JOURNAL

OF THE

UNITED STATES ARTILLERY

PUBLISHED BY AUTHORITY OF THE

STAFF OF THE ARTILLERY SCHOOL.

VOLUME II.

1893.

ARTILLERY SCHOOL PRESS,
FORT MONROE, VIRGINIA.

UNITED STATES ARTILLERY SCHOOL,

FORT MONROE, VIRGINIA.

The *Journal of the U. S. Artillery* is by authority of the Staff, published at the Artillery School as a quarterly.

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Subscription $2.50
For countries in the postal union $3.00
Single numbers $1.00

Subscriptions in all cases date from January 1st. Address all communications and remittances to the editor, at Fort Monroe, Virginia.

AGENTS.

NEW YORK—*Dyrsen & Pfeiffer*, successors to
F. W. Christern, 254 5th Avenue.

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HADFIELD'S MANGANESE STEEL AND CHROMIUM STEEL PROJECTILES.

By Captain EDMUND L. ZALINSKI, Fifth Artillery, U. S. A.

The advances made in the manufacture of steel armor have given it a momentary supremacy over the gun. The best made so-called armor-piercing projectiles are frequently shattered as if made of glass when striking the Harveyized plates. The very high velocities now attainable are of no avail in the absence of suitable projectiles.

Unless an overwhelming energy with reference to the resisting ability of the plate is developed, perforation is out of the question. Failing to perforate, we must resort to smashing it by tremendous blows delivered from guns of very large caliber.

For either work a projectile must be provided which, whilst very hard, must have an enduring toughness.

Such have not yet been evolved. The most successful ones have been made of alloys of manganese and chromium with carbon steel.

We are indebted to the investigations of Robert Hadfield for manganese steel, and to his son R. A. Hadfield for its development, and a more definite knowledge of its properties as well as those of silicon, aluminum and chromium steels. Of these alloys, it appears that only chromium and manganese steels are of direct interest to the artillerist for the manufacture of projectiles. The most successful of the projectiles of the present are either of chromium steel or a combination of chromium and manganese. Both manganese and chromium steel contain carbon, and their characteristics are largely influenced by the percentage and character of the latter present. Manganese steel has from about seven to twenty per cent. of manganese. It has a variable effect on the characteristics of the alloy. With 1.5 per cent. manganese steel is brittle, with further increase from 4 to 6.5 per cent. it is so brittle that it may be pulverized under the hand hammer; but when the manganese rises above 7 per cent. the ductility of the water-cooled metal increases in the most striking way, till the manganese reaches 13 per cent. to 14 per cent. When the manganese exceeds this the ductility falls off abruptly, the strength remaining constant till it passes 18 per cent., when this also diminishes suddenly. It is generally free from blow-holes, has good tensile strength and astonishing ductility in combination with great hardness. The hardness is such, however, as to make it difficult to machine by ordinary methods. It yields quite readily however to the emery wheel. It is very hard to ordinary abrasion. Water cooling increases the hardness but slightly, if at all, whilst it increases ductility greatly. Annealing does not materially reduce its hardness. Whilst manganese steel cannot be made as hard as the hardest carbon steel nor as tough as the best soft carbon steel, it can be made to combine a greater hardness with a greater toughness than is obtainable with carbon steel.

A singular feature of its ductility is that, in being stretched, as in tests for elongation, it stretches nearly uniformly throughout its length (outside of the jaws of the testing machine), leaving the reduced part of nearly uniform cross-section, instead of reducing nearly tapering to the plane of fracture, as is the case with ordinary steel. It is practically unmagnetizable when it contains 13 per cent. manganese.

