LI.—*The Influence of Remelting on the Properties of Cast Iron. Notes on Sir W. Fairbairn's 1853 Experiments.*

By THOMAS TURNER, Assoc. R.S.M., Demonstrator of Chemistry, Mason College, Birmingham.

IN a recent paper, published in the Journal of this Society (Trans., 1886, p. 130), I have entered at some length into a consideration of the experiments conducted by Sir William Fairbairn to ascertain the effect of repeated remelting on the properties of cast iron (*B. A. Report*, 1853, p. 87). I endeavoured to show "that the effect attributed to remelting may be sufficiently explained by a consideration of the chemical changes which took place." These changes I then believed to be a gradual increase of silicon (owing to the metal being melted in a cupola in contact with fuel), accompanied by the fact "that sulphur considerably increased about the fourteenth and fifteenth melting, rendering the metal hard, white, and brittle."

In the discussion which followed the reading of that paper, it was stated by Professor Unwin, who assisted in these experiments, that remelting was not conducted in a cupola, as I had been led to suppose in the first place, but that an air-furnace was used for this purpose. Since then a fortunate opportunity has been presented to me for the examination of what are probably the only specimens of these test bars now in existence. The result of this examination has been to considerably modify my original conclusions as to the details of the changes, though it has amply confirmed my contention that the effects observed could be sufficiently explained by a consideration of the changes in chemical composition.

My former conclusions were based upon the following analyses, which were given in the original paper on the authority of Professor Calvert:—

No. of meltings.	Percentage of		
	Si.	S.	C.
1	0·77	0·42	2·76
8	1·75	0·60	2·30
10	1·98	0·26	3·50
18	2·22	0·75	3·75

It will be shown later that these analyses are altogether erroneous, and at present I am not able to make out any connection whatever

between the numbers given above and the actual composition of the specimens.

For the specimens I have been able to examine, I am indebted to the kindness of Professor Unwin, and I would here record my deep indebtedness to him for resigning into my hands, for the purpose of chemical analysis, specimens which he highly prized, and which are of special value as the only remains of the experiments of 33 years ago. It may be well to mention here that the identity of these pieces is thoroughly assured. In forwarding them Professor Unwin said, "There is absolutely no doubt that the pieces sent you were broken off Fairbairn's remelted bars. I have preserved absolutely no other specimens of cast iron, so there has been no mixing of two sets. The only possible doubt is as to the numbering."

As a doubt might be possible in the latter respect, a short account may be given of the pieces received. Of these there were seven in all, each being 1 inch square in section, as described in the original paper. The largest piece was about 1 inch in length also. Five of the specimens were numbered (Nos. 1, 8, 14, 15, 18), the labels being gummed on, and having been attached over 25 years ago. In each case the character of the metal exactly agreed in hardness and appearance with the description given in the original paper, which contains a minute account of the fractures. In two of these pieces, Nos. 15 and 18, we have a further confirmation in the sketches given in the paper, which exactly correspond with the metal examined. In one case a specimen was not numbered. Its appearance was very characteristic, white on the outside, but with a small circle of grey inside about three-eighths of an inch in diameter. This appearance was sketched in the original memoir, and made it certain that the piece was from the sixteenth melting. In one case, the label had become quite illegible. As there was a considerable amount of iron rust on this label, it was not possible to restore the ink marks by ordinary processes. The label was therefore carefully detached and held up to the light. The figure 1 was plainly seen, and part of a second figure could also be discerned. From its shape and other circumstances this could be only either a 2 or a 3, and the evidence appeared to be strongly in favour of 12 as the right number. Professor Unwin said of it, "I have a strong suspicion that this is the bar of maximum transverse strength (12th), but of course I have no proof. I think it is almost certain I should have retained a specimen of that bar." In hardness it was intermediate between 8 and 14, and its composition also favoured this view, so that the identity of this specimen may be considered assured.

The chemical examination was rendered more than usually difficult, owing to the comparatively small quantity of material to be operated

upon, and the necessity for the preservation of a portion of each piece for reference at any future time.* In one case also (the 18th melting), the specimen was so hard that it could not be touched by a file or drill, and a sample for analysis could only have been obtained at great risk to the specimen itself. As Professor Unwin prized this particular piece more highly than several of the others, and as the analyses already made rendered the action quite evident, it was not considered well to proceed further than an estimation of combined carbon in this case. When it was found that my analyses gave results so very different from those of Professor Calvert, I thought it well to forward my results, so far as they had then gone, to Professor Unwin, suggesting that samples should be sent to some independent chemist of known experience in iron analyses. As a result, a small quantity of borings from each bar was forwarded to Mr. J. P. Walton, Assoc. R.S.M., of the Wishaw Iron Works, and his analyses afford strong confirmation to my own conclusions. In some cases, especially with manganese and phosphorus, the agreement is not so good as might be desired, though in each case the general direction of the change is correctly indicated. But in forwarding his results Mr. Walton said, "I am sorry that the quantity of material does not allow of my ordinary processes being followed in every case." The same remark would apply to my own analyses; for if the supply of material had been more abundant the details of the operations would have been modified in several instances.

