LECTURE ON THE PRINCIPLES WHICH SHOULD GUIDE THE CONSTRUCTION OF HEAVY ORDNANCE, AND ON THE MATERIALS FOR THE SAME.*

It cannot be too strongly affirmed that formulæ are but the expression in accurate language of physical law; and yet we find it asserted by the Woolwich Authorities, as it is in their last Red Book, that the law of distribution of strains "is not exactly known," that there are two laws the results of which vary from each other by 60 per cent. and that one of them which is indisputably wrong is simpler than the other, and yet that its results have been shown to be fairly trustworthy in practice, and yet again in the same sentence that the actual tension "probably lies somewhere between the two results."

If there be any who advocate the use of solid steel guns they would do well to reflect that while they are providing a strong and costly metal to resist the initial strain which may be represented by 4,233 lbs. per cubic inch, they are employing the very same costly material where the strain will not exceed 1-4th of that amount.

BUILT-UP GUNS.

Here we have a series of concentric cylinders, shrunk one over the other so as to distribute the strains more equally.

By the formula which I have given elsewhere the various strains are calculated.

If then the maximum be within the limit of elasticity of the material it is evident that this gun will never fail.

But if the dimensions of the rings be not calculated by the proper formula so that the shrinkages be suitable to the modulus of elasticity, a very different state of affairs would exist.

In this case one or more of the rings may be strained beyond its elastic limit, a permanent set may take place, each successive firing may increase the derangement of the strains, and finally by increasing the strain in the inner tube it may give way by cracking.

This has been the fate of many of the Woolwich guns, and amongst others the celebrated 81-ton gun

The strength of a built-up gun, if properly designed, increases as the number of concentric rings increases, thus if six rings were used instead of three the diagram of strains would be approaching to Fig. 2, upper dotted lines, and if the system of wire were adopted it would be practically a straight line at the top.

The cost of construction increases very considerably with the number of rings, as does the probability of error from imperfect workmanship, whilst with wire there is no extra cost of construction, and no accuracy of workmanship is required as the initial strains are not the result of shrinkage, but are actually measured as the iron is coiled on.

Moreover steel in the form of wire is much stronger than in larger masses, and the extra cost per ton of the wire would be much more than compensated for by the lesser weight of material and the greater facility of its application.

In a gun of many concentric coils, and especially a wire gun, we can so adjust the initial strains that the tension on the inner tube during explosion may be reduced *ad libitum*, and indeed it may always remain under compression.

I believe therefore that chilled cast iron might be used for the inner tube and the rifling cast in it and afterwards ground out by an emery lap.

The Elswick guns are certainly stronger than the Woolwich guns, because the rings are more numerous and more carefully adjusted. The same may be said of Sir Joseph Whitworth's gun were the successive coils laid on with proper shrinkage.

In his 35-ton gun Sir Joseph has four coils over the tube at the powder chamber against two in the Woolwich.

The maximum strains would be as follows:—

Woolwich gun, steel tube	7·02 tons.	
" 1st iron coil	9.38	"
" 2nd " "	13.74	"
Whitworth steel throughout	10·00	"

It is therefore evident that the Woolwich gun with a very inferior material outside the tube is strained in the second coil beyond the elastic limit and permanent set would take place.

I have probably said enough to convince you that the Woolwich gun is of very faulty construction, and those who are interested in the question will find this fully demonstrated in my late paper on the construction of heavy ordnance.

Before leaving the question of construction I must make a few further remarks about shrinkage, regarding which I cannot but think there still exists a good deal of misconception.

For instance, it seems to be thought by some that when the gun is at rest all the tension of the outer rings must be supported by the inner tube and therefore that the amount of possible tension is limited by the compression which the thin inner tube will bear.

This is altogether erroneous, because the compression is not borne solely by the inner tube, and by properly proportioning the thickness and shrinkages of the rings we can distribute the compression pretty much *ad libitum*.

Again, I find it stated by Major Morgan in the paper which he read hereon "Breech loading and Muzzle Loading for Guns," "that the utmost strength that can be obtained by shrinkage is *to double the strength which would be given by the same material without shrinkage*."

I must entirely dissent from such a statement, and without going into calculations in this place, I will point to the drawing, Fig. 9, which shows the strength of a gun 12 inches bore and 22½ inches thick, built of a material the elastic limit of which is 19 tons per square inch. The full lines represent the strains under firing when the material is strained to 10 tons per square inch, and when the five concentric rings are put on with a proper tension. In this state the gun will resist an internal pressure of 24 tons per square inch.

Sir William Palliser advocates a soft yielding material for the inner tube, and he is right, for such moderate pressures as will not give the tube a permanent set, and when he has a heavy mass of cast iron outside.