It has not yet been made into armor-piercing projectiles, except in combination with chromium. It possesses qualities which may make it useful in compound or built-up projectiles which will be referred to later. Its qualities should make it suitable for armor. With a higher percentage of carbon and Harveyized, or correspondingly treated, it should offer great resistance to penetration or crushing. Should it not be possible to bring its face to a sufficient degree of hardness a compound all-steel armor might be devised, the main part being of manganese steel and the face being of carbon steel of the thickness and carbon suitable for the greatest resisting hardness. The treatment which would harden the carbon steel face would only serve to toughen the manganese steel backing. The greatest objection to its use for armor is the difficulty of machining. But this may be overcome, if it is found by experiment that it possesses superior resisting qualities. An ingot of manganese steel has been sent to the United States to be rolled into an armor plate and tested for penetration. If properly treated there are reasons for expecting notable results.

The differences and similarities of the conduct of manganese and carbon steel, when suddenly cooled, are shown in the following table: *

Properties.	Effects of sudden cooling.	
	Carbon steel.	Manganese steel.
Hardness:	Enormous increase.	Slight increase.
Percentage of carbon in hardening state:	Very great increase.	Moderate increase.
Density:	Decrease.	Usually no change, but continue slight increase.
Size of grain:	Nil, or decrease.	Increase.
Separation of components:	Decrease.	Increase.
Ductility:	Enormous decrease.	Enormous increase.
Tensile strength:	Increase.	Increase.

The most remarkable feature of manganese steel is the great increase in ductility when cooled suddenly; this effect being directly opposite to that produced on carbon steel similarly treated.

CHROMIUM STEEL.

The simple addition of chromium to carbon steel serves to harden the metal whilst adding to its tensile strength. The alloy is susceptible of being tempered so as to obtain greater hardness than is possible with carbon steel, whilst retaining great tensile strength and some ductility. The alloy does not weld readily. The magnetic properties remain about the same as of carbon steel.

Tables II and V from Mr. Hadfield's paper on chromium steel present interesting comparisons between aluminum, silicon and chromium steel.

* I am indebted to the various papers of Mr. Henry M. Howe, of Boston, Mass., for tables and information as to manganese steel. E. L. Z.

TABLE II. *Comparison Table of Tensile and Bending Tests of Forged Chromium, Silicon, and Aluminium Steels, all the Materials having been annealed.*

	Per Cent.				Limit of Elasticity in Tons per sq. inch.	Breaking Load in Tons per sq. inch.	Extension per Cent. on 2 inches.	Reduction of Area per Cent.	Bending Test of Annealed Forged Bars.	Remarks.
	C.	Si.	Al.	Cr.						
Si. steel **A** .	.14	.24	. . .	. . .	15.17	25.00	37.55	60.74	Bent double cold	
Al. steel **A** .	.15	. . .	.38	. . .	20.00	26.00	40.35	60.74	Bent double cold	
Cr. steel **B** .	.16	. . .	. . .	.29	17.00	25.00	45.55	65.90	Bent double cold	
Si. steel **B** .	.18	.73	. . .	. . .	19.00	29.50	34.02	52.66	Bent double cold	
Al. steel **C** .	.18	. . .	.66	. . .	18.00	27.00	33.00	52.14	Bent double cold	
Cr. steel **E** .	.12	. . .	. . .	.84	19.00	28.00	42.50	61.20	Bent double cold	
Si. steel **C** .	.19	1.60	. . .	. . .	25.00	33.00	35.10	54.52	Bent double cold	
Al. steel **F** .	.21	. . .	1.60	. . .	13.00	26.00	36.35	67.00	Bent double cold	
Cr. steel **G** .	.21	. . .	. . .	1.51	19.00	33.50	38.07	55.88	Bent double cold	
Si. steel **D** .	.20	2.18	. . .	. . .	25.50	34.00	36.50	59.96	Bent double cold	
Al. steel **H** .	.24	. . .	2.24	. . .	18.50	28.50	33.00	48.62	Bent double cold	
Cr. steel **H** .	.39	. . .	. . .	2.54	24.50	44.00	24.50	33.84	Bent double cold	
Si. steel **H** .	.26	5.53	. . .	. . .	25.00	25.00	0.37	2.00	Would not bend	
Al. steel **I** .	.22	. . .	5.60	. . .	27.00	36.00	6.45	6.16	16 broken	
Cr. steel **J** .	.77	. . .	. . .	5.19	20.00	55.00	8.20	6.88	Bent double cold	Carbon in chrome sample too high to make direct comparison.

