{64n.A.}{56}$	1940	steel	brass	1KA 40
39	D102	NS64	9G	$\frac{64n.A.}{57}$	1941	steel	2- steel 1- brass	—
40	5086	Q64	9F	$\frac{62n.A.}{55}$	1940	steel	steel	—
41	159	NS62	9F	$\frac{62n.A.}{55}$	obliterated	steel	steel	—
42	3317	SF64	9C	64n.A./57	1937	aluminum	brass	—
43	D119	NS64	9A	$\frac{64n.A.}{56}$	1941	steel	steel	—
44	none	Q62	9F	$\frac{62n.A.}{55}$	1940	steel	steel	T T
45	4760	ET64	9A	$\frac{64n.A.}{56}$	1940	aluminum	brass	1KA 39
46	DN184	Q64	9F	$\frac{64n.A.}{57}$	1940	steel	steel	—
47	910	EF62	Headband Missing					
48	8391	EE54	9A	$\frac{64n.A.}{57}$	1941	steel	steel	D&C 1940
49	6513	EF66	9A	$\frac{66n.A.}{59}$	1940	steel	steel	D&C 1940

Headbands Having Manufacturer's Stamping Shown in Figure 9A
"Metallwarenfabrik"

Helmet No.	Date of Manufacture	Metal Used for Headband
45	1940	aluminum
49	1940	steel
15	1941	steel
22	1941	steel
43	1941	steel
48	1941	steel

Total No. of Helmets - 6

Headbands Having Manufacturer's Stamping Shown in Figure 9C
"B&C, Berlin"

Helmet No.	Date of Manufacture	Metal Used for Headband
42	1937	aluminum
10	1938	aluminum
32	1939	aluminum
36	1939	aluminum
29	1940	aluminum
21	1940	steel
30	1941	steel

Total No. of Helmets - 7

Headbands Having Manufacturer's Stamping Shown in Figure 9E
"Schuberth-Werk"

Helmet No.	Date of Manufacture	Metal Used for Headband
4	1938	aluminum
7	obliterated	steel
18	obliterated	steel
33	obliterated	steel

Total No. of Helmets - 4

Headbands Having Manufacturer's Stamping Shown in Figure 9F
"Schuberth Werk"

Helmet No.	Date of Manufacture	Metal Used for Headband
31	1939	aluminum
2	1940	steel
3	1940	steel
5	obliterated	steel
8	1940	steel
11	1940	steel
14	1940	steel
17	1940	steel
20	1940	steel
23	1940	steel
24	1940	steel
25	1940	steel

26	1940	steel
31	1940	steel
34	1940	steel
37	1940	steel
38	1940	steel
40	1940	steel
41	obliterated	steel
44	1940	steel

Total No. of Helmets - 20

Headbands Having Manufacturer's Stamping Shown in Figure 9G
"Metall- Lederverarbeitung"

Helmet No.	Date of Manufacture	Metal Used for Headband
6	1940	aluminum
12	1941	steel
16	1941	steel
39	1941	steel
9	1942	steel
28	1942	steel

Total No. of Helmets - 6

Headbands Having Manufacturer's Stamping Shown in Figure 9H
"B&C, Litzmannstadt"

Helmet No.	Date of Manufacture	Metal Used for Headband
13	1942	steel
19	1942	steel
35	1942	steel

Total No. of Helmets - 3

Date of Manufacture of Headbands	No. of Headbands	Metal Used for Headbands
1937	1	aluminum
1938	2	aluminum
1939	3	aluminum
1940	3	aluminum
1940	19	steel
1941	8	steel
1942	5	steel

APPENDIX B

Ballistic Tests of German and American Helmets

Part A - Ballistic Tests of German Helmets

German Helmet No. 7

Projectile - caliber .30 soft steel
34 grain projectile #G-1-S

Round	Velocity Ft/sec.	Results	Round	Velocity Ft/sec.	Results
1	860	PP, SB	10	1175	PP, 1.1" crack on MB
2	1015	PP, MB	11	1120	PP, SB
3	960	PP, SB	12	1350	PTP, .3x.3" petal
4	1000	PP, SB	13	1120	PP, .5"x.5" petal
5	1190*	PP, 0.9" crack on MB	14	1110	PP, 2 - .5" cracks
6	1000	PP, SB	15	1140	PP, 1.1" crack
7	1050	PP, 0.95" crack on MB	16	1110	PP, CIP, 2 - .6" cracks
8	1015	PP, 0.6" crack on MB	17	1250*	PTP, .5 x .5" petal
9	1070	PP, 0.9" crack on MB			

Ballistic Limit - 1220 feet/sec.

