a stone structure would be the cheapest. There were upwards of 60,000 cubic yards of masonry in this work, and the total cost was £72,000; the cost per cubic yard, taken in block, being less than 7s.

Mr. PETER W. BARLOW said, he had compared the cost of timber and brick viaducts, and taking into consideration the relative durability of the two materials, and the cost of repair, he thought it was highly desirable to use brick. Of course it greatly depended on the nature of the foundations, but where they were good, a brick structure was decidedly the best. He believed that Mr. Bruff's viaduct was a cheap structure; but he was inclined to think that the hollow spaces, or voids in the piers, had the effect of weakening them, and he preferred Mr. Cubitt's plan of building them solid throughout.

Mr. BRUFF observed, that he was induced to make the remarks he had done because it was recorded in the Minutes of the Institution* that 6s. 9d. per cubic yard was a cheap price for the Dinting Vale viaduct, constructed of timber; whereas in this instance 6s. 6d. per cubic yard was shown to be the cost of a brick structure. From the known cost of similar constructions, he thought the Chapple viaduct would bear a favourable comparison. For instance, the large viaduct on the Hastings line, at Brighton, with a less average height, cost a much greater sum. The price paid at the Chapple viaduct, for brick-work in mortar, was 23s. per cubic yard, and for cement-work 28s. per cubic yard, besides an allowance for centering, backing up, &c., which considerably enhanced the cost, but the whole was accomplished for the prices which he had stated.

No. 828.—“On the manufacture of Malleable Iron; with the results of experiments on the strength of Railway Axles.” By George Benjamin Thorneycroft, Assoc. Inst. C.E.†

Several papers on the strength of iron have already been laid before the Institution, but neither in them, nor in the more elaborate publications of Mushet, Scrivener, and others, are to be found satisfactory reasons for the changes which apparently take place, in bars of malleable iron, under certain circumstances; that metal is, however, now so extensively employed, in situations where its fracture may be productive of such disastrous results, that any observations tending to produce greater certainty, or uniformity, in the manufacture, may claim indulgent consideration. It is in

* *Vide* Minutes of Proceedings, 1846, vol. v., page 217.

† The discussion on this paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

this spirit, that the Author brings his paper before the Institution, in fulfilment of the engagement entered into on his election, disclaiming, at the same time, any pretence to scientific research into the chemical constitution of metals, but giving the result of the experience of forty-eight years in the manufacture of iron, first as a workman, then as a manager, and for the last thirty-two years as an iron master.

Malleable iron may be divided into two distinct classes,—“Red-short,” and “Cold-short;” the former being generally produced from the rich ores, and the latter from the poorer, or leaner ores.

The pig iron made from the rich ores (under the cold-blast process only) is not so fluid as that from the lean ores; when however it has been converted into malleable iron, it is tough and fibrous when cold, but is troublesome and difficult to be worked by the smiths, at less than a white heat; this want of ductility has caused it to be denominated “Red-short.”

The pig iron produced from the lean ores possesses, on the contrary, more fluidity, and it is thence well adapted for small castings, but when it is manufactured into malleable iron, although in the hands of the smith it is ductile and is easily worked, even at a dark red heat, it becomes, when cold, weak and unfitted to support sudden shocks, or continued strains, and is hence called “Cold-short.”

It is obvious, that to obtain qualities of iron suitable for the various purposes to which it is now applied, a judicious mixture of these two kinds must be made; but even this will not suffice, unless the pig iron, forming the basis, be of a proper quality. It may be received as an axiom, that good malleable iron can only be made from good dark, and bright grey pig iron, smelted from iron ore alone, or with a very small admixture of any extraneous substance. Iron made from white pig iron alone, is never ductile, although it may be cold-short, whilst it differs materially from the red-short iron, made from rich ores: in fact it possesses no good quality either hot, or cold, and may be termed “Rotten-short.”

