

Correspondence.

Mr. Adamson. Mr. DANIEL ADAMSON observed that the Paper was wanting in this particular, namely, that it took no cognizance of what was alloyed with the iron. The only difference in all the irons in the world, arose from the alloys with which the metallic iron was combined. This much he could say, in proportion that the alloying element was increased, so was the infirmity of such metals at colour heat augmented. Blue heat certainly was not an exposition of the condition; as it was manifested in several colours, and the higher alloyed metal would break up at black heat. In a Paper which he had read at Paris, "On the Mechanical and other properties of Iron and Mild Steel,"¹ he had given in an Appendix the chemical compositions, which materially assisted in understanding the infirmity of alloyed metals. The greatest practical importance he attached to colour heat was relative to railway axles, in which the heat caused the grease to boil off. The temperature then was dangerous; and such axles subjected to concussions were liable to be broken. The fly-shafts of marine engines could only be protected in case they became overheated, by stopping the engines, and allowing the shafts to cool. Cooling them suddenly in cold water was sure to set up local cracks, and to end in complete rupture.

Mr. Andrews. Mr. T. ANDREWS observed that the interest of the Paper would have been enhanced had the Author given a complete chemical analysis of the various steels and wrought-iron employed, and also ascertained the exact temperature conditions of the metals at the time of observation in each experiment. As regarded wrought-iron, his own practical experience generally coincided with the Author's experimental observations; neither iron nor steel ought to be worked at a blue, or black heat, or considerable injury might ensue. It appeared from a Paper "On the Modification of tensile strength and ductility which Iron and Steel undergo when heated to between certain temperatures," read by Mr. E. Cornut before the seventh congress of Engineers-in-Chief of the Association of Proprietors of Steam Boilers, held at Bordeaux,² and from the observations of Mr. C. Huston, Mr. C. Walrand, and others therein alluded to, that there was a peculiar modification of tensile

¹ The Journal of the Iron and Steel Institute, 1878, p. 383.

² "Iron," May 1st, 1885.

strength and ductility in iron and steel at temperatures ranging from about 572° to 662° Fahrenheit. These researches, and the Author's experiments might therefore be advantageously considered together, and reference might also be made to a Paper by Mr. W. Worby Beaumont, Assoc. M. Inst. C.E., "On Modern Steel as a Structural Material."¹ The strength of both iron and steel was undoubtedly materially influenced in a variety of ways by temperature conditions; low temperature increasing the tensile endurance to some extent, but reducing the power of resistance to sudden impact. Mr. Andrews was engaged in investigating some of these conditions, and the effects of varied temperature on the strength of large forgings, in an extensive research. Steel was a complex crystalline chemical substance, and did not appear always to manifest that complete homogeneity and uniformity of structure and behaviour which some persons considered it to possess. The elaborate research, "*Théorie Cellulaire des Propriétés de l'Acier*," communicated in 1885, to the French Academy of Sciences by Messrs. Osmond and Werth, of the Creusot Works afforded some valuable indications of the peculiar internal structure of steel. Other of its variable properties when under corrosive action in sea-water had been electrically considered in some of Mr. Andrews' recent Papers.² Mr. Osmond had communicated with him stating that the interchanges of electro-chemical positions of steels in sea-water, and the mode of their corrosion, which Mr. Andrews had observed, had tended to confirm electrically the experimental views he had expressed as to the cellular structure of steels. The microscopic researches of Dr. H. Clifton Sorby, on the structure of steel,³ also further greatly assisted in affording information on the physical structure and nature of steels, an apprehension of which was essential to a correct prognosis of the ultimate suitability and permanency of these newer metals for structural purposes. Owing to its compound crystalline character steel might, perhaps, be regarded as more liable to injury from varying temperatures than wrought-iron, especially in circumstances where inequality of expansion and contraction might obtain. Mr. Isherwood, of the United States Navy, had observed that steel shafts were liable to become brittle under certain conditions of high temperature, which practically might arise in the case of heated

¹ Society of Engineers, Transactions for 1880, p. 109.

² Transactions of the Royal Society of Edinburgh, vol. xxxii., Part I., p. 205. Minutes of Proceedings Inst. C.E., vol. lxxvii., p. 323; vol. lxxxii., p. 281.

