

AD-A954 828

DTIC ACCESSION NUMBER

LEVEL

LEVEL

PHOTOGRAPH THIS SHEET

INVENTORY

INVENTORY

WAL 710/794

DOCUMENT IDENTIFICATION

15 MAR 1946

This document has been approved for public release and sale; its distribution is unlimited.

DISTRIBUTION STATEMENT

ACCESSION FOR

NTIS GRA&I

DTIC TAB

UNANNOUNCED

JUSTIFICATION

per lti

BY

DISTRIBUTION /

AVAILABILITY CODES

DIST

AVAIL AND/OR SPECIAL

A-1

DISTRIBUTION STAMP

UNANNOUNCED



DATE ACCESSIONED

DATE RETURNED

DATE RETURNED

REGISTERED OR CERTIFIED NO.

REGISTERED OR CERTIFIED NO.

85 808 072

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDAC

UNCLASSIFIED

WATER TOWN  
Cy # 2a

AD-A954 828



WATERTOWN ARSENAL  
LABORATORY

464/014  
7/10/44

EXPERIMENTAL REPORT

NO. WAL. 710/754

HELMETS

Investigation of Helmets Conducted at Watertown Arsenal

1940-1945

BY  
A. Hurlich  
Metallurgist

UNCLASSIFIED

DATE 15 March 1946

WATERTOWN ARSENAL  
WATERTOWN, MASS.

~~CONFIDENTIAL~~  
UNCLASSIFIED

Watertown Arsenal Laboratory  
Report No. WAL 710/794  
Project B-7

15 March 1946

HELMETS

Investigation of Helmets Conducted at Watertown Arsenal

1940-1945

OBJECT

To summarize the problems under Project B-7.

SUMMARY

This report summarizes the investigation conducted at the Watertown Arsenal during the period 1940-1945 in connection with the development and manufacture of helmets for the American army. After the standardization of the M1 helmet numerous production problems arose that required extensive laboratory research and experimentation for their solutions. A Helmet Industry Integration Committee was organized to focus the attention of all interested Ordnance and industry personnel upon the solution of specific problems.

The Watertown Arsenal Laboratory was responsible for the development of a specification to control the quality of the Hadfield manganese steel purchased for the helmet application, and aided in the development of the edge annealing process which was successfully applied to stress relieve helmets after the deep drawing operation.

Metallurgical and ballistic programs associated with the development of a superior helmet and with the investigation of helmets employed by the armies of foreign nations are also summarized.

*A. Hurlich*  
A. HURLICH  
Metallurgist

APPROVED:

R. C. LEECH  
Capt., Ord. Dept.  
Acting Director of Laboratory

UNCLASSIFIED

The production of military materiel in the United States was so vastly expanded after our entry into World War II that it became necessary to institute alloy conservation programs so that stock piles of scarce and strategic alloying elements could be most effectively employed. Although the possibility of a shortage of manganese was never imminent it was considered advisable to investigate substitute low alloy steels in case high manganese steels became unprecureable. These investigations were initiated as early as October 1940 and continued until July 1942 when it was definitely decided that the nonmagnetic requirements for the American helmet would not be relaxed and that low alloy magnetic steels would not be considered for the helmet application.

In the beginning of 1941 a helmet of completely new design was accepted as standard equipment by the Army and immediate production of the new item, designated Helmet, Steel, M1, was begun. A large number of production problems concerning both the steel employed for helmets and the helmet manufacturing processes arose and were brought to the attention of the Watertown Arsenal Laboratory by the Office, Chief of Ordnance. The solution of these problems involved an extensive series of investigations and the formation of a Helmet Industry Integration Committee for the purpose of accumulating and disseminating information of interest to the helmet steel and helmet manufacturers.

The most recent investigations concerned with helmets relate to the development of a helmet and a helmet liner involving new designs and different materials in an attempt to develop a helmet of improved ballistic characteristics as compared to the M1.

Helmets used by the armies of the following countries were submitted to the Watertown Arsenal Laboratory for metallurgical and ballistic testing:

Germany  
Japan  
France  
Czechoslovakia  
The Netherlands  
Irish Free State

The following is an account of the various investigations of helmets and helmet materials which have been conducted at the Watertown Arsenal Laboratory from 1940 up to the time of writing of this report.

#### I. Investigation of Substitute Low Alloy Steels

Beginning in October 1940, the Watertown Arsenal Laboratory undertook the procurement and testing of a large number of heat treatable alloy steels for possible use in helmets. These steels were obtained from the manufacturers in the form of sheets varying from 0.035" to 0.045" in thickness and were subjected to a series of experimental heat treatments and ballistic tests at Watertown Arsenal. The need for a cooperative research and development program in which steel manufacturers, helmet manufacturers, and Ordnance agencies would participate became apparent and a number of companies were approached regarding the formation of a Subcommittee for Aircraft Armor and Helmet Steels.