He would be right also in applying such a tube to the Woolwich guns as at present constructed, or to any hooped gun constructed as it is without proper regard to initial tension. In such a case the yielding soft tube would gradually accommodate itself to its position, and in doing so would vary and possibly to some extent equalize the discordant strains among the outer rings, and the tube would not crack as the steel tube of the Woolwich gun does, and the gun might last a very long time under severe trial, but none the less would it be (all but certainly) undergoing a gradual deterioration, and its fracture might come unawares and probably be attended with fatal consequences.

Sir William Armstrong on the other hand advocates a hard steel tube and yielding iron rings outside.

Here again if the rings are properly proportioned he may make a good gun. If they are never strained beyond the elastic limit and if the steel tube also is also under the same conditions, then it matters not how hard it is, the gun will never fail by bursting.

Nay, so far as it is true that the nature of the material and its behaviour is regulated by the tensions, that a chilled cast iron inner tube bound round with steel wire or encased in steel rings or even iron hoops properly, properly proportioned, would make a perfectly safe gun.

EFFECT OF HEATING.

It is maintained by some eminent men that this heating is due to the actual transmission of heat from the powder gases to the interior surface of the gun, and thence by conduction through its mass.

This I hold to be entirely erroneous. Very little heat is so transmitted and the greater part of the heat set up is due to the vibration of the molecules of the material set up by the sudden application of the force of the explosion

As I had the misfortune to differ altogether from Dr. Siemens on this point during the late discussion at the Institution of Civil Engineers, I wrote to Professor Tyndall asking his opinion. In his reply he did not give any opinion of his own, but informed me that Count Rumford had made a special investigation on the subject, and that his conclusions agreed with mine. I have since referred to Rumford's paper, which is not in the old edition of his Works, but is contained in the new edition published in 1870 by the American Scientific Society.

His experiments are very interesting and conclusive, but there is one thing which at first sight seems to militate against the theory, and that is that the heating effect is greater when the charge is fired without a shot and even without a wad. This however is really confirmatory of the theory.

1st. Because under these circumstances the temperature of the gases thus being uncompressed, is lower.

2nd. Because the rapidity of their escape being greater, the time of contact is less.

The real reason of the increase of heating is that the velocity of the impact is enormously increased, although its statical intensity is very much less.

A pressure of 100 tons per square inch applied very gradually, say in 10 seconds of time, would set up very little heat, but a pressure of 1 ton applied at a velocity of 6,000 or 7,000 feet per second would generate a great deal, and thus it is that the lower pressure of the unconfined powder gases acting with the enormously increased velocity, sets up more heat than the higher pressure guns when confined by a wad and heavy shot in front of it.

Rumford's experiments, therefore, entirely confirm my own view.

But I can carry the matter further and show that independent of experiment we may conclude that it must be so.

Heat can only pass from one medium to another at a certain rate, that is to say, only a certain number of units of heat can enter a square foot of steel or iron in a second of time. This number of units depends *firstly* upon the nature of the material. It is different in lead or copper from what it is in iron or steel.

It depends *secondly* upon the state of the absorbing surfaces. According to Professor Tyndall the rate of absorption is equal to the rate of radiation, and this is very much less in a polished surface than in a rough one.

3rd. It depends upon the difference of temperature of the media but not directly on the difference except when these differences are very small.

See experiments on loss due to radiation.

That a considerable degree of heat is set up is, however, indisputable, but unfortunately, we do not know the law of distribution, nor the degree of its intensity.

As, however, it is due to the sudden strains induced in the material, we may conclude that the rise of temperature at any part is proportionate to the induced strain.

In the next place, we may assume that the rise is instantaneous throughout the mass. It has been suggested that the strain must take time to travel through the mass of the gun, that in fact it is a wave passing from the interior to the exterior, and decreasing in intensity as it goes on, and that if the gun was thick enough, the interior might have returned to its normal state before the strain reached the outside, but in the thickness we have to deal with in guns, such a consideration may be neglected.

The velocity of transmission of the strain would be not less than 11,000 or 12,000 feet per second, so that as regards the time the pressure is inside the gun the period of transmission through two feet of material would be quite unimportant, and may be practically considered as instantaneous, or rather that the whole of the strains, and therefore the whole of the heat, is set up throughout the mass at one and the same time.

Now it may be shown from the formula, that if the whole of a built-up gun be heated by any given amount, say 100° Fahrenheit, the strains would remain unaltered, provided all the rings were properly proportioned, and this would also be the case in a gun built according to the formula, and especially so in a wire-built gun.

If, on the other hand, the rings be put on hap-hazard or by rule of thumb, the increase of temperature may seriously affect the strains, and this is a new element of danger in the Woolwich guns, and all others unscientifically put together.

---

*Lecture delivered at the United Service Institution by James A. Longridge, M.I.C.E.