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Captain E. G. FISHBOURNE, R.N., C.B. in the Chair.

IRON AND STEEL AS MATERIALS FOR RIFLED CANNON.

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If the value of a material were to be estimated by the place which it occupies in the world, in regard to its usefulness for serving the multifarious purposes of mankind, then to the class of metals known as iron and steel in their many modifications must be ascribed an importance and position superior to any of the other mineral substances which have been placed at our disposal.

Iron, including steel, is the great staple article of Britain, and is the chief agent by means of which this country has been enabled to maintain the prominence she holds among the other nations.

In this country alone above five million tons are produced annually; and the increasing applications of those materials, which we daily see going on around us in every branch of the arts of peace, as also their extensive usefulness in connection with the art of war, render it highly necessary that every intelligent individual should have some acquaintance with the leading peculiarities of those substances; and the object of the present lecture is —

1st. To point out generally the nature and the leading characteristics of those materials; and

2nd. To consider their comparative fitness for one of the purposes to which they are applied as munitions of war, namely, rifled cannon.

As there is no other subject in connection with the wide range of practical mechanism engaging more attention at the present time than the one now under consideration, and which is already so well known in many of its details, it cannot be expected that much additional light will be thrown upon it in the present instance, or that any claim for originality can now be made; still it is to be hoped that the first part of the lecture may be useful to some, and that the facts which have come out under my own observation and experiments, which are referred to in the latter part, may be instructive to all.

Although iron is frequently referred to in the Old Testament Scriptures, yet we cannot find that it was extensively used until a much later period; the hindrance to its introduction probably arising from the extreme difficulty experienced in separating it from the earthy matters with which it is found in the condition of "iron ore."

The ores of iron are found extensively scattered all over the world, yet, comparatively speaking, few are now considered as fitted for the purposes of the iron-maker; questions of quality, means of effecting reduction, and other commercial questions, chiefly determine their value.

In Sweden and in some other countries iron ore is found in solid rocks, forming veins in the granite of enormous thickness, such ore being comparatively pure. This ore is supposed to be of volcanic origin, and, being generally in conjunction with igneous rocks, it in all probability at some remote period was belched out from the molten matter within the globe.

But in this country most of our iron is found mixed up with indurated clay or mud, in lumps or nodules; and it is supposed that these lumps are the mud of such veins of volcanic iron ore ground down by the geological floods of an early era.

These lumps are generally found in beds, and frequently just above and under and alternating with the seams of coal by means of which they are to be smelted, and also in close proximity to the refractory material called fire-clay, which is so valuable an agent in their reduction.

Previous to the smelting process, by which the iron is separated from the earthy matter, it is found necessary to subject the ore to a preliminary process of calcining, or, as it is commonly termed, roasting, which is simply a subjecting of the ore to a continuous dull red-heat for a considerable period in order to drive off the foreign matters which are injurious to the quality of the iron, and also to produce a greater degree of oxidation, as well as to open up the ore and render the smelting process more easily effected.

The degree of heat employed in roasting, the period of time required, and the description of kiln or oven which is used, depend entirely on the nature of the particular ore, and are found to differ in almost every locality: in all the object is the same, namely, to keep the ore at such a temperature and for such a length of time as will be sufficient to expel the injurious gases; those conditions of procedure in the great majority of cases being derived from experience rather than from any chemical knowledge of the changes to be effected.

Up to this stage the ore has but little resemblance to the valuable metal which it contains, and the first great step in advance is to eliminate the earthy matter and set the iron free.

This is effected in different ways; but the general method is to put the ore and fuel into the furnace together, then to generate an intense heat by means of a strong blast of wind, until the refractory ore is overcome and the iron begins to melt.

Without some other agent to assist, the process of separation would be very imperfectly accomplished: it is found necessary to employ what is termed a flux. This flux material is also thrown into the furnace along with the ore and fuel, and the chief object of the flux is to unite with the earthy matter and set free the iron.

With argillaceous or clay ore a calcareous flux, generally limestone, is

used; with a calcareous ore an argillaceous flux is employed, or, what is better, a mixture of both descriptions of ore in due proportion.

Under the high temperature within the furnace, the two earthy substances assimilate and form the glassy slag or scoria, which, being lighter, floats upon the liquid iron at the lower part of the furnace, and runs off by an opening left on purpose; while the iron (when a sufficient quantity is collected) is run out upon the floor into the pig-iron of commerce.

From the circumstance that the melting iron is in such intimate contact with the fuel, and from having to pass through it like water through a filter, the quality of the iron is necessarily much affected by the nature of the fuel, and as it so happens that the presence of sulphur, phosphorus, and other impurities is found to affect the conditions of strength and other properties of the iron, those descriptions of iron that are made with the purest mineral fuel are the best, supposing other conditions to be the same, and best of all is the iron smelted with the charcoal from wood, which is obviously more free from those injurious properties that belong, more or less, to all mineral fuel used in the iron manufacture on a large scale, with which I am acquainted.

By subjecting mineral coal to the process of coking, it is purified to a considerable extent, still the iron which is made even with coke is not of such high quality as that made with the still purer fuel of wood charcoal.