The first meeting of the Subcommittee was held at Watertown Arsenal on 14 February 1941. Due to the large number of participating companies, of which some were interested only in aircraft armor and others only in helmets, it was decided to divide the group into two separate Subcommittees of which one was the Subcommittee for Helmet Steels and Body Armor. Lt. Col. S. B. Ritchie, Director of Laboratory at the Watertown Arsenal was named Chairman of the Subcommittee, and Mr. P. L. Barter, Vice-President, McCord Radiator and Manufacturing Co. was named Industrial Vice-Chairman of the Subcommittee. The following ten companies were represented in the Subcommittee:

American Rolling Mill Co.	-	Middletown, Ohio
Aluminum Co. of America	-	New Kensington, Pennsylvania
Carnegie-Illinois Steel Corp.	-	Chicago, Ill.
Eastern Rolling Mill Co.	-	Baltimore, Md.
Great Lakes Steel Corp.	-	Detroit, Mich.
Ingersoll Steel & Disc Div. of Borg-Warner Corp.	-	New Castle, Ind.
Jessop Steel Corp.	-	Washington, Pennsylvania
McCord Radiator & Mfg. Co.	-	Detroit, Mich.
Simonds Saw & Steel Co.	-	Fitchburg, Mass.
Youngstown Sheet & Tube Co.	-	Youngstown, Ohio

Of these ten companies, the McCord Radiator & Mfg. Co. was the sole manufacturer of helmets and the Carnegie-Illinois Steel Corp. the sole producer of the Hadfield manganese steel used first for the M1917 helmet and later for the M1 helmet. The remaining eight companies produced heat treatable alloy steels or aluminum alloys in sheet form.

A cooperative research and development program was set up to investigate and develop helmet steels containing minimum amounts of strategic alloying elements and having good formability and high ballistic properties. Between February and October 1941 a total of 120 samples of helmet steels representing 15 different compositions were tested at the Watertown Arsenal. Tests included preliminary heat treatments and ballistic tests on flat sheets, forming tests, ballistic tests on formed and heat treated helmets of promising compositions, hardness and thickness surveys of formed helmets, and metallographic examination. A summary of some of these tests is contained in Table I. Certain of the compositions possessed optimum ballistic properties in the austempered condition while others possessed good ballistic properties in the air hardened condition. The data obtained at the Watertown Arsenal Laboratory were transmitted to the various members of the Subcommittee.

The second and final meeting of the Subcommittee for Helmets and Body Armor was held in Washington, D. C. in October 1941 at which time it was announced that the requirement for a nonmagnetic helmet steel would not be relaxed and that consequently heat treatable magnetic steels would not be considered for use in helmets. Experimental work on magnetic steels continued, however, until July 1942 when the Office, Chief of Ordnance notified this arsenal to suspend investigation of magnetic steels. In October 1942 the Armor Subcommittees were reorganized and the Subcommittee for Helmets and Body Armor was disbanded.

A considerable amount of work was performed at this arsenal upon two heat treatable low alloy steels, both of which are considered satisfactory substitutes for Hadfield manganese steel in the M1 helmet. These steels are NAX 9120<sup>2</sup>, a low carbon, low alloy Si-Cr-Mo-Zr alloy manufactured by the Great Lakes Steel Corp. and Amola<sup>3</sup>, a high carbon, low alloy molybdenum bearing steel produced by the American Steel and Wire Co. Since, however, these steels are magnetic they were never considered for use in production.

## II. Problems Associated with the M1 Helmet

A helmet of new design developed by the Infantry Board was presented at the Feb. 1941 meeting of the Subcommittee for Helmet Steels and Body Armor. The helmet consisted of a deep drawn shell capable of covering a much greater portion of the head than the old M1917 helmet, compare Figures 1 and 2. A radical innovation in helmet design consisted of having the suspension fitted into a stiff plastic liner of the same shape as the helmet and fitting snugly into it. The liner could be worn either separately as a field hat or covered by the steel helmet when in combat areas. The steel helmet was considered strengthened by the fact that since the suspension was attached to the liner, no rivet holes or other points of weakness were required in the body of the helmet shell.

The McCord Radiator and Manufacturing Co. was at that time the sole company in the United States engaged in producing helmets for the Army and was in the process of manufacturing large numbers of the M1917 helmet. The McCord plant accepted a development contract to produce the new style helmet; the first group of which was made in March 1942. The production of the M1917 helmets continued until September 1942 after which time only the new M1 helmet was produced.

Serious production difficulties attended the manufacture of the M1 helmet from the very beginning. The magnitude of these difficulties is illustrated in the following paragraph extracted from a letter from the Office, Chief of Ordnance, to the Office of the Quartermaster General:

"Manufacture of helmets connected with the present war commenced with the production of the M1917 'Dishpan' type in February 1941. The M1 'Pot' helmet was adopted by the Army in the summer of 1941 and the change over in production took place in September of that year. This change presented a serious manufacturing problem in the combination of the deep straight sided pot shape, the limitation that only Hadfield manganese steel might be used, and a limitation on blank thickness in order to be within a maximum finished weight limit. Notwithstanding the experience of the McCord Radiator & Manufacturing Company in manufacturing a million of the M1917 helmets, breakage in the drawing and forming operations of the new type averaged 30% during manufacture of the first 200,000 helmets. This percent of breakage was progressively decreased through the continued study and experience of McCord, and the assistance of the Carnegie-Illinois Steel Company, until it leveled off at an average of slightly less than 2%, which may be considered better than normal with the problems involved."

The Watertown Arsenal Laboratory was not involved in any problems concerned with the M1 helmet until October 1941 at which time samples of flat helmet stock from various lots of steels exhibiting good, average, and poor formability were forwarded to this arsenal from the McCord plant for metallurgical examination. It was concluded that stringers of undissolved carbides and grain boundary segregations of carbides resulting from inadequate heat treatment were responsible for the poor forming characteristics of the submitted samples. Hadfield manganese steel exhibits excellent ductility and formability only when the structure is completely austenitic. This information was also transmitted to the Carnegie-Illinois Steel Corp., the manufacturer of helmet steel.

