DISCUSSION.

Mr. Cruickshank, said the paper was a most interesting and instructive one, and he thought the members were already deeply indeb ted to the Author for his experimental work not only in steel, but in other materials, wood, stone, cement, and so on. The literary works on these subjects he had published were recognised all over the world as standards of reference, particularly with regard to our colonial and other woods, and the speaker was very glad of this opportunity of expressing his opinion. and that of many others, in appreciation of Professor Warren's experimental work.

Mild steel, as engineers understood it, was not steel at all, from a practical point of view,—the term could be changed with advantage, and a line drawn between so-called mild steel, and the steel which tempers, at the point where it does temper. The Professor had given a large amount of information and the tests recommended themselves, still, while appreciating the necessity and importance of having this information, from a practical point of view in the construction of machinery we did not require to give any very great consideration to these refined tests. Machines were always constructed with a certain margin, the factor of safety might be 5 to 1, and boilers, cylinders, etc., he actually tested up to double their working pressure—so long as these tests did not go up to the elastic limit, from a practical point of view they knew they were perfectly safe. Anything that takes place after the elastic limit is passed represents permanent set, and the material is injured. In the construction of boilers, if we take the bursting pressure at 500lb. per sq. inch, we assume it safe to use a working pressure of 100lb., and test up to 200lb. It is usually believed we have a factor of safety of 5, but taking the elastic limit it was really only 2½. therefore the so-called factor of safety did not really exist to the extent usually believed.

Another point, testing was not by any means usually to be relied on. Speaking from a fair experience, he had known connecting rods, piston rods, shafts, spindles, and so on, develop flaws at right angles to the section and being taken out and put under the hammers, cracking, yet at the same time test pieces taken from the same have yielded results in Professor Warren's machines to which no one could take any exception, elongation, contraction of area etc., being all right, and showing all the qualities of really good material. He had seen boilers give way after being blown down, with a sudden fracture like the shot of a cannon when being cleaned, and develop air cracks in parts that to appearance were perfectly sound. Test pieces were cut out and gave the same good results as in the rods, shaft, etc., mentioned.

He referred to the shaft of the s.s. Perthshire, that was drawn and closely examined within six months before it fractured, and was apparently sound, yet it broke nearly straight off without the slightest notice, showing that with all our scientific knowledge and care in testing, we cannot make infallible machinery yet. The strength of shafting is of great importance, and is engaging the attention of all engineers, yet it seemed that although we made shafts double the calculated strength we do boilers, with a factor of safety of 10 instead of 5, their strength is uncertain. The larger a shaft is the more likely it is to be flawed, and the more likely there is to be a very considerable difference between the strength of the material at the centre of the section and that of the outside. We have met this difficulty so far by increasing the sectional area, and no more credit is given for steel than for iron shafts, the one breaking as readily and as often as the other.

With regard to the physical properties of steel, elongation, contraction, tensile strength, etc., the standard physical proportions are well known, for certain applications of work. but the uncertain stresses and strains to which in many cases it is subject make calculation of no account at all.

He had brought a specimen of iron to the meeting, one of the most remarkable things he had seen, and he was sure no engineer present could tell what it was. It was completely crystallised, and the nature of the material entirely and distinctly changed, no man could say it was a piece of wrought iron. It was a piece of the paddle shaft of the s.s. Newcastle, which broke suddenly not long ago, after being in work some fifteen years. It looked more like a mining specimen than anything else. It showed how in the ordinary course of working the nature of the metal had changed, and the question was, how could these changes be prevented. This state was produced by what is usually termed fatigue of the metal, but Professor Warren objected to that term.

As for the difference of iron, mild steel, and steel, they cut into each other almost imperceptibly, and depended very much on the amount of carbon in the material. From .2 to .15 of 1 per cent. of carbon gave us a material eminently suitable for the construction of machinery; as the amount of carbon is increased, the steel gets harder, until it cannot be used. Mild steel as used for boilers is not of too high tensile strength, for then it would not have the ductility so supremely important for this class of work. With regard to nickel steel, he saw from the tables given that it possessed some extraordinary qualities, but it remains to be seen whether it will prove suitable for engine and boiler construction. He raised the point as to whether there was any difference in its properties at a higher temperature, say 370 deg. or 400 deg. When they considered the conduct of copper at the usual temperature of modern high pressure steam, and its loss of strength of from 20 to 25 per cent., this matter was important. It was an admission that engineers had not much confidence in it when we found steam pipes hooped round with iron every few inches. Copper was thus different from iron and steel, which increased in strength up to 500 deg. or 600 deg. temperature. Another thing was that there were no reliable data as to copper in compression at varying temperatures. Points like this were where laboratory experiments like those of Professor Warren were of supreme value, and some one would have to solve these questions. The speaker believed the Professor was as likely to do so as anyone.

