DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 191

SOME FACTORS AFFECTING THE LIFE OF MACHINE-GUN BARRELS

BY

W. W. SVESHNIKOFF, Assistant Physicist

Bureau of Standards

JUNE 4, 1921

PRICE, 10 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

SOME FACTORS AFFECTING THE LIFE OF MACHINE-GUN BARRELS

By W. W. Sveshnikoff

ABSTRACT

Star-gage measurements on six machine-gun barrels at various stages of firing indicate that when the life limit is reached, exhaustion is due to a combination of the abrasive action of the bullet and the abrasion by hot gases.

In this experiment the amorphous martensite which appears on the surface of the bore of the fired gun has been reproduced on machine-gun steel by the heat from an electric arc, the formation of the martensite being due to the extremely rapid cooling caused by the large mass of cold metal near the highly heated surface.

Cracking of the bore is due to dimensional changes of the hardened brittle surface of the steel resulting from the sudden changes in temperature between separate shots. The cracks originate at irregularities in the surface of the bore.

CONTENTS

I. INTRODUCTION

It is the object of this investigation to study some of the principal factors which affect the life of a machine gun. Previous investigations have been confined to a study of the life of large guns, where firing conditions are different from those of machine guns. The great value of the latter lies in the accuracy of its aim and its rapidity of fire, which are to a great extent dependent upon the construction of the barrel.

The firing of the gun causes the wearing away and surface cracking of the bore, with its gradual enlargement from the breech end.

By this means the rifling is destroyed and the projectile loses its velocity and proper speed of rotation, thus causing inaccuracy in flight. At this stage the barrel is considered useless, especially for barrage firing.

The life of a machine-gun barrel is numerically measured by the number of rounds which can be fired before the barrel loses its accuracy. It is difficult to predict accurately the life of such barrels, as it has been found that there is considerable variation

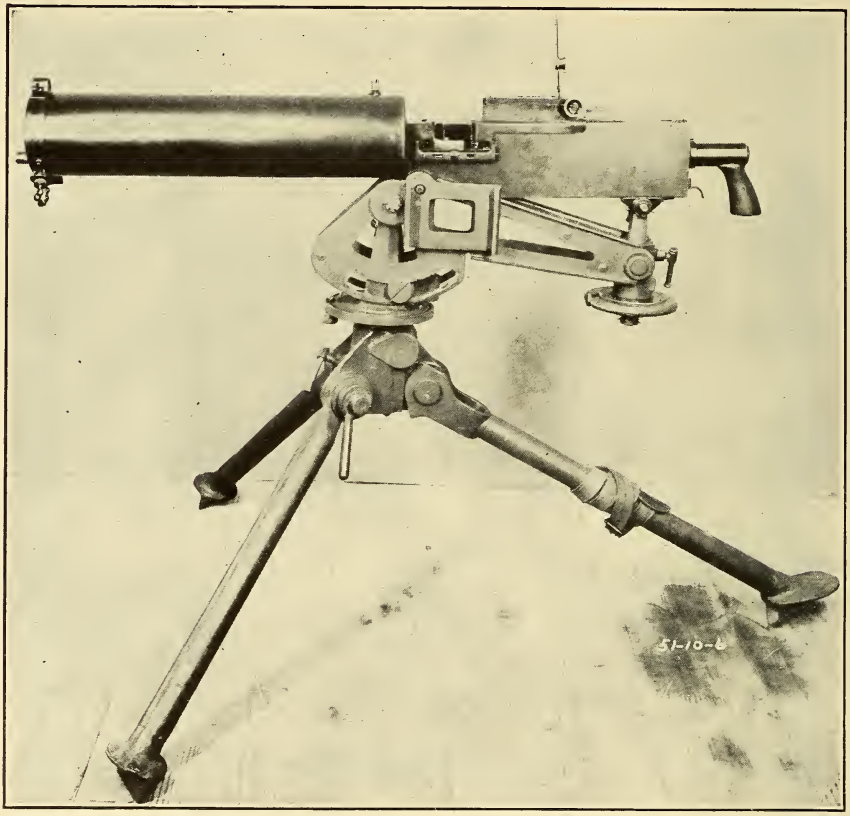


Fig. 1.—*Typical machine gun (Browning 1917 Model)*

in similar barrels in the number of rounds which can be fired before the barrel is reduced to scrap metal. The life of the machine-gun barrel depends to some extent on some other causes not discussed in this paper, for example: The rate of firing, the number of rounds fired in each burst, the time intervals between bursts, the effectiveness of the water cooling, the type of ammunition used, the cleaning of the barrels, and the atmospheric conditions and temperatures. The effect of temperature and pressure for one shot during the fraction of a second required for the bullet to travel the whole length of the barrel may be described as follows: The combustion of the charge creates an extremely high temperature (about 2800° C) with a pressure of about 51 000 pounds per square inch in the breech end. The effect of this high temperature and pressure is greatest near the breech end of the barrel. The pressure and temperature are respectively decreased with forward movement of the bullet because of the increase in available volume of the barrel and the greater heat absorption by the larger exposed surface of the bore.

II. DISCUSSION OF THE RELATIVE ABRASIVE ACTION OF THE BULLET AND THE GASES

Relative variations in the diameters of grooves and lands as the firing of a machine gun progresses are shown in Fig. 2.[1] The curves represent measurements made with star gages on six barrels and are accurate within a few ten-thousandths of an inch.[2] From a comparison of the average diameter of the bullets and the average diameter of the bore in the grooves, it would appear that the bullet is not in contact with the grooves in a majority of cases. Possibly the bullet is slightly enlarged in girth due to the deformation to which it is subjected upon entering the rifling. Consequently, the base of the bullet will in early firing come into contact with the grooves, and at the same time the bullet (being of greater diameter than the diameter of the lands) is in contact with the lands, which results in considerable friction. Star-gage measurements show that after firing about 2000 rounds the grooves at the breech end are eroded to such an extent that the surface of the bullet no longer makes a sealing contact. At the distance of about 21 inches from the muzzle, as shown in Fig. 2, the increase in diameter along the lands is greater than that in the grooves. At about 15 inches from the muzzle and from this point in the direction of the muzzle the increase in diameter in the grooves is greater than on the lands. A continuous increase in diameter on the lands and grooves from the muzzle to the breech ceases at a distance of about 9 inches from the muzzle. This, it is thought, may be due to deposition of volatilized material at this section of the barrel.

[1] Curves plotted from data obtained from the Ordnance Department, U. S. Army.

[2] The diameter in the lands and consequently in the grooves varies slightly for the separate guns. However, the difference between the two diameters as they increase after a certain number of rounds is practically constant for various guns. The increase in diameters is the same for guns which originally had the same diameters both in grooves and in the lands.