The quality of the fuel used in the smelting furnace, and in the subsequent processes, is very important, for the produce of the best ores may be rendered utterly worthless, by the use of inferior fuel; on the other hand, iron made from rich ores, and having great strength when cold, but which cracks in working at a red heat, if smelted with very pure coal, or charcoal, retains all its strength, whilst it becomes much more ductile than if an inferior quality of fuel had been used. Hence, when a strong ductile iron is required, the best fuel must be employed in its manufacture.

The introduction of hot-blast, for smelting iron, rendered necessary a careful investigation into the comparative use of hot and of cold

blast pig iron, in the manufacture of bars; the result of this would appear to indicate, that if the same quantity of materials be used in both cases, equally good bar iron will be produced; but it is more difficult to convert the hot-blast pig iron into "number one" bars, and the waste is greater, than when cold-blast iron is used.

It is certain, that whilst good grey pig iron can only be produced, by cold-blast, from the best materials, iron of apparently excellent quality, can be made, by hot-blast, from the most sulphureous ore and fuel; indeed to this alone must be attributed the bad reputation of hot-blast iron for certain purposes. Castings for the forge and mill, such as rolls, housings, hammers, anvils, &c., which require great strength, as being subjected to considerable strain, or to sudden concussion, should not be made of hot-blast iron. Wherever strength and durability are required, a mixture of qualities of iron is essential, in order to produce metal having a bright grey fracture, slightly mottled, which is the best quality. Any nearer approach to grey renders the casting weaker, as the more highly carbonized cast iron becomes (whether hot-blast, or cold-blast), the softer and weaker it becomes, and it can only have strength imparted to it, by a due admixture in re-melting. This mixture is generally the result of the experience of the workman, as no definite system has been laid down, nor have a sufficient number of experiments been made, to establish any certainty on the subject.

The same kind of distinction takes place in the texture, as in the character of malleable iron; that is, the red-short quality is most inclined to possess a fibrous texture, and the cold-short to present a crystalline, or granular fracture, though these characteristics can be materially modified, or altogether changed, by judicious mixture and by re-working, and even fibrous iron can be made very ductile; this quality however will become granular, when a number of bars, all of the best quality, are bound together, and subjected, in the process of fagoting, to a sufficient degree of heat to weld them into a homogeneous mass; but if that mass be worked down again with a moderate heat, into bars of the same size as those from which it was originally made, the fibrous texture will have been recovered. Such iron, whilst in the granular state, will bear impact better than if it had been made of bars whose texture was originally granular.

Malleable iron becomes granular from two causes; first in consequence of being made from naturally cold-short pig iron, and secondly from a peculiar manipulation during the process of "puddling." If the iron be made up into balls as soon as the granulated particles will stick together, or, as the workmen term it, "put together young, before it has got into nature," the texture will be fine, and close-grained, and the fracture will present a bright

granular appearance; such iron will not, however, bear sudden impact, nor will it become fibrous in texture, by working, until it is reduced to very small bars, or into plate-iron. All granular iron is much harder when cold, and will endure longer, than fibrous iron, although it is not so well adapted for general purposes.

It is easy to give a fibrous fracture to iron, by welding the "pile" or "faggot" at a low heat, so that the interior does not become thoroughly solid; but if a pile be subjected to a sufficient degree of heat to make it perfectly sound, and the iron presents a fibrous fracture throughout, when reduced to $1\frac{1}{2}$ inch square, or round bars, the quality must be very good.

It has often been asserted, that the peculiar quality of some of the Yorkshire iron ores, caused the fine granular texture by which the malleable iron of that county is distinguished; the Author has, however, uniformly dissented from this opinion; and in order to test the fact, some pig iron was converted into bars in Yorkshire, and a portion of the same metal was sent to the Shrubbery Iron-works, Wolverhampton, where it was worked up into bars of the same size: the result of this experiment completely verified the Author's opinion, as bars of the finest granular fracture, and of the strongest fibrous texture, were produced from the same quality of Yorkshire pig iron.

Identical results were obtained from Staffordshire pig iron, when subjected to different kinds of manipulation.