TABLE V.—*Comparative Hardness of Chromium, Silicon, and Aluminium Steels (all unannealed).*
These tests were made by Professor T. TURNER, *Mason College, Birmingham, with the Sclerometer.*

Silicon Steel.					Aluminium Steel.						Chromium Steel.						Remarks.
No.	Analysis per Cent.			Relative Hardness in Turner's Scale.	No.	Analysis per Cent.				Relative Hardness in Turner's Scale.	No.	Analysis per Cent.				Relative Hardness in Turner's Scale.	
	C.	Si.	Mn			C.	Si.	Mn	Al.			C.	Si.	Mn	Cr.		
898 A	.14	.24	.14	20	**1167 A**	.15	.18	.18	.38	20	**1176 B**	.16	.07	.18	.29	22	Relative hardness of other substances:— Lead . . . . . 1 Copper . . . . 8 Softest iron . . 15 Very hard white iron 72
898 B	.18	.79	.21	20	**1167 B**	.20	.12	.11	.61	21	**1176 E**	.12	.08	.18	.84	21	
898 C	.19	1.60	.28	24	**1167 D**	.17	.10	.18	.72	20	**1176 F**	.27	.12	.21	1.18	24	
898 D	.20	2.18	.25	24	**1167 F**	.21	.18	.18	1.60	21	**1176 H**	.39	.14	.25	2.54	24	
898 E	.20	2.67	.25	26	**1167 G**	.21	.18	.18	2.20	21	**1176 J***	.77	.50	.61	5.19	55	*This has been partially hardened by heat treatment. In Nos. 1176 J, K, and L, the carbon necessarily present explains the hardness. Judging from the behaviour of B, E, F, and H, there is no reason to doubt the possibility of obtaining a soft 5.6 or even 9 per cent. chromium steel, provided the carbon is under .50 per cent.
898 F	.21	3.46	.29	30	**1167 H**	.24	.18	.32	2.24	20	**1176 K**	.86	.31	.29	6.89	38	
898 G	.25	4.49	.36	33	**1167 I**	.22	.20	.22	5.60	22	**1176 L**	.71	.36	.25	9.18	43	
898 H	.26	5.53	.29	36													

The results obtained in some English tests of Hadfield chromium steel projectiles are given in the following extracts from the same paper:*

"In 1882, the writer's firm supplied chromium shells to the English Government, one of which, a 6-inch, successfully penetrated an 8-inch wrought iron plate, and was so little injured that it could have been fired again; also about the same time a 9.2-inch projectile, which penetrated a 16½-inch wrought iron plate and 8½ inches into a second plate placed behind. The same firm has since been successful in passing considerable numbers into the English service. A short resumé of their latest tests may be of interest. By kind permission of the War Office, the results are illustrated by photographs of the plates and projectiles used.

"Although principally makers of smaller calibers, as regards 'armor-piercers,' one of those experimental shells, 13.5 inches, weighing 1120 lbs., fired from the 63-ton breech-loading gun at a velocity of 1950 feet per second, penetrated an 18-inch compound plate, a 6-inch wrought iron plate, 20 feet of oak backing, a further 10½-inch wrought iron plate, and was then found broken beyond a 2-inch wrought iron plate—that is, a total penetration of 36½ inches of armour plating. This projectile was believed by the Ordnance Committee to pass *whole* through the 18-inch compound and 6-inch wrought iron plates. Fig. 3 shows the penetration effected.

"One of their reception lots, viz., 300 6-inch projectiles, from which two were selected by the Government Inspector, gave the following results (Figs. 4 to 8 show the results of the tests).

"Each shell was fired against a separate 9-inch compound armour plate, with a striking velocity of 1825 feet per second, and a striking energy of 2250 tons. The faces of these plates contained 1.25 per cent. of carbon, so that the tests were severe.