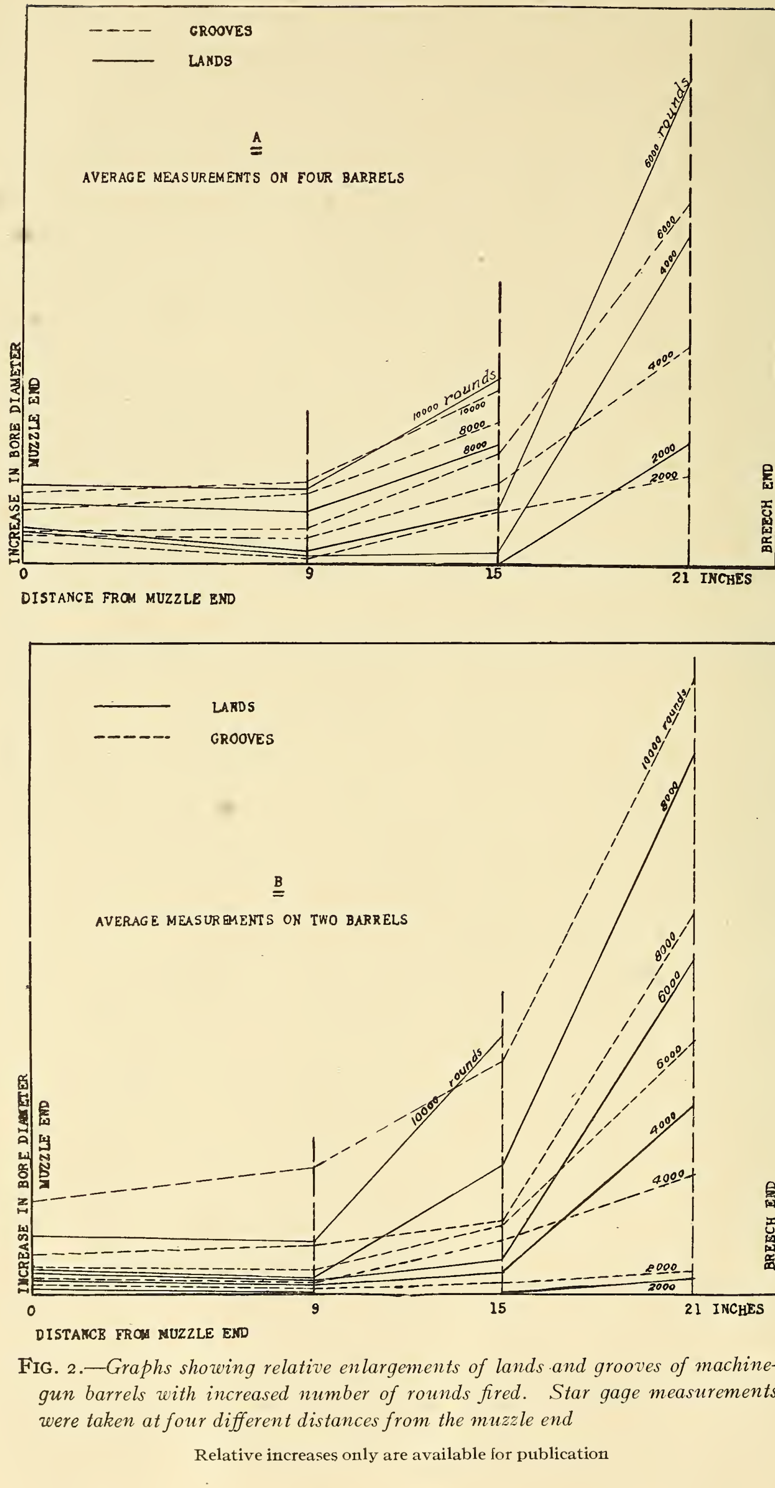


FIG. 2.—*Graphs showing relative enlargements of lands and grooves of machine-gun barrels with increased number of rounds fired. Star gage measurements were taken at four different distances from the muzzle end*

Relative increases only are available for publication

The increase in the diameter on the lands is greatest in the breech end and is very slight at the muzzle. This may be explained by (1) the higher temperature at the breech near the burning powder, and (2) the longer interval of time for which this part of the barrel is exposed to the high temperature. This second conclusion is based on Earle's [3] assertion that about 50 per cent of total time of travel of a projectile from origin of rifling to the muzzle is spent in traveling one caliber down the bore. A similar condition obtains to a smaller degree in the machine-gun barrel. The greatest abrasion is naturally at the breech end, where the bullet enters the rifling. The diameter of the lands is gradually increased as successive bullets enter the rifling, and the zone of the greatest abrasion due to this action is extended for a short distance down the bore.

The increase in the diameter in the grooves is greater also at the breech and diminishes toward the muzzle. Higher temperature and pressure at the breech end, as previously explained, are responsible for the greater abrasive action of the overheated gases.

The hot stream of gases rushes between the bullet and the walls of the grooves with great velocity. There is slight contact between the bullet and the grooves, and each shot increases the average diameter of the latter by melting or possibly by vaporizing the metal. This washes the grooves throughout the entire length of the barrel. With the resulting enlarged free space between the grooves and the moving bullet, the abrasive action of the gases is increased because of the larger volume of gases escaping through the free space.

It will be noted in Fig. 2 that the differences in the diameter on the lands after 2000 rounds have been fired is negligible throughout the first 15 inches from the muzzle, while the diameter in the grooves increases considerably in comparison throughout this entire distance. It is also shown that with an increased number of rounds the increase in the diameter of the grooves is greater than the increase in the diameter of the lands. If the wearing away of the surface of the bore by the gases were the same on the lands and in the grooves, the increase in diameter of the former should be at least equal to the increase in the diameter of the latter for the same number of rounds. But the grooves show a greater increase in diameter than the lands, which suggests that the greater erosion in the grooves, over this distance (15 inches from

[3] Ralph Earle, Transactions of the American Institute of Mining Engineers, **56**, p. 495; 1917.

muzzle) is mainly due to the escape of highly heated gases around the seat of the bullet.

Consequently when a machine-gun barrel reaches its life limit its exhaustion is due to a combination of the abrasive action of the bullet and abrasion of gases, but to a greater degree to the former. The action of the bullet obliterates the lands, which results in the destruction of the rifling, beginning at the breech end. The destruction of the rifling causes the loss of the gun's accuracy, thus terminating its usefulness.

III. THE STRUCTURE OF THE SURFACE LAYER IN THE BORE OF THE FIRED GUN

1. EFFECT OF TEMPERATURE ON THE SURFACE OF THE BORE

The temperature of the surface of the bore rises rapidly with the increased number of rounds fired. The effect of the high temperature penetrates only to a very slight depth, as the gun is rapidly cooled by the large mass of metal of relatively low temperature adjoining the highly heated layer. In the case of machine guns, the combustion is not completed at the time the bullet leaves the muzzle, and consequently, because of the rapidity of the fire, cold air has no opportunity to enter the barrel and exert a cooling effect. In the case of intermittent firing with the machine gun, air enters the barrel and naturally some cooling is obtained. Below the heated surface of the bore the steel has only a moderate temperature. After a limited number of rounds has been fired, only the thin surface of the bore is injured. This is shown in a microscopic examination of the original cross sections, Figs. 3, 4, and 5. The thin structurally changed surface layer

