# VIII. *Experiments on Wootz. By Mr.* David Mushet. *Communicated by the Right Hon. Sir* Joseph Banks, *K. B. P. R. S.*

Read February 14, 1805.

The following experiments were made at the request of Sir Joseph Banks, on five cakes of wootz, with which he supplied me for that purpose. As the cakes, which were numbered 1, 2, 3, 4, 5, were not all of the same quality, it will be proper first to describe the differences observable in their external form and appearance.

No. 1 was a dense solid cake, without any flaw or fungous appearance upon the flat, or, what I suppose to be, the upper side. The round or under surface was covered with small pits or hollows, two of which were of considerable depth; one through which the slit or cut had run, and another nearly as large towards the edge of the cake. These depressions, the effects, as I suppose, of a species of crystallization in cooling, were continued round the edges, and even approached a little way upon the upper surface of the wootz.

The cake was a quarter of an inch thicker at one extremity of the diameter than at the other, from which I infer, that the pot or crucible, in which this cake had been made, had not occupied the furnace in a vertical position. Its convexity, compared to that of the other five, was second. Upon breaking the thin fin of steel, which connects the half cakes together, I found it to possess a very small dense white grain. This appearance never takes place but with steel of the best quality, and is less frequent in very high steel, though the quality be otherwise good.

Upon examining the break with attention, I perceived several laminæ and minute cells filled with rust, which in working are never expected to unite or shut together. The grain otherwise was uniformly regular in point of colour and size, and possessed a favourable appearance of steel.

No. 2. This cake had two very different aspects; one side was dense and regular, the other hollow, spongy, and protuberant. The under surface was more uniformly honey-combed than No. 1; the convexity in the middle was greater, but towards the edges, particularly on one side, it became flatter. The grain exposed by breaking was larger, bluer in colour, and more sparkling than No. 1. In breaking, the fracture tore but slightly out, and displayed the same unconnected laminæ with rusty surfaces, as were observed in No. 1. Beside these, two thin fins of malleable iron projected from the unsound side, and seemed incorporated with the mass of steel throughout. Towards the centre of the break, and near to the excrescence common to all the cakes, groups of malleable grains were distinctly visible. The same appearance, though in a slighter degree, manifested itself in various places throughout the break.

No. 3. The upper surface of this cake contained several deep pits, which seemed to result from the want of proper fluidity in fusion. They differed materially from those described upon the convex sides of No. 1 and 2, and were of that kind that would materially effect the steel in forging.

The under or convex side of this cake presented a few crystalline depressions, and those very small; the convexity was greater than that of No. 1 and 2, the fracture of the fin almost smooth, and only in one place exhibited a small degree of tenacity in the act of parting. In the middle of the break, about half an inch of soft steel was evident; and in different spots throughout numerous groups of malleable grains, and thin laminæ of soft blue tough iron made their appearance.

No. 4. Was a thick dense cake possessed of the greatest convexity; the depressions upon the under side were neither so large, nor so numerous as those in No. 1 and 2, nor did they approach the upper surface of the cake further than the acute edge. This surface had the most evident marks of hammering to depress the feeder, or fungous part of the metal, which in the manufacturing seems the gate or orifice by which the metal descends in the act of gravitation.

The break of this cake, however favourable as to external appearance, was far from being solid. Towards the feeder it seemed loose and crumbly, and much oxidated. The grain divided itself into two distinct strata, one of a dense whitish colour, the other large and bluish, containing a number of small specks of great brilliancy. Several irregular lines of malleable iron pervaded the mass in various places, which indicated a compound too heterogeneous for good steel.

5th cake. This was materially different in appearance from any of the former. It had received but little hammering, yet was smooth and free from depressions, or honey-comb on both surfaces. The feeder, instead of being an excrescence, presented a deep concave beautifully crystallized.

In breaking, the fracture tore out considerably, but presented a very irregular quality of grain. That towards the under surface was small and uniform, but towards the flat or upper surface it increased in size, and in the blueness of its colour, till it passed into the state of malleable iron.

The break of this steel, though apparently soft, was the least homogeneous of the whole, and throughout it presented a very brilliant arrangement of crystal, which in other steel is always viewed with suspicion.