It will thus be seen that at the very threshold of the manufacture there are causes in operation that seriously affect both the quality and the cost; and that, although in the manufacture of ordnance, a material of the very best description is the desideratum, still in the wide range of the arts there is, at the same time, a demand for every quality. It thus happens, and that to a great extent, that price rather than excellence is the predominating influence that determines the manufacture.

Iron may be divided into three great classes; these are known as cast and wrought iron and steel; indeed, for all practical purposes, they may be looked upon as three distinct metals.

Cast iron is the material as it runs from the first process of the smelting furnace, and is that from which both wrought iron and steel are made.

During the smelting process, the iron has absorbed a considerable quantity of carbon, as well as still retaining several other ingredients and original impurities, the presence of which renders cast iron capable of being melted and remelted a number of times, and used for the various purposes of the iron-founder, and the metal is sufficiently liquid to admit of being poured into moulds of any form with the greatest facility; hence, if cast iron had the toughness or strength, and the other good qualities of either of the other modifications of this metal, namely, wrought iron or steel, it would necessarily have the preference, not only on account of its cheapness, but also from the great readiness with which it can be poured into almost any variety of intricate outline, at a small expenditure of fuel, wages, or plant.

Cast iron, when considered as a material for the iron-founder of general articles, is mostly affected by the proportion of carbon which is present.

The carbon renders the iron more liquid when in the fluid state, and softer when in the solid condition, at the same time it is not quite so strong in regard to its tenacity, although possessed of more toughness

than iron containing a less quantity of carbon; hence the founder is to a great extent guided in the selection of pig-iron for particular articles by the quality of the compound.

For castings where great strength is aimed at, considerable judgment is necessary in the selection of a mixture that will secure all the conditions of softness or hardness, closeness of the grain, and that degree of toughness and strength, which may be necessary.

There are many instances on record of cast iron having shown an amazing amount of strength, toughness, and general endurance, both as guns and in other constructions; still, at the best, it is uncertain, and, as will be seen hereafter, it is not strong, and is proverbially treacherous to depend upon, as it gives no warning before rupture; and hence the time has arrived when, for ordnance especially, it seems about to give place to a better material, either wrought iron or steel, or perhaps a combination of both.

The malleable, ductile, tough, and fibrous material termed wrought iron, which is so extensively used by the smith for every branch of art, is made directly from cast iron by an elimination from that compound of its carbon, sulphur, silicium, phosphorus, and other impurities, by a process of oxidation.

This purification of cast iron produces a material with entirely different characteristics; it becomes much stronger, has greater toughness, is highly infusible; it loses the property of becoming liquid, and is therefore unfitted for the founder's purposes. At the same time, however, it acquires another property, almost equally valuable, for, when brought to a high temperature, it acquires a viscous or sticky character, so that if different pieces in this condition are brought together, they adhere, and if a blow is given or pressure applied, the separate pieces are made to adhere permanently.

This remarkable property is termed welding, and is the basis of the art of forging, as practised by the smith.

The conversion of cast into wrought iron is effected in different ways, although the same principle is adopted in all, namely, to burn out the silicium and carbon.

One arrangement is, to drive off these matters by fusing with charcoal while a hot blast is playing on the liquid mass; but the more usual plan in this country is to subject the liquid to the well-known process of puddling. The cast iron is melted in a furnace in which a hot oxidising flame is brought to bear upon the fluid; by means of iron tools the mass is moved and stirred and turned over in every direction so as to expose every portion of the iron, in turn, to the influence of the flame.

Under this influence it gradually loses its fluidity, and acquires the viscous or sticky property. It is then parted into lumps of a size suitable for manipulation; each lump is afterwards subjected to a still further process of purification, and one which is dependent on another principle for its efficiency.

The lump of viscous iron may now be compared to a very dirty sponge that requires to be several times wetted and wrung in order to make it pure and clean.

On its removal from the puddling furnace this lump of viscous iron matter, like a dirty sponge, is put under a heavy hammer or other

apparatus, the blows or squeezing of which drive off the impurities, and the mass is worked out still further by means of rolls into a long bar of coarse and dirty iron, unfit for the smith, and which is afterwards cut into short pieces. These pieces are piled up into a bundle, and are again put into a furnace and subjected to another heating; the iron is again brought to the welding state for another washing, and is again subjected to another beating from the steam hammer, and a squeezing from the rolls, all which still further improve the purity and the quality of the iron bar.

For the production of the better descriptions of iron, this process of purification, of cutting up, re-welding, and hammering or rolling, is repeated several times until the proper quality is attained. Of course such treatment, while it improves the material, also increases the cost in a still greater proportion.

Even after the best treatment, the wrought iron of commerce is not chemically pure, although its combination with the grosser impurities does not seem to be of that intimate character that exists in cast iron. It still contains carbon, silicium, and other matters, which fill up the minute vacant spaces between the fibres which compose the structure of the bar.

In consequence of the great affinity which iron has for sulphur, phosphorus, and other impurities that affect its quality, the quality of wrought iron is much dependent on the character of the fuel employed in its manufacture; the purer the coal the better is the iron, and hence that which is made with wood-charcoal is necessarily the purest and best, although, at the same time, it is most expensive.