In February 1942 this arsenal was requested to investigate the possibility of using a nondestructive magnetic test to differentiate between helmets of satisfactory and unsatisfactory ballistic properties. It had been brought to the attention of the Office, Chief of Ordnance, that a magnetic test was being used by the Canadians as an inspection test in the manufacture of the British type helmet. It was concluded as the result of investigations conducted at this arsenal that it is not possible to devise a magnetic test which will distinguish in all cases between helmets having different ballistic properties. A sensitive magnet placed a few inches away from a helmet was found capable of picking out those which are badly decarburized. Inadequate heat treatment which results in the presence of undissolved carbides was found to greatly lower the ballistic resistance of Hadfield manganese steel without affecting, however, the magnetic properties of the material.

This arsenal was not subsequently consulted until April 1943 when the Office, Chief of Ordnance, directed this laboratory to investigate the cause of helmet cracking which occurred during service at Camp Livingstone, La. Further reports of service cracking of helmets were received from other Army posts in this country and from the North African theatre of operations. Of 245,000 helmets which had been examined prior to May 1943 at seven Army posts in this country and in Africa, a total of 6,062, or 2.5% were found defective due to cracking which occurred after the helmets were issued. Several hundred cracked helmets were subsequently returned to the McCord Radiator and Manufacturing Company where they were examined for the number and the locations of the cracks. Groups of approximately 100 helmets each, one of which was returned from Camp Pickett, Va. and one from North Africa were forwarded to this Arsenal from the McCord plant for metallurgical examination.

The Watertown Arsenal was requested to send a metallurgist to the McCord plant to observe the helmet manufacturing processes and to outline with personnel from the McCord plant and the Detroit Ordnance District a cooperative program covering the investigation of the factors responsible for service cracking. Early in the course of the investigation of the cracked helmets, it became apparent to this laboratory that an intimate correlation must exist between the service cracking of helmets and the breakage which occurs during manufacture. It was reasonable to assume that possibly milder degrees of the same factors responsible for production breakage were also responsible for the cracking which occurred in service. Although nothing could be done to alleviate the cracking of helmets already issued to the troops, the causes of such cracking had to be determined immediately in order to institute the proper corrective measures to prevent the subsequent cracking of current production helmets.

Early in 1943 two new companies entered the helmet field, the Schlueter Manufacturing Company of St. Louis, Missouri undertook the manufacture of helmets and the Sharon Steel Corp. of Sharon, Pa. the manufacture of Hadfield manganese steel helmet stock. Although all of the service cracking was initially found to have occurred in helmets which had been produced by the McCord Radiator and Manufacturing Company during the period prior to September 1942, it was considered advisable to investigate the products of both helmet producers and both helmet steel manufacturers. The first two groups of samples investigated comprised 65 samples of satisfactory and defective helmets and helmet steel submitted by the Schlueter Manufacturing Company and 86 samples of similar material submitted by the McCord Radiator and Manufacturing Company. Various other groups of helmets and helmet steel were subsequently forwarded to this arsenal for metallurgical examination. The results of these investigations were reported to the interested agencies in a series of Watertown Arsenal Laboratory Memorandum Reports 5,6,7.

The results of the examination of numerous lots of helmets and helmet steel indicated a close relationship between production breakage and the following factors:

1. Steel Quality Factors

- a. Surface decarburization resulting in the formation of surface layers of martensite.
- b. Streaks of globular carbides resulting from insufficient time at the austenitizing temperature for complete carbide solution.
- c. Grain boundary segregations of carbides resulting from too low austenitizing temperatures.
- d. Martensite streaks below the surface of the sheets resulting from residual ingot piping.

2. Helmet Fabrication Factors

- a. Severity of cold working as manifested by residual stresses and hardnesses developed.
- b. Stress-raising notches at the edge of the helmet produced by nicks in the trimming dies.
- c. Condition of the dies: roughness, alignment, cleanliness, lubrication, etc.
- d. Effect of variation in gage thickness of helmet stock upon the hold-down force and the severity of cold working.

Up to the time that this arsenal was consulted regarding the service cracking of helmets, Specification AXS-645 (Rev. 1), "Helmet, Steel, M1" covered the purchase of the steel and the fabrication and assembly of the helmet. The only requirements as to steel quality consisted of a magnetic test and a 180° cold bend test. The magnetic test consisted of determining whether a sensitive compass placed  $2\frac{1}{2}$  inches away from the helmet would be deflected. This test was too insensitive to be capable of detecting surface decarburization unless the decarburization was extremely severe, in which case the helmet would most likely have been broken in the drawing operation and consequently would never reach the stage where the magnetic test would be applied. The 180° cold bend test was found to provide a good check on steel quality and is a satisfactory criterion of the formability of the helmet steel. The 180° bend test was not, however, applied by the helmet fabricators to check the quality of the steel delivered to them and was applied neither often enough nor rigidly enough by the steel producers to lead to the rejection of sufficient quantities of the steel possessing inferior formability.

Since the helmet fabricators could exercise no control over the steel quality factors previously listed, it became obvious that a specification covering the steel used for helmets should be developed. A draft of a specification incorporating the opinions of this laboratory was prepared and submitted to the Office, Chief of Ordnance on 17 September 1943. After various recommendations and suggestions offered by the Office, Chief of Ordnance, the steel mills, and the helmet fabricators, were incorporated in the original draft, Specification AXS-1170, "Steel, Nonmagnetic, Sheet and Strip (for Body Armor and Helmets)", was invoked on 25 March 1944 to cover the quality of the steel being used for helmets and body armor components.

A series of tests designed to accept only that steel which may be expected to perform satisfactorily when drawn into helmets were incorporated into the specification. These tests consist of a magnetic test developed at this arsenal, microscopic examination of samples selected at random from the material being tested, a 180° bend test which was a part of the former helmet specification, and a ballistic test of selected samples.