### *General Remark.*

Uniformly the grain and density of the wootz are homogeneous, and free from malleable iron towards the under or round surface; but always the reverse towards the feeder or upper side.

### *Remarks in Forging.*

No. 1. One-half of the cake was heated slowly by an annealing heat to a deep red, and put under a sharp broad-mouthed chissel with a small degree of taper. It cut with difficulty, was reheated, and cracked a little towards one end of the slit or cut originally in the cake.

The heat in this trial was so moderate, that I was afraid that the crack had arisen from a want of tenacity, occasioned by the heat being too low.

The other half was heated a few shades higher, and subjected to the same mode of cutting; before the chissel had half way reached the bottom, the piece parted in two in the direction of the depression made by the cutting instrument. The additional heat in this instance proved an injury, while the cracking of the steel in both cases, particularly the former, was a certain proof of the abundance, or rather of the excess of the steely principle.

The fractures of both half cakes, now obtained for a second time, were materially different from that obtained by the simple division of the cake. The grain was nearly uniform, distinctly marked, but of too gray a colour for serviceable steel. Two of the quarters being drawn into neat bars under hand hammers at a low heat, one of them contained a number of cracks and fissures. The fracture was gray, tore out a little in breaking, but was otherwise yolky and excessively dense. A small bar of penknife size was improved greatly in drawing down, and had only one crack in thirteen inches of length. The grain and fracture were both highly improved by this additional labour; the tenacity of the steel was greater, and it stood firmly under the hammer at a bright red heat.

The other two quarters of this cake were squared a little, and successively put under a tilt hammer, of two hundred weight, going at the rate of three hundred blows per minute, and drawn into small penknife size. One of the bars from an outside piece, always the most solid, was entirely free from cracks, and had only one small scale running upon one side.

These bars exhibited a tougher break, than those drawn by hand; the colour was whiter, and the grain possessed a more regular and silky appearance.

### *Forging* No. 2.

One half of this cake was heated to a scarlet shade, and put under the cutting chissel; it was at first struck lightly, then reheated, and cut comparatively soft; but a small crack had over-run the progress of the chissel. Its softness in cutting was attributed to an evident want of solidity. The other half cake felt harder under the hammer, but proved afterwards spongy throughout the mass. In the act of cutting, a loose pulverized matter was disengaged from some of the cells, possessed of a shining appearance.

The fractures obtained in consequence of the division of the half cakes, presented a flattish crystallized appearance, more resembling very white cast iron, than steel capable of being extended under the hammer. One of the middle cuts was entirely cellular with crystallized interiors, and incapable of drawing; the corresponding cut of the other half cake was drawn into a straight bar three quarters of an inch in breadth, and three-eighths thick, but was covered with cracks and flaws from end to end. The colour of the break was one shade lighter than No. 1, it tore less out, was equally yolky, and possessed on the whole an aspect very unfavourable for good steel.

The other two outside quarters were also drawn into shape, one under the tilt hammer, and the other by hand. These were more solid in the fracture, possessed fewer surface-cracks, stood a higher degree of heat, tore out more, and exhibited a silky glossy grain, at least two shades lighter in the colour than the centre pieces.

### *Forging 3d Cake.*

One half of this cake, first subjected to be cut, was found softer than any of the preceding, and exhibited no symptom of cracking. The other half was cut at three heats, but found loose and hollow in the extreme. A considerable portion of the same brilliant powder, formerly noticed, was here again disengaged. It was carefully taken up for examination, and found to be very fine ore of iron in a pulverescent state, very obedient to the magnet, and without any doubt an unmetallized portion of that from which wootz is made.

This curious circumstance led me to examine every pore and cell throughout the whole fragments. On the upper surface of two of them I found small pits containing a portion of the ore, which had been slightly agglutinated in the fire, but still highly magnetic. The upper surface of the present cake, close by the gate or feeder, contained a large pit filled with a stratum of semi-fused ore, surmounted by a mass of vitrified matter, which bore evident marks of containing calcareous earth.

Those who have devoted sufficient attention to the affinities of iron and earths for carbon, will be surprised to find that, on this particular subject, the rude fabricators of steel in Hindostan have got the start of our more polished countrymen in the manufacture of steel.

Two bars of wootz were formed from this cake, and these in point of quality inferior to any of those formerly produced. The appearance of the metal was more varied, less homogeneous, and contained more distinct laminæ with rusty surfaces, than either of the two former cakes.