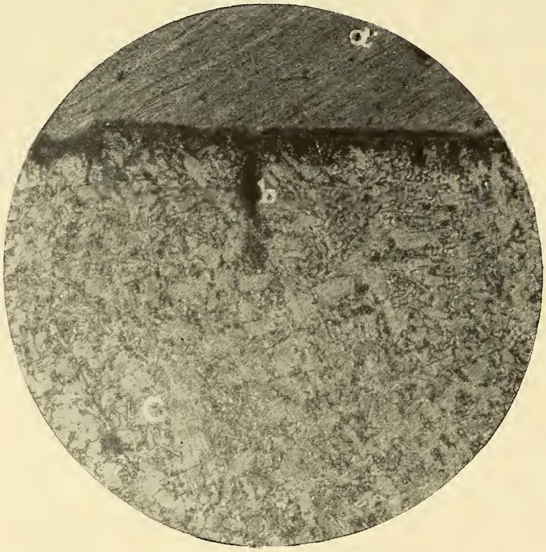


FIG. 3.—*Cross section of a gun barrel showing the thin structurally changed surface layer caused by firing 3880 rounds. × 200*

(*a*) Electrolytic protective layer of copper;
(*b*) Highly heated layer;
(*c*) Original structure of steel

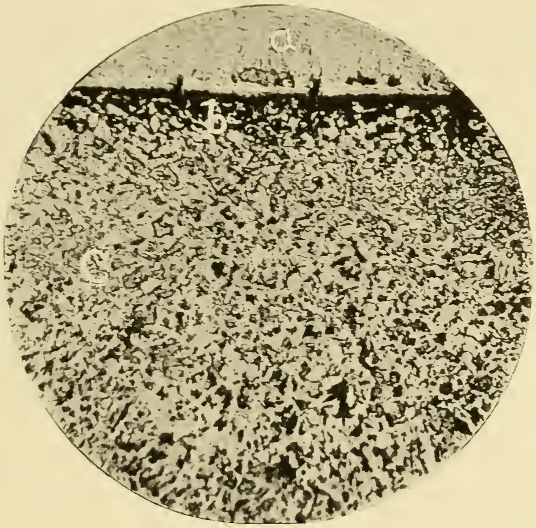


FIG. 4.—*Cross section of a gun barrel showing the thin structurally changed surface layer caused by firing 8000 rounds.* $\times$ *250*

(*a*) Electrolytic protective layer of copper;
(*b*) Highly heated layer;
(*c*) Original structure of steel

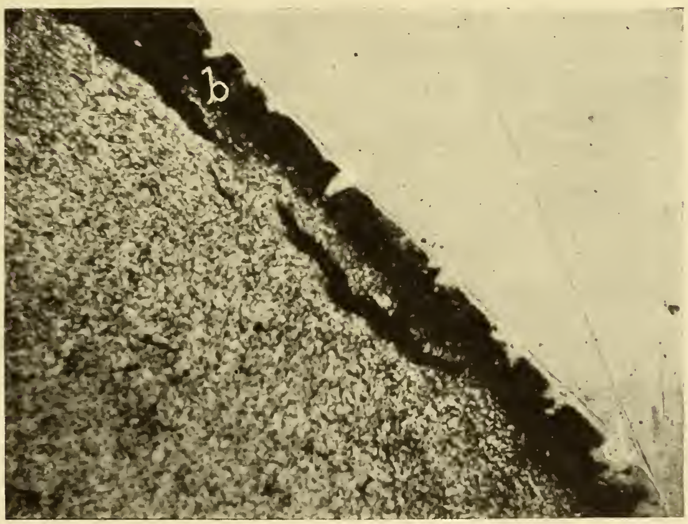


FIG. 5.—*Cross section of a machine-gun barrel after firing 8000 rounds* $\times$ *250*

(*a*) Electrolytic protective layer of copper
(*b*) Highly heated layer;
(*d*) Thin white layer

41566°—21——2

originates at the breech end of the barrels, where the duration of heating has been longest and the temperature highest. The depth and length of this surface layer depends upon the temperature of heating, and it grows toward the muzzle with continual firing. For a gun fired 8000 rounds the depth of this layer at the breech is about 0.0013 inch.

Fig. 5 also shows the appearance of the thin white layer on the surface of the bore, but because sufficient information concerning it is not now available its nature and structure are not discussed in the present paper.

2. EXPERIMENTS AT THE BUREAU OF STANDARDS ON THE INTENTIONAL PRODUCTION OF THE HEATING EFFECT BY AN ELECTRIC ARC

In studying this phase of the problem experiments were carried out with intentional production of this heating effect on the steel by an electric arc.

The temperature of combustion of nitrocellulose powder is estimated to be about 2800° C. The temperature of the hottest part of the arc from a positive carbon electrode is estimated by C. W. Waidner and G. K. Burgess [4] to be between 3600 and 4700° C, which is considerably higher than the temperature of combustion of powder. In either case a temperature higher than the melting point of steel is obtained. The temperature attained by the metal of the bore increases with an increase in available heat. The available heat is increased by an increased rate of firing. A prolonged exposure of the surface of the gun to this heat would even result in fusion of the surface layers.

According to Prof. Zay Jeffries [5] depression of the Ac^1 transformation point under conditions existing within a gun at the time of firing should be slight. The change of melting point due to the increased pressure within the gun is so small as to be negligible.

Machine-gun barrel steel stock used for the arcing experiments conforms to the following chemical specification:

	Per cent
Carbon	0. 40 to 0. 50
Manganese	. 60 to . 70
Phosphorus	Maximum, . 045
Sulphur	Maximum, . 035
Silicon	0. 20 to . 30
Chromium	. 40 to . 50

Figs. 6, 7, and 8 show the cracking produced in the heated surface by arcing with a copper electrode. The structure of the

[4] C. W. Waidner and G. K. Burgess, The temperature of the arc, B. S. Sci. Papers, No. 8; Sept. 1, 1904.
[5] Zay Jeffries, Trans. Am. Inst. Min. Eng., 58, p. 581; 1918.

Fig. 6.—*The cracks produced in the surface of steel by the heat of an electric arc (a copper electrode was used). Etched with 2 per cent nitric acid.* × 100

The dark central part is the hole made by the arc. The white portion of the specimen immediately surrounding the cracks is metallic copper. The structure of the specimen in the area around the cracks is entirely martensitic, merging rather abruptly with the original ferrite-sorbite structure of the specimen

Fig. 7.—*Same surface as in Fig. 6, but after continued polishing of sample. Etched with two per cent nitric acid.* × 100

specimen in the area around the crack is entirely martensitic and merges rather abruptly with the original ferrite-sorbite structure in the specimen. Figs. 6 and 8 also show main and tributary cracks following the grain boundaries. The white portion of the specimen immediately surrounding the crack is metallic copper which has been deposited by the electrode during the arcing. A flow of copper has also occurred along the grain boundaries which are brought out by the high temperature.

To avoid the copper deposit, a specimen of this machine-gun steel was exposed to the heat of an electric arc drawn from a carbon electrode. Fig. 9 shows main and tributary cracks in the surface of the specimen caused by this method of arcing. During this test a reddish brown deposit, which probably consists of iron and manganese oxides, was formed on the surface adjacent to the heated area. This experiment was repeated several times, and in each case a deposit of iron, spongy in appearance and devoid of structure, was apparent at the point of arcing. The deposit was filled with inclusions, probably oxides, while the structure of the surrounding metal appeared to be martensitic, merging sharply with the original sorbitic ground mass.

