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REPORT NO. 710/247

HISTORY OF ARMOR PLATE IN ITS APPLICATION
TO TANKS, AND GENERAL DATA ON ITS DEVELOP-
MENT IN THE UNITED STATES

By

INDEXED

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1st. Lieut. Ord. Dept., U.S.A.

December 28, 1918
WATERTOWN ARSENAL
WATERTOWN, MASS.

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HISTORY OF ARMOR PLATE IN ITS APPLICATION
TO TANKS, AND GENERAL DATA ON ITS DEVELOP-
MENT IN THE UNITED STATES.

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EXPLANATORY:

This history of armor plate and its application to tanks was compiled by Capt. N. C. Peebles of the Raw Materials Section, Ordnance Department, and is not a report of a similar development work that was done on armor plate by Dr. Sargent, Chief of the Metallurgical Section, of the Ordnance, and his associates.

PERSONNEL ENGAGED:

Capt. N. C. Peebles, Raw Materials Section, Ordnance Dept.
Mr. Blue, Carbon Steel Company, Pittsburg, Pa.,
Mr. Perkheiser, and
Several Steel Manufacturers.

CABLES:

There were no special cables on the subject of armor plate as it was understood from the beginning that it would be necessary to procure armor plate in this country for the tanks manufactured. Cable #341, dated Oct. 24, 1918, signed "Harbord" requests samples of armor plate. These samples were prepared under the methods of developing armor plate as outlined by Dr. Sargent, but were not entirely completed at the time the armistice was signed and the order for these was cancelled.

WORK ORDER:

Work Order No. 1372 requests "Perform experimental work necessary to obtain best and most efficient light armor plate

that can be produced for use of armored vehicles. To educate Government personnel."

PROCUREMENT ORDER:

Purchase Memorandum No. 1291 from Engineering Division, Motor Equipment Section was issued Aug. 17, 1918, requesting that this work be done and Procurement Order No. P14398-2391 ME was issued by the Procurement Division to cover this work.

PROCURING:

In the month of December 1917, the first serious effort to procure Armor Plate for the 6-ton (American-Renault) tanks was made. Prior to the existence of finished drawings, more than twenty steel concerns were approached with regard to their facilities, as well as their willingness to attempt its manufacture. It was considered necessary to place contracts with the steel manufacturers for the completed article, as much of the drilling and machining would have to be done prior to the heat treating and hardening processes which prepare the metal for the necessary ballistic tests. Very few of the American steel makers had had any experience in light Armor Plate manufacture, and most of those having attempted it in the past had developed most uncertain results.

SPECIFICATIONS AND TESTS:

The specifications for testing of Light Armor Plate required for Ordnance work had not included metal thicker than .25", while the Renault tank used approximately 70% in weight, .60" plate, the balance being divided between .312" and 25".

The Engineering Division, with the help of the Procurement Division, created ballistic tests founded on standards taken from the British and French. It is understood, however, that the French on certain types of plate, test one piece out of every twenty-five, while the test for this work, as contemplated by the Ordnance Department, would run from one to ten shots at each plate.

In the latter part of 1917, only one manufacturer expressed any interest in attempting this work, as there was little or no data available in this country concerning its manufacture.

The American designs call for a considerable amount of flanging and pressing of this Armor Plate which, according to data at hand, had not been accomplished elsewhere. It was found that the dome and the supporting base on the turret could be formed in a practical production manner, where in France and England, castings had formerly been used. This was perhaps the most notable development in Armor Plate for tanks. It was so successful that just prior to the signing of the Armistice, work was begun on the forming of the body of an entire turret which would reduce the machining and drilling to a minimum, greatly facilitate production and enhance the resisting qualities of the steel. These statements are made, based on the remarkable results obtained from the forming of the dome. It is apparent that the additional working of the steel under proper conditions, increased its resisting

power to machine gun and rifle fire. By the forming of the body of a turret in one piece, practically all angles would be eliminated and a series of convex curves resulting therefrom would still further increase the resisting qualities.

Following are the ballistic tests as originally adopted, with changes indicated in the second group, showing the great care given to testing of the steel, prior to the reduction of shots per plate:

(a) For .25" thickness of plate, ballistic test as prescribed in Form 434, "Instructions to Bidders", and general specifications governing manufacturing and inspection of gun carriages, artillery vehicles and similar ordnance material issued by the Ordnance Department, U. S. Army, will apply.