The magnetic test consists of placing a small sample of the Hadfield manganese steel being tested against the poles of a small, horizontally suspended Alnico magnet and pulling the magnet away from the vertical along the arc of a circle whose radius is the length of the thread from which the magnet is suspended, see Figure 3. This magnetic test is capable of readily and simply distinguishing between manganese steel free from surface decarburization and steel which is decarburized. As explained in the Footnote on page 1, Hadfield steel is austenitic when quenched from elevated temperatures because of the presence of the austenite phase promoters, carbon and manganese. At the very high temperatures employed during heat treatment, Hadfield steel is very susceptible to surface decarburization which proceeds as a result of the selective oxidation of the carbon at the surface of the steel and continues by diffusion of carbon from below the surface to the surface where it reacts with oxygen and passes off as CO and CO<sub>2</sub>. This depletion of carbon from the outer surfaces of the steel decreases the stability of the austenite phase sufficiently to cause transformation of the austenite to martensite upon quenching. Since austenite is nonmagnetic and martensite is strongly magnetic, the magnetic test described above is able to differentiate between the two conditions. A deflection from the

vertical of less than 6 inches is considered normal for steel of acceptable quality. A deflection of greater than 10 inches is indicative of sufficient decarburization to cause excessive breakage during forming. Steels which show a magnetic deflection of between 6" and 10" are of borderline quality and should be more thoroughly retested.

Martensite is extremely hard and brittle and the presence of a very thin layer of martensite on Hadfield steel has been found responsible for greatly increased breakage during forming of the helmets. Bending of decarburized Hadfield steel causes cracking of the thin martensitic layer. These small cracks act as stress-raisers which result in the propagation of the cracks through the otherwise tough and ductile austenitic steel.

The 180° cold bend test was found to be an excellent gage of overall ductility and formability. The bend test not only checks upon factors which influence the results of the magnetic test and microscopic examination, but also responds to other ductility factors which are influenced by chemical composition, melting practice, and hot or cold working processes. The bend test is thus an excellent integrating test for ductility. The test is performed very simply, a small piece of Hadfield steel is bent double upon itself in the jaws of a vise and the surface of the bend is examined for cracks. The appearance of bends of steels of varying quality is shown in Figure 4.

Metallographic examination of suitably prepared cross-sectional specimens of Hadfield manganese steel is capable of revealing the defects which reduce the formability of the steel. Figure 5A is a photomicrograph showing the thin surface layer of martensite resulting from decarburization during processing. Cracking of the martensite layer as the result of deforming a sheet of manganese steel is illustrated in Figure 5B. Figures 5C and D show grain boundary networks of carbide caused by heating the steel to an insufficiently high temperature prior to quenching. The manufacturer must select and control the heat treating cycles very carefully; high temperatures and long holding times favor excessive decarburization while low temperatures and short holding times favor the formation of grain boundary carbide networks and streaks of undissolved carbides such as pictured in Figure 6.

Hadfield steel helmet stock is processed differently by the two steel producers. The Carnegie-Illinois Steel Corp. melts the steel in an open hearth furnace whereas the Sharon Steel Corp. employs an electric arc furnace. At Carnegie, the ingots are routed through either slabbing or blooming mills. The slabbing mill product is rolled into plates while the blooming mill product is rolled into bars. Both plates and bars are rolled down to 0.146" thick strips, and the strip reduced to the final 0.044 + .003" gage by hot rolling the strip which is stacked in packs of four. The steel is given a final water quench from a temperature of approximately 1840°F. and then blanked into the 16 $\frac{1}{2}$ " diameter circles from which the helmets are formed. Because of the fact that much of the steel processing is conducted at elevated temperatures, Carnegie steel has in the past been very subject to surface decarburization and poor surface conditions such as roughness and rolled in scale. As a result of the imposition of Specification AXS-1170, the Carnegie-Illinois Steel Corp. installed, at considerable expense, new and closely controlled equipment which has greatly improved the quality of their product.

At the Sharon Steel Corp., ingots of Hadfield steel are hot rolled down to 2" thick slabs which are then reduced to a thickness of .109" in hot strip mills. The strip is then reduced to the final gage of 0.044" by a series of cold rolling operations with four intermediate annealing treatments. Steel produced by Sharon tends to be less decarburized and to have smoother surfaces than steel produced by Carnegie because of the fact that the reduction to the final gage is performed by cold rolling rather than by hot rolling.

The ballistic requirements for Hadfield steel helmet stock were developed at this arsenal after the completion of comprehensive firing tests at sheet stock of various thicknesses<sup>8</sup>. More recently, a statistical examination of numerous ballistic records accumulated after Specification AXS-1170 became effective enabled this laboratory to recommend<sup>9</sup> a revision of the ballistic test based upon sound quality-control concepts. This proposed revision has not, at the present time, been accepted.

The British helmet developed during World War I was subjected to an acceptance ballistic test in which the helmet had to resist the penetration of a lead shrapnel ball weighing 41 to the pound at a striking velocity of 700 f/s. When this country went into production of the M1917 helmet, the British ballistic test was modified to the extent that the American helmet had to resist the penetration of a 230 grain cupro-nickel jacketed caliber .45 pistol bullet at a velocity of 650 f/s. Although the helmet is practically never expected to be impacted in service by pistol ammunition, this very illogical and unrealistic ballistic test of helmets has persisted to this very day in spite of the repeated attempts of this laboratory to either eliminate or modify the test.

A very confusing situation regarding the caliber .45 pistol ball ammunition arose early in 1944 when it was first discovered that, since the chemical and physical characteristics of the ammunition components were not controlled by specifications, various lots of projectiles showed distinctly different ballistic characteristics when used to test helmets and helmet steel stocks. In some cases the lead cores of the caliber .45 bullets were made of commercially pure lead whereas, in other cases, they were made of lead alloyed with considerable amounts of antimony and tin. The alloyed lead was very much harder and more resistant to deformation than the pure lead, and projectiles containing alloyed lead cores exhibited very much superior penetrative power. In addition, some lots of ammunition were jacketed with gilding metal while others were jacketed with copper clad steel. These variables caused considerable confusion before they were eliminated and helmet testing projectiles were standardized<sup>10,11</sup>.

