Chemistry, Physics, Technology, etc.

THE REAL REASONS WHY CASTINGS IN IRON ARE ACCURATE COPIES OF THE MOULD.

BY ROBERT MALLET, C.E., F.R.S.*

The fact that cast iron does take very accurately the form of the mould in which it is cast has been for a length of time attributed to the supposed fact that the metal expands in volume while passing from the liquid to the solid state—a supposition which for more than a century has passed current, though without any sufficient proof. In a paper read before the Royal Society on the 11th of June last, an abstract of which, taken from the “Proceedings” of that society, has appeared in *The Engineer* for the 3d July last, I have disproved by two independent experimental methods the supposed fact that cast iron does expand in consolidation from fusion. The paper itself will probably be published in full by the Royal Society in the latter part of this year. Meanwhile it may be stated that the methods pursued consisted in, first, the determination of the specific gravity of liquid cast iron, by weighing equal volumes of the liquid metal and of distilled water, the specific gravity of the same cast iron at 60° Fahr. being also determined; secondly by determining the dimensions of a spherical shell of cast iron heated to bright redness, and then filled with liquid cast iron before being heated, when filled, and during the cooling back to the temperature of the atmosphere, when its dimensions were found the same as at the beginning; also by determining the specific gravities of the circumferential and central portions of the ball of cast iron when cold which had filled the shell. The central portions were found much less dense than the circumferential parts, as is well known to be the case in all castings in iron, of whatever size and form; but if the expansion in volume had taken place in the ball cooling by radiation, the central portions must have been found much more dense than the circumferential parts. The agreement of these two independent trains of experiment removes all doubt as to the completeness of the proof that cast iron does *not* expand in volume in passing from the state of liquid fusion to that of solidity by cooling; and it is therefore certain that the degree of exactness with

*Reprinted from *The Engineer* of September 11th, 1874.

which cast iron takes the form of the mould into which it is cast is to be otherwise accounted for. It is not necessary I should here advert to the objects in relation to certain lunar volcanic theories with which the above experiments were undertaken, nor to the conditions under which cast iron in the solid state may or may not float on cast iron in fusion; the latter facts, erroneously interpreted, having been, in fact, the foundation upon which the supposed notion of the expansion of cast iron during consolidation has been based. For these and the details of the experiments I must refer to the paper itself. In the meantime some useful deductions of a practical character may be drawn from the facts ascertained. Were it the fact that cast iron in solidifying *did* expand in volume, a little consideration will show that such expansion would result, not in the casting being an accurate copy of the mould—whether of green or dry sand, or loam—but must be a distorted copy, the expansion in volume of the metal filling the mould being, in effect, the same as if it were exposed to the hydrostatic pressure of a liquid pumped into it, the yielding to which would be greatest where the walls were least resistant, or where the force to which they are exposed is greatest—namely, where the surfaces exposed to pressure were the largest. Thus, for example, a flat plate moulded from a pattern of equal thickness throughout would when cast, be no longer of equal thickness throughout, but have one or both of its broad surfaces forced outwards so as to make the plate thickest towards the central parts, whilst the edges and corners of the plate which consolidate first would remain nearly unaltered, and the metal be found not even completely forced into contact with those parts of the mould; in fact, no form of casting except that of a sphere could under the supposed conditions of expansion in volume remain an undistorted ectype of the pattern, nor could any rigidity in the mould prevent this, the expansive force being by hypothesis irresistible, like that of water freezing into ice.

Cast iron does, however, as is well known, take the form of the mould, as formed of sand or loam by the usual methods of the founders, with great fidelity. We must except, however, the case of chills or massive moulds of cast iron, the liquid metal cast into which is so instantly chilled by contact as not to form a very accurate transcript of the mould. But though cast iron does take a very sharp and accurate transcript of the mould when cast, it does not do so to a greater extent than do several metals to which the supposed property