"No. 1 projectile (round 2553, Figs. 4, 5, and 8) penetrated the plate to the eighth layer of oak backing. It was whole, showed no cracks, and very slightly altered in shape.

Diameter of body before firing, 5.963 inches; after firing, 5.974 inches = +.011 inches.
Length before firing, 16.68 inches; after firing, 16.47 inches . . = —.210 inches.

* "Alloys of iron and chromium," by R. A. Hadfield: *Journal of the Iron and Steel Institute*, No, II for 1892.

"No. 2 projectile (round 2554, Figs. 6, 7, and 8) gave the same penetration, was also whole, showed no cracks, and altered in diameter of body .013 inches, and shortened .210 inches.

"Thus the above shells were only altered one-hundredth of an inch in diameter, and a little over two-tenths in length. (Figs. 4 to 8).

"The following results are, however, probably still more remarkable. A Hadfield 6-inch projectile was fired through a 9-inch compound plate. Being uninjured, it was ground up, fired a second time, and again penetrated another 9-inch compound plate. It was ground up and fired a third time at a 9-inch plate, when it broke up. It is, however, only fair to the projectile to state that the third plate was an experimental one, in which the face had been hardened by special tempering methods. Probably the projectile would still have been whole if fired at an ordinary compound plate. This projectile, after being fired twice, is shown in Fig. 9.

"Another remarkable result is that of a 6-inch bursting shell made by the same makers. This shell was the usual service weight, 100 lbs., but had a core of about double the capacity of an ordinary armor-piercing projectile (the latter are usually termed "shot"), and consequently its walls were of much thinner section and of less strength. This was fired at a 6-inch compound plate, which it penetrated, and was found uninjured 2000 yards (or nearly a mile and a quarter) on the other side. Beyond a slight chip off the point, the shell was unaltered in form, free from cracks, and could have been fired again. This shell is indicated by Fig. 10. The broken shell (Fig. 10^a) subjected to the same test was by another maker. The result with the latter shows that a steel shell, if not properly prepared, is little better than a cast iron projectile.

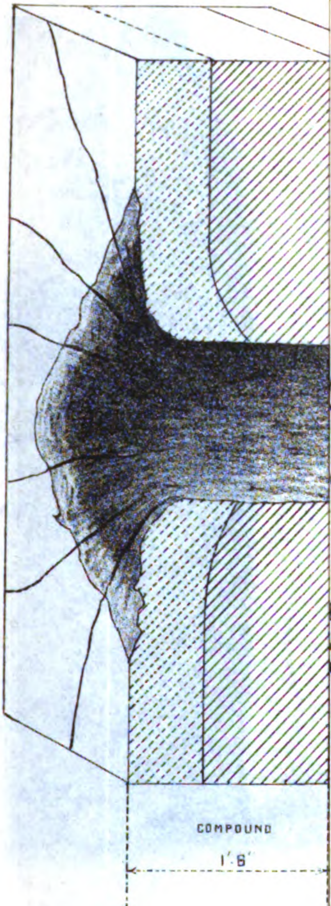
"An exceptionally severe set of trials is that shown in Figs. 11 to 13. The projectiles were selected at random from ordinary service supplies. The ordinary reception trial is to fire a 6-inch projectile against a 9-inch compound plate, but in this trial the compound plate was 10½ inches thick. As will be seen, notwithstanding the severe test, the four projectiles were practically uninjured, having neither set up nor broken. If the armour had been attached to the side of an ironclad, a few feet higher velocity would have resulted in a complete penetration into the interior of the ship. In other words, at short ranges, with the comparatively light 6-inch breech-loading gun, giving a velocity of say 2000 feet per second, all, excepting the largest modern ironclads, are easily vulnerable at point-blank range. (Figs. 11 to 13).