The methods adopted in my analyses were as follows. Of each sample, two quantities, each of 2 grams, were dissolved in aqua regia, and evaporated to dryness on the water-bath. After heating at 100° for some time, the residue was extracted with a little hydrochloric acid and the silica separated and weighed. To the filtrate a little barium chloride was added, the solution nearly neutralised, and allowed to stand at least 24 hours. After filtering off the barium sulphate, the solution was treated in one case for manganese and in the other for phosphorus. The first was separated by means of ammonium carbonate, and precipitated by bromine in concentrated solution, alkaline with ammonia. The phosphorus was weighed as pyrophosphate of magnesia after precipitation as molybdate. The total carbon was determined by combustion, according to the method I have described (*Birmingham Philosophical Society's Proceedings*, vol. iv, Part II, p. 404; incorrectly abstracted, *Abstr.*, 48, 1161), while, to save material, the combined carbon was estimated colorimetrically. Of these methods, it should be observed that the phosphorus is probably rather low, owing to details in the methods

* At least half of each of the specimens Nos. 8, 12, 14, 15, 16, and 18 have been returned to Professor Unwin. These pieces may be useful for future reference.

employed, while the values for combined carbon show the direction of the change rather than the actual amount of this constituent. The results are given in Table A.

TABLE A.—*Analyses by T. Turner.*

No. of melting.	Total carbon.	Combined.	Silicon.	Sulphur.	Manganese.	Phosphorus.
1.....	2·67	0·25	4·24 4·19	0·04 0·02	1·81 1·74	0·40
8.....	2·97	0·08	3·27 3·20	0·05 0·04	0·55	0·48
12.....	2·94	0·85	2·55 2·53	0·10 0·11	0·23	0·50
14.....	2·98	1·31	2·17 2·14	0·13 0·14	0·17	0·53
15.....	2·87	1·75	1·95 1·96	0·14 0·15	0·15	0·56
16.....	2·88	*	1·88 1·96	0·20 0·22	0·14	0·61
18.....	—	2·20				

The methods adopted by Mr. Walton for the determination of sulphur and silicon were almost identical with my own. The phosphorus was weighed as molybdate. The results are given in Table B.

TABLE B.—*Analyses by J. P. Walton.*

No. of melting.	Silicon.	Sulphur.	Manganese.	Phosphorus.
1.....	4·22	0·03	1·32	0·53
8.....	3·15	0·06	0·61	0·58
12.....	2·47	0·13	0·45	0·60
14.....	2·24	0·12	0·29	0·57
15.....	1·93	0·18	0·19	0·59
16.....	1·80	0·17	0·10	0·61

It will be seen that Mr. Walton's determinations of silicon and sulphur agree very fairly with my own. In phosphorus, the agreement is not so good, the difference in the eighth and twelfth meltings being 0·1 per cent. However, these differences are not such as to

* Varied in parts; outside white, inside grey.

materially affect the iron, and their cause has already been partly indicated. The most serious divergence is seen in the first melting, where a difference of 0·5 per cent. of manganese and 0·13 per cent. of phosphorus occurs. In this case the whole of the specimen was used in the analysis, so we were unable to check the result in duplicate as was intended. It must be remembered, however, that owing to the small quantity of material at our disposal the precipitates of manganese generally weighed but a few milligrams, so that if the results agree in showing the direction in which the change took place, it is perhaps as much as can be reasonably anticipated.

From these analyses, I have endeavoured to deduce the probable composition of the specimens examined. In most cases, the numbers are the mean of those previously given; but in a very few instances when any considerable difference was observed, I have ventured to attach rather more importance to a particular determination which appeared most trustworthy. The results are given in Table C.

TABLE C. — *Composition of Test Bars.*

No. of melting.	Total carbon.	Combined.	Silicon.	Sulphur.	Manganese.	Phosphorus.
1.....	2·67	0·25	4·22	0·03	1·75	0·47
8.....	2·97	0·08	3·21	0·05	0·58	0·53
12.....	2·94	0·85	2·52	0·11	0·33	0·55
14.....	2·98	1·31	2·18	0·13	0·23	0·56
15.....	2·87	1·75	1·95	0·16	0·17	0·58
16.....	2·88	—	1·88	0·20	0·12	0·61
18.....	—	2·20				

It will be found on comparing these results with those previously given by Calvert, that with the solitary exception of the total carbon in the first melting, our conclusions are entirely at variance. In particular, it will be seen that the silicon, on the numbers for which my previous conclusions depended, varies in an exactly opposite direction, and over a very different range to that which was previously supposed.