The quality of wrought iron is also greatly dependent on the original selection of the mixtures of cast iron for puddling, and on the care, skill, and close attention which are brought to bear upon all its successive stages; hence iron comes to differ as much in its qualities and properties as any two materials of the same class could be expected to be capable of doing, and more so than that of any other similar substances with which I am acquainted.

This difference, however, is only detected when high conditions are aimed at, then close observation discloses innumerable shades of quality, that escape the observation of the majority of workers in iron, who use the material for purposes where the object required is easily secured.

The conversion of cast into wrought iron by the removal of carbon and silicium completely changes the characteristics of the material. It has lost the brittle property; it now yields and stretches before it breaks; the permanent yielding point is now higher than the former breaking point, and the breaking point is double that of the yielding point.

These are all strong conditions in its favour, but at the same time it has many serious defects.

It is difficult to produce in large masses that are perfectly sound throughout; the smith or forgerman has little control or authority over its behaviour when in the welding furnace, and hence it is extremely difficult to produce large forgings perfectly sound, even with the best treatment; there is, therefore, still great room for improvement, so as to ensure a perfectly homogeneous mass, possessing all the good properties of the malleable, welding, tough material, and which, at the same time, shall be free from its numerous defects, veins, and unsoundness; yet it is but just to

add, that, with all its many defects, there is no material at the present time which can be so implicitly relied upon and trusted with so much security against fracture from sudden vibration, as a piece of good sound wrought iron.

The material called steel is an intermediate compound between cast iron and the former material of wrought iron.

Steel is comparatively a pure iron, containing a small per-centage of carbon with some other substance in combination, which is rather obscure, and regarding which there is considerable difference of opinion. This combination gives the material some very peculiar characteristics of its own, and is entirely different in character from either of the metals out of which it is made.

Steel can either be made from wrought iron or from cast iron.

The latter arrangement is the cheapest process, but the former method affords the most certain results at the present time, and that is the system chiefly resorted to in making the finer qualities of steel.

To make good steel of high quality, a bar of pure wrought iron is selected, mostly Swedish, which has been made with charcoal in all its previous stages. The iron bars are put into a fire-brick chest, along with a quantity of charcoal powder; every part of the bar being surrounded with the carbon, the air being excluded, the whole is made white-hot, and kept in that condition for several days, generally about a week, according to the amount of conversion that is required. During this period the pure white-hot iron imbibes a new property from the charcoal into its own nature.

A chemical action takes place, and the wrought iron has been thus gradually turned into steel. Such steel, however, is very imperfect. The defects are chiefly owing to its local irregularities of conversion, for although the entire mass of the bar may have had the proper quantity of carbon put into it, yet it is found to be much improved through mixing the particles, either by welding several bars together into one bar, or even the mere working of a single bar under the hammer has the effect of equalizing and greatly improving the quality.

The most effectual way, however, of obtaining a thorough mixture of the particles is to break the original steel bars into small pieces, then to melt them together in a crucible into liquid steel, and then to mix and pour this metal into an ingot, which, when solid, is then drawn into a bar of steel of the required dimensions.

By this means of putting carbon into pure iron, cast steel is produced, which is the finest in quality of any of the varieties of this valuable metal. But good passable steel can be made directly from cast iron, simply by not carrying the puddling process on to the full extent of wrought iron. Such material is called puddled steel; and although at the present time it is not equal in quality to that which is made in the other way, still it is very much cheaper, and when more experience has been gained so as to determine the best descriptions of cast iron that are suitable for this particular process, as also the precise period when to discontinue the puddling operation, so as to leave the proper quantity of carbon in the metal, there can be no doubt but that such cheap steel will be extremely valuable for many purposes, seeing that puddled steel is malleable, and has even a higher tenacity than wrought iron.

A very fine material is now produced extensively by breaking up the

rough bars of puddled steel and melting them into a cast steel, and which for many purposes is found equal to ordinary cast steel as made from Swedish iron; so far as I am aware, however, it is not so good for edge tools.

Good steel can be made in a still more summary manner by means of the "Bessemer process." The crude cast iron, when in a melted state, is poured into a large refractory vessel previously heated, and a strong blast of air is forced through the fluid, producing a violent agitation.

The silicium and carbon in the iron unite with the oxygen in the air, and are driven off from the metal, until the remaining mass is almost pure wrought iron.

There is then added to the iron (in order to make it steel) a definite quantity of carbon; it is introduced in the condition of liquid cast-iron, of known mixture and quality; the whole is then thoroughly mixed, and the entire process is completed in about half an hour from the time of first pouring in the cast iron to the final running out of the steel into moulds or ingots.

By the Bessemer process large masses of steel can be made more easily than by any other method yet introduced, and apparently at less cost, and there is no doubt that in time this process will produce uniform quality.

Steel in all its combinations is a most valuable metal; in its ordinary state it is closer in structure, has greater power of resisting compression, and possesses a higher tenacity than wrought iron, even of the best quality, and as such it commends itself to the engineer for the manufacture of the best class of articles, notwithstanding its greater cost, and the still greater expense which has to be incurred in its fabrication into the requisite forms. But it has another property, which causes it to transcend in value all other metals, namely, the capability of being tempered to any degree of hardness or softness.