(b) For .312" thickness of plate, 5 shots of service ammunition (2700 f.s. - 150 grains) fired from machine gun at one point on the plate at a range of 10 yards. The above test to apply to all plates of .312" thickness containing a flat surface of not less than approximately 64 square inches clear of holes. On plates not having an uninterrupted area as great as 64 square inches, one shot fired from a service rifle at the same range, using same ammunition, will suffice.

(c) Each plate of the first 300 sets of plates, .6" in thickness shall be subjected to five shots, fired with service ammunition bullets reversed at range of 10 yards (2700 f.s. - 150 grain) striking within a circle of 5" in diameter. If the plates so tested appear satisfactory to a properly constituted government agent, consideration shall be given to the dropping of this test for the remaining plates of .6" thickness. All plates of .6" thickness shall be subjected to five shots fired at a range of 50 yards, all striking within a 10" circle, using armor piercing bullets (2800 f.s.). The above tests shall apply to all plates of .6" thickness, containing flat surface of not less than approximately 144 square inches, clear of holes. On plates not having an uninterrupted area as great as 144 square inches, one shot with bullets reversed at 10 yards, and one shot using armor

piercing bullets at 50 yards, will suffice. Plates on "b" and "c" will be considered as having passed the ballistic test when complying with that part of paragraph 35, page 41, of form No. 434, "Instructions to Bidders" issued by the Ordnance Department, U. S. Army, which reads, "The quality of steel must be such that the plates shall not be penetrated, cracked, broken or materially deformed except that very fine hair cracks formed in the back side of the bulge made by an impact may be permitted." A deep hole made by an armor piercing bullet is not considered a deformation of the plate.

Second Group

(a) Plates .25 inch thick shall be tested by firing a U.S. Rifle, caliber .30, and a supro-nickel-jacketed 150-grain bullet with a muzzle velocity of 2700 feet per second for direct impact at a range of 20 yards.

(b) Plates of .312 inch thickness: Plates containing a flat surface of not less than approximately 64 square inches clear of holes shall be tested by having five shots of service ammunition (2700 f.s. - 150 grain) fired from machine gun at one point on the plate at a range of 10 yards. Plates not having an uninterrupted area as great as 64 square inches shall be tested by having one shot fired from a service rifle at a range of 10 yards using the same ammunition.

(c) All plates of .6 inch thickness shall be tested by having 3 shots fired at a range of 50 yards widely separated, using armor piercing bullets (2800 f.s.). All plates of 0.6 inch thickness not having an uninterrupted area as great as 144 square inches shall be tested by having one shot, using armor-piercing bullets at 50 yards.

The .60" plate it is believed has been given the most severe test of any plate manufactured by the Allies. This plate is so placed on the tank that it receives practically all of the heavy right angle fire, considered most destructive. Contrary to general opinion and theories expressed on the subject, this plate was held down to approximately 390 Brinnell, which allowed

a deeper penetration from Armor Piercing bullets than various plates recommended, which showed initially a higher resisting power by stopping the bullet nearer to the surface. Practical tests have demonstrated that where the harder types of plate set up a crystallization after concentrated fire of Armor Piercing shots, the softer metals, as adopted by Captain Peebles, showed the maximum endurance. Following is the analysis:

Name; Carbon : Silicon: Sulphur Phosphate Mang. Nickel Chrome
 : 38-.45 : 15.25 :.04 & less:.04 & less:.40-.60:1.00-1.50:.50-.70:

The lighter gauges of plate, namely, .312" and .25", were produced from various analyses at first, and of necessity would have to have a considerably higher Brinnell.

In the early summer of 1918, Captain Peebles secured, through the courtesy of Mr. Prunel, a representative of the French Government, several analyses of steels made by Schneider & Co., and the following was immediately adopted:

<u>Name</u>	<u>Carbon</u>	<u>Silicon</u>	<u>Sulphur</u>	<u>Phos.</u>	<u>Mang.</u>	<u>Nickel</u>	<u>Chrome</u>	<u>Molybdenum</u>	<u>Treat</u>
	.24-29					4.7-5.2			<u>Ment.</u>
DO	0.24	0.150	0.040	0.040	0.250	5.000		0.500	<u>Temper-</u>
									<u>ed in</u>
									<u>water</u>
									<u>:820°C</u>
									<u>:drawn</u>
									<u>:200°</u>

It is considered without question the highest type of Armor Plate steel which has been manufactured in this country for metal of the above given thicknesses and its particular application.

