to be obliterated in after years, and create a taste and love for study, and a yearning to increase their store of knowledge, instead of leaving school with a mind disgusted with the dryness and severity of studies of little service to them hereafter in practical life.

HARDENING AND TEMPERING.

By Joshua Rose, M.E.

Since the hardening of steel consists of first heating and then rapidly extracting the heat, it follows that this latter part of the process may be performed otherwise than by the use of water—such, for example, as by placing the article in a current of cold air, or, if it is thin, by placing it between two cold plates of iron. In these processes, however, the heat is not extracted quickly enough to give a great degree of hardness; hence, cold plates are rarely used, unless in cases where straightness and truth are of primary importance, and where straightening processes to be applied after hardening, are inadmissible.

When extreme hardness is required, it is not uncommon to quench the steel in mercury, which will harden to a much greater degree than water.

To increase the efficiency of water, it is not unusual to boil it, which draws off the air contained in it, and there is no doubt that the superiority of water which has been long used for hardening, is largely, if not altogether, due to its comparative freedom from air.

The considerations which determine the most desirable degree of hardness or temper are whether resistance to abrasion, the capability of sustaining great pressure upon a fine edge, or elasticity, are the qualifications sought to be imparted.

When elasticity is sought, tempering is absolutely necessary, because the degree of hardness accompanying elasticity is that represented in the color test by the shades of blue. But when the requirements include the elements of strength (as is always the case in cutting tools, and is sometimes the case in articles hardened to resist abrasion), then the degree of temper is modified to accommodate the strength, for steel hardened right out, that is, made as hard as fire (without burning it) and water will make it, is sometimes brittle and comparatively weak, but it resumes its normal strength as its normal softness is restored. Hence if a cutting tool is of strong section, it is, in the best practice, hardened right out, but if it was found that the edge was, from excessive duty, liable to break off, it would be tempered to a straw color, or still lower, even down to a blue if the requirements for strength demanded it. It is self-evident, however, that since the cutting capability of a tool is mainly dependent upon its degree of hardness above that of the material to be cut, the harder a tool can be made to stand the duty without breaking, the more and the better duty it will perform.

There is, it is true, a great difference of opinion with regard to the propriety of tempering many strong tools to a straw color, especially in the case of planer tools for iron. Some of our most expert mechanics will temper such tools to a straw color, while others, equally expert, will give them all the water—that is, harden them right out and not lower the temper at all. There is among them all, however, a common practice of using the full degree of hardness in the tool when the metal to be cut is hard, as is sometimes the case in even common unchilled castings, and, since the harder the metal, the more force it requires to sever it, it would seem that a tool strong enough for the hard metal should be sufficiently so for the soft metal. On the other hand, the tool is sometimes made less keen for the hard than for the soft metal, and the difference in the tool shape may give as much increase of strength as the increase of its hardness tends to weaken it.

Here let it be noted that the difference of opinion referred to is not in any way due to a difference in the steel, for, of two men operating the same tools in the same machine and upon similar work, one will simply harden and the other harden and temper the tools. Let he who would excel, however, never use tools of a lower temper than that which he finds will safely withstand the strain, and never rest satisfied until, under equal conditions, he can use tools as hard as the best of others engaged upon similar work, for in most cases it will be found that an advantage of shape is the cause of being able to use a tool of increased hardness.

Under equal conditions, and under any given process, steel hardened with the outer or forged skin removed, will be harder, though tempered to the same color, than if that skin remained, which appears an anomaly, since it is universally conceded that the forged surface is the closest-grained and most refined steel. An explanation, however, may be found in the probability that the forged skin, or scale, operates as a separating film or lining between the metal and the water, retarding the extraction of the heat from the steel; but, be this as it may, it must always be allowed for in tools in which the temper is drawn to give strength. Suppose, for example, the conditions require that a tool be filed to exact shape before being hardened, and that the proper temper for that class of tool, if hardened with the forged skin on, would be a pale straw, the temper with that skin off would require to be about a coffee-colored brown; or if, in the first case, a deep reddish brown, then, in the second case, a clear reddish purple.

The surface of a piece of steel that is thoroughly hardened always appears white, provided that its surface was not covered with any substance during the heating process, and if any dark places or patches appear, it is an evidence that in those parts the steel is not so thoroughly hardened. For most color tempering, except it be for springs subject to excessive duty in proportion to their size and shape, the presence of such dark spots upon good refined cast steel, such as tool steel, is not of sufficient importance to appreciably impair the value of the tempering. If shear steel, blister steel, machine steel, or any of the common qualities of steel are used, the whiteness of the surface is, however, a sure indication of the hardness of the steel, providing it was heated with its surfaces uncovered and quenched in water; but if the surface of any steel be coated with any of the substances sometimes used (and to be hereafter specified), to prevent decarbonisation, black or dark spots will not be an indication of local softness.

In large bodies of steel, the heat is not extracted from the internal metal sufficiently quick to harden the interior to the same extent as the exterior. Furthermore, it is often necessary to have a free current of water in order to extract the heat sufficiently rapidly to harden the exterior, because the internal metal supplies heat to the external, thus partly counteracting the cooling effects of the water. In such cases, however, the coldest of water under pressure, and, if practicable, with salt added, may be employed.

In such sizes of steel as are used for cutting tools and instruments, it is not found that the internal metal is appreciably softer than the external, provided that the steel was heated equally all through.

In articles tempered to any degree not lower than a red purple under the color test, it is not found that removing the surface after hardening alters the temper, or, in other words, articles not tempered (by color) to a lower degree than a very light purple, appear to possess their degree of temper equally all through the metal; hence, subsequent grinding and polishing does not impair the hardness, unless the operation should heat them. But in all the degrees of temper represented in the color test, the blue purples and blue, removing the surface of the metal after tempering, will sensibly reduce the temper; the amount of the reduction depending upon the depth to which the surface was removed. The difference, however, will be found to be less in the case of refined cast steel than when the quality of steel is that ordinarily used for springs. It is stated to have been found by experiment that the bare removal of the blue tint from a pendulum spring by immersing it in weak acid, caused the chronometer to loose nearly one minute in each hour. It is also stated as a well-known fact, that such springs get stronger in a minute degree during the first two or three years they are used, from some atmospheric change; while springs plated with gold, silver, or nickel, remain constant, though the covering or plating may be so thin as not to compensate for the loss of the blue surface removed for the plating process. Be that, however, as it may, certainly is it that the elasticity of tempered steel is rapidly affected by various conditions. Thus the springs of engine pistons partly loose their elasticity in the course of time, whether from the heat or from rusting, it is hard to say. Springs operating under dry heat get harder, but whether this is not due to the crystalisation of the metal, is an open question.

It does not appear that the method of tempering affects the durability or elasticity, since the deterioration mentioned applies to springs tempered either on hot plates of iron, in sand, in heated fluxes, or by burning oil, or blazing as it is termed.

On page 305 of this number will be found an article by the same writer on "The Cooling of Steel during Hardening."