It appeared highly probable, from the observations that occurred in forging, and in the examination of the cake, that the original proportion of mixture was such as would have formed a quality of steel softer than No. 1 and 2; but as steel of such softness requires a greater heat to fuse it, than when more fully saturated with carbonaceous matter, it is probable that the furnace had not been sufficiently powerful to occasion complete fusion of the whole mass, and generate a steel homogeneous in all its parts.

### *Forging 4th Cake.*

Both halves of this cake cut pleasantly, and with a degree of tenacity and resistance, mixed at the same time with softness beyond what was experienced in any of the former cakes. Two quarters of this cake were drawn under the tilt hammer, and one by hand. The resulting bars were nearly perfect. A slight scale was observable upon the bar, from that quarter which contained the figure. The fracture was solid, though not homogeneous as to quality and colour, and it appeared pretty evident, that a considerable portion of one side through the whole bar was in the state of malleable iron, and of course not capable of being hardened. It was a subject of considerable regret, that the cake the most perfect and the most tenacious of the whole, in the process of forging, should get an imperfection which rendered it useless for the perfect purposes of steel.

### *Forging 5th Cake.*

The first half of this cake cut uncommonly soft for wootz, but by cracking before the chissel still exhibited a want of proper tenacity. The next half cut equally soft, but with more tenacity. Two quarters of this cake drew readily out under the tilt hammer, and a third was drawn by hand at a bright red, sometimes approaching to a faint white heat. None of the bars thus obtained were uniformly free from cracks and scale, although the fracture exhibited a fair break of a light blue colour, and the grain was distinctly marked, and free from yolks.

### *General Remarks.*

The formation of wootz appears to me to be in consequence of the fusion of a peculiar ore, perhaps calcareous, or rendered highly so by mixture of calcareous earth along with a portion of carbonaceous matter. That this is performed in a clay or other vessel or crucible, is equally presumable, in which the separated metal is allowed to cool; hence the crystallization that occupies the pits and cells found in and upon the under or rounded surface of the wootz cakes.

The want of homogeneity, and of real solidity in almost every cake of wootz, appears to me to be a direct consequence of the want of heat sufficiently powerful to effect a perfect reduction; what strengthens this supposition much is, that those cakes that are the hardest, *i. e.* that contain the greatest quantity of carbonaceous matter, and of course form the most fusible steel, are always the most solid and homogeneous. On the contrary, those cakes, into which the cutting chissel most easily finds its way, are in general cellular, replete with laminæ, and abound in veins of malleable iron.

It is probable, had the native Hindostan the means of rendering his cast steel as fluid as water, it would have occurred to him to have run it into moulds, and by this means have acquired an article uniform in its quality, and convenient for those purposes to which it is applied.

The hammering, which is evident around the feeder and upon the upper surface in general, may thus be accounted for. When the cake is taken from the pot or crucible, the feeder will most probably be slightly elevated, and the top of the cake partially covered with small masses of ore and steel iron, which the paucity of the heat had left either imperfectly separated or unfused. These most probably, to make the product more marketable, are cut off at a second heating, and the whole surface hammered smooth.

I have observed the same facts and similar appearances in operations of a like nature, and can account satisfactorily for it as follows.

The first portions of metal, that are separated in experiments of this nature, contain the largest share of the whole carbon introduced into the mixture. It follows of course, that an inferior degree of heat will maintain this portion of metal in a state of fluidity, but that a much higher temperature is requisite to reduce the particles of metal, thus for a season robbed of their carbon, and bring them into contact with the portion first rendered fluid, to receive their proportion of the steely principle. Where the heat is languid, the descent of the last portions of iron is sluggish, the mass below begins to lose its fluidity, while its disposition for giving out carbon is reduced by the gradual addition of more iron. An accumulation takes place of metallic masses of various diameters, rising up for half an inch or more into the glass that covers the metal; these are neatly welded and inserted into each other, and diminish in diameter as they go up. The length, or even the existence of this feeder or excrescence, depends upon the heat in general, and upon its temperature at different periods of the same process. If there has been sufficient heat, the surface will be convex and uniformly crystalline; but if the heat has been urged, after the feeder has been formed and an affinity established between it and the steelified mass below, it will only partially disappear in the latter, and the head or part of the upper end of the feeder will be found suspended in the glass that covers the steel.