At the same time he repeated that from a practical point of view an engineer cannot be too cautious, and cannot rely altogether on tests obtained from the machine. Certain things happen which we cannot explain. He had seen steel plates, and tested perhaps two or three dozen of them, with one perfectly rotten in a particular part, and it was a mere chance that the whole of the material had not been passed as of first-class quality. The members quite realised and appreciated the value of testing machinery, but it by no means followed that any test whether of iron, steel, or copper could be absolutely relied on.

Mr. German said: Referring to the question of chemical composition of the material having effect on its physical qualities, the company he was connected with had a great quantity of rails laid in humid country, and they found some resisted corrosion better than others. Their experience showed that the softer rails corroded the quickest. Recently they had sent home specimens of the rails they had found the best resisters of corrosion, and also some of those easiest affected. Both kinds were tested, but they had received very little satisfaction from the results of the tests. He considered the best resisting rails were those which contained a high percentage of silicon. He would have liked to have heard Professor Warren's opinion on the subject.

Professor Warren, in reply, said that there was no doubt that the working stress of a material was governed by the elastic limit, but in testing, the elastic is somewhat indefinite. If a piece of steel was pulled out to the apparent elastic limit and then given a rest and pulled again, the elastic limit was apparently raised, and one could go on doing thus until the material gave out. The whole thing hinged on the question of what was the elastic limit. He had defined it in a sense in his paper, and said that it was the point at which the strains of the material cease to be proportional to the stresses producing them. But that point can only be found with the most delicate instruments. With a machine recording .00001 of an inch, he found the elastic limit to be 16 tons, while with another he found it to be 14½ tons, the only difference being the means of measurement.

Strictly the working stress on a material is proportional to the range of stresses, and the greater the range, the smaller must be the working stresses. The range was obtained thus, if the material has to stand 10 tons per sq. inch in tension and the same in compression, the range of stress is 20 tons, if varying between 10 and 30 tons in compression only, the range is still 20 tons.

Wohler's researches were directed to ascertaining the safe working load under all conditions, he announced the law relating to the gradual application of a load to material. Mild steel will probably stand 28 tons to the sq. inch before it fractures, but if the load be repeated, after about five million applications it will be found to break with about two-thirds of that. If, on the other hand, it is subjected to alternate stresses of tension and compression, such as must be produced in a railway axle, then Wohler's experiments proved that the bar was broken after five million applications with one-third of the 28 tons. The Professor here explained on the black-board the conditions set up and determining formulae.

Mr. Cruickshank asked how would the conditions of a shaft of a propellor which came out of the water and down again with a thump be determined?

Professor Warren said it would only be two-thirds as strong as when without the alternating stresses. Concerning the reliability of tests, it was obvious that with a flawed propellor shaft, a test when not cracked would be different from one when the shaft was not cracked.

With regard to the price of nickel steel, improved means of manufacture would better this. Less risk was run with a hollow shaft than with a solid one, the maximum stress occurred at the outside. In tension there was no difference between large and small pieces of material.

Mr. Cruickshank remarked that sometimes the central portion of a large shaft looked like a bunch of matches.

Prof. Warren said the stresses in a propeller shaft were like those in a railway axle, very complex; and no doubt a large shaft would break with a smaller proportional stress than a small one. In the case of the "Perthshire," the enlargement of micro-flaws in the shaft caused ultimate fracture; in a large forging there was a larger chance of such flaws. The remedy is not so much to increase the diameter as to substitute material with a higher elastic limit. Nickel steel answers that completely. Mr. Noyes had sent him bars of nickel steel from Krupp's with about six per cent. nickel, the very quality for propeller shafts and railway axles. He did not think that there was any evidence that the wrought iron was made crystalline by repeated stresses. Kirkcaldy had shown them that a piece of material appeared crystalline or fibrous according to the way in which it was fractured. No doubt the propeller shaft referred to was fractured by fatigue strain. While nickel steel nearly doubled the cost of a railway axle, it doubled the safe load; and no doubt the price of it would come down, as that of mild steel had done. It was quite a new material, and that was why he had taken so much trouble to test it. It's elastic limit is considerably over the tensile strength of crucible steel, while at the same time it had greater ductility. He believed it would be difficult to weld, and a quality of 25 per cent. nickel would not work at all.

The President (Mr. H. B. Howe) said the thanks of the members were due to Professor Warren for bringing this matter before them. He was struck with what this steel would stand when nicked, with ordinary crucible steel axles, a blow with a chisel is almost sufficient to start failure without any very great strain. For railway axles it would be very good; he fancied it was the price only that kept it out of the market. It's ductility seemed o make it applicable for boiler plates. Locomotive engineers looked for a material that would give as good results as copper for fire-boxes. Ordinary steel from the very best makers is not reliable at all times; possibly in one place it will behave as if very hard, while in another it will handle like copper or lead. He tendered the thanks of the meeting to Professor Warren, who in replying, suggested the suitability of nickel steel for locomotive fire-boxes.