The discovery of the fact that a piece of soft steel, when heated, and then suddenly cooled, no matter by what means, assumes a hardness approaching that of the diamond, is perhaps the most important of any in connexion with the whole range of metals, and has been of the greatest service to mankind.

In addition to this property of hardening, when the said hard substance is exposed to a gentle heat, it gradually begins to give up a portion of its hardness, until at length it loses it altogether; and as it so happens that at the same time that the hardness is gradually departing, a definite change of colour of the surface of the steel accompanies the softening process, this change of hue becomes a correct measure of the change in hardness, and thus the precise degree of hardness or temper that may be required for any purpose can be attained with great certainty and uniformity.

Steel, wrought iron, and cast iron can all be rendered softer and less brittle by means of the annealing process, which is simply causing the materials to be made red hot, then keeping them in that state for a short time, and afterwards allowing the whole to cool down very slowly, so that every part may cool at a uniform rate, and no part or particle be under any restraint from premature withdrawal of heat, thus causing local contraction and hardness.

By prolonging the period of cooling, a mass of steel comparatively

brittle acquires the character of toughness in a remarkable degree, and this process of annealing now plays an important part in all modern efforts to use steel either for guns or armour plates, or for anything exposed to jar or sudden vibration.

Such is a brief description of the metals—cast iron, wrought iron, and steel—which are now attracting so much attention in the world, more especially in regard to their adaptation and application as materials for war purposes, and which are now to be shortly considered in regard to their several and relative fitness for the manufacture of rifled cannon of large calibre.

The numerous and repeated failures that have occurred, and are still occurring, in the application of iron and steel for the above purpose during the past few years, and even at the present time, clearly show, that that which is wanted, necessarily implies some high conditions which are very difficult to secure, and which appear all the more difficult to those who are the most concerned, and whose province it is to endeavour to obtain them.

For small arms, and even for cannon of the smaller class, there is not much trouble experienced in applying almost any good material, whether bronze, iron, or steel; but in dealing with heavy breech-loading guns of large calibre, elements of weakness are brought into view which are exceedingly difficult to provide for and meet successfully.

The severe proof to which rifled guns are now subjected, consisting of seven rounds, with two of the charges of gunpowder being equal to one quarter of the weight of the projectile, is found to thoroughly search and try their soundness, both in regard to the materials and the workmanship, and is sure to develop any seriously defective part, if such exists; but the mere withstanding of the proof rounds is found not even sufficient to thoroughly test the perfect soundness of a gun.

In wrought-iron guns, which have resisted proof successfully, minor defects will sometimes appear after a number of ordinary service rounds; such defects have required a repetition of charges to bring them out into view for examination, each successive round acting like the blow of an enormous sledge-hammer, and gradually producing an alteration of form in the bore or in other parts of the structure.

Again, there are some of the steel class of materials that have been tried, apparently with great success, which have not only stood proof, but have been fired a great number of times, and yet prematurely have been ruptured; the effect of the firing seems to derange the crystallization, and to have been like the repeated blows of the hammer driving home the wedge, until a separation of the particles is effected.

It is also found, however paradoxical it may appear, that the strongest material after a certain point, whether of wrought iron or steel, makes the weakest gun; that wrought iron as it approaches the character of steel, while becoming better adapted in several respects, is getting all the worse in other respects still more important; and that when steel is annealed and otherwise treated, until it seems to be losing all the good qualities for which it is so celebrated, that then it is becoming all the better adapted for the sudden jar and vibration of a gun, but at the same time it is losing some of those good qualities which chiefly recommend it as a competitor with wrought iron for the construction of rifled cannon.

So far as my present experience goes, we are still in want of the proper, the perfect material for the interior of the bores of large guns, a material that will afford bores invariably sound and perfect, and which will remain so in the same manner as an ordinary musket barrel, and which at the same time shall be as safe against bursting, as guns built up of wrought iron on Sir William Armstrong's principle, which in that respect may be considered perfect, and as fulfilling all that is or can be desired or reasonably expected.

The extraordinary effect that is sometimes produced in the bores of rifled guns made of any description of metal which will not be in danger of bursting, from its hardness, is much greater than is generally supposed, and is only known to those who are more immediately concerned, ordinary bronze gun-metal being acted upon in the manner that lead would be, only in a less degree. The shot or shell in such rifled guns requiring considerably more power to set it in motion as compared with the round ball from a smooth bore—the abrupt check of the wave of gas suddenly arrested in its progress—the amount of work to be done in whirling the projectile up to such a velocity in so short a space of time—the lengthened period during which the pressure exists in the rifled gun—as also the extremely violent action of the highly worked gunpowder which is used in England,—all these causes combine to render the effect of the powder upon the interior of large rifled guns very considerable, and involve a high standard of quality in the materials employed.

Before considering the fitness of any particular metal for the manufacture of rifled guns, let us enumerate some of the properties which are absolutely requisite to insure perfection.