The same or similar phenomena take place in separating crude iron from its ores, when highly carbonated, and difficult, from an excess of carbon, of being fused.

The division of the wootz cake by the manufacturers of Hindostan, I apprehend is merely to facilitate its subsequent application to the purposes of the artist; it may serve at the same time as a test of the quality of the steel.

To ascertain, by direct experiment, whether wootz owed its hardness to an extra quantity of carbon, the following experiments were performed with various portions of wootz of common cast steel, and of white crude iron, premising that in operations with iron and its ores, I have always found the comparative measure of carbon best ascertained by the quantity of lead which was reduced from flint glass.

*1st Cake.*

| | Grains. |
|---|---|
| Fragments of wootz - - - - | 65 |
| Pounded flint glass three times the weight - | 195 |

This mixture was exposed to a heat of 160° Wedgewood, and the wootz fused into a well crystallized spherule of steel. A thin crust of revived lead was found below the wootz, which weighed 9 grains, or $\frac{139}{1000}$ the weight of the wootz.

*2d Cake.*

| | |
|---|---|
| Fragments of wootz - - - | 80 |
| Flint glass, same proportion as above - - | 240 |

The fusion of the mixture in this experiment was productive of a mass of lead weighing 10 grains, equal to $\frac{1}{8}$th the weight of the wootz.

*3d Cake.*

| | Grains. |
|---|---|
| Fragments of wootz - - - - | 75 |
| Flint glass - - - - - | 225 |

The mass of lead precipitated beneath the steel in this experiment, amounted to 9 grains, or $\frac{12}{100}$ the weight of the wootz employed.

*4th Cake.*

| | |
|---|---|
| Fragments of wootz - - - - | 93 |
| Flint glass - - - - - | 279 |

Lead obtained, precipitated from the glass by means of the carbon of the wootz $14\frac{1}{2}$ grains, equal to $\frac{156}{1000}$ the weight of the wootz.

*5th Cake.*

| | |
|---|---|
| Fragments of wootz - - - - | 69 |
| Flint glass - - - - - | 207 |

The lead revived in this experiment amounted to 7 grains, which is equal to $\frac{102}{1000}$ the weight of the wootz.

*6th. Cast Steel formed with $\frac{1}{60}$th part its Weight of Carbon.*

| | |
|---|---|
| Fragments - - - - - | 90 |
| Crystal glass - - - - - | 270 |

Lead revived $8\frac{1}{2}$ grains equal to $\frac{94}{1000}$ the weight of the steel introduced.

*7th. White cast Iron dropt while Fluid into Water.*

| | |
|---|---|
| Fragments - - - - - | 103 |
| Crystal glass - - - - - | 309 |

The fusion of this precipitated $23\frac{1}{2}$ grains of lead which is equal to $\frac{228}{1000}$ the weight of the cast iron.

*Recapitulation of these Experiments.*

| | | |
|---|---|---|
| 1st cake of wootz revived of lead | - - | ,139 |
| 2d ditto | - - - - - | ,125 |
| 3d ditto | - - - - | ,120 |
| 4th ditto | - - - - - | ,156 |
| 5th ditto | - - - - | ,102 |
| Steel containing $\frac{1}{60}$ of its weight of carbon | - | ,094 |
| Cast iron | - - - - - | ,228 |

It would appear to result from these experiments, that wootz contains a greater proportion of carbonaceous matter, than the common qualities of cast steel in this country, and that some particular cakes approach considerably to the nature of cast iron. This circumstance, added to the imperfect fusion which generally occurs in the formation of wootz, appear to me to be quite sufficient to account for its refractory nature, and unhomogeneous texture.

Notwithstanding the many imperfections with which wootz is loaded, it certainly possesses the radical principles of good steel, and impresses us with a high opinion of the ore from which it is formed.

The possession of this ore for the fabrication of steel and bar iron, might to this country be an object of the highest importance. At present it is a subject of regret, that such a source of wealth cannot be annexed to its capital and talent. Were such an event practicable, then our East India Company might, in their own dominions, supply their stores with a valuable article, and at a much inferior price to any they send from this country.