³ The Journal of the Iron and Steel Institute, 1885, p. 203.

Mr. Andrews, necks, or journals. He remarked "that the increase of temperature referred to increases the brittleness of iron and steel, and of steel more than iron, as it accounts for many fractures impossible to otherwise explain of marine engine shafts." Again, "steel shafts are much more subject to these accidents than iron ones, and at high temperatures the brittleness of steel due to temperature is greater than that of iron." The treacherous after behaviour of steel in some instances, such as the failure of steel steam-boilers recently recorded by Mr. Maginnis,¹ and the disastrous sudden fracture of the steel locomotive crank-axle at Penistone on the 16th of July, 1884, which had only been in work about fourteen months, even where it passed satisfactory tensile tests, etc., could not always be accounted for on the Author's supposition of temperature injury during manipulation. Moreover, steel generally was liable to develop growing internal flaws, possibly emanating from some of the unevenly distributed nuclei of its crystalline formation.² These growing flaws, which, owing to the homogeneity of its nature were always more or less liable to develop in steel, constituted a serious source of unknown danger considered by "L" in his letter thereon, in "The Engineer," December 25th, 1885. Such flaws seemed at present undetectable, and generally with steel no intimation was afforded previous to the occurrence of fracture, the behaviour of iron in most instances being the reverse in this respect. These circumstances showed that there was considerable risk in the use of steel for many purposes, and although steel primarily endured a higher tensile-strain than wrought-iron, it did not necessarily follow that this was an infallible indication of its universal applicability, after endurance, or permanent stability under all conditions.

Sir Henry
Bessemer.

Sir HENRY BESSEMER cited one special case (which came under his personal observation) in support of the views put forward in the Paper, and he agreed with the Author in believing that many of the so-called "mysterious properties of steel" owed their peculiarity to having been worked at a "half-heat." On one occasion he had seen a plate, which rolled like copper at a white heat, go to pieces in the act of rolling when it was continued after the plate had ceased to be visible in the dark; and it was found that these broken pieces could be rolled when quite cold without fracture, and were perfectly tough strong metal when annealed. This was an extreme case and was, he had no doubt, largely the result

¹ "The Engineer," 1885.

² The Journal of the Iron and Steel Institute, 1885, p. 272.

of an overdose of phosphorus in the metal of which the plate was made. Sir Henry Bessemer.

Mr. J. COLVILLE, while generally approving of the Paper, must take exception to the remarks with respect to the conduct of mild steel after having successfully withstood hot bending, even if at a blue heat, as he certainly did not think such "almost sure to fly to pieces when cold;" neither could he agree as to plates suffering by being laid upon each other immediately after being rolled. Mr. Colville.

Mr. A. COOPER regarded the subject of the Paper as a most important one, both to the makers and to the users of steel. He was sure if it were better understood and appreciated by ship-builders and boiler-makers, much less would be heard of the mysterious crackings of steel-plates and bars, as from numerous instances which had come under his knowledge he believed that fully one-half of the plates and bars that cracked in the hands of the users whilst being worked, or after being worked, "hot," as they termed it, failed solely because the working had been continued after the temperature of the piece had fallen below dull red; as subsequent testing had proved in almost every instance that the steel had been not only chemically correct, but also that it would stand almost any amount of punishment either when red-hot or when quite cold, but at the medium temperature, probably when passing through the "blue heat" period, it had been unreliable. Mr. Cooper.

Mr. F. W. DICK observed that there was very little that could be taken exception to, and very little to add to the Paper. It was a matter for congratulation that the Author so strongly advocated the working of steel when red-hot, or when cold only. The Steel Company of Scotland had for many years endeavoured to impress upon the users of steel that on no account must it be worked at a blue heat. Another important point noticed by the Author, and one which should be kept well in mind, was that all steel which had been worked at a blue heat should be subsequently annealed; it should be brought to a full red heat. The manner of cooling, if not too rapidly effected, was not of so much importance. The Author had referred, page 122, to the apparent effect on "medium-hard" steel, of long continued exposure to blue heat. It would be well not to give too much credence to this until the circumstances were fully known. Probably the test-pieces were "strained," by shearing or otherwise, before being placed in the core-oven. The blue heat was insufficient to relieve such strains. It would be noticed from the last line of page 122 that the test- Mr. Dick.