The desideratum, then, for the interior and general structure of rifled guns is a material which should possess all the following characteristics:—

1st. That it shall be capable of withstanding the violent action of the most active gunpowder against rifled projectiles without producing the risk of fracture or even inordinate deterioration in the bore, and that it shall not be in danger of bursting at any future time by the effect of continual firing causing deterioration of the quality of the metal.

2nd. That the material to be employed shall have sufficiently high tenacity and general strength as will not render necessary the employment of a greater weight of gun than what is considered requisite by the artilleryman to absorb the recoil.

3rd. That the material shall be sufficiently hard, so that the surface of the interior of the bore shall not in any way be indented or bruised, or otherwise acted upon, by the powder or projectile, or even by the premature fracture or explosion of a cast-iron shell within the bore.

4th. That the material shall be such, as that guns can be easily manufactured without much risk of radical defects, and that the guns, when properly made and proved, may with confidence be considered right in all respects, and without any doubt or uncertainty as to their positive soundness or future stability when in actual service.

5th. That the guns when made shall not be too costly.

Having already hinted that none of the existing metals, whether cast iron, wrought iron, steel, or even bronze, so far as I am aware, fulfil their function in all these conditions, still, having no other available source but

these, especially iron or steel, to fall back upon, let us consider some of their respective properties, and appreciate their fitness in proportion to their several merits; that being the best which promises these several conditions in the highest degree, and in the order of their greatest importance to the soldier in the hour of battle.

In order to be able to arrive at a correct comparison of the several metals, it is not only necessary to know definitely their respective resistance to compression and extension, but we also want to know with equal certainty their relative toughness, elasticity, and general behaviour, when exposed to strain combined with extreme vibration.

In regard to these two latter properties, little has yet been done to reduce them to the actual test of definite experiment, hence we can only infer from the general facts shown by the behaviour of the guns constructed of the several materials, and, as a rule, this is a very safe guide, providing there is sufficient experience on which to guide the judgment.

With regard to the strength of the several materials, especially their resistance to compression and extension, there are abundant data and full opportunity of obtaining positive knowledge so far; from which, however, if the other properties of toughness and elasticity are not considered, we are apt to draw a very unsafe conclusion.

With reference to the first of these properties, namely, compressibility, it is remarkable that the resistance to compression in each of the three materials referred to is more nearly equal than any of their other properties.

The pressure per square inch which is required in either metal to produce a permanent sensible indentation or shortening, about equal to three thousandths of an inch in measurement, ranges from 30,500 lbs. to 40,700 lbs.

This does not refer to the ultimate force which is required to crush the specimens into fragments, because for a gun that is of no consequence, as such an extreme test is not called into requisition. The proper material must be such that there is no sensible compression produced in the vicinity of the bullet-chamber by the force of the explosion or projectile. Hence the measure of strength or fitness is the point where the material begins to set permanently, and, so far, that is the best material which requires the greatest pressure.

Ten specimens of cast iron, parts of guns of the highest quality, but which have been severally burst, gave 35,000 lbs. per square inch; producing an average compression of three thousandths of an inch. The softest being 30,000 lbs., the hardest 40,300 lbs.

Ten specimens of rolled wrought-iron bar, made specially for guns, the specimens being selected at random and reduced from bars three inches square, all of the highest quality and suitable for guns, gave an average of 33,000 lbs. per square inch, with an average compression of three thousandths of an inch. The softest requiring 31,000 lbs., the hardest 35,000 lbs.

Ten specimens of wrought iron, cut from large gun-forgings of superior quality, gave an average of 26,900 lbs.; producing an average compression of three thousandths of an inch. The softest being 22,800 lbs., the hardest 31,000 lbs.

Ten specimens of soft cast steel of the finest quality, and that either withstood the proof-rounds, or which failed before the seven proof-rounds were completed, gave an average of 35,500 lbs. per square inch, with an average compression of three thousandths of an inch. The softest being 25,000 lbs., the hardest 46,000 lbs.

Ten specimens of cast steel, more highly converted than the former, and in quality almost fit for cutting instruments, but which broke first round at proof, gave an average of 76,000 lbs. per square inch, with an average compression of three thousandths of an inch. This kind of steel therefore need not be considered as of any value, however good in other respects, it being totally unfit for guns or armour-plates from its brittleness or want of the necessary toughness to withstand the vibration.

A specimen of cast steel, cut from a gun made by Mr. Krupp, of Essen, but from a gun which failed at proof, gave 25,300 lbs. per square inch, with a compression of three thousandths of an inch.

Four specimens of steel and iron, welded together like layers of sandwiches, gave in the direction of the fibre, that is, pressing the steel and iron upon the edge of the sandwich, an average of 26,000 lbs per square inch, with an average compression of three thousandths of an inch.

Four specimens upon the flat of the sandwich, thus pressing the two metals closer together, gave an average of 25,400 lbs. per square inch, with an average compression of three thousandths of an inch.