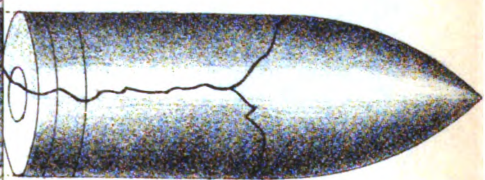
"In recent American trials it is reported that French-made projectiles, of 6 inches diameter, fired against 10½-inch nickel steel plates penetrated from 9.70 inches to 26 inches, the average penetration being 15 inches. In the case of the Hadfield projectile, fired against a 10½-inch compound plate, the penetrations averaged 26½ inches. It must be remembered that in the American trials, while the nickel steel plates offered greater resistance, the velocity and striking energy, 2075 feet and 2989 foot-tons, respectively, were much higher than those used in the English tests, viz., 1830 feet and 2200 foot-tons. Therefore, whilst the results cannot very well be compared, it will be seen that the English projectiles, with a lower velocity and striking energy gave excellent results. Probably with the same striking energy as at the Annapolis tests they would have penetrated uninjured a 12-inch compound plate."

Mr. Hadfield states that the chromium steel shell contains from 1¼ to 2 per cent. of chromium. The proportion of carbon is not mentioned, nor is it stated whether other elements such as manganese may not be used.

The Hadfield processes have been adopted by the Taylor Iron and Steel Company of Highbridge, New Jersey. They are now manufacturing shell according to Hadfield methods for the United States Navy. The results obtained by the Hadfield projectiles are therefore of direct interest to us. Whether they will succeed in producing armor-piercing shell able to cope with Harveyized plates remains to be seen. But so much has been accomplished by skillful combinations and treatment that there are fair promises of favorable results.

An analysis of the Holtzer projectile gave the following results:





king Velocity = 1950 feet per second.
Energy = 34,280 foot tons.
l Penetration = 36½ inches of steel and iron.