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of expanding or consolidation has never been attributed. Thus zinc affords castings of exquisite sharpness from sand moulds, as all those must have remarked who have seen the superb ornamental castings in that metal for architectural and other purposes which form the staple trade of the great German and Belgian zinc foundries. Lead also, when carefully preserved while in fusion free from oxidation and cast in slightly greased moulds so as to reduce any oxide formed therein, affords castings of exquisite sharpness, as may be observed in those of the ancient lead work of the roofs of churches and other buildings of from 200 to 300 years ago in France and Belgium. Gold, silver, copper, and most of their alloys, on the contrary, afford generally more defective castings and wanting in sharpness. The circumstances upon which these opposite results arise are extremely complicated, and to fully elucidate them would require more space than can be here afforded; they involve conditions mechanical, chemical, and molecular, affecting both the metal cast and the nature of the mould in which it is cast, as well as the relations of these to each other. Amongst these the following are, perhaps, the most important: First, the density of the metal itself. Whatever be the nature of the metal, it fills the mould when full under a certain hydrostatic pressure due to the height of the liquid column and to the density of the metal, and whatever the metal may be, this is the mechanical force by which it is compelled to follow and fill while liquid the sinuosities of the mould. Let us suppose the liquid head constant, say $2\frac{1}{2}$ feet or 30 inches, we readily see how enormous a difference there yet is in the mould-filling force due to density alone in the five metals, aluminum (which gives extremely defective castings), zinc, cast iron, lead, and gold, their densities being:—

	Specific gravity.	Lbs. per sq. inch under 30-in. head.
Aluminum, . . .	2·560	2·820
Cast iron, . . .	7·110	7·856
Zinc, . . .	7·146	7·896
Lead, . . .	11·360	12·552
Gold, . . .	19·340	21·371

Thus, in the last of these metals the hydrostatic pressure tending to fill the mould completely is about seven and a-half times greater than in the case of aluminum, and yet both these metals produce inferior castings, while the three intermediate metals afford sharp and good ones. Secondly, the specific capillarity when in fusion, and

viscosity while passing from the liquid to the solid state. Different metals are liquid in very different degrees while in perfect fusion, and therefore require very different degrees of pressure to force them into angular cavities. Upon this point physicists have as yet given us but little exact information. The greatest diameter of spherical drops capable of being assumed by any metal when taken in connection with its density is, however, a rough measure of the resistance which each presents to being forced into angular cavities of a mould of such material that it is not wetted by the liquid metal; thus fluid solder will readily penetrate between the edges of two clean tin plates, but will not enter at all if the plates be tarnished or blackened by a candle flame. Drops of mercury cohere at larger diameters than those of liquid lead. So also different metals differ in the range of viscosity through which they pass between their state of most perfect liquidity and that of solidity. Lead and some of its alloys, such as plumbers' solder, pass through a very long range of viscosity; brass and copper do so likewise, though in less degree; cast iron, and in general all the metals that crystallize most readily and best, pass through a very brief stage of viscosity. Where the melting point of the metal is a low one, one of the effects of this prolonged viscous stage, during which the metal contracts by loss of heat, is that its withdrawal from the sides of the mould is not compensated by a sufficient continuance of hydrostatic pressure, owing to imperfect liquidity. Cast iron is remarkably free from this objection; its melting point being very high and its range of viscosity small and confined to a small range of temperature, the metal is maintained, though constantly contracting by loss of temperature, in close contact with the mould by hydrostatic pressure up to within a brief period of its setting. Thirdly, upon the tendency of the metal to oxidate or combine with other elements presented to it in casting, and producing compounds less fusible than the metal itself, greatly depends the perfection or imperfection of the castings produced from it. Fluid zinc oxidates but very slowly up to a temperature somewhat above its melting point, but it oxidates rapidly at and above a bright red heat; hence zinc gives perfect castings; but when it is alloyed with copper the melting point of the brass is raised to such a point that the zinc oxidates very rapidly, and produces that "tailing" and general scurfiness of surface which is the plague of the brass founder, and the oxide of zinc is not

reducible back to metal at the temperature at which brass is cast by any chemical agent capable of being introduced into the substance of the mould. In cast iron, on the other hand, its tendency to oxidate by contact with the atmosphere when in fusion is opposed by the presence of silicon and carbon in the metal itself, and any oxide superficially formed is reduced back to metal with great facility by the hydrogen and carbonic oxide evolved from the moisture and charcoal, or coaldust, or other carbonaceous matter entering into the constituents of the mould. Gold is inoxidizable, but possesses a vigorous affinity for sulphur, and it is probable that the film which may be observed upon the surface of molten gold in casting, and which produces "tailiness" in the ingot or bar, consists of some sulphur compound taken up from the gases from the fuel employed for fusing it. Copper also casts badly, as when in fusion it is constantly either taking up carbon or oxygen as the heat of the furnace is either a reducing or an oxidating one, and the great cleanness of castings produced from phosphorized copper arises from the presence of the small amount of that element precluding it from taking up carbon, on the one hand, and shielding it from oxidation on the other. Fourthly, a high melting point and a high specific heat are favorable to the production of perfect castings, as prolonging the time during which *cæteris paribus* the metal filling the mould is subjected to its own hydrostatic pressure, thus more completely forcing it into sinuosities and expelling air bubbles or other gaseous matters. If the fusing point be very low, as in the case of lead or tin, the viscous point is so rapidly reached by the loss to the mould of the small amount of heat present in the metal that there is but little chance of air bubbles or particles of unreduced oxide being previously forced out. Fifth, the absolute amount of contraction of any metal between the temperature at which it is poured and that of the atmosphere, forms also an element in the perfect correspondence of the casting to the form of the mould in which it was cast. On comparing this rough sketch of some of the principal conditions upon which the degree of perfection of castings in various metals depends, it will be obvious that amongst all the metals commonly used for castings in the arts, cast iron occupies an extremely favorable position: its density is sufficient to press it when liquid effectively into the mould, its capillarity is not very great, its range of viscosity is small, and it