In March 1944 a Helmet Industry Integration Committee was formed for the purpose of accumulating and distributing information which would assist the manufacturers of helmets and helmet steel in improving their products and solving their production problems. The membership of the Committee follows:

<u>Chairman</u>	Brig. Gen. J. Kirk Chief, Small Arms Branch Office, Chief of Ordnance, Washington, D.C.
<u>Deputy Chairman</u>	Major F. M. Volberg Small Arms Branch Office, Chief of Ordnance, Washington, D.C.
<u>Assistant Chairman</u>	Mr. H. E. Moser McCord Radiator & Mfg. Co., Detroit, Mich.
<u>Ordnance Representative</u>	Capt. W. W. Hewitt Small Arms Branch Office, Chief of Ordnance, Washington, D.C.

<u>Members</u>	<u>Plants</u>	<u>Representative</u>
McCord Radiator & Mfg. Co.	Detroit, Mich.	H. E. Moser
Schlueter Mfg. Co.	St. Louis, Mo.	C. A. Schlueter
Carnegie-Illinois Steel Corp.	Chicago, Ill.	M. J. Day
Sharon Steel Corp.	Sharon, Pa.	C. W. Weesner
Watertown Arsenal (ex officio)	Watertown, Mass.	A. Hurlich

In March 1945, when their plants entered upon production of the M1 helmet, Mr. M. L. Fox of the Parish Pressed Steel Co. and Mr. R. J. Sullivan of the Reading Hardware Corp. were admitted to membership in the committee. Numerous meetings of the committee were held at Watertown Arsenal and at several of the plants involved.

After the completion of the investigations concerned with the quality of helmet steel, helmets which were returned because of cracking in the field were subjected to metallurgical examination. The locations of the cracks in the helmets were recorded in accordance with the grid shown in Figure 7. The cracks were divided into three types; cracks extending from the edge of the helmet visor and apparently originating from distant notches, cracks extending from the edge of the helmet visor and not originating from notches, and vertical cracks confined to the body of the helmet and not extending to the rim. Typical helmet cracks are shown in the photographs of Figure 8,

The distribution of the cracks observed in the various lots of helmets examined at this arsenal are shown in Figure 9. The upper chart shows the frequency distribution of the various types of cracks observed in 95 service cracked helmets returned from Camp Picket, Va. and the lower chart shows the frequency distribution of cracks in helmets from North Africa and from various Army posts in this country. Figure 9 demonstrates that the service cracking of helmets is confined to three unique zones: (1) the visor, extending from 320° to 40° (ref. Figure 7), where the cracks generally extend up from the rim; (2) the right rear of the helmet, from 130° to 160°, where the cracks occur in the body of the helmet; and (3) the left rear of the helmet, from 190° to 240°, where the cracks occur similarly to those in the right rear of the helmet.

Hardness surveys taken in the regions in which cracking occurs showed a distinct relation between the extent of cracking and the amount of cold-working. The regions of the helmet which are most susceptible to service cracking are work-hardened to hardnesses in the range of Rc 50-54 whereas regions in which the incidence of service cracking is very low have been work-hardened to only Rc 40-48, note the upper chart of Figure 9.

In view of the extremely severe cold deformation experienced in deep drawing the M1 helmet from a flat disc in one major operation, it is to be expected that very high residual stresses would be present in the finished helmet. Residual stress determinations made at this arsenal<sup>12</sup> on uncracked helmets indicated the existence of residual stresses which may approach the magnitude of the tensile strength of the material. In general, the highest stresses were found in the vicinity where service cracking generally occurs.

It was at one time proposed to thermally stress-relieve the helmet after the drawing operation. Research at the United States Steel Corp. Research Laboratory<sup>13</sup> which was later confirmed at this arsenal showed that a stress-relieving temperature above 500°F. could not be employed because decomposition of the cold-worked austenitic steel occurred at temperature above 500°F. Since very little, if any, stress relief could be expected to occur at such low temperatures, thermal treatment was believed to show no promise in relieving the high stresses induced by cold working.

Metallographic examination of 50 service cracked helmets disclosed that 75% of them possessed steel quality deficiencies consisting of combinations of the following defects; surface decarburization; grain boundary carbide networks, and streaks of undissolved carbides. In a highly stressed structure such as the M1 helmet, factors, such as the foregoing, which promote brittleness would be extremely dangerous. Metallographic examination also disclosed that cracking can also occur in helmets made from steel free from metallurgical defects. It was concluded from the examination of service cracked helmets that the production of the M1 helmet involves extremely severe forming operations which stress the steel to a degree sufficient in itself to be responsible for some of the breakage encountered in manufacture and in service.

After the improvement in steel quality resulting from the imposition of Specification AXS-1170 and as the result of the examination of service cracked helmets, it appeared necessary to investigate the helmet manufacturing processes with the viewpoint of alleviating some of the severe forming operations. The shell of the M1 helmet is produced from a 16½" diameter flat disc in one deep drawing operation. The excess metal around the rim is trimmed off, and the visor is then formed by a spanking operation which consists of holding down the inner surface of the front of the helmet against a die and striking the outer surface with a descending die which stretches the front of the helmet to form the visor. This operation completes the formation of the helmet shell. Breakage in production occurs in all three operations, but is most severe in the initial deep drawing stage.