Mr. Dick. pieces had seemingly been sheared. Plates were constantly stacked hot in rolling-mills, and any brittleness induced in the manner surmised by the Author could not have escaped notice. The points to be remembered in this connection were:—

1st. Initial strains existing in steel were not eliminated by raising to a blue heat. The heating must be continued to full redness before such strains were got rid of.

2nd. Steel strained at a blue heat and allowed to cool, continued in a state of strain, and was much injured, and this injury was much greater than if the steel had been strained while cold.

3rd. Steel which had been injured by strain at a blue heat was restored to its original condition by raising it to a red heat and allowing it to cool.

Some six years ago experiments were made at the works of the Steel Company of Scotland to determine the influence of manganese on the behaviour of steel at the blue heat. Wide variations in the quantities of manganese present (from 1 per cent. to 0·2 per cent.), produced no apparent differences in the results, and this led to various brands of iron plates being subjected to similar tests. It was needless to add that the iron plates were similarly affected at the blue heat. The presumption was that manganese was not the cause, although it might have some effect upon the brittleness of steel at this temperature.

Mr. Gillott. MR. THOMAS GILLOTT observed that the tenderness of iron at a heat below redness had been known in the best Yorkshire iron-works for probably more than fifty years, and “blue shortness” was a recognized weakness. So far as his experience went, steel was more troublesome in this respect than iron, but it was scarcely correct to attribute failures generally to working either iron or steel after a red heat had been passed. Nor need many of the cracks often heard of be called mysterious, if the history of failing plates was fully traced from the ingot onwards. Contraction cracks in steel ingots were often caused by the irregularities of a worn-out ingot mould; and some cracks could be welded up when hammering, but would always leave a line of weakness across the finished material. A slight red shortness might cause a flaw when being worked hot that would prove a weak spot when cold, in a plate that would, when tested in the usual way, prove as ductile as could be wished. One condemned by him after rolling had slight cracks across in one part of a plate 14 feet by 6 feet 10 inches by $\frac{5}{8}$ inch, and although so ductile that it was scarcely possible to break shearings after heating and quenching, there was a line of weakness across the plate

due to red-shortness that doubtless would have fractured in Mr. Gillott's work had it been used. An analysis of the red-short part gave carbon 0·120, silicon trace, sulphur 0·041, phosphorus 0·068, manganese trace. The chief trouble generally arose with large plates, such as those used for the fronts of marine-boiler furnaces, and requiring to be flanged for the boiler-shell and furnaces. Could these plates be flanged in a press at one heat, no doubt less would be heard of failures in steel; but taking the results of his own experience, in a total number of about two thousand five hundred furnace front plates for marine-boilers, there were nearly nine hundred different patterns; so that, for commercial reasons, flanging in successive heats, and straightening at a single heat afterwards, could scarcely be avoided. Could marine-engineers agree on standard patterns, better methods of flanging than those generally in use might be adopted. After straightening and facing the flanges, slight adjustments of the flanges to the extent of not more than $\frac{1}{4}$ inch had to be made, because the time during which plates would remain hot enough for working, when not over-heated, is not more than five to ten minutes, depending on their thickness. These adjustments were generally effected by applying heaters and setting by hand-hammers, or, in other words, performing the work in the precise way objected to by the Author. The heaters were not applied "to take the chill out," as they were just as much used in summer as in winter, but to enable the work to be done; and as many flanges for attachment to the shell of a marine-boiler were as much as 9 inches deep for a plate $\frac{7}{8}$ inch thick, some method of adjusting had to be adopted which would locally heat a plate for a slight adjustment, without causing inaccuracies in parts already correct. Any annealing after such an operation would simply entail a further adjustment, as it was hardly possible to draw a large flanged plate out of a furnace without distortion, and it rarely happened that such plates were flat when allowed to cool freely.