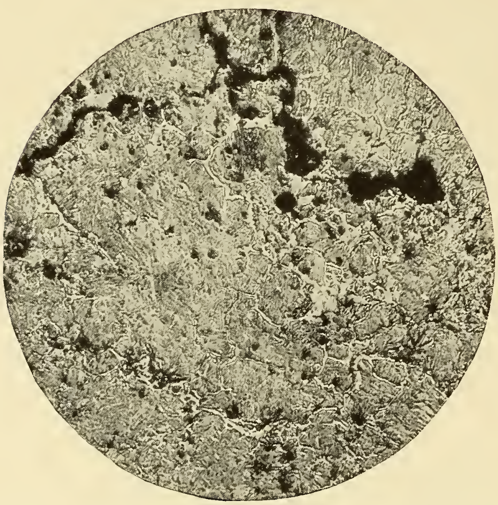


Fig. 8.—*Micrograph showing cracking in the specimen submitted to electric arc from the copper electrode. Grain boundaries developed. Molten copper tends to follow grain boundaries. Indicative of the origin of these boundaries while the copper was still plastic and capable of flowing. Etched with 2 per cent nitric acid.* × *100*

Fig. 10 shows the dark grain outline in the martensite bordering the edge of the view shown in Fig. 7.

In the specimen of machine-gun barrel steel examined which had been submitted to arcs from the copper and carbon electrodes, the occurrence of grain boundaries is significant of the high temperature to which the metal has been heated. The grain boundaries are best shown in Figs. 6 and 8. They are well developed at a short distance from the fused area, and they end abruptly just within the area which had been changed to marten-

FIG. 9.—*Micrograph showing main and tributary cracks produced in the surface of steel by the heat of an electric arc (a carbon electrode was used). Etched with 2 per cent HNO_3 in alcohol.* $\times$ *400*

The microstructure of the area surrounding the crack is martensitic, merging sharply with the original sorbitic ground mass site. In the specimen heated by the copper electrode the boundaries adjacent to the fused area are filled with copper, but in the specimen heated by the carbon electrode fused iron has filled in the cracks for a shorter distance.

The micrographs show that the metal had been exposed to a very high temperature, permitting volatilization of the amorphous metal between the grains.[6] The amorphous phase has a higher solution pressure than the crystalline phase, and although volatilization would probably occur in both of these phases, the greater loss would occur in the amorphous phase. After volatilization had proceeded along the grain boundaries for a slight

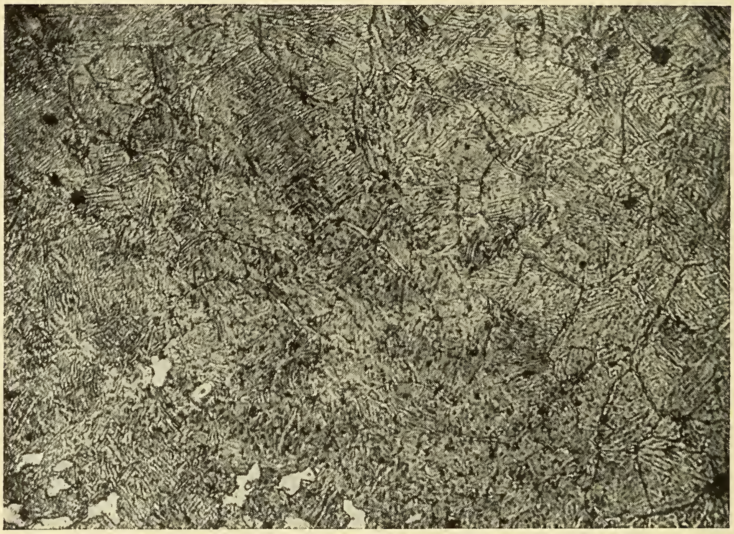


Fig. 10.—*Micrograph showing development and termination of grain boundaries in the martensitic mass. Section taken adjacent to sorbite-ferrite ground mass of unaltered area of the specimen. Etched with* HNO_3. $\times$ *500*

depth, the pool of molten metal gradually followed the depressions which had been formed.

The conditions of the change in structure and the grain-boundary development are direct results produced by the high temperature. The pool of molten copper could not have been deposited under a temperature of 1075° C. The steel fused in the case of an arc from the carbon electrode would not have melted under a temperature of 1500° C.

In the micrograph shown in Figs. 6 and 8 the branches of the crack appear to show a preference for the grain boundaries. This

---

[6] W. Rosenhain and D. Ewen, Intercyrstalline cohesion in metals, J. Inst. of Metals, 8, p. 149; 1912

would also point toward the high-temperature origin of these cracks. It is known that fracture produced in steels at high temperatures is intercrystalline.[7] It has further been demonstrated that the cohesion between adjacent crystals of iron at temperatures above about 650° C is not as great as the cohesion between units of the same crystals.[8] Furthermore, the maximum expansion or contraction occurs in steel passing through the Ar_1 or Ac_1 ranges. At and above these temperatures the metal lacks sufficient mobility to adjust itself to the rapid changes in volume; consequently internal stresses begin their attack on the weaker portion of the metal; that is, the grain boundaries. By the time a temperature of 550° C has been reached in cooling, most of the stresses incident to contraction and expansion have expended their energy and caused the appearance of an intercrystalline fracture. Below that temperature the path of a crack caused by tensional stresses should pass indiscriminately through the metal without regard to its relative crystalline or amorphous condition.

Belaiew and Rosenhain [9] reported that the thin surface layer in the bore of a fired gun consisted of martensite, and the investigations of Prof. H. Fay [10] confirm their report. Prof. Fay carried out his experiments with pressure plugs, previously subjected to cold work, which were inserted in a gun later fired. In the examination of these plugs he found the effect of hardening with cracking in the vicinity of the cold-worked areas. This indicated that the hardness of the surface was due to a combination of mechanical deformation and a process of martensitization. Prof. Fay considered these cracks to have appeared before the change of structure had taken place. Further, the structure, in his opinion, when it first changes appears as troostite, which develops into amorphous martensite. Prof. Fay's observation of a change from the sorbitic to the troostitic stiucture in the case mentioned did not occur in the specimen of machine-gun steel examined.

It is difficult to conceive of a troostitic structure forming from a sorbitic ground mass, because such transformation occurs in the direction which is the reverse of the usual change. However, the sorbitic ground mass may be transformed into martensite, which subsequently breaks down and is caught at the troostite transition

---

[7] J. C. Humfrey, Influence of intercrystalline cohesion upon the mechanical properties of metals, Iron and Steel Institute, Carnegie Scholarship Memoirs, **5**, p. 85; 1913.

[8] Zay Jeffries, The amorphous metal hypothesis and equicohesive temperature, J. Am. Inst. of Metals, **11**, p. 306; 1917.

[9] Belaiew, Rosenhain, International Association for Testing Materials, Proceedings, **2**, Sec. A; 1912.