German Helmet No. 7

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
18	lost	*285°, 3½" up from rim	PP - impacted at high obliquity near hole in side of helmet, causing 0.7, 0.3" cracks at hole.
19	992	0°, 3" up from rim	PP, Diam. of indent - 3.0"
20	1057	305°, 3" up from rim	PP, Diam. of indent - 2.0"
21	1048	Crown of helmet	PP, Diam. of indent - 3.5"
22	1060*	Crown of helmet	PP, Diam. of indent - 2.5"
23	1072*	Crown of helmet	PTP, 1.3" x 1.0" piece blown out

Ballistic Limit - 1066 feet/sec.

German Helmet No. 8

Projectile - caliber .30 soft steel
150 grain projectile, #G-1-A

Round	Velocity Ft/sec.	Results
1	445	PTP, 1.2x.5" piece blown out, 1.0" crack
2	300	PP, 0.7" horizontal crack
3	333	PP, hit 1" from #2, 2.6" crack between #2 and #3
4	455	PTP, 0.7 x 0.4" piece blown out
5	415*	PTP, 1.0 x 0.6" piece blown out
6	310	PP, 1.1" crack
7	360*	PP, 1.8" horizontal crack

Ballistic Limit - 388 feet/sec.

*Starting from the middle of the visor as 0° and proceeding clockwise around the circumference.

German Helmet No. 8

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
8	992*	355°, 3½" up from rim	PP, diam. of indent - 2.5"
9	1060	10°, 3" up from rim	PTP, 1.5 x 0.4" piece blown out, 1"crack
10	1022*	top of crown	PTP, 0.9 x 0.9" piece blown out

Cracks through previous rounds #2, 3, and 7 were lengthened by the subsequent impacts of the caliber .45 ball projectiles. Piece blown out at round #6 by later impacts on front of helmet. Very brittle behavior.

Ballistic Limit - 1007 feet/sec.

German Helmet No. 9

Projectile - caliber .30 soft steel
150 grain projectile, #G-1-A

Round	Velocity Ft/sec.	Results	Round	Velocity Ft/sec.	Results
1	585	PTP, 0.6 x 0.7" petal	7	400	PP, 1.0" crack
2	500*	FPTP, CIP, 1.7"horiz.crack	8	450	PP, disregard
3	275	PP, SB	9	392	PP, 1.0" horiz. crack
4	350	PP, SB, 1.0"horiz. crack	10	515*	PTP, 0.5x0.4" piece blown out
5	575	PTP, 0.8 x 0.5" petal	11	370	PP, 1.7" horiz. crack
6	455	PTP, hit #3, .5 x .4" piece blown out	12	455	FPTP, CIP

Ballistic Limit - 508 feet/sec.

German Helmet No. 9

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
13	883	340°, 4" up from rim	PP, diam. of indent - 2.5"
14	963	20°, 3½" up from rim	PP, diam. of indent - 2.5"
15	lost	Hit previous rounds #3, #4	PTP, 1.0 x 0.6" piece blown out
16	1046*	top of crown	PTP, 1.0 x 1.5" piece blown out
17	1004*	145°	PP, diam. of indent - 2.5"

Ballistic Limit - 1025 feet/sec.

German Helmet No. 10

Projectile - caliber .30 soft steel
34 grain projectile - #G-1-S

Round	Velocity Ft/sec.	Results
1	1070	CP, 0.4 x 0.3" piece blown out
2	1025*	FPTP, 3 cracks radiating from penetration
3	1040*	PTP, 0.6 x 0.6" piece blown out

Ballistic Limit - 1033 feet/sec.