There was little doubt that more plates were adjusted by applying heaters, instead of again using the furnace, than was absolutely necessary; but it was open to question whether two or three furnace-heats did not damage iron or steel more than applying heaters after one furnace-heat. No accurate record was kept of fractures in Yorkshire iron when adjusted as described, but he thought that not one plate in twenty would be cracked by setting or riveting, and such cracks, when there were any, would nearly always occur where parts had been somewhat over-heated in the furnace. The difficulty of obtaining perfectly uniform heat in a

Mr. Gillott. furnace 16 to 18 feet long and 8 to 10 feet wide, with a large semi-circular plate having some flanges 9 inches and others 5 inches deep, occupying the available length and breadth of the surface, would be recognized by those having experience in such work; so that it was by no means easy to secure sufficient heat all over it without a slight excess in some part. Work of this kind could not be treated like the small strips used by the Author, and his own impression was that iron was less damaged by blue heats for setting than it would be by additional furnace-heats.

As regarded mild steel, his experience led to the conclusion that it was more liable to fail at a blue heat than best iron. Frequently, when through the drawing-in of the unflanged edge of a furnace front plate while being flanged, a furnace-hole had been oval to the extent of $\frac{3}{4}$ inch, and a stretcher-bar had been put across the shorter diameter, whilst the plate was hot for straightening, so as to obtain greater roundness when cold, by the short diameter contracting on the stretcher, and without injury in the case of iron, but not so with steel. As an instance of this, a mild steel plate for the furnace front of a boiler, 12 feet 3 inches in diameter, with two furnace openings of 3 feet 6 inches, had a stretcher-bar placed across the vertical diameter of one furnace that was slightly oval, and it cracked the flange through at the upper point, although the distance between the upper unflanged edge and the inside of the furnace opening was only $5\frac{1}{2}$ inches. Yet this plate, which was full $\frac{1}{16}$ inch thick, when tested showed a tensile strength of 28·8 tons per square inch, and elongated 25·625 per cent. in 10 inches, the contraction of area being 42 per cent., and the fracture silky. The strips when heated and quenched were bent to $1\frac{1}{2}$ inch between the folds, and the carbon sampled 0·15 per cent.

With respect to the composition of steel, his own experience appeared to indicate that if mild steel contained from 0·10 to 0·15 of phosphorus, although capable of sustaining severe bending-tests as it left the rolls, it tended to become brittle by successive heats, far more so than steel in which phosphorus was low. The radius of the curves to which the specimens were bent was also of great importance, but was probably kept uniform, although this was not easy.

Mr. Hudson. Mr. J. C. HUDSON hoped to be able to indicate a direction in which experiments might be made to find the reason why steel was difficult to work at a blue heat, and more so than when hot or cold. He would consider briefly plate-steel, such as was used in boiler-making, bent when cold, when red-hot, and when at a blue heat. In bending a piece of steel-plate from straight to a curve,

the outer surface of the curved plate would be stretched, and the inner surface compressed. But as the power of steel when cold to resist a tensile strain was usually considered less than that required to compress it, it might be supposed the plate would be distorted by stretching more than by compression, in order to accommodate itself to the altered condition of a plate when straight and when bent; and as steel had a great range of elongation under a tensile strain before breaking, evidently a plate might be bent a number of times before fracture. The elasticity of steel would also aid this plate in resisting fracture. Steel when red-hot, or at a higher temperature, would stand bending, as the metal then was more plastic, and the power to resist compression was considerably reduced, and when bending it the outer surface of the curve might be stretched, but the inner surface would be compressed, which compression would reduce the stretching on the outer surface, and considerably reduce the fatigue on the metal. But suppose that steel at a blue heat had lost the power of elongation, or had it considerably reduced, and that the power to resist compression remained practically the same as when cold, then it would appear that a plate bent under this condition of temperature would be rapidly fatigued on the outer surface of the curve, and a fracture would follow owing to the metal being then unable to resist the strains consequent to cooling. From the foregoing he ventured to suggest that the reason why steel was difficult to work at a blue heat could be readily investigated by experiments on the metal at this temperature, and under tensile strain, when he believed it would be found to have lost to a great extent its power of elongation, when also its power to resist compression was not much reduced. His observations of the fracture of steel worked at this temperature confirmed him in this view.

