ON THE HARDENING OF IRON AND STEEL.

The following is the paper by Prof. Akerman which was "taken as read" at the meeting of the Iron and Steel Institute, the discussion having been postponed :—

Hardening has, as is well known, been employed from time immemorial in order to make steel hard, but it is also a long time since it became known that the strength and tenacity of iron could be increased by the same operation. The knowledge of the effects of hardening, especially on iron, is, however, by no means so complete, and still less so generally diffused, as is desirable. This question has, besides, acquired increased interest through the Paris Exhibition, and above all from the Terrenoire exhibit of Siemens-Martin castings of extraordinary strength and free from blow-holes; and, as at the meeting of the Iron and Steel Institute, in Paris, I ventured to give expression to the view that the reason why the strength of undrawn Martin castings may be equal to that of drawn ingot-metal of the same degree of hardness must be sought for in the compression induced by the hardening, I have considered it to be my duty to endeavour to explain the reasons of this in greater detail. For this purpose, however, it is necessary in the first place that we endeavour to make ourselves acquainted with the nature of hardening. If we inquire what the circumstances are on which it depends, whether more or less of the so-called combined carbon in a malleable iron or steel exists as hardening or cement carbon, it immediately appears that the latter is changed into the former by a heating to a red heat succeeded by a violent forcing together, continued until cooling is almost complete; while hardening-carbon, on the other hand, is changed into cement-carbon by long-continued heating followed by slow cooling, without extra compression. In order to show that iron and carbon may be combined by pressing together more easily than otherwise, Caron upon an anvil, covered with charcoal in fine powder, hammered out quickly a strongly-heated piece of iron, which in this way was steeled on the surface, while another piece of the same iron heated as strongly, which was imbedded in similar charcoal powder, and allowed to cool in it without hammering, did not show the least sign of steeling. In the case of strong hardening of hard steel, we have the most powerful compression, for the rapid cooling produces a great difference of temperature between the outer and the inner layers of the piece, the more cooled exterior layers compressing the interior with greater force in proportion, partly as the latter are expended by being more strongly heated, and partly as the limit of elasticity of the substance is high, so that there is not too great a loss of the compressing force by the extension of the exterior layers. Again, that hammering favours the conversion of cement-carbon into hardening-carbon, or the more intimate union of the carbon with the iron in which it occurs, more than rolling, may at least, occasionally, to some extent, be attributed to the more powerful compression exerted by the hammer, but still more to the circumstance that the iron or steel, when the rolling is ended, commonly has a far higher temperature than when it has been drawn out under the hammer. For if the iron or steel be still red hot when the drawing is finished, a part of the carbon converted into hardening-carbon, or more intimately united with the iron during the compression to which it has been subjected, may be again changed into cement-carbon during the succeeding slow cooling. There is thus a very complete correspondence between the occurrence of hardening and cement-carbon and their mutual conversion in malleable iron and steel on the one side, and the relations of the combined carbon and the graphite in pig-iron on the other.

METHODS OF HARDENING.