Representatives of the Carnegie-Illinois Steel Corp. suggested the replacement of Hadfield manganese steel by a modified steel containing a lower carbon content (.80-.90% instead of 1.20-1.50%) and containing  $\frac{3}{8}\%$  nickel in addition to the normal manganese content. The Carnegie-Illinois Steel Corp. had some experience with the modified steel and had found it to work-harden to a lesser extent than normal Hadfield manganese steel. The Ordnance Department, therefore, approved the production of three experimental heats of the nickel Hadfield steel to determine if production breakage would be reduced. At this point it should be mentioned that the McCord Radiator & Manufacturing Co., which has cooperated enthusiastically with the Ordnance Department as long as the steel manufacturers were under pressure to produce steel of higher quality, exhibited extreme reluctance to engage in experiments calling for any effort on their part. The McCord people continuously objected to putting experimental lots of steel through their production line and objected to any suggested change; making changes only when ordered to do so by the Ordnance Department.

The experimental heats of modified Hadfield steel were drawn into M1 helmets with very low production breakage. Samples sent to this arsenal for metallurgical examination indicated that the modified steel work-hardens to a lesser extent than does normal Hadfield steel, is more ductile than the normal steel when drawn into helmet form, and has but slightly inferior ballistic properties<sup>14</sup>. Due to the fact that some lowering of the ballistic characteristics would occur with the use of the modified Hadfield steel, the Ordnance Department decided to abandon further experimentation with this steel.

Shot blasting of the outer surface of the helmet was attempted in an effort to put the skin in compression to eliminate service cracking. Stress analysis had previously demonstrated that the outer surface of the helmet was generally in tension. It was found at this arsenal<sup>15</sup> that shot blasting the outer surface of the helmet made the helmet extremely brittle under ballistic attack. The stresses induced by forming the helmet shell are so disposed that they cause service cracking, but at the same time maximize the ballistic characteristics of the helmet.

Early in 1944 the Schlueter Manufacturing Company of St. Louis, Mo. encountered a bothersome fabrication difficulty consisting of a high incidence of delayed visor cracking. As a result of this difficulty the plant was forced to adopt a very cumbersome inspection procedure whereby the helmets were carefully examined for cracks, held in storage for 15 days, then reexamined for cracks, prior to shipping. Lt. H. D. Seymour of the St. Louis Ordnance District conceived the idea of annealing the rim of the visor to eliminate the visor cracking. The annealing was initially performed by a rapid heating and quenching cycle performed in a seam welding machine. A band approximately  $\frac{1}{4}$ " in width along the rim of the visor was thus annealed. Test performed upon sample edge annealed helmets submitted to this arsenal<sup>16</sup> indicated that the annealing process effectively prevented the formation of edge cracks and restored the original ductility to the rim of the visor.

After further experimentation, Lt. Seymour in conjunction with the Chio Crankshaft Company of Cleveland, Ohio, developed the use of the Tocco high frequency induction heating unit to edge-anneal helmets. Helmets were submitted to this laboratory which had been edge-annealed around the entire circumference of the helmet rim after the final forming operation. It was concluded at this arsenal<sup>17</sup> that the edge-annealing of the entire circumference of the M1 helmet satisfactorily stress-relieved the edge without impairing the ballistic properties of the helmet. This laboratory recommended the application of the annealing process prior to trimming. It was felt that greatly increased trimming die life would result from having the sheared area in the annealed condition, that notches in the trimmed edge would be eliminated and that the visor spanning breakage would be reduced.

Experimental groups of helmets were accordingly processed in compliance with this laboratory's recommendations with extremely successful results<sup>18</sup>. This arsenal advised the Ordnance Department to institute the edge-annealing process in the manufacture of the M1 helmet. The Schlueter Manufacturing Company immediately installed edge-annealing equipment and has not suffered any delayed visor cracking since the introduction of the process. In May 1945 this laboratory was commended by Brig. Gen. Kirk, Chief of the Small Arms Branch, Office, Chief of Ordnance, for its part in the successful development and institution of the edge-annealing process.

### III. Attempts to Design Helmets of Improved Ballistic Properties

In the summer of 1944 it was determined in the Detroit Ordnance District that the M1 helmet could be drawn somewhat shallower than was being done in practice without impairing the fit of the liner in the helmet. At the direction of the Office, Chief of Ordnance, experimental lots of helmets of reduced draw were prepared from helmet discs of various thicknesses and were sent to the Watertown Arsenal for ballistic tests. The ballistic tests showed a marked increase in the resistance of M1 helmets as the thickness of the helmet was increased from an average of 0.032" to 0.037" in the gone under test. The plastic liner of the M1 helmet was found to behave in a brittle manner and to have no effect upon the ballistic resistance of M1 helmets. Replacement of the liner by an equivalent weight of steel in the helmet shell resulted in a considerable increase in the ballistic efficiency<sup>19</sup>.

Investigations of various materials in an effort to design improved body armor disclosed that aluminum alloys backed by nylon fabric provided excellent resistance to the penetration of small caliber shell fragments. Experimental helmets were formed from 24 ST aluminum alloy (4.5% copper, 1.5% magnesium, 0.6% manganese, balance aluminum) using the forming dies employed for M1 helmets. The helmets were drawn from 0.120" thick discs which are equivalent in weight to 0.043" of Hadfield steel. Examination of sample helmets submitted to this arsenal<sup>20</sup> indicated that dies designed to form helmets from Hadfield steel were unsuitable for the forming of aluminum, resulting in excessive thinning of the crown of the helmet. A photograph of an aluminum helmet made in the shape of the M1 helmet is shown in Figure 10. The holes in the helmet shell shown in Figure 10 were made by caliber .22 fragment simulating projectiles developed at this arsenal.