[10] Prof. H. Fay, Trans. Amer. Inst. Min. Eng., **55**, p. 468; 1917.

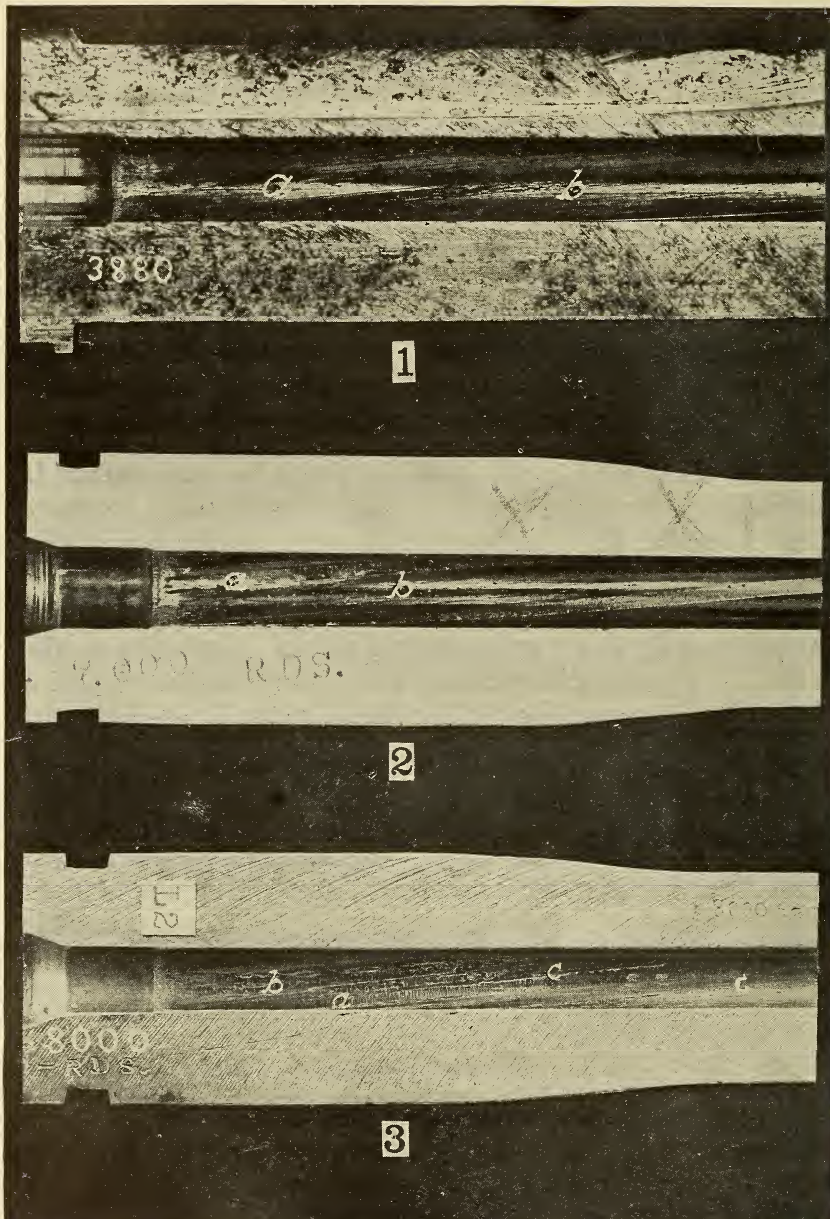


FIG. 11.—*Part 1 (gun barrels Nos. 1, 2, and 3). Longitudinal sections of machine-gun barrels after firing different numbers of rounds*

(*a*) Cracks in lands
(*b*) Cracks in grooves;
(*c*) Juncture cracks

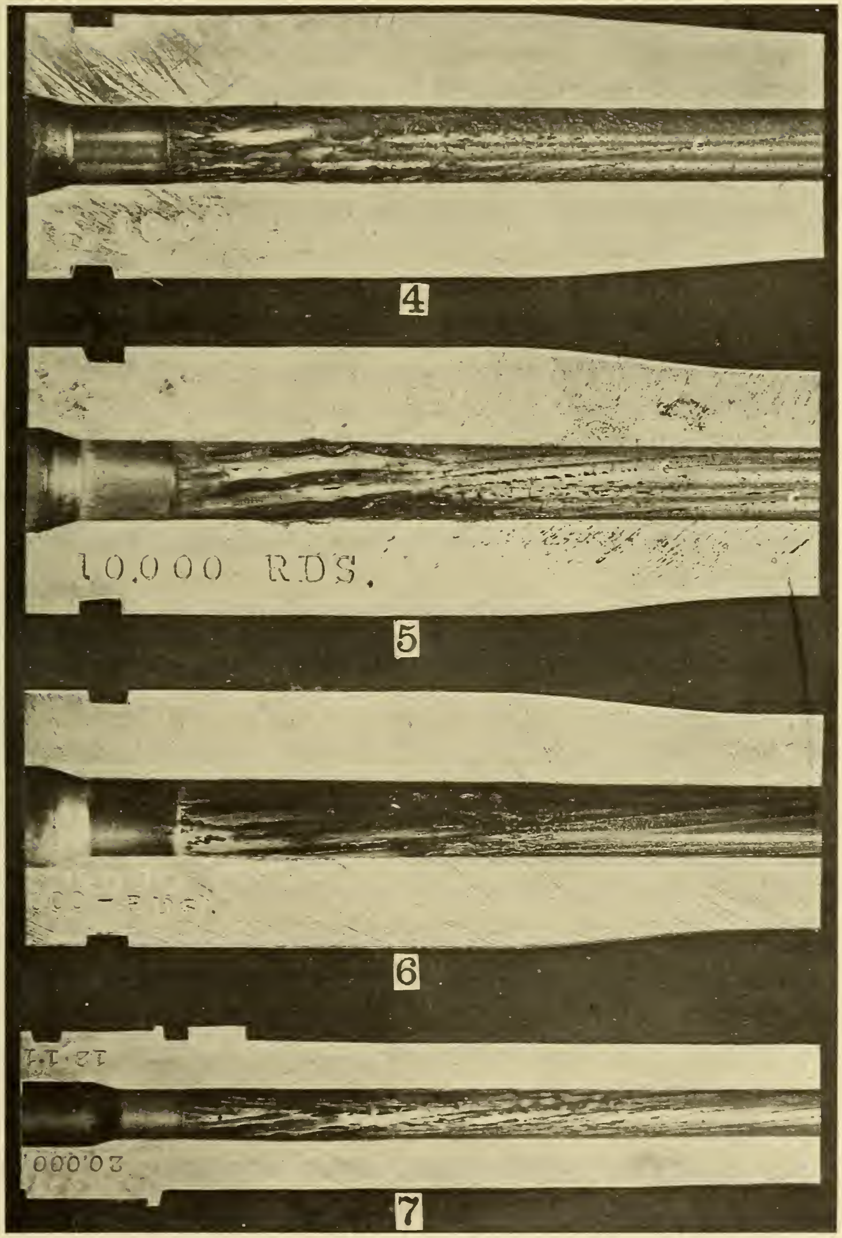


FIG. 11.—*Part 2 (gun barrels Nos. 4, 5, 6, and 7). Longitudinal sections of machine-gun barrels after firing different numbers of rounds*

(*a*) Cracks in lands;
(*b*) Cracks in grooves;
(*c*) Juncture cracks

These photographs were obtained from the Technical Staff of the Ordnance Department, U. S. Army.

point. Troostite is a decomposition product of martensite. It usually forms on tempering a martensitic steel, but it can be formed directly by quenching. In either case the martensite-troostite-sorbite cycle appears to favor the formation of martensite before troostite can occur. The occurrence of the amorphous martensite in the surface layer of the gun can be conceded.