The manufacturer of this steel accepted his contracts based only on ballistic tests. However, at all times, they were more

than willing to co-operate in experimenting without cost to the Ordnance Department on new analyses and new treatments. The Carbon Steel Company, of Pittsburgh, and their sub-contractors are responsible for the forming and shaping of Armor Plate and its most successful production. A recent delegation from the French Government who were considering the purchase of similar plate at the plant of the manufacturer, refused to believe that this material was formed as described, until they saw it in manufacture.

Contrary to methods used by the British and French, a considerable portion of this Armor Plate was drilled and machined on the edges after the hardening process. It is believed that had the manufacturer continued a few months more, practically all of the machine work would have been done while the metal was in its softest condition. The reason for doing so much of the machining after the hardening, was that the French design of plates was so complicated and so costly that a loss of a finished plate at the ballistic test would be too severe.

In the summer of 1918, sufficient material had been produced to assure the manufacturer of certain small percentage of loss at the ballistic test. On the .60" plate, the average loss was slightly over 10%. It is to be remembered that 70% of the material in weight was of this thickness.

CONCLUSIONS:

Should the work of developing Armor Plate be continued, there is no question but that wonderful results would be accomplished.

The Steel Companies had already accomplished unexpected results, such as being able to form the plate into special shapes in a practical production manner. During the Steel Companies' period of experiment the highest type of Armor Plate Steel was developed that this country has ever known. Enough material had been produced to assure complete armor plate for tanks.

(signed) N. C. PEEBLES,
Captain, Ord. Dept., U.S.A.

HISTORY OF ARMOR PLATE UNITS
APPLICATION TO TANKS AND DATA ON ITS DEVELOP-
MENT IN THE UNITED STATES.

The drawings for the Renault Type Tank arrived in this country in November 1917. These drawings were complete in detail but owing to the fact that the metric system was used, considerable redesigning was necessary to adapt them to American manufacture. Some parts of the French design of armor were made from castings and since this had never been done in this country, it was not thought advisable to take the time necessary to experiment with this method but to build up these parts from either straight or formed plates.

Until the drawings could be revised as outlined above, an effort was made to procure the steel and with only preliminary drawings about twenty steel concerns were approached in December 1917, with regard to their facilities as well as their willingness to attempt its manufacture. It was considered necessary to place contracts with the steel manufacturer for the completed armor, as much of the drilling and machining would have to be done prior to the heat treating process which prepares the metal for the necessary ballistic tests. Very few American steel makers had had any experience in light armor plate manufacture.

SPECIFICATIONS AND TESTS

In order to save time the French specifications and tests for this armor were adopted in general. It is understood that the French only tested one plate out of twenty-five. The Ordnance Department knowing this material was in the nature of an experiment in this country decided that every plate should be tested severly until enough armor had been produced to bring it past the experimental stage. Accordingly two groups of tests were arranged. It will be noted that parts (a) and (b) of both groups are identical but that part (c) of the second group applies after the first 300 sets of plates.

(a) For .25" thickness of plate, ballistic test as prescribed in Form 434, "Instructions to Bidders", and general specifications governing manufacturing and inspection of gun carriages, artillery vehicles and similar ordnance material issued by the Ordnance Department, U. S. Army, will apply.

(b) For .312" thickness of plate, 5 shots of service ammunition (2700 F.S. - 150 grains) fired from machine gun at one point on the plate at a range of 10 yards. The above test to apply to all plates of .312" thickness containing a flat surface of not less than approximately 64 square inches clear of holes. On plates not having an uninterrupted area as great as 64 square inches, one shot fired from a service rifle at the same range, using same ammunition, will suffice.