German Helmet No. 10

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
4	866*	220°, 3½" up from rim	PP, diam. of indent - 2-3/4"
5	951	310°, 4½" up from rim	PTP both sides, 1.3 x 1.0" piece blown out, bullet emerged at 60°, folding back 2.5 x 1.5" petal
6	887*	260°, 4" up from rim	PTP, 1.8 x 1.1" piece blown out

Ballistic Limit - 878 feet/sec.

German Helmet No. 12

Projectile - caliber .30 soft steel
150 grain projectile - *G-1-A

Round	Velocity Ft/sec	Results
1	320	PP, SB
2	333	PP, SB
3	420*	PP, SB
4	485*	PTP, 1.4 x 0.6" petal folded back

Ballistic Limit - 453 feet/sec.

German Helmet No. 12

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
5	899	300°, 3-3/4" up from rim	PP - diam. of indent - 3"
6	lost	240°, 3½" up from rim	PP - diam. of indent - 3"
7	lost	15°, 3½" up from rim	PP - diam. of indent - 3"
8	1013*	325°, 3" up from rim	PP - diam. of indent - 2½"
9	1034*	170°, 3" up from rim	PTP - 1.7 x 1.5" piece blown out, bullet went through and struck front of helmet at 345°, 2" up from rim and caused 5" crack from round #8 to rim.

Ballistic Limit - 1024 feet/sec.

German Helmet No. 22

Projectile - caliber .30 soft steel
34 grain projectile - #G-1-S

Round	Velocity Ft/sec.	Results
1	1130*	FPTP, 3 - 1/2"cracks radiating from impact
2	1170*	PTP - 0.5 x 0.4" petal folded back

Ballistic Limit - 1150 feet/sec.

German Helmet No. 22

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
3	989	150°, 2½" up from rim	PP, hit at high obliquity, disregard
4	1037	230°, 3½" up from rim	PTP, 1.1 x 1.1" piece blown out bullet emerged through helmet at 55°, 2.0 x 1.3" piece folded back.
5	993	295°, 3½" up from rim	PTP, hit hole in helmet, 1.2 x 0.6" piece blown out
6	960	20°, 2" up from rim	PTP both sides of helmet, 1.5 x 1.0" piece blown out, bullet hit back of helmet at 180°, on drilled hole, causing 3 - 1½" cracks radiating from hole
7	944	235°, 2" up from rim	PTP, 1.3 x 1.5" piece folded back
8	922	top of crown	PP, diam. of indent - 3½"

Ballistic Limit - 933 feet/sec.

Part B - Ballistic Tests of American Helmets

American Helmet No. I1 (McCord Lot 584C)

Projectile - caliber .30 soft steel
34 grain projectile - #G-1-S

Round	Velocity Ft/sec.	Results	Round	Velocity Ft/sec.	Results
1	1110	PTP, .3 x .3" piece blown out	4	995	PTP, .3 x .4" piece folded back
2	970	PTP, .3 x .4" piece folded back	5	945*	PTP, .3 x .4" piece folded back
3	670	PP, SB	6	890*	FPTP, 0.9" crack

Ballistic Limit - 918 feet/sec.

American Helmet No. I1

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
7	893	0°, 3" up from rim	PTP, 1 x 1½" piece folded back
8	lost	40°, 2½" up from rim	PP, diam. of bulge - 4.0"
9	lost	90°, 3½" up from rim	PTP both sides of helmet
10	847*	295°, 3" up from rim	PTP, 1 x 1" petal folded back
11	lost	340°, 4" up from rim	PTP, 1.2 x 1.3" petal folded back
12	822*	295°, 1" up from rim	PP, diam. of bulge - 2"

Ballistic Limit - 835 feet/sec.

American Helmet No. 12 (McCord Lot 589A) Projectile - caliber .30 soft steel 34 grain projectile #G-1-S

Round	Velocity Ft/sec.	Results
1	910*	PTP, .4 x .4" petal folded back
2	690	PP, SB
3	710	PP, SB
4	925	PTP, .4 x .3" petal folded back
5	900*	FPTP, .8" crack through impact

Ballistic Limit - 905 feet/sec.

American Helmet No. 12 Projectile - caliber .45 ball (steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
6	893*	40°, 3½" up from rim	PP, diam. of bulge - 4"
7	916*	80°, 4" up from rim	PTP, both sides of helmets, 0.7 x 0.6" petal folded back

Ballistic Limit - 905 feet/sec.