Swedish iron often presents, in the same bar, both a fibrous and granular appearance. This arises from the method of manufacture, which is very simple:—One end of a long pig of iron is placed in a charcoal refinery, and as much metal is melted off as will make a bloom; but the workman commences working it as soon as it begins to melt, and continues to do so until the quantity required for the bloom is melted off into the fire; and when the mass will adhere together, the bloom is brought out and hammered into a bar. It must be evident that by such a process the first portion will have been subjected to a much greater amount of manipulation than the latter, and thus two qualities of iron, or degrees of malleability, are produced in the same bar.

Independently of the alterations of texture, which arise from peculiarities in the process of manufacturing iron, great changes are induced by certain actions upon it, when cold. Compression, or impact upon the end of a bar of iron, will alter its texture from a fibrous to a granular character. This is well exemplified by two tools, used by forgemmen. The first is the "gag," which is a short bar of iron, of about 2 inches diameter, employed for holding up the

end of the large helve, during the intervals of working; it is subjected to impact endways, whenever the lower end is placed on the anvil, and the other receives a vertical blow, from the helve falling about an inch upon it. However fibrous may be the quality of iron used for making the "gag," it soon becomes brittle, and literally falls to pieces, as if it were made of cast iron.

The second instance is that of the tool employed in puddling, one end of which is constantly subject to blows from a small hammer, in order to detach the metal which adheres to the other extremity: after being some time in use, it frequently breaks at a slight blow, exhibiting a perfectly granular fracture.

If a bar of fibrous iron be bent down at a short angle, the fibres of one side are compressed, and those of the other side elongated, and after being bent back again, the fracture on the compressed side will exhibit a granular appearance, having evidently lost the fibre and been broken off short.—(Plate 12, Figs. 6, 7, and 8).

A bar of iron reduced in the centre, and used as the connecting-rod of a steam-engine, by being subjected to constant vibration, or bending, will soon break at the middle, and the fracture will be perfectly granular, although it may have been originally made of the best quality of iron. The connecting-rod for working the large shears, in rolling-mills, and the rods of deep pumps, when they are so small as to bend, or vibrate at each stroke, are further examples of this action.

Iron-shafting in mills, working horizontally, being generally too strong to bend, or to vibrate, apparently retains its fibrous quality, even when twisted asunder by a sudden action; but if it be so deficient in strength as to bend and vibrate, whilst at work, it soon loses its fibrous nature and is destroyed.

Railway axles should be made parallel from journal to journal, and be of sufficient strength to prevent any vibration in rotating. If this general rule were adopted, there would not be any change in texture, and consequently a less number of fractures would occur. If it be considered necessary to reduce the substance of the middle of an axle, it would be safer to use good granular iron at first, as it is naturally much stiffer and less liable to bend and vibrate, than fibrous iron, and would probably not change its form so soon, or receive injury, whilst working under ordinary circumstances.

It is, however, the Author's opinion, that axles should be perfectly rigid, so as not to bend, or vibrate, even if that should have to be accomplished by making them somewhat larger in the centre, like the connecting-rod of an engine.

Many other causes of change could be adduced, but enough has

been stated to prove, that the compression of iron, when cold, is certain to change fibrous, into granular iron, and that vibration, or bending, even to a slight extent, if continued for any length of time, has the effect of compressing all the particles consecutively.

A series of experiments was carefully made, for the purpose of ascertaining, practically, the best form for railway axles, so as to obtain the greatest strength with a given weight of material. From these experiments it would appear, that the forms generally adopted are very erroneous, especially in reducing the substance of the middle of the axles, and in turning rectangular shoulders near to the journals.

Fig. 1, Plate 12, exhibits an experiment to determine the best position for placing the wheel on the axle, so that the journal may possess the greatest amount of strength for resisting the forces tending to break it. One end of the axle was firmly keyed into a strong frame of cast iron, the neck of the journal being in a line with the front of the frame, as shown at **F**; it was then subjected to the impact of a heavy ram, falling a distance of 9 feet, vertically to the plane of that part of the axle which was struck; the force of impact of each blow being equal to 5 tons, and the whole amount of impact equalling 30 tons; in this case the end broke off at the sixth blow.