Professor D. E. HUGHES observed that if blue heat did affect the strength of steel, then it could only be through some molecular change in its structure, and this could be easily determined by testing its magnetic capacity. The day must soon come when a sample of iron or steel would no longer be broken or destroyed in order to find out the molecular condition of its structure. Electricity or magnetism should be able to do this. He had already shown, in his induction balance, that by its aid the slightest change could be detected in the molecular structure of iron and steel, and any strain or flaw be at once found out, and he had shown that, when a current of electricity was sent through a wire or bar of iron, a very slight mechanical strain reduced the self-induction of the bar 40 per cent. It was by physical means alone that the

Professor
Hughes.

Professor Hughes. hope could be indulged of penetrating inside a bar of iron or steel, and the exact molecular structure be revealed at any given point or after any given treatment; and although at present no practical instrument existed suitable for tests on all shapes and sizes of iron or steel, the day must come when the present almost brutal method of testing iron and steel would give way to more scientific, and far more reliable tests than could be obtained without the aid of physical means. He had tried to solve this question—he was trying still—and others would succeed, even if he failed, as the problem had been already solved from a scientific point of view. Needing only a practical instrument, which could do in rough usage and on any scale, that which could at present be accomplished with comparatively small samples.

Mr. Sandberg. Mr. C. P. SANDBERG remarked that the alleged great advantage of the use of steel instead of iron, in effecting a saving of 25 per cent. of fuel in steel boilers, through the possibility of using higher pressure, was enough to prove its progress, but it would necessarily be checked by this unexplainable phenomena of cracks, snapping, and fractures, as stated in the Paper. It had been the same on the introduction of steel rails, but this has now almost disappeared, and Bessemer steel for rails was now produced with great regularity. This, and the absence of fractures, had been principally arrived at by reducing the hardness, though at the expense, unfortunately, to some degree in their wearing qualities; and he anticipated that if a demand should now arise for harder steel rails, there would be some increase of fractures. It would be of great importance to treat this hard steel more carefully than mild steel, by finishing the working or rolling it out before it had declined to a blue heat, and then cooling it slowly and regularly without cutting it when cold. In fact, it should always be borne in mind that the less steel was touched after leaving the rolls, the less was the probability of spoiling it, and this applied especially to hard steel. Mr. Sandberg strongly advocated the employment of chemical, as well as mechanical tests in the manufacture of steel rails, and that the latter should be subjected to the same conditions of trial as they would be exposed to in actual practice. He much regretted that there was a total absence of chemical tests to represent quantitatively what was meant by mild, very mild, and hard steel. The Author should have given, in conjunction with the mechanical tests, the constituents of the various samples of steel, including not only the carbon and silicon, but the other constituents, such as phosphorus, sulphur, and manganese. If makers and inspectors could afford to do this for steel

rails, they could surely do so for steel plates. He was not prepared Mr. Sandberg. to say that the chemical results would in all cases explain abnormal or curious features developed by mechanical testing, but they would in most instances explain matters, and thus give the key to correction. The chemical testing of different productions, obtained by different processes, was of great value as a guide; but serviceable steel might be had of variable composition, therefore he did not approve of specifying for steel of one fixed chemical composition only. He should like to learn from the Author how the temperatures defined as blue, and black heat had been taken.

Where bad results, such as snapping and fractures, occurred in steel, it was no easy matter to decide whether such behaviour was due to bad steel or to bad workmanship; for improper treatment could spoil even the best steel; and it was in this view that the Paper was of great practical interest to all users of steel-plates. However, the results of his inspection of steel-rails, and which might also apply to steel-plates, tended to show that regularity of production was rarely if ever obtained from a new maker at the first start, from want of experience both of the machinery and of the mill, which was not got in a day; and this might explain occasional bad results; but it should by no means be disheartening, for it would soon disappear, and was almost unavoidable. As regarded a statement that inferior German steel had been used for bayonets supplied to the British army, he thought the saving in first cost of an article like that was wrong. Such articles should be made solely of Swedish steel, one of the peculiar advantages of which was a high degree of "body," or a capacity to stand many repeated heatings without becoming soft.