American Helmet No. 13 (McCord Lot 594A) Projectile - caliber .30 soft steel 34 grain projectile, #G-1-S

Round	Velocity Ft/sec.	Results
1	815	PP, 0.2" crack on MB
2	750	PP, SB
3	900*	PTP, .4 x .3" petal folded back
4	870*	PP, 0.5, 0.3, 0.1" cracks through impact

Ballistic Limit - 885 feet/sec.

American Helmet No. 13 Projectile - caliber .45 ball (steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
5	lost	345°, 2½" up from rim	PP, diam. of bulge - 4"
6	949*	60°, 3" up from rim	PTP, both sides of helmet 1.0 x 0.5" petal folded back
7	893*	25°, 3½" up from rim	PP, 3" x 4" indent

Ballistic Limit - 921 feet/sec.

American Helmet No. I4 (McCord Lot 594B) Projectile - caliber .30 soft steel
150 grain projectile - #G-1-A

Round	Velocity Ft/sec.	Results	Round	Velocity Ft/sec.	Results
1	745	PP (small fragment G-1-S) accidently used	4	415	PP, 0.4" crack
2	515	PTP, .3 x .4" piece blown out	5	508	PTP, .6 x .5" petal folded back
3	420*	PP, .6 x .5" petal folded back	6	475*	PTP, .5 x .5" petal folded back

Ballistic Limit - 445 feet/sec.

American Helmet No. I4 Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
7	904*	20°, 3½" up from rim	PP, diam. of bulge 3½"
8	lost	355°, 3½" up from rim	PTP, 1 x 1" petal folded back
9	976	90°, 3½" up from rim	PTP, 1.2 x 0.6" piece blown out PTP both sides of helmets
10	950*	315°, 2½" up from rim	PTP, 2 - 1½" cracks through penetration

Ballistic Limit - 927 feet/sec.

American Helmet No. I5 (McCord Lot 595E) Projectile - caliber .30 soft steel
150 grain projectile, #G-1-A

Round	Velocity Ft/sec.	Results
1	465	PTP, .5 x .3" petal folded back
2	357	PP, SB
3	435*	PTP, .5 x .6" petal folded back
4	420*	FPTP, 2.1" crack through impact

Ballistic Limit - 428 feet/sec.

American Helmet No. I5 Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
5	lost	20°, 4" up from rim	PP, diam. of indent - 4-1/4"
6	969*	335°, 4" up from rim	PTP, 1.0 x 0.6" petal folded back
7	927*	310°, 2½" up from rim	PP, diam. of indent - 4"

Ballistic Limit - 948 feet/sec.

American Helmet No. 16 (McCord Lot 595A)

Projectile - caliber .30 soft steel
150 grain projectile, #G-1-A

Round	Velocity Ft/Sec.	Results
1	430*	PTP, 0.3 x .5" piece blown out
2	485	PTP, 0.5 x .4" piece bent back
3	370*	PP, SB

Ballistic Limit - 400 feet/sec.

American Helmet No. 16

Projectile - caliber .45 ball
(steel jacketed projectile)

Round	Velocity Ft/sec.	Location of Impact	Results
4	lost	0°, 3½" up from rim	FP, diam. of indent - -½"
5	939*	75°, 3½" up from rim	PP, diam. of indent - 4"
6	964*	325^{c}, 3" up from rim	1.0 x 0.7" petal folded back

Ballistic Limit - 952 feet/sec.

APPENDIX C

Weights of Helmets and Helmet Shells

Weights of German Helmets

Helmet No.	*Weight As-Received Grams	Weight of Helmet Shell Grams	Helmet No.	Weight As-Received Grams	Weight of Helmet Shell Grams
1 (Paratrooper)	1692	1029	19	1418	1138
2	-	1238	20	1359	1087
3	1378	1060	21	1254	984
4	1349	1122	22	1311	1064
5	1291	1033	23	1390	1104
6	1179	971	24	1285	1003
7	1399	1145	25	-	1166
8	1353	1112	26	-	1114
9	1368	1119	27	-	966
10	1312	1096	28	-	1238
11	1372	1031	29	-	985
12	1327	1074	30	-	1036
13	1385	1111	31	-	1064
14	1368	1014	32	-	1116
15	1401	1151	33	-	1029
16	1255	1010	34	-	1185
17	1404	1158	35	-	1109
18	1346	1089	36	-	1030

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*Only helmets which were complete with headbands, leather linings, and chin straps were weighed in the as-received condition.