It will thus be seen, according to these experiments, which were all made on carefully prepared specimens, exactly one inch in length and half an inch in diameter, that the average resistance to three thousandths of an inch compression, or shortening, was as follows :—

	lbs.
1. Cast steel - - - - -	35,500
2. Cast iron - - - - -	35,000
3. Wrought-iron bar - - - - -	33,000
4. Wrought-iron forgings - - - - -	26,900
5. Sandwich steel and iron on edge - - - - -	26,000
6. Sandwich steel and iron on flat - - - - -	25,400
7. Krupp's cast steel - - - - -	25,300

The chief point to be observed in regard to the compression of cast steel, which is the highest on the list, namely, 35,500 lbs., is the wide range from the softest to the hardest, from 25,000 lbs. to 46,000 lbs.; this characteristic of want of uniformity is found to be its prevailing feature and failing, and is the case with all the steels, even from the best houses which have come under my examination; and from the nature of its manufacture it is perhaps impossible to make steel positively uniform.

But if it could be made uniform, and if to the harder steels could be superadded the property of toughness so as to keep together, and if at the same time the brittleness could be withdrawn so as to give it the opportunity of recovering from vibration, it would then be invaluable both for guns and armour-plates; but so long as the cast-steel manufacture is uncertain in its produce, no matter how good it may be occasionally, the gun-maker will look upon it with suspicion, as a single failure produces so much mistrust.

The second on the list is cast iron, which is also very high, 35,000 lbs., and so far is good, but, like steel, it has also a wide range, from 30,000 lbs. to 40,300 lbs. If this metal had tenacity and toughness in proportion to its incompressibility it would, from its cheapness, have the decided preference; but so long as England is aiming at high results in her gunnery, the want of those properties will prove a strong objection to its adoption for rifled guns, unless cast iron can be much improved in tenacity and made more certain in its general character.

The third on the list is wrought-iron bar at 33,000 lbs., with the small range of from 31,000 lbs. to 35,000 lbs.; and this is the peculiar feature of wrought iron, it is never high nor never low; on the contrary, wrought iron from any particular maker, who is careful in the manufacture, is found to be nearly uniform, and, being possessed of great toughness and being without brittleness, it is exceedingly reliable so far as its strength will permit.

The fourth is that of wrought-iron forgings, which is considerably under bar iron, 26,900 lbs., also with a wider range than bar, and hence the less valuable so far—from 22,800 lbs. to 31,000 lbs.; the hardness and softness of large forgings being so much affected by the locality of the blows upon the mass.

The fifth and sixth upon the list are the Sandwich specimens, which are not of so much importance, except that as combinations they have been found to stand in some applications where steel failed from brittleness, and where soft iron was found to yield from lateral bulging; and no doubt the low position is partly due to the condition of the iron, and also to the soft quality of the steel which was necessarily used in order to get a good sound welding between the two classes of material, the iron and steel.

The softest material on the list is the famous cast steel made by Mr. Krupp of Essen. Only two specimens were operated upon, and gave 25,800 lbs. As will be seen, the hardness of this material is considerably under wrought iron, and, so far, is that much inferior in this respect. This material is so soft as to admit of being flattened down to any extent; indeed, the same remark applies to most of the good qualities of steel which are under 40,000 lbs.; they continually yield more and more by the increase of pressure, and the structure of the steel shows a wonderful adaptation for keeping together without cracking at the edges, unlike almost any of the other descriptions of material. This property is greatly in its favour, both for guns and armour-plates; and if it could be made to resist a sudden shock as well as it does the effect of mere pressure, it would be exceedingly valuable.

It will thus be seen that the several classes of material here referred to do not differ so much in the foregoing respect as might be expected, unless we are to include the extremely hard qualities of steel, which are from their hardness and brittleness obviously unfitted for guns; such qualities of steel rise up to 80,000 lbs., and can only be made available for the purposes in question by a long course of annealing, which is a process that may be continued until the metal is as soft as the lowest specimens which have been referred to; such softness, however, diminishes their value in proportion to its amount.

In regard to the other property, namely, that of tenacity, there is a

much greater difference existing between the cast iron, wrought iron, and steel, and it has also to be observed that they differ still more in their amount of elasticity and capability of stretching before fracture.

Cast iron and hard steel invariably break at the moment of perceptible elongation when the specimens operated upon are in short pieces, while wrought iron and soft steel have a considerable amount of elasticity, and only begin to permanently elongate after a certain load per square inch has been suspended, and they gradually continue to stretch with every increase of load until final rupture takes place.

As the measure of strength of any material wherewith to construct a gun, is the point at which permanent elongation commences, that point should have the chief attention; still it is requisite for comparison to specify the ultimate strength as well, in order to show the margin of strength which lies beyond this point; thus the several metals can be compared in regard to their relative fitness so far as the property of tenacity is concerned.

From several hundred experiments made with the higher qualities of cast iron which were collected with a view to obtain the strongest iron for cast-iron guns, the ultimate tenacity was found to range from 10,886 lbs. up to 31,480 lbs., or an average of 21,173 lbs. per square inch.

This is considerably above the strength of the greater proportion of the cast iron of commerce. The average of the Nova Scotia iron, specimens of which have recently been tested, gave only 15,821 lbs., and some of the Scotch pig-iron selected at random only gave 12,912 lbs.

It will be observed that the foregoing are the ultimate breaking points of cast iron, and gave no stretching or appreciable warning before fracture.