An aluminum alloy helmet of improved design was subsequently made and is now being tested. A photograph of this helmet is shown in Figure 11. When fitted with a sized nylon fabric liner, the helmet shown in Figure 11 is considerably more resistant to the penetration of fragment simulating projectiles than is the M1 helmet and liner. The nylon liner, unlike the standard M1 plastic liner adds considerably to the ballistic value of the helmet.

#### IV. Investigation of Foreign Helmets

A group of fifty German helmets captured in North Africa in 1943 were examined at this arsenal<sup>21</sup>. Markings indicated that the helmets were manufactured during the years 1937 through 1942. Helmets manufactured prior to 1940 were made from a nickel-silicon steel of the following analysis range:

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>
.27/.34	.50	1.7/1.9	1.2/2.2	.30

Helmets made from 1940 on were produced from a silico-manganese steel of the following analysis range:

<u>C</u>	<u>Mn</u>	<u>Si</u>
.30/.40	1.0/1.5	1.3/1.7

The changeover in analysis was probably dictated by the shortage of nickel which developed during the war. German infantry helmets contain adjustable leather linings held in place by means of concentric metal bands attached to each other with interlocking steel springs, note Figure 12. Headband components produced prior to 1940 were made 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. German helmet shells are believed to have been hot formed and subsequently liquid quenched for hardening to Rockwell C 49-54.

German infantry helmets have an average weight of  $47.3 \pm 1.7$  ounces, or approximately one ounce more than the M1 helmet and liner. German helmet shells average approximately 20% thicker than the M1 helmet, ranging from 0.048" to 0.052" at the sidewalls as compared to 0.041" to 0.043" for similar locations in the M1 helmet. Ballistic tests of German helmets with various types of projectiles indicate a superiority to American helmets that is roughly proportional to the difference in thickness.

Among the fifty German helmets was one paratrooper helmet, photographs of which are shown in Figure 13. This helmet was very heavy, weighing 59.6 ounces. The flaring rim common to the German infantry helmet is absent in this helmet because otherwise severe air drag would result as the parachutist descends.

A single German Helmet examined at this arsenal in 1942<sup>22</sup> very closely resembles the German helmet worn during World War I, see Figure 14. The lining consisted of three cushions stuffed with horsehair attached to leather flaps. The helmet was made from a medium carbon steel containing 1.2% chromium and was heat treated to a hardness of Rockwell C 48-54. The helmet weighed 41.4 ounces and the shell averaged 0.040" in thickness.

Two Japanese helmets recently examined at this arsenal<sup>23</sup> were found to be made of steel of the following compositions:

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>	<u>V</u>
.33	1.30	.26	.84	.70	.24	Nil
.36	1.25	.20	.53	.72	.30	.20

The helmets were uniformly hardened to approximately Rockwell C 50 and averaged 0.048" in thickness. The pigskin leather linings have three adjustable flaps to which are stitched pockets containing cotton filled cushions, see Figure 15. The helmet shells are symmetrical from front to back and from side to side. The Japanese helmets were found to have excellent resistance to the penetration of caliber .45 bullets and to fragment-simulating projectiles, but exhibited brittleness upon complete penetration.

A Dutch helmet examined at this laboratory<sup>22</sup> in 1942 was made from a nickel-silicon steel (.35% carbon, 1.7% silicon, 2.0% nickel) which was hardened to Rockwell C 49-54. The helmet shell averaged 0.042" in thickness and exhibited a high-resistance to penetration but was brittle upon complete penetration, see Figure 16.

French and Irish Free State helmets examined at the same time as the Dutch helmet<sup>22</sup> were both formed from Hadfield manganese steel (.85/1.07% carbon, 11.5/13.8% manganese). The French helmet, see Figure 17, was extremely thin, averaging 0.030" in thickness, and consequently exhibited very low ballistic resistance.

The Irish helmet averaged 0.033" in thickness and had somewhat better ballistic characteristics than the French helmet. The Irish helmet had a very deep drawn shell, see Figure 18, which was undoubtedly formed in a series of operations with intermediate annealing cycles. The final hardness of the Irish helmet was extremely low, Rockwell B 73-85, which is the hardness of Hadfield steel in the dead soft condition.

#### V. Future Developments in Helmets

At the present time an experimental helmet made of aluminum alloy fitted with a nylon liner demonstrates considerably improved ballistic resistance over the standard M1 helmet. It is believed that continued experimentation with non-metallic materials and with combinations of metallic and non-metallic materials may result in further improvements.

It is recommended that investigations for the purpose of developing non-ballistic acceptance tests for helmets be encouraged. The ballistic

acceptance test employed throughout World War II is considered extremely unreliable and has been the source of frequent difficulty. The application of quality control procedures to the raw material and the specification of minimum and maximum thicknesses or weights of the finished helmet components appear to provide desirable criteria for acceptance.