Mr. H. SHARP stated that the injurious effects of working steel Mr. Sharp. at a blue heat had been well known to many steel-makers for some years. An elaborate series of experiments on this subject had been made by Mr. J. F. Barnaby, Admiralty Overseer, at the Cyclops Works, Sheffield, the results of which had been published by the Admiralty,¹ and he felt that he could not add more to the subject than had been published by that gentleman. There was one point, however, which he thought it might be well to mention, namely, the practice which was carried on in many boiler-yards of making steel plates hot preparatory to bending them in plate-bending rolls. A long experience has satisfied him that this

¹ "Influence of temperature on the strength and ductility of steel and iron." 1881. "Effects of heat on the bending qualities of iron." 1881. "Effect of repeated heating and cooling on tensile strength of steel and iron." 1882.—[Inst. C.E., Tracts folio, vols. 29, 32.]

Mr. Sharp. process was most injurious to steel, and he had no doubt that many of the unsatisfactory results given by steel boilers might be attributed to this cause.

Mr. Webb. Mr. F. W. WEBB submitted the following particulars of bending-tests and tensile-tests made in the testing departments of the Crewe Works of the London and North-Western Railway :—

I. BENDING TESTS ON STRIPS SHEARED FROM ONE ORDINARY ANNEALED BOILER-PLATE (62-12 V). Carbon 0·19. Bent through angle of 135°, forming where bent angle of 45°.

Number of Pieces.	Number of Times Bent and Straightened.	Remarks.
2	2	Two strips sheared off plate (not re-annealed). Broke during second straightening.
3	7½	Three pieces made red-hot and tested in that condition. Broke during eighth straightening.
3	1	Annealed and made blue-hot and bent in that condition. Broke during first straightening.
1	Nil	One piece hammered at a blue heat. Broke during attempt to bend at a blue heat.
2	Nil	Hammered at a blue heat and allowed to get cold. Broke during attempt to bend.
2	2	Hammered at a blue heat and then annealed; bent cold. Broke during second straightening.
2	3	Pieces of the ordinary plate simply annealed and bent cold. Broke during third straightening.

II. EXPERIMENTS ON THE TENSILE-STRENGTH OF BOILER-PLATES TESTED UNDER THE CONDITIONS STATED BELOW.

Number of Pieces Tested.	Breaking Weight per Square Inch.	Extension taken on a Length of 10 inches.	Remarks.
3	Tons. 30·96	Per cent. 23·6	Ordinary plate. Annealed and tested cold.
1	38·04	4·3	Bent three times while blue-hot to angle of 30°, and tested cold.
2	35·24	10·05	Hammered while blue-hot. Tested when cold.
2	30·26	23·8	Hammered while blue-hot, and annealed. Tested cold.
3	31·95	7·5	Bent once when blue-hot. Tested cold.
3	30·74	22·1	Bent once blue-hot. Annealed, and tested cold.
3	31·65	22·5	Bent red-hot. Tested cold.
3	32·42	12·5	Annealed plates. Bent, and tested cold.
3	30·60	23·63	Annealed plates. Bent, re-annealed, and tested cold.
2	38·80	11·4	Tested while blue-hot.

From the bending-tests, it was obvious that plates which had been hammered, bent, or rolled while blue-hot were very liable to fracture when afterwards subjected to bending or concussive action. The annealing appeared to restore the ductility to a plate which had been worked blue-hot, to a great extent, but not completely. The bending was performed by gentle blows from a steam-hammer; and the angle 135° was selected merely for convenience. None of the plates under tensile strain broke across the place where they were bent. The main effect appeared to be on the elongation of the plates, which was much reduced by hammering and bending either when blue-hot, or when cold; though in each case it was nearly restored by annealing. The increased tensile-strength of the plates tested blue-hot was remarkable. The plates also stretched by fits and starts. The elongation was less, and the strength greater than ordinary plates. All the tests, both bending and tensile, were from the same boiler-plate (62-12 V).

* * The results of a series of experiments, undertaken by Mr. W. Parker, M. Inst. C.E., at the suggestion of a Member of Council, on the question of steel becoming brittle when worked at a blue heat, will appear in a future volume.—SEC. INSR. C.E.