IV. CRACKING OF THE BORE OF MACHINE-GUN BARRELS

1. VISUAL EXAMINATION OF CRACKING

Firing of a machine gun causes fine cracks to appear in the surface of the bore. These cracks progressively increase in length, depth, and width with the number of rounds fired, as shown in Fig. 11, which growth is accompanied by increased area of the surface of the bore being exposed to the high temperature. In Fig. 3 the effect of heating upon the walls of the cracks will be observed.

From a study of the cracks in the bores of a number of machine-gun barrels it was found that the cracks are better developed and more numerous at the breech end, as this is the point where the temperature is at a maximum. From the examination of longitudinal sections of gun barrels fired it was found that the effect of cracking was at a maximum at a short distance from the origin of rifling and not at the origin, as one would expect. As firing is carried further, the bore is more rapidly destroyed at this point than at other portions of the barrel. It is believed that this condition is due to the fact that the stream of hot gases leaving the cartridge is partially deflected by the shoulder and neck of the shell.[11] Thus it is only natural that they are directed toward a point at some distance from the origin of rifling where a maximum temperature is reached. This effect is shown in Fig. 11, barrels 4, 5, and 6.

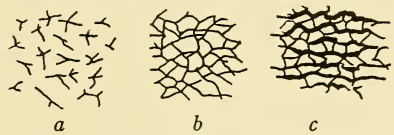
The cracks decrease progressively in depth and extend from the breech toward the muzzle. The majority run spiral-longitudinally in the grooves and transversely on the lands, as shown in Fig. 11. Cracks at the sharp junction of the lands and grooves usually are more pronounced and continue unbroken throughout the length of the barrel toward the muzzle, and often appear in those sections of the bore beyond a point where other cracks seem to have disappeared. On the other hand, all other cracks having the same longitudinal direction in the grooves are broken or dis-

[11] This refers to the bottle-neck shell ordinarily used.

continuous. The destruction of the lands, that is, lowering caused by the abrasive action of the bullet, is greater than the erosion on the grooves caused by the abrasive action of gases, but the cracking in the lands is somewhat less than that in the grooves. (See Fig. 11, barrels 1, 2, and 3, point "a," lands, and point "b," grooves.)

2. THEORY OF PROF. D. TSCHERNOFF [12]

Various explanations have been offered to account for the development of cracks in the bore of fired gun barrels. An extract from the theory of Prof. Tschernoff,[13] based solely on the physical action of heat, is given below:

> The first evidences of erosion are manifested in the appearance of dull spots upon the brilliant surface of the bore, principally in the upper part of the chamber, in the vicinity of the centering cone, and on the cone itself at the origin of the rifling. Examination of gutta-percha impressions shows that these spots are made up on networks of small cracks, extremely fine and very shallow. As a rule, the meshes of these nets are not closed in the incipient stage (Fig. 12 *a*); but as the firing is continued, the little isolated cracks extend, joining the neighboring ones and forming a network of continuous meshes (Fig. 12 *b*).
>
> 
>
> FIG. 12.—*Sketch illustrating Prof. Tschernoff's theory of the appearance of the cracks in the bore of a gun*
>
> With repeated firing, the little cracks increase in width and depth, but on the centering cone, and at the origin of the rifling, this increase is particularly noticeable in the cracks parallel to the axis (Fig. 12 *c*). The gases of the charge and the unburned particles of powder penetrate between the projectile and the bore and follow the lines of least resistance, cutting them deeper. This deepening of the cracks parallel to the axis of the bore clearly indicates mechanical action of the products of combustion.
>
> On the lands and on the edges of the grooves, transverse cracks or scorings predominate; as soon as a fissure appears in a plane at right angles to the axis of the bore, the rotating band of the projectile enters it, tears away particles of steel, and enlarges it at each shot. The erosion sometimes proceeds so far as to remove the lands completely, or even to make hollows where the lands were.

Tschernoff in his explanation of the formation of transverse cracks in the surfaces of the lands maintains that longitudinal expansion of the lands does not occur, being prevented by the restraining influence of the cooler layers which underlie the highly heated skin, the cooler layers being in turn restrained by their integral union with the body or bulk of the lands.

---

[12] Prof. Tschernoff made his observation on the longitudinal sections of two Russian 3-inch pieces which had been fired about 3000 times.

[13] Capt. H. Pelloux, of the French Artillery, Translation of the Tschernoff theory of erosion, Journal of U. S. Artillery, **41**, p. 346; 1914.

The lands, however, do have the opportunity to expand laterally, in which direction most of the expansion upon heating occurs. Upon cooling, a longitudinal contraction does not occur on the body of the lands. At the other extreme, the metal at the surface, which has been highly heated, tends to contract equally in both longitudinal and transverse directions, but the great longitudinal stress which is thus set up upon cooling in the surface layer is beyond the elastic limit of the previously heated metal, so that it cracks transversely.

This explanation affords some comfort in endeavoring to describe conditions leading to transverse cracking. However, the greater lateral expansion which the author mentions should be accounted for. If the explanation of transverse expansion accounts for the longitudinal stresses, a similar explanation should suffice to account for the lateral or transverse stresses. These, he contends, are held within the elastic limit.

However, the surface metal heated to the temperature which his explanation requires would have expanded in all directions so that parallel conditions should apply in the formation of longitudinal cracks. The absence of pronounced longitudinal cracks, and the fact that the majority of the cracks in the lands are transverse, appears to make Tschernoff's explanation partially untenable.

3. RELATION BETWEEN THE DIRECTION OF THE CRACKS AND THE MACHINE MARKS

Differences in the direction of the cracks in the lands and the grooves were noted in machine-gun barrels which had been fired for different numbers of rounds. The same differences in the direction of the cracks for the guns of large calibers were reported by several investigators. It was apparent that the cracks and the machine marks from tools were invariably in the same direction. The machine marks in the unfired barrel are also transverse in the land and of spiral-longitudinal direction in the grooves, as illustrated in Fig. 13.

This is due to the method of rifle manufacture, as may be seen from the following:

The barrel blank is drilled first with a rotating motion perpendicular to the long axis, which operation is followed by reaming The motion of the reamer coincides with that used in drilling. The lands are made in this manner, and naturally from the rotation of the machine tools, marks from machining are transverse to the long dimension of the land. The grooves are made by moving the rifling head of the scrape cutter on a spiral curve. The operation produces machine marks which run in the direction of rifling, which is spiral longitudinally.