TABLE I  
Chemical Analyses and Ballistic Characteristics  
of Steels Investigated at Watertown

Manufacturer	C	Mn	Si	Ni	Cr	Mo	V	Zr	Heat to °F.	Quench	Draw °F.	Hardness Rc	Ballistic Characteristics
Achorn	.98	.46	.38	—	—	—	—	—	1475	oil	850	45	po
Eastern Rolling Mill	.11	4.42	.83	2.75	17.55	—	—	—		not reported		45	go
Great Lakes Steel Corp.	.18	.84	.87	.12	.78	.12	—	.10	1630	water	400	40	go
"	.18	.84	.87	.12	.78	.12	—	.10	1630	water	600	29/32	po
"	.18	.84	.87	.12	.78	.12	—	.10	1630	water	800	29/32	po
Ingersoll Steel & Disc	.36	.63	.17	3.46	1.54	.43	—	—	1630	water	1000	15/18	po
"	.36	.63	.17	3.46	1.54	.43	—	—	1500	air	400	46	po
"	.45	.94	1.99	—	.50	.99	.25	—	1575	air	400	51	go
"	.45	.94	1.99	—	.50	.99	.25	—	1600	air	—	20	go
U. S. Armor Corp.	.50	1.03	.30	—	—	.20	—	—	1600	oil	—	25	go
Carnegie-Illinois	.35	.76	1.91	2.24	—	—	—	—		not reported		51/52	excel.
"	.35	.76	1.91	2.24	—	—	—	—		normalized			go
"	.35	.76	1.91	2.24	—	—	—	—	1600	oil	900	40	go
"	.35	.76	1.91	2.24	—	—	—	—	1600	oil	1000	35	go
"	.70	.87	.21	—	—	.28	—	—	1550	salt at 675°F.	46/47		go
"	.70	.87	.21	—	—	.28	—	—	1550	salt at 630°F.	50		go

#### BIBLIOGRAPHY

1. "Helmets and Body Armor in Modern Warfare", Bashford Dean, Yale University Press, New Haven, Conn.
2. Watertown Arsenal Laboratory Report No. WAL 710/439, "Comparison of Helmets Made from NAX and Hadfield Manganese Steel", J. F. Sullivan, A. Hurlich, 20 June 1942.
3. Watertown Arsenal Laboratory Report No. WAL 710/543, "Ballistic and Metallurgical Investigation of Anola Steel Helmets", E. L. Reed, 20 August 1943.
4. Watertown Arsenal Laboratory Report No. WAL 710/430, "Development of a Test for Hadfield Manganese Steel Helmets", J. H. Hollomon, 3 June 1942.
5. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/571, "Defective Helmet Steel", A. Hurlich, 28 August 1943.
6. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/575, "Metallurgical Examination of Defective and Satisfactory Helmets and Helmet Steel Stock Furnished by the McCord Radiator and Mfg. Co., Detroit, Mich.", A. Hurlich, 23 December 1943.
7. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/586, "Metallurgical Examination of 20 M1 Helmets, Made by the Schlueter Mfg. Co., Which Cracked in Service", A. Hurlich, 29 January 1944.
8. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/635, "Ballistic Tests of 0.040-0.050" Hadfield Steel Sheet With Caliber .45 Ball Projectiles for Development of Specification Requirements", A. Hurlich and N. A. Matthews, 18 May 1944.
9. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/727, "Statistical Basis for Revision of a Ballistic Specification for Acceptance of Helmet Steel", J. F. Sullivan and A. Hurlich, 3 March 1945.
10. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/357, "Comparison of the Physical, Chemical, and Ballistic Properties of Various Lots of Caliber .45 M1911 Pistol Ball Ammunition Used for the Proof Testing of Helmets and Body Armor Components", A. Hurlich, 4 December 1944.
11. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/740, "Analysis of Caliber .45 M1911 Pistol Ball Ammunition Submitted by Aberdeen Proving Ground, Md.", B. Phelps, 27 April 1945.
12. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/673, "Helmets - Determination of Residual Stresses in Helmets", R. Beeuwkes and E. N. Hegge, 1 July 1944.

BIBLIOGRAPHY (Contd.)

13. Report File No. WAL 710/639, "Factors Involved in Stress-Relief Annealing of Cold-Worked Hadfield Manganese Steel", E. S. Davenport, and R. A. Grange, United States Steel Corp. Research Laboratory, Report No. 502, October 1943.
14. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/609, "Metallurgical and Ballistic Investigation of a 3<sup>1</sup>/<sub>2</sub>% Nickel Modified Hadfield Manganese Steel Proposed for Use in the M1 Helmet", A. Hurlich, 12 April 1944.
15. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/476, "A Preliminary Study of the Effect of Shot Blasting upon the Ballistic Characteristics of the M1 Steel Helmet", A. Hurlich, 28 February 1944.
16. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/612, "A Study of the Seam Welding Process Applied to Prevent Stress Cracking of the Visor of the M1 Helmet", A. Hurlich, 13 April 1944.
17. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/679, "Ballistic and Metallurgical Investigation of Helmets Edge-Annealed in a 'Tocco' Induction Heating Unit", A. Hurlich, 18 July 1944.
18. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/283, "Ballistic and Metallurgical Investigation of M1 Helmets Edge-Annealed in a 'Tocco' Induction Heating Unit Prior to Trimming", A. Hurlich, 16 October 1944.
19. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/720, "Resistance of M1 Helmets of Varying Thicknesses and of M1 Helmets Fitted with Plastic Liners to Perforation by the Soft and Hard Types of Caliber .45 M1911 Ball Ammunition", A. Hurlich, 30 January 1945.
20. Watertown Arsenal Laboratory Memorandum Report No. WAL 710/778(c) "Metallurgical Examination of Experimental Helmet T24", P. V. Riffin, 17 September 1945.
21. Watertown Arsenal Laboratory Report No. WAL 710/670, "Metallurgical and Ballistic Investigation of Fifty Captured German Helmets", A. Hurlich, 28 June 1944.
22. Watertown Arsenal Laboratory Report No. WAL 710/418, "Metallurgical Examination of Helmets From Germany, The Netherlands, France, and the Irish Free State", E. L. Reed and A. Hurlich, 26 March 1942.
23. Watertown Arsenal Laboratory Report No. WAL 710/776(c), "Metallurgical and Ballistic Comparison of German, Japanese, and American (M1) Helmets", A. Hurlich and J. F. Sullivan, 21 September 1945.