possesses the paramount advantage that whatever oxide may be formed in the casting processes is precluded from becoming diffused throughout the mass by the silicon and carbon present, and that any oxide formed on the surfaces in contact with the mould is instantly again reduced by the hydrogen and carbonic oxide evolved from the mould itself. In these conditions, indeed, cast iron may be said to stand unrivalled amongst metals in the perfection of the castings made from it, and they are quite sufficient to account for that perfection without calling in the now disproved supposition that it expands like ice at the moment of consolidation. The experimental determination of the specific gravity of liquid cast iron adverted to at the beginning of this paper affords us the means—and for the first time—of determining the total dilatation in volume as well as the linear dilatation of cast iron of the quality experimented upon, viz., the fine-grained, bright gray tough cast iron employed by mechanical engineers. As the specific gravities of this iron when cold and when melted were 7.170 and 6.650, so that the unit in volume when cold being taken as 1000, was increased to 1078.2 at the temperature somewhat above the melting point at which the iron was poured; the total dilatation in volume being thus 0.0782, and this divided by three—i. e., neglecting all but the first term of the series—gives for the total linear dilatation 0.02606, which, taking the whole range of temperature between 60° and 2400° , and if we assume the dilatation uniform throughout the range, gives a coefficient of dilatation of 0.00001086 for 1° Fahr. This, however, is not quite correct, as the rate of dilatation increases rapidly within a few degrees of the melting point. The dilatation found as above is also in excess of that due to the precise range between 60° and the melting point of cast iron, the higher temperature in my experiment being somewhat above the melting point, exceeding it by probably about 200° Fahr. My direct object being simply to prove that melted cast iron is not denser—as has been stated—than the same cast iron in the solid state, and not that of ascertaining the exact dilatation due to the precise range between 60° Fahr. and the melting point; we are enabled, however, incidentally to deduce the latter with approximate accuracy. I must reserve, however, for a future communication some further remarks upon this part of the subject, as also upon the interesting phenomena of the movements observable in large masses of liquid iron, as in the

largest crane ladles, which have been erroneously appealed to as affording proof that liquid cast iron is denser as its temperature is higher.

MECHANICAL SCIENCE.

An Address delivered before the Mechanical Section of the British Association at its meeting in Belfast, Sept., 1874.

BY PROFESSOR JAMES THOMSON, LL.D.

[Continued from Vol. lxviii, page 294.]

A great improvement has within the last two or three years been devised and practically developed by Sir William Thomson. Instead of using a hempen sounding line, or a cord of any kind, he uses a single steel wire of the kind manufactured as piano-forte wire. He has devised a new machine for letting down into the sea the wire with its sinker, and for bring both the wire and the sinker up again when the bottom has been reached. With his apparatus, in its earliest arrangement and before it had arrived at its present advanced condition of improvement, he sounded, in June 1872, in the Bay of Biscay, in a depth of 2,700 fathoms, or a little more than three miles, and brought up again his sinker of 30 lbs. weight, after it had touched the bottom; and brought up also an abundant specimen of ooze from the bottom, in a suitably arranged tube attached at the lower end of the sinker.

An important feature in his machine consists in a friction-brake arrangement, by which an exactly adjusted resistance can be applied to the drum or pulley which holds the wire coiled round its circumference, and which, on being allowed to revolve, lets the wire run off it down into the sea. The resistance is adjusted so as to be always less than enough to bear up the weight of the lead or iron sinker, together with the weight of the suspending wire, and more than enough to bear up the weight of the wire alone. Thus it results that the arrival of the sinker at the bottom is indicated very exactly on board the ship by the sudden cessation of the revolving motion of the drum from which the wire was unrolling.