(c) Each plate of the first 300 sets of plates .6" in thickness shall be subjected to five shots, fired with service ammunition bullets reversed at range of 10 yards (2700 f.s. - 150 grain) striking within a circle of 5" in diameter. If the plates so tested appear satisfactory to a properly constituted government agent, consideration shall be given to the dropping of this test for the remaining plates of .6" thickness. All the plates of .6" thickness shall be subjected to five shots fired at a range of 50 yards, all striking within a 10" circle, using armor piercing bullets (2800 f.s.). The above tests shall apply to all plates of .6" thickness, containing flat surface of not less than approximately 144 square inches, clear of holes. On plates not having an uninterrupted area as great as 144 square inches, one shot with bullets reversed at 10 yards, and one shot using armor piercing bullets at 50 yards, will suffice. Plates on "b" and "c" will be considered as having passed the ballistic test when complying with that part of paragraph 35, page 41, of form No. 434, "Instructions to Bidders" issued by the Ordnance Department, U. S. Army, which reads, "The quality of steel must be such that the plates shall not be penetrated, cracked, broken or materially deformed except that very fine hair cracks formed in the back side of the bulge made by an impact may be permitted." A deep hole made by an armor piercing bullet is not considered a deformation of the plate.

Second Group

(a) Plates .25 inch thick shall be tested by firing a U.S. Rifle, caliber .30, and a supro-nickel-jacketed 150-grain bullet with a muzzle velocity of 2700 feet per second for direct impact at a range of 20 yards.

(b) Plates of .312 inch thickness: Plates containing a flat surface of not less than approximately 64 square inches clear of holes shall be tested by having five shots of service ammunition (2700 f.s. - 150 grain) fired from machine gun at one point of the plate at a range of 10 yards. Plates not having an uninterrupted area as great as 64 square inches shall be tested by having one shot fired from a service rifle at a range of 10 yards using the same ammunition.

(c) All plates of .6 inch thickness shall be tested by having 3 shots fired at a range of 50 yards widely separated, using armor piercing bullets (2800 f.s.). All plates of .6 inch thickness not having an uninterrupted area as great as 144 square inches shall be tested by having one shot, using armor piercing bullets of 50 yards.

Several contractors were approached on the subject of furnishing this armor plate to stand the above test and the Carbon Steel Company of Pittsburg was selected to make this armor plate. The analysis was left to them and since they have had considerable experience in making armor plate, they

tried a specification that had been used for the U. S. Navy, which was as follows:

Analysis 1.

<u>Carbon:</u>	<u>Silicon:</u>	<u>Sulphur:</u>	<u>Phosphorus:</u>	<u>Mang.:</u>	<u>Nickel:</u>	<u>Chrome:</u>
.38-.45	.15-.25	.04 max.	.04 max.	40.-.60	1.00-1.50	.50-.70

This analysis was found to give very good results for the .6" thickness of plate, but considerable trouble was experienced in getting said results from the lighter gauges .312 and .25.

In the early summer of 1918, Captain Peebles secured, through the courtesy of Mr. Prunel, a representative of the French Government, several analyses of steels made by Schneider & Co., and the following was immediately adopted.

Analysis 2.

<u>Carbon:</u>	<u>Silicon:</u>	<u>Sulphur:</u>	<u>Phos.:</u>	<u>Mang.:</u>	<u>Nickel:</u>	<u>Molybdenum:</u>
24-29			max.	max.	4.7-5.2	
0.24	0.150	.04	.04	.250	5.000	5.000

It will be understood that a large number of analyses and heat treatments were experienced before the adoption of the above, and credit must be given to the Carbon Steel Company, Pittsburg, for their untiring efforts to produce the results obtained.

MECHANICAL PROCESSES INVOLVED

Steel for this armor plate was made in both the electric furnace and the open hearth furnace and very good results were obtained from both of these methods. It was found that to obtain the best results, it was necessary to roll the steel at a fairly high temperature and as a high finish was not necessary, this method showed better ballistic results than when the steel was rolled at a lower temperature.

HEAT TREATING

The heat treatment from which the best results were obtained for the .6" thickness plate was to heat to 1600 degrees fahrenheit and hold to that temperature for 15 minutes. The steel was then quenched in water, being held in a specially designed clamp to prevent warping. This clamping device was a departure from previous practice, in that the clamp was at all times immersed in the water and the plate was taken directly from the furnace and slid into the clamp. It was found that the small amount of time necessary for the plate to pass into the clamp did not materially effect the straightening of the plate and

saved considerable labor, as the previous practice had been to lower the clamp containing the plate into the quenching liquid. After quenching the .6" plates were drawn in a furnace or in a salt solution. When they were drawn in the furnace the temperature used was approximately 800 degrees fahrenheit and they were allowed to remain approximately 30 minutes. If they were drawn in salt solution, temperature was about 600 degrees fahrenheit, and in both cases they were cooled in air.