Proceeding to the hardening, we find that experience has sufficiently shown that its effect mainly depends upon the contents of combined carbon in the iron, upon the differences of temperature between the iron or steel and the hardening fluid, and further on the rapidity of the cooling. The last-mentioned again is dependent on the quantity of the hardening fluid, its specific gravity, power of conducting heat, specific heat, boiling-point, and heat of vaporisation. Of the four liquids, mercury, water, oil, and coal-tar, therefore, the first named hardens much more powerfully than water, water considerably more powerfully than oil, and oil more powerfully than coal-tar. Further the hardening power of water is altered not only by differences of temperature, but also by the addition of different substances which change its properties in the respects just mentioned. Finally, the rapidity of cooling, so important for the degree of hardening, is also dependent on the way in which the piece is held down into the hardening fluid. For if it be kept still in a hardening fluid of low specific gravity and small conductivity and specific heat, the quantity of the hardening fluid is not of the same importance as if the piece be unceasingly moved about in it; but in the latter case the cooling of the piece is apt to be unequal, inasmuch as by the moving about the front parts are cooled somewhat more rapidly than the back ones. This is also the case if by hardening in running water we make the quantity of the hardening fluid, so to speak, unlimited. The front part of the piece, or that which is termed up-stream, is then, of course, cooled most rapidly; and in order, in such a case, to attain an even hardening it is necessary to turn round the piece rapidly and unceasingly. The layer of steam which, in the case of hardening in a substance so easily converted into vapour as water, is formed around the warm piece is an obstacle to the contact of water with it, and thus diminishes the speed of cooling along with the degree of hardening which is dependent upon it; but if care be taken that in one way or another the steam be easily and rapidly carried away as it is formed, the rapidity of cooling, on the other hand, on account of the great heat of vaporisation of water, is very considerably promoted by this conversion into vapour. Small pieces, therefore, are also very well hardened in water-dust finely distributed by means of a stream of air or steam; and the highest degree of hardening may, according to Herr Jarolimek, be attained in this way with so moderate a quantity of water that all the water-dust which comes into contact with the warm piece is brought by it into the form of steam. These influences, exerted by the formation of steam, must also be taken into consideration when, in order to attain an inferior degree of hardness, warm water is used instead of cold. It cannot accordingly be denied that there are many factors exceedingly difficult of calculation, which exert an influence on the speed of cooling and thereby on the degree of hardness. Nor is it much to be wondered at that mistakes are readily committed in hardening, and that great practice is required in order to be able confidently to reckon on a certain effect; and finally, that a workman accustomed to hardening considers that only a single method which he has been in the habit of employing can be used for a certain purpose, while another equally skilful workman can only attain the same result by a method essentially different. It further appears that the rapidity of the first cooling, from the 600° to 700° C., to which steel has commonly been heated, to 300° to 400° C., has a manifold greater influence on the degree of hardness than the succeeding cooling. Thus, Herr Jarolimek has shown that steel wire may be very well hardened both in watery vapour and in molten tin, lead, and even zinc, though the last-named metal does not melt under 400° C., while the cooling of the same steel wire from 300° or 400° to 0° C., does not cause any true hardening, however rapidly it may proceed. In order that steel wire may be hardened in this way, it is not, however, allowed to remain any considerable time in the molten bath of metal, for by long-continued heating following such a hardening the degree of hardening is afterwards diminished more and more. If it be taken out again after being dipped in the bath for quite a short time, and afterwards allowed to cool in the air, the degree of hardening for small articles is equal to that attained by ordinary hardening with the tempering following upon it.

THE EFFECTS OF HARDENING.

Of the effects produced by hardening, it was in old times mainly the hardness on which attention was fixed, and from this is derived the old saying that a substance does not take hardening if it do not thereby become so hard that a common file can no longer exert any noteworthy influence upon it. From time immemorial a distinction has also been made between iron and steel in this way, that the former, with common hardening in water, is not hardened in the sense just indicated, while steel, on the contrary, is hardened. We sometimes hear it brought as an objection against the old way of distinguishing between iron and steel, that it is difficult to determine whether a piece, after common hardening in water, is to be considered as having taken true hardening or not. But such a reason is, in fact, quite unwarranted, because, according to the old view, only the varieties approximating most closely to each other of the *hardest* iron and the softest steel can be mistaken for each other, and such a mistake is indeed of little importance when compared with the great mistake just referred to of *soft* iron for soft steel. If it be wished wholly to avoid the possibility of making mistakes between hard iron and soft steel, this even ought to be attained very easily by the method of determination, in which a sharp-edged splinter of a certain mineral—felspar for instance—scratches iron, although after being heated to a moderate red heat, it has been suddenly cooled in cold water, while steel, after similar treatment, cannot be scratched by the same mineral. The substance