The other end of the axle was then keyed into the frame, with the neck of the journal projecting, seven-eighths of an inch, beyond the front of the frame, as shown at **E**; on being subjected to five blows from the ram on **A** and fifteen blows on **B**, under the same conditions as before, this end did not break off until the twentieth blow, the total amount of impact being 100 tons; thus proving, that by simply moving the face of the wheel back from the neck of the journal, the strength to resist impact was increased in the ratio of 100 to 30.

Figs. 2 and 3, Plate 12, exhibit the results of an experiment to determine the strength of an axle, having a shoulder behind the wheel, and one having no shoulder. In this case an axle $3\frac{1}{4}$ inches in diameter at the centre was cut in two, so that the quality of the iron might be the same in both experiments; one-half had a collar of $\frac{1}{4}$ th of an inch left against the part intended to receive the nave of the wheel, which part was turned to $4\frac{1}{8}$ inches diameter; the other had no collar, but was turned parallel towards the centre of the axle.

The first half (Fig. 2) was then keyed into the frame, as in the other experiments, and impact to the amount of 55 tons was applied at **R**, when the end broke at the eleventh blow of the ram, the face of the fracture being quite granular. The other end (Fig. 3) was next keyed into the frame, and impact to the amount of 155 tons was

applied at **R**, when thirty-one blows were required to break it off, and the face of the fracture was perfectly fibrous throughout. These experiments prove that the relative strengths, to resist impact, where there is no shoulder, and where there is one, is in the ratio of 155 to 55.

Figs. 4 and 5, Plate 12, exhibit the results of an experiment to determine the best form for the centre of an axle. In this experiment a parallel axle $4\frac{3}{8}$ inches diameter, was supported and subjected to impact at points corresponding to the position of the wheels, and after receiving fifteen blows from the ram, the end was deflected $1\frac{1}{2}$ inch from a straight line (Fig. 4).

This axle was then drawn down in the middle, to $3\frac{7}{8}$ inches diameter, the opposite end being subjected to impact, under the same circumstances, and after the same number, of fifteen, blows of the ram, the deflection from the straight line was 5 inches (Fig. 5); thus proving that the strength of a parallel axle compared with one which has been reduced in the middle, is in the proportion of 5 inches to $1\frac{1}{2}$ inch.

Again, it is well known, that the strength of round bars to resist transverse strain, is as the cubes of their diameters, which in the case above cited would give the parallel axle an advantage over the reduced axle in the proportion of $83\cdot74$ to $58\cdot18$; and as the same law obtains in reference to torsion, if the velocity is the same, the strength to resist torsion will be in a like proportion.

The communication is accompanied by three diagrams, Nos. 4506-8, from which Plate 12 has been compiled.

MR. THORNEYCROFT said, that though many discussions had taken place, at different times, on the subject of the crystallization or granulation of axle-bars, no decision had yet been arrived at on the subject. He was prepared to concur with Mr. Stephenson in the opinion, that if the iron was fibrous when worked into an axle *no subsequent jarring motion would alter its character*. The granulation of iron might arise from various causes, but nothing so surely effected it, as when a bar of iron was gradually bent, so that the fibres on the inner side would be compressed, whilst those on the outer side were extended; and as this process was continued, so the granulation progressed. He did not think that "nicking" the iron would materially influence the appearance of its fracture, nor would a blow, which merely caused a jar, destroy the fibrous character of the iron.

This was well exemplified by two pieces of iron, exhibited to the members, which had been used as liners for a tilt hammer.

STRENGTH OF WROUGHT IRON. EXPERIMENTS ON RAILWAY AXLES.

PLATE 12.

FIG. 6.

Granular Fractures.

FIG. 7.

Fibrous Fracture.

FIG. 8.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.