The above mentioned drawing operation was necessary on account of the necessity for machining a large proportion of these plates after heat treatment. This was the French practice as the machining was very expensive, and it was not though wise to subject after being machined to the ballistic test with the possibility of losing a large proportion.

The heat treatment for the analysis No. 2 used on .312 and .25 inches thickness of plate was somewhat different. This thickness of plate was heated in the same manner but was quenched in oil, being held in a similar clamp to prevent warping. It was found after experimentation that no drawing was necessary and very good results were obtained with this analysis without the drawing. It will be remembered that machining on the light armor plate was all done before the heat treatment, so that the hardness of the plate was not a factor.

A number of the plates of the Renault Type Tank were formed or drawn. Credit for the development on this work must be given to the H. K. Porter Company, Pittsburg, who achieved very good results on this line. The work was carried to such an extent that a complete turret was developed which could be made from two pieces to obviate considerable machine work and a large number of angles, which it is thought would increase ballistic resistance of the completed article.

The Diebold Safe & Lock Company, who were sub-contractors on considerable machining, decided to plane the bevelled edges of the plates of which there were a large number. This was done on large planers which they had in their factory. It will be remembered in this connection that the .6" thickness armor plate was machined in the heat treated condition. It was decided that the brinnell hardness on these plates should run between 360 and 375. Owing to the inability to keep the hardness at this point though it was found during the operation of this contract that some plates were received and machined which run as high as 470 brinnell hardness. It was of course, extremely difficult to machine these plates but it was done, with best results on planing with the use of "Clarite" Steel hardened in an air blast.

A later development for handling the .6" plates on a large production basis which was developed in co-operation with the Carbon Steel Company by the American Motor Truck Company of Newark, Ohio, also sub-contractors for machining was to cut the plates almost to size with an oxy-acetylene flame, and then grind the edges to size on a small grinder. This burning operation was found to be very successful and, of course, it was not necessary to keep the Brinnell hardness down for any plates that were cut in this manner. A number of interesting machines were used on this work among which might be mentioned an oxygraph and a radiograph. The radiograph was devised for cutting the straight sides of the plates. This machine could be set to cut bevelled edges to an angle and very good results were obtained. Simpler devices were developed by sub-contractors to achieve the same results by hand. The oxygraphs mentioned above were an elaboration of a pantograph having a cutting torch to do the cutting. This machine is able to cut any shape to very accurate limits.

After the burning operation mentioned above, it was, of course, necessary to smooth off the edges of the plates and bring them to size, and an ordinary knife grinder was developed for this work which gave very good results. Several attachments of interest were brought out which facilitated this work considerably.

Although the burning operation mentioned above allowed the Brinnell hardness of the plates to be very high, this fact made it more difficult to drill the plates of which there was considerable to be done on each one. Very good results in this drilling were obtained with flat Celfor drills. This drill was made like a blacksmith's drill, with a rib running lengthwise through the center. The best results were obtained using hand feed and the average speed per hole through .6" armor with a 21/32 drill was about two minutes per hole. It is understood, of course, that this would vary considerably depending upon the hardness of the plate.

A number of the plates have peep holes in them. These peep holes were slots which were bevelled out on the inside of the armor to allow the operator of the tank to see outside without exposing himself unnecessarily. Since this operation was a milling operation and it was not thought that it could be done in any other way, considerable doubt was expressed at first as to whether it could be accomplished, owing to the hardness of the plate. It was found, however, that very good results could be obtained by drawing the temper of the steel with an oxy-acetylene torch only where it was to be machined after which the machining was done very easily.

The Fench design of this armor specified key head bolts. The same design was specified by the Ordnance Department, and

the matter of cutting the notches for these keys proved to be quite difficult. Owing to the small size of the notches, it was found to be impossible to cut them with a chisel or air hammer, but finally the oxy-acetylene cutting torch was again brought into use and excellent results were obtained by this method.

The lighter armor plate was fabricated in a clean condition and practically all the work was done on shears and punches. It was found, however, that owing to the analysis of the steel that machines of at least twice the capacity were necessary and would be required for ordinary commercial open hearth steel. It was found that plates could be sheared very accurately to size and that no grinding on edges was necessary. It was also found that punching could be held to very close limits with the proper equipments in jigs.

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