This similarity in the direction of the cracks and the machine marks in the grooves and lands would appear to indicate that these marks are the starting points of the heat-contraction cracks. Naturally, if one fires from a machine-gun barrel with an absolutely even bore, without rifling and with a perfectly polished surface, cracks, if any, should appear and develop equally on all parts of the surface. On the other hand, if the barrel has a rifled surface or any marks on the bore, cracks would be expected to originate at these irregularities, such as the corners of the grooves, and later at all parts of the bore which in the beginning had uneven surfaces.

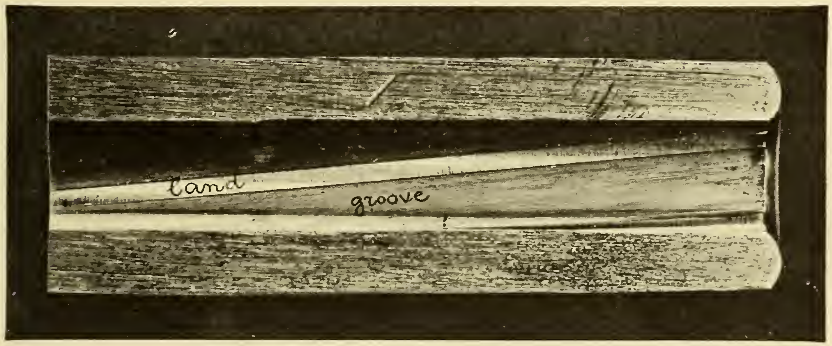


FIG. 13.—*Interior view of the gun bore, showing the direction of marks of the cutter of the machine tool in the grooves and the lands of the unfired barrel*

The most marked of these irregularities naturally would be the points at which cracks originate, as it is a fact that steel ruptures quickly where there are any sharp changes of direction in its surface.

The cracks in the grooves and the lands follow the path of the machine marks. Once begun they move in the direction of least resistance, following the direction of the marks made by the machine tool in the already defective surface. Each shot naturally causes the crack to grow larger and deeper. It has been found that the cracks in the machine-gun barrel produced by actual firing are sharp ended, as shown in Figs. 14 and 15. Prof. Howe[14] stated in regard to the sharp-ended cracks in cannon barrels, that if they were deepened by abrasions of gases, they would be

[14] Prof. Howe, The erosion of guns, Trans. Amer. Inst. Min. Eng., 58, p. 542; 1918.

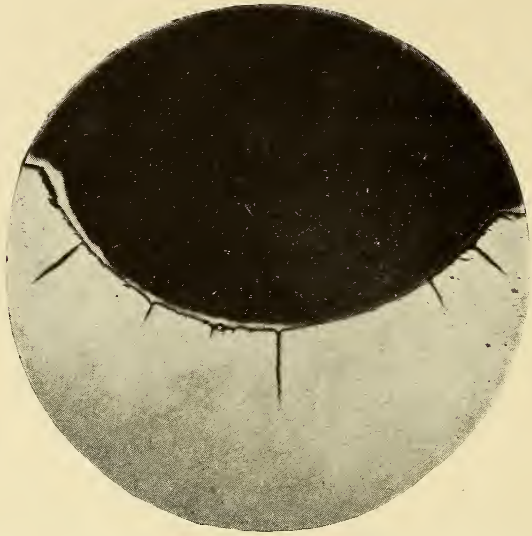


FIG. 14.—*Cross section of a machine-gun barrel fired 3880 rounds, showing cracks running radially from the bore. Specimen was taken at origin of rifling.* × 8.8

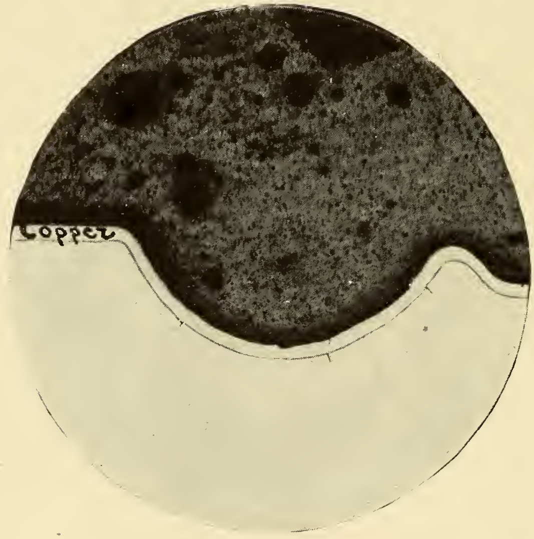


FIG. 15.—*Cross section of a machine-gun barrel fired 3880 rounds, showing cracks running radially from the bore.* × 6.2

Specimen was taken about 4 in. from the origin of rifling.

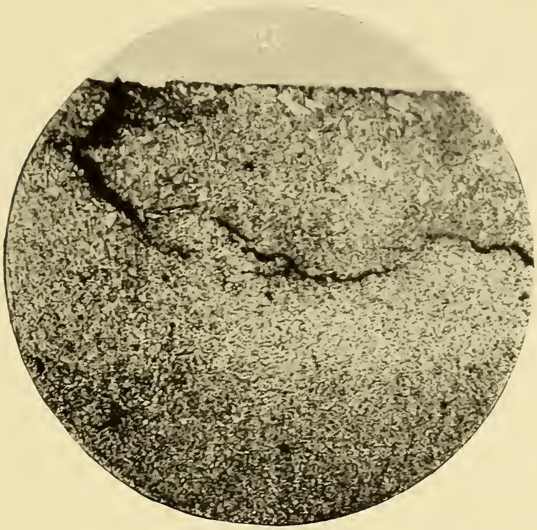


FIG. 16.—*Cross section of a machine-gun barrel after firing 4000 rounds, showing circumferential and radial cracks.* × *250*

(*a*) Electrolytic protective layer of copper

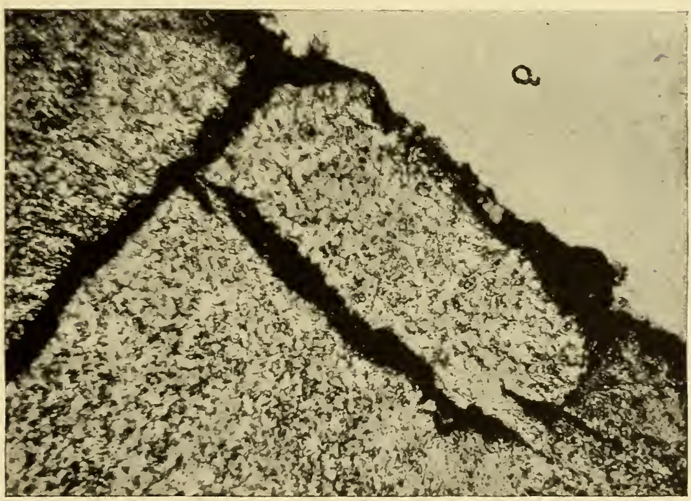


FIG. 17.—*View similar to that of Fig. 16 after firing 8000 rounds.* × *250*

Note complete connection of circumferential cracks, which will cause the separation of the piece on continued firing

(*a*) Electrolytic protective layer of copper round bottomed, and that the spindling of the cracks showed that they were opened mechanically. The heat cracks produced in the steel by arcing, which extend into the body of the metal, are sharp ended, as is shown on the micrographs, Figs. 6 and 9.