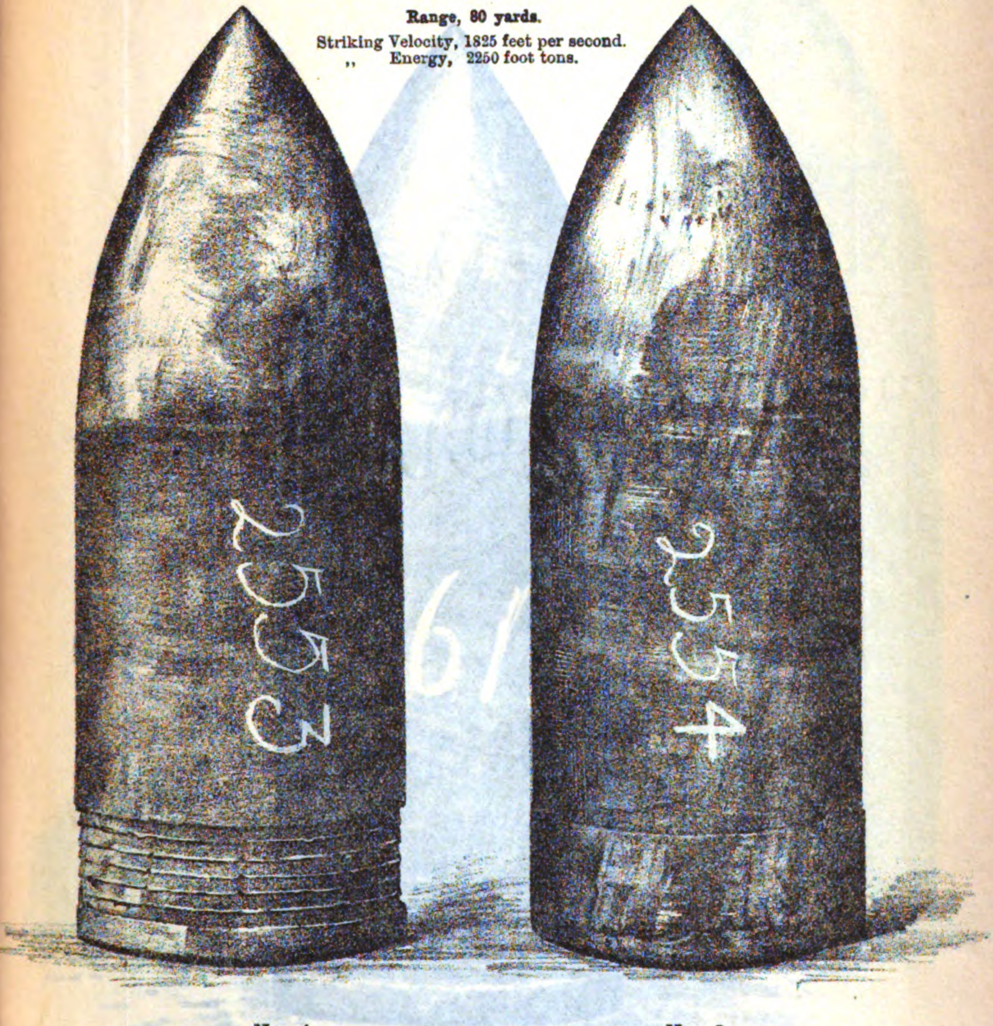
Penetration effected
fired at S

Ballantyne, Hanson & C° Edinburgh & Lon

Fig. 8.

Range, 80 yards.

Striking Velocity, 1825 feet per second.
,, Energy, 2250 foot tons.



No. 1. **No. 2.**

Hadfield's 6-Inch Chromium Steel Projectiles after each has penetrated a 9-Inch Compound Armour Plate and 8 feet of Oak Backing.

The above illustrations represent the two Projectiles after each has penetrated the 9-Inch Compound Armour Plates and 8 feet of Oak Backing represented in Figs. 4, 5, 6, and 7.

No. 1 altered, after firing, ·01″ in diameter.
No. 2 ,, ,, ·013″ ,,

Ballantyne, Hanson & Co. Edinburgh & London.

Fig. 9.

This Figure represents a Hadfield 6-Inch Chromium Steel Projectile which, after penetrating a 9-Inch Compound Plate, was fired a second time from the same gun, and penetrated uninjured a second 9-Inch Compound Plate. The illustration is taken from the Projectile after its *second* penetration.

Ballantyne, Hanson & Co. Edinburgh & London.

Fig. 10A.

Steel Projectile by another maker of same pattern, and submitted to same test. The illustration represents the whole of the material that could be found after the test. Probably the hardening was improperly carried out, but it shows that, under certain circumstances, steel may break up as badly as cast iron against armour plates.

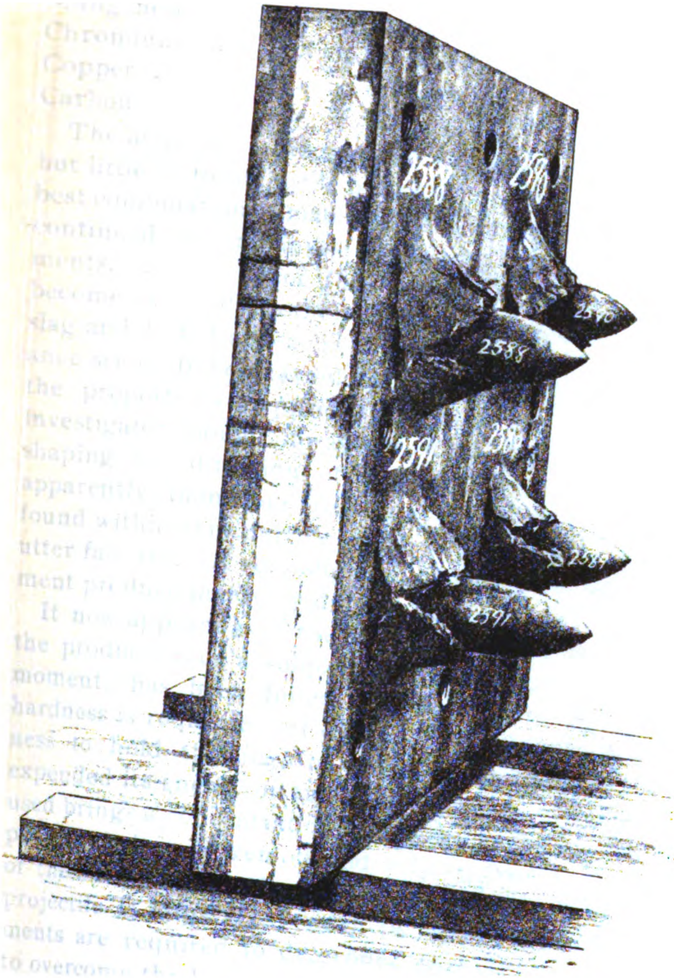
Fig. 10.