Of late years, and up to the present time, cast iron has generally been used for heavy guns, but its low tenacity and brittle, uncertain character renders it peculiarly unfitted for this purpose, and more especially is it unfit for rifled guns, as in them not only is the strain considerably increased, but the duration of the strain is prolonged in addition, thus producing a rupture before the particles have recovered from the vibration.

It is therefore inferred that, until an element of toughness can be given with certainty to that weak material, it can never be thoroughly depended upon in the construction of the armament of the future, notwithstanding its cheapness and facility of construction.

Although a small piece of cast iron under the testing process gives no warning, yet cast-iron guns which have stood the proof rounds, if closely watched, begin to show the lines of future failure long before the period of ultimate fracture, and the practised observer can generally indicate the probable number of rounds that will elapse before the gun gives way altogether.

At the same time there are several instances on record of cast-iron guns having exhibited an extraordinary amount of endurance, but the toughness is variable and uncertain, and nothing uncertain is to be commended.

From several hundred experiments that have been made with wrought iron cut from bars intended for the manufacture of Armstrong guns, the following result has been obtained.

The point of yielding permanently gives an average resistance of 28,000 lbs. per square inch, while the point of ultimate rupture gives an average of 57,120 lbs., or rather more than double that of the point where

permanent elongation commences; the margin that lies between these two amounts is of great importance as a condition of safety, but the chief point is that where the stretching begins.

After the first yielding by the addition of extra weight, the wrought iron specimen gradually stretches until it has been considerably reduced in diameter; and such parts as have been so reduced have a greater tenacity per square inch than when in the previous normal condition. The iron has to a small extent assumed the character of wire, which from the drawing process is always stronger than the iron out of which the wire is made.

This increase, however, if given to wire, is lost afterwards when the iron or wire is brought to a welding heat, and hence for gun purposes this property cannot readily be taken advantage of.

From ten specimens of wrought iron cut out of heavy forgings, a lower result has been obtained than from bar iron, such forgings being inferior in all respects.

In such masses, from their not having an equal amount of working in proportion to the extent of heating to which they are exposed, the tenacity is not so high as that of the more highly worked rolled iron when it comes direct from the rolls. In forgings, the average point of yielding permanently was 23,760 lbs.—average point of ultimate fracture being 48,160 lbs. The forgings from which the specimens were cut were all of high quality.

When rolled bars of the best quality are wound into coils, and then welded into cylinders for gun manufacture, the iron as a general rule is found to suffer to about 3,481 lbs. per square inch on the average.

The following shows the average results both in regard to yielding and breaking:—

Yielding	{	Iron in bar - - - -	31,100
point.	{	„ cylinder - - - -	27,852
Rupture	{	Iron in bar - - - -	58,986
point.	{	„ cylinder - - - -	55,500

The loss is due to the necessary heating being greater in proportion than the working.

From experiments that have been made to ascertain the tenacity of welds of iron of different qualities, and under different circumstances, it has been found that with iron of the finest quality, when brought to the proper heat in a fire free from impurities in the fuel, and with the joint scarfed so as to increase the area, the strength is equal to that of the solid iron, which is of course all that could be desired, and is in round numbers about 25 tons, or 56,000 lbs. per square inch.

With all other descriptions of weldings which I have yet tested, the result is lower than the above, down even to 12,000 lbs. per square inch, the same care having been observed in every instance.

Two pieces of the best quality of iron butted together, under the best conditions which I have been able to effect up to the present time, have only given an average ultimate tenacity of 32,140 lbs. per square inch, which is only a little over the half of the iron bar.

Iron butt welded to steel under the best conditions invariably breaks at the weld, and shows only an average tenacity of 26,800 lbs.

But even this depends entirely on the nature of the iron and the steel; any increase of hardness or of the steely property, either in the iron or in the steel, affects the strength of the weld in many cases down to 10,000 lbs. and even still lower.

In the construction of the Armstrong guns the bar iron is first wound into a spiral coil, and then a welding heat is taken through the entire mass, and by means of a steam hammer it is welded into a homogeneous cylinder.

With iron of the very best quality which we have as yet been able to obtain, the highest average tenacity of the welding of the coil has been 32,140 lbs. per square inch, the iron being 55,500 lbs.

With other iron also of high quality and of still greater tenacity, the welds have been lower down, even to 10,000 lbs. per inch; hence such iron, however strong, is, from the steely property, unsuitable for being made into coils; the defect being due to the reluctance shown by harder and stronger iron to unite when raised to a temperature that will not otherwise injure the quality of the material, and cause it to blister.

It will thus be seen that the ultimate strength of a coil in the circumferential direction is about 55,500 lbs. per inch, while in that of its length it is only 32,140 lbs. per inch, and when stronger and harder iron is employed it is even much less in the latter direction and the difference is proportionately greater; hence such steely iron must be avoided for purposes where much dependence has to be put on the welding.

In building up guns of cylinders, this high tenacity afforded by the coil system circumferentially, and the opportunity which it gives of knowing the soundness of the gun structure in every part, and from the fact that every part of the gun is put under the full exercise of its duty from the commencement,—this arrangement of building up guns will always have an immense advantage over guns made of a single solid forging in point of strength and security against bursting of the whole structure; and even when the coiled cylinder is considered as a means of obtaining the inner lining or bore of a rifled gun, a purpose for which it is by no means so perfect, yet even in that respect it is superior to the bore which is formed within the heart of an immense forging, of dimensions suitable for a large gun, such a mass of forging being always more or less defective even under the best and most careful workmanship.