It may be mentioned, however, that doubts have been cast on the accuracy of Calvert's analyses by several writers of experience on this subject, though they had not the opportunity of examining the specimens. Thus Snelus, writing over 15 years since, in the first volume of the *Journal of the Iron and Steel Institute* (p. 37), when speaking of the results observed in Fairbairn's experiments, said he believed the explanation to be, "that at each successive melting the silicon, and perhaps to a slight extent the carbon, decreases; but the iron gradually takes up sulphur and phosphorus from the fuel, and

the deterioration due to these elements more than counterbalances the increased strength due to diminished carbon and silicon." In *Chemistry Applied to the Arts and Manufactures*, 8, 861, when discussing the effects of remelting iron in a cupola, the above opinion of Snelus is put forward, and the remark made, "The chemical analyses of some of these samples, which were made by Calvert, do not appear to support these conclusions. The analytical results, however, as will be seen from an examination of the figures, are so remarkable that it is evident they are *not reliable*, and it is desirable that they should be repeated." It may also be remarked that other analyses published by Calvert at the same period (*Inst. C.E.*, 1852—53, 354) show that Eglinton iron was rather highly siliceous, containing 3.12 per cent. of silicon, while in the present instance it is returned with only 0.77 per cent.

It will be seen that, like myself, Snelus was of opinion that remelting had been performed in a cupola. But, in spite of this slight misunderstanding, the correctness of his explanation is very remarkable. In my former paper, depending on Calvert's analyses, I have endeavoured to account for the effect observed as due to a gradual increase of silicon, combined with a considerable absorption of sulphur in the later meltings. My failure to detect Calvert's error in the proportion of silicon was due, in part at least, to a lack of knowledge of the influence of definite quantities of each of the other elements present. This knowledge I have endeavoured to render more systematic in my last paper, "On the Constituents of Cast Iron," recently read before the Iron and Steel Institute. A comparison of the values given in that paper with Calvert's analysis of the first melting, will show that his results are quite untrustworthy, since his values are those which are characteristic of a *white* iron, while the metal operated on was a soft grey.

The action during remelting in a reverberatory furnace is essentially oxidising, and it is therefore natural to expect that the chemical changes would be the same during remelting as during "refining," puddling, and the open hearth or Bessemer process. This expectation is realised on examining Table C, the only point of difference being found in the gradual increase of sulphur.

In Fig. 1 the chemical changes produced during remelting are represented by curves. These closely correspond in general character with those given by Windsor Richards, and other authorities, for the early part of a Bessemer blow. The exception, to which I have previously referred, noticed in the case of sulphur, is a little obscure in origin, though the fact is undoubted. The effect of this is of the utmost importance, and to make it more visible the scale used for sulphur is 20 times that used for the other elements.

Fig. 1.
INFLUENCE OF RE-MELTING ON THE PROPERTIES OF CAST IRON.

If we now glance briefly at the variations of each element and the effect on the character of the product, we observe—

1. Phosphorus increased from 0·47 to 0·61 per cent. This was probably due to loss of material during oxidation, the phosphorus remaining in the metal. A little may also have been gained in other ways; but I am not aware of evidence to show that an increase of phosphorus within the limits mentioned would materially affect the product.

2. Manganese decreased from 1·75 to 0·12 per cent. This would tend to improve the metal during the earlier meltings.

3. Silicon was reduced from 4·22 to 1·88 per cent. The first effect of this reduction was to produce softer metal and lower combined carbon, since silicon was present in quantity in excess of that necessary for the softest metal. On further reducing the silicon, the metal became stronger and harder. But in these experiments the reduction was not carried sufficiently far to cause any deterioration due to deficiency of silicon; for under ordinary circumstances a metal with 1·88 per cent. of silicon would be soft, close-grained, grey, and of very considerable tenacity.

4. Sulphur increased from 0·03 to 0·20 per cent., and in this change we have one of the most important alterations which took place. In the paper recently read before the Iron and Steel Institute, I have stated “that 1 part of sulphur neutralises the effect of at least from 5 to 10 parts of silicon,” and have suggested that—

For soft foundry iron, sulphur should not exceed	0·13 p. c.
„ hard or mottled iron, about	0·20 „
„ white iron, over	0·25 „

Now in the sixteenth melting we find that silicon, which tends to produce grey iron, has been reduced to 1·88 per cent., while sulphur, which tends to produce white iron, has increased to 0·2 per cent., or just to that amount which is favourable for the production of hard or mottled iron. The bar itself is described as being white on the outside, with about three-sixteenths of an inch grey in the middle, and therefore agreeing with what might be anticipated from its composition.

5. The total carbon underwent very slight alteration. The slight apparent increase at first is quite in accordance with what has been observed in the puddling process and Bessemer converter.

6. The combined carbon was reduced during the earlier meltings, but again increased as the metal became harder, reaching a maximum of over 2 per cent. These changes are dependent on the alterations in the other elements present, especially sulphur and silicon.

In conclusion, I would express my belief that the experiments of Sir

W. Fairbairn, with the corrected analyses, afford us valuable information as to the influence of chemical composition on the mechanical value of cast iron. But they do not afford information as to the effect of remelting, except under the circumstances of these experiments. This effect will obviously depend on the original composition of the iron, and the character of the changes which take place in its constituents during remelting. At present I am not aware that we have any valid grounds for asserting that remelting, *apart from chemical change*, is either beneficial or otherwise on the character of the product.