Helmet No.	Weight As-Received Grams	Weight of Helmet Shell Grams	Helmet No.	Weight As-Received Grams	Weight of Helmet Shell Grams
37	-	1168	44	-	1108
38	-	1112	45	-	981
39	-	1085	46	-	1104
40	-	1192	47	-	993
41	-	1054	48	-	1169
42	-	1031	49	-	1256
43	-	1090			

Average weight of 21 complete helmets - 1340 ± 49 grains (47.3 ± 1.7 ounces)
Average weight of 49 helmet shells - 1088 ± 58 grains (38.4 ± 2.0 ounces)

Weights of American Helmets

Weights of Helmet Shells (with chinstraps) Grams	Weight of Liner Grams
1050	255 (9.0 ounces)
1072	
1060	
1064	
1076	
1049	
1058	
Average - 1061 ± 8 grams (37.4 ± 0.3 ounces)	

APPENDIX D

Dimensions of Headband Components of German Helmets

Dimensions of Headband Components of German Helmets

Steel Components

Outer Headbands

Helmet No.	Mfgr.	Date of Mfg.	Thickness - Inches
11	Schuberth-Werk	1940	.019
24	Schuberth-Werk	1940	.020
25	Schuberth-Werk	1940	.019
30	B&C Berlin	1941	.019
37	Schuberth-Werk	1940	.019

Inner Headbands

Helmet No.	Thickness - Inches	Width - Inches
11	.010	1.38
24	.010	1.38
25	.010	1.38
30	.010	1.38
37	.0095	1.38

Aluminum Alloy Components

Outer Headbands

Helmet No.	Mfgr.	Date of Mfg.	Thickness - Inches
4	Schuberth-Werk	1938	.027
10	B&C Berlin	1938	.027
29	B&C Berlin	1940	.027
31	Schuberth-Werk	1939	.027
36	B&C Berlin	1939	.027

Inner Headbands

Helmet No.	Thickness - Inches	Width - Inches
4	.015	1.38
10	.015	1.38
29	.015	1.38
31	.015	1.38
36	.015	1.38

Springs

Helmet No.	Thickness - Inches	Width - Inches
3	.011	0.57
11	.010	0.57
24	.0095	0.57
25	.009	0.57
29	.010	0.57
30	.011	0.57
31	.010	0.57
37	.010	0.57

APPENDIX E

Correspondence

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Bird/mdl
Ext. 5845

WAR DEPARTMENT
OFFICE OF THE CHIEF OF ORDNANCE
WASHINGTON, D. C.

Wtn 386.3/52
0.0.386.3/690
Attn: SPOTS

23 November 1943

Subject: German Helmets

To: Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attn: Major Matthews

1. Fifty (50) captured German helmets have been obtained from Intelligence Division, Army Service Forces, and are forwarded from New York direct to your Arsenal.

2. It is requested that upon receipt of these helmets, studies be made of the ballistic, metallurgical, and strain characteristics of the steel used in their construction and that they be analyzed for other physical characteristics for comparison with the Ml Helmet.

By order of the Chief of Ordnance:

(S/T) Rene' R. Studler
Colonel, Ord. Dept.
Assistance

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Wtn 386.3/54
O.O.386.3/711
Attn: SPOIS

1st Ind.

Matthews/anv

C.O., Army Service Forces, Ord. Dept., Watertown Arsenal, Watertown 72, Massachusetts, 15 December 1943.

To: Chief of Ordnance, Pentagon Bldg., Washington 25, D. C.
Attn: SPOIS

1. As requested in basic letter, two (2) captured German helmets are being returned to his office today as per shipping order, SAD 3452, dated 7 December 1943.

For the Commanding Officer:

G. L. COX
Lt. Col., Ord. Dept.
Assistant

1 Incl. w/d
SAD 3452 (in trip.)

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