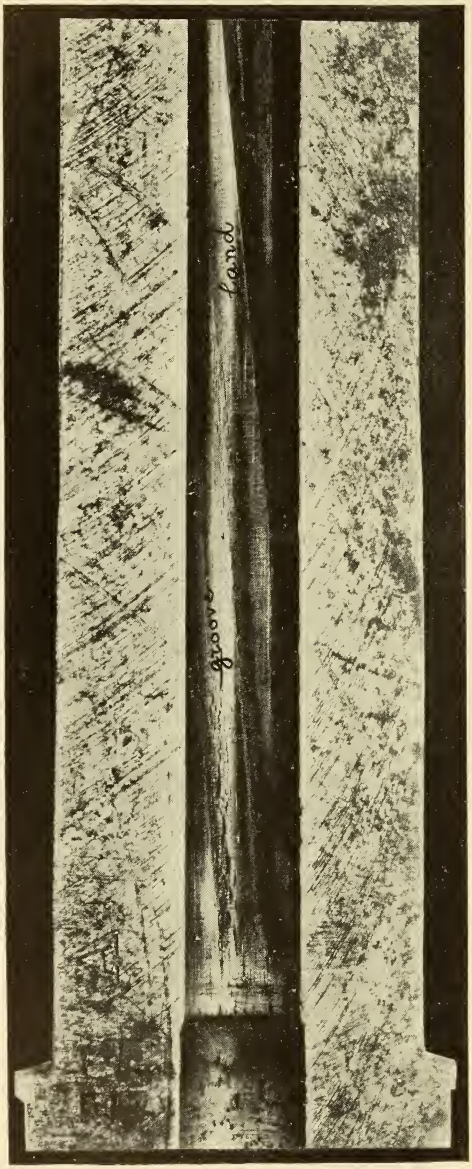


Fig. 18.—*Interior view of gun bore showing cracks agreeing in direction with the marks of the cutter of the machine tool. Gun fired 3880 rounds.* × 2.3

Besides the radial cracks, Figs. 14 and 15, which start from the surface of the land and groove proceeding outward, cracks also form circumferentially. Circumferential cracks may originate (1) at the junction of highly heated metal with metal heated only to a moderate temperature, or (2) at any point subject to the tensional stresses created in the expansion and contraction of the steel. The crack illustrating (2) is shown in the micrographs, Figs. 5, 16, and 17. Circumferential cracks would connect the radial cracks together, thus helping in the destruction of the rifling, with an enlargement of the bore resulting.

In an effort to obtain a very high finish in manufacture, "lapping" the barrels after rifling was tried by moving a lead core which fits the lands and grooves through a bath of flour emery and oil. The "lapping," which follows the rifling in its spiral motion, does not completely remove the machine tool marks in the grooves, as it is in the same direction. However, moving in a direction perpendicular to the machine marks made by drilling in the lands gives a better finish. The "lapping" of the barrels, as is the practice in manufacture, fails to increase the life of the guns. It is believed, however, that by an extremely long "lapping," giving a higher polish to the surface, the life of the barrel would be increased.

The transverse cracks in the lands appear and extend in the same direction as the transverse machine marks: the scoring action of the bullet causes the loss of their transverse direction with increased number of shots. In the grooves, however, the cracks remain distinctly longitudinal, agreeing with the direction of the machine marks, as shown in Fig. 18. Forming in the machine tool marks, the cracks themselves became connected, following the outlines which already exist between the marks.

4. COMPARISON OF CRACKS IN THE LANDS AND THE GROOVES

From the above it is understood that most marked irregularities occur at the juncture of the lands and grooves, and these irregularities produce cracks which are more pronounced than any of the other cracks in the grooves (Fig. 11, points "c"). These cracks can be observed even when the rifling of the barrel is spent, and they clearly indicate the former position of the lands.

The explanation of Prof. Tschernoff [15] may also be of interest in regard to the origin of these particular cracks. He states that the contraction and expansion act differently in the grooves than in the lands in accordance with their design, the lands being heated from three sides, while the grooves are heated from one side only. The difference in contraction and expansion of these two adjoining parts might increase the effect of cracking and help the formation of the most pronounced cracks at these particular points.

The cracks in the lands probably develop at the same time as in the grooves. Difference in the extent of cracking in the grooves, where cracks are more pronounced than in the lands, is due to the differences in the abrasive action of the bullet. The motion of the bullet is perpendicular in its direction to the machine-tool marks in the lands; in the grooves, however, the motion of the bullet is in the same direction with the machine-cutting marks. As previously stated, the bullet is in slight contact with the grooves

[15] Prof. Tschernoff, The Artillery Journal of Russia, 7; 1912.

only for a limited number of rounds. The lands, however, are under considerable friction. One would hardly expect the scoring-polishing effect in the grooves to be equal to that in the lands. As a result of these differences in abrasion, cracks in the lands are reduced in their lateral dimensions by the wearing away of their upper walls. Cracks in the grooves are not exposed to the abrasive action to the same extent, consequently they are able to develop greater lateral openings. If the machine-gun barrels are not fired beyond the complete obliteration of the rifling, the difference in the color of the lands and the grooves may be noted. Hence the bullet lowers the lands with each passage but scores (polishes) the grooves at the same time to a much lesser extent, and only during a limited number of rounds. Hence the formation and growth of cracks in the grooves is not retarded as in the lands by the abrasive action of the bullet.

It is believed that a slight rounding of the sharp junction between the lands and the grooves as well as the upper corners of the lands in the rifling should decrease the susceptibility to cracking in these particular points and should prolong the life of the rifling for the reasons previously outlined.

V. SUMMARY.

This investigation indicates that when a machine-gun barrel reaches its life limit its exhaustion is due to a combination of the abrasive action of the bullet and abrasion by hot gases, but to a greater degree to the former.

The author's experiments using the electric arc show that the rapid cooling (which is due to the large mass of cold metal near the highly heated inner surface of the steel) from temperatures near the melting point of the metal produces a martensitic layer. A similar layer is produced in the firing of a machine gun, indicating that the temperature conditions for the development of martensite can be made by the electric arc to approach those which occur in the gun under actual fire.

The selective hardening of the steel sets up surface strains, and the surface of the bore is readily cracked on account of the dimensional changes of the hardened brittle surface of the steel resulting from sudden changes in temperature between separate shots. The cracks that originate at irregularities in the surface of the bore, are attributable to the method of manufacture of the barrels.

The work herein reported was carried out under the direction of G. K. Burgess, chief, Division of Metallurgy of the National Bureau of Standards. J. S. Vanick, research operator of the Ordnance Department, gave valuable assistance in the microscopical examination of the specimens and the duplication of arc experiments. H. Fay, Massachusetts Institute of Technology, S. Tour of the Technical Staff, and Capt. S. G. Green of Small Arms Division of the Ordnance Department, U. S. Army, made criticisms and suggestions.

WASHINGTON, September 10, 1920.