This remark does not apply with the same force to the bores of guns when formed from a smaller forging in which the exterior only has been left as a shell or tube; the outside of such a forging, when properly treated, has a tenacity in all directions equal to that of the solid forging, consequently it is not so strong as the coil in the circumferential, at the same time it is considerably stronger in the longitudinal, direction, and is much more free from defects than the heart of a greater mass in larger forgings.

Turning to cast steel, we find that the range of tenacity is extremely wide—from 114,000 lbs. down to 67,000 lbs. per square inch—but it so happens that the higher qualities, judging from Woolwich experience, are altogether unsuited from their brittleness and great tendency to fracture, and, considering that no metal should be taken into account but that which can be depended upon, I shall only refer to qualities that have been successful in resisting the proof rounds. This quality averages about

80,000 lbs., and it is generally found that the weakest are really the strongest, and if the supply of suitable steel could be obtained with unvarying precision in regard to that degree of hardness, tenacity, and toughness, which is sometimes produced, it would be all that could be desired; but, unfortunately, it is fickle, treacherous, and uncertain, and hence for certain parts of the Armstrong gun that were formerly of steel, and for which some of the properties of steel are desirable, wrought iron of fine quality is now substituted, which, so far as not breaking is concerned, answers the purpose most satisfactorily, although not so good as steel in other respects.

The gun supplied by Mr. Krupp, which was formerly referred to, but which failed at proof, gave a tenacity of 72,000 lbs.; judging from the appearance of this metal beforehand, its softness and perfect soundness, I had great expectation of its being all that could be desired, but was disappointed.

Such a mass of homogeneous steel, after having been cast into an ingot, all its impurities floated to the surface, then well worked under the hammer, and afterwards properly annealed, has a degree of perfection in the bore in regard to entire freedom from specks, seams, or flaws, superior to any wrought-iron structure, coiled or forged, and some remarkably fine guns have been constructed with such steel linings, having the main structure of the gun built up with wrought-iron hoops to give the requisite strength to the steel lining. Such a combination gives the perfect bore and the strong gun, but there is not yet sufficient experience to enable me to assert positively, that the steel will not give way under long-continued firing; but the great difficulty lies in the inability of the steel-maker to insure uniformity, for an occasional gun bursting destroys all confidence.

Such are the several metals now used as materials for guns. Cast iron is the cheapest but the least trustworthy. Wrought iron, built of coiled cylinders, will afford the greatest strength, and is the least likely of all to burst by continued firing; and although in the first instance it will cost three times as much as a cast-iron gun, yet, as its endurance is more than ten times greater, judging from recent results, and as it is never likely to burst with any reasonable amount of firing, I consider it the safest investment, even in a money point of view.

The wrought-iron solid-forged gun, when moderately sound, is much superior to the cast-iron gun, but is inferior to the built-up wrought-iron gun; and, considering the chances of defective bores in the large masses of solid forgings, it will be found as expensive as the latter, and not nearly so reliable.

Cast steel is the most expensive of all, yet, from its soundness in the bore, if it could be made as trustworthy as wrought iron, and if at the same time it could be depended upon for the certain possession of toughness, it would be perfection, notwithstanding the cost; but the uncertainty of manufacture which now exists must first be completely removed before it can be compared with wrought iron as an instrument for men to fire and stand alongside with perfect assurance of safety; and, as wrought iron is so reliable and the cost moderate, there is no particular want felt for steel to constitute the entire body of the gun.

What the world requires is a quality of steel that will be perfectly reliable as an interior lining to a wrought-iron built gun; such a com-

bination will secure all the conditions that are wanted to meet the requirements of the artillerist at the present time.

Such steel should be considerably harder than wrought iron, at the least equal to 50,000 lbs. required to produce sensible shortening on a square inch, but at the same time it must be without brittleness and possessed of toughness at least equal to soft wrought iron, entirely free from honeycomb defects throughout, and which can be produced in a manner and by a process so definite, that there will be no change in the supply and no risk run of uncertainty in the quality of a crystalline structure that shall not be rendered brittle by continued firing, but which shall be as permanently safe and hold on, like good sound wrought iron.

These are high conditions not yet reached, so far as I am aware—not that it is not occasionally attained by some of the best steel makers, and hence there is hope to encourage perseverance; but at the present time, even with the greatest care, the precise quality is uncertain; still, by inferring from the progress recently made in the manufacture of iron and steel, and the great advantage which will accrue to those who are successful, we may reasonably expect that, by aiming high and with a well-directed effort, those conditions will ultimately be realized, and the gun-maker, by a judicious combination of a steel bore within a built-up wrought-iron structure, will be enabled to give the soldier a perfect instrument on which he can implicitly rely, and which will last for ages; meanwhile, considering the materials of iron and steel, as we now find them, and after balancing all the several advantages and disadvantages, wrought iron is the most reliable, even if not so perfect in other respects.