This Figure represents a Hadfield Chromium Steel Projectile of special large bursting capacity (over 100 cubic inches). It was fired through a 6-Inch Compound Plate, and, with the exception of having the point broken off, was found uninjured 2000 yards in rear of the plate.

Ballantyne, Hanson & Co. Edinburgh & London.

Fig. 13.

Range, 80 yards.
Average Striking Velocity, 1830 feet per second.
" " Energy, 2300 foot tons.



End of 10½-Inch Compound Armour Plate penetrated by Four Hadfield's 6-Inch Chromium Steel Projectiles.

All the Projectiles were uninjured, and if they had been fired with the same velocity as used at the Annapolis trial (2075 feet per second), they would probably have penetrated uninjured a 12-Inch Compound Plate.

Ballantyne, Hanson & Co Edinburgh & London.

	Point of projectile.	Body of projectile.
Silicon	0.822 per cent.	0.419 per cent.
Phosphorus	0.011 per cent.	0.044 per cent.
Manganese	0.306 per cent.	
Chromium	1.69 per cent.	2.28 per cent.
Copper	0.121 per cent.	trace.
Carbon	1.32 per cent.	1.26 per cent.

The analysis of the material of a projectile, however, conveys but little as to the mode of casting or the after treatment. The best combination of materials, etc., can only be arrived at by long continued patient investigation and usually many disappointments. A portion of the ingredients put into the melting pot become oxidized or otherwise transformed and disappear in the slag and do not appear in the resulting alloy. Such disappearance seems to be unavoidable and experience alone can indicate the proportions required to produce any desired alloy. The investigator cannot always trust to reasoning by analogy in shaping the direction of his experiments. He meets with apparently anomalous results at every step. Success may be found within very narrow limits, on either side of which appear utter failures. A very slight change of composition or of treatment produce markedly different results.

It now appears as if the metallurgist has done his utmost in the production of a simple bolt to perforate armor and, for the moment, has been foiled. It is obvious that the maximum hardness is requisite, but with it there must be sufficient toughness to hold the mass of the projectile together until it has expended its energy on the plate. As it is now, the sharp point used brings a concentration of the shock on a small portion of the projectile; it is broken off and a beginning is made of rupture of the shell, inviting further disintegration. The energy of the projectile is largely expended in its own destruction. Experiments are required to determine that form of head best suited to overcome the hardened resistance of the Harveyized plate, it being assumed that the projectile is of as hard and *tough* material as is attainable and it is propelled with the maximum velocity. Increase in sectional density may aid in the punching effect desired, if a sufficiently stiff metal may be found to resist the tendency to upset. The point may be made considerably blunter without increasing materially the resistance of the air. But should it be found necessary to give the front of the projectile a shape which largely adds to the resistance of the air, it may be desirable to add a point of soft metal or of a thin shell, easily crushed and not affecting the power of impact of the bolt.

Should we fail in producing a sufficiently hard and tough simple bolt of one piece of metal, it would then be advisable to try a built-up projectile of a striking core of very hard material with a jacket shrunk on having great tensile strength. The artillerist cannot afford to accept his defeat as final.