XI.

THEORIES OF HARDENING.

THE hardening of steel is such a marked phenomenon, and one of so great importance, that it has always attracted a great deal of attention, and many theories have been put forward in explanation.

Before chemistry was brought to bear upon the subject the proposed theories were based upon assumption, and as there were no proofs one had as much right to consideration as another, and none seemed to be altogether satisfactory.

Since science has taken up the question the theories are about as numerous as the investigators, and while no one can claim as yet to have settled the matter definitely, each one has an apparent basis of reason deduced from observed facts.

Among early observations it was noted that when unhardened steel and hardened steel were dissolved in acid a much larger amount of carbon was found in the solution of the unhardened than in that of the hardened steel. This led, first, to the distinction of combined carbon and graphitic carbon, a distinction that has been maintained through subsequent investigations. It seems to be well established now that there is a definite carbide of iron, Fe_3C, and some observers believe it to be the hard substance in hardened steel.

Following this came the announcement that these conditions, *combined* and *graphitic* carbon, represented two different forms of carbon, and they were designated as *cement* carbon and *hardening* carbon; also as *non-hardening* and *hardening* carbon. Later investigation having established the existence of the carbide Fe_3C, this was claimed to be the hard body, but this has not met universal acceptance.

Another investigator, studying by means of the pyrometer and observing heat phenomena, concludes that hardening is due to an allotropic condition of the iron itself; that when iron is heated above the recalescent-point, and presumably below granulation, it becomes in itself excessively hard; that sudden cooling prevents its changing from this form, and so, when there is carbon present, the result of quenching is great hardness.

When steel is allowed to cool slowly to below recalescence, the iron assumes another form, and one which cannot be hardened by quenching; this latter is known as α iron, and the hardening kind as β iron. A later investigator finds it necessary to have a third allotropic form to meet some of the phenomena, which he designates by another Greek letter.

Another investigator establishes independently the saturation-point, which was pointed out and published twenty years ago, viz., somewhere about 90 to 100 carbon; he fixes the saturation-point at 89 carbon and gives the formula $Fe_{24}C$. He assumes that this is an exceedingly unstable carbide, that it is formed between recalescence and granulation, and can only be fixed by quenching, and that when steel is quenched the fixing of this carbide is the cause of hardness.

A still later investigation establishes this saturation-point at about 100 carbon by observing that in hardened steel of 135 carbon there is a combination of 100 carbon which is the excessively hard part of the steel, and a portion containing the remaining 35 parts of carbon that is not quite so hard, and he suggests a fourth allotropic form to cover this part.

It is also suggested that steel should be considered and treated as an igneous rock; judging from the appearance of magnified micro-sections, this suggestion appears to be a happy one for the purpose of making comparisons.

The above theories of hardening, and others, are not to be regarded as antagonistic or contradictory, doubtless there are germs of truth in every one of them, or each one may be merely the individual's way of suggesting an explanation of the same observed phenomena, so that when a final conclusion is reached each may be found to have been travelling in the same direction by a different path. It is certain that able, patient, painstaking, men are working faithfully to produce a solution of the problem, and even if their ideas, as briefly given above, do seem to be contradictory it would only evince deeper ignorance and a stupid mind in any who should attempt to ridicule or unduly criticise honest work before it is completed. While these investigations are going on, and before any definite conclusion is reached, is there any well-established safe ground for the steel-worker and the engineer to stand upon? There certainly is a good working hypothesis for all to use, and one which it is believed will always be the right one to follow no matter what the final explanation of the remarkable phenomena of hardening, tempering, and annealing may prove to be.

After many years of careful experimenting and study

Prof. J. W. Langley came to the conclusion that no matter what the final result might be as to carbides, allotropic conditions, etc., that if steel were considered as iron containing carbon in solution, whether it were a chemical combination or a mere solution, and that cold steel be regarded as a congealed liquid in a state of tension, then all known phenomena could be accounted for, and all known conditions could be produced with certainty by well-known applications of heat and force.

When carbon is in the so-called combined condition, then the solution may be compared to pure sea-water; when the carbon is partly combined and partly graphitic, the solution may be compared to muddy sea-water, the mud representing the graphitic carbon.

When the carbon is practically all graphitic, as in over-annealed steel, then the solution may be compared to thoroughly muddy fresh water.

This hypothesis of solution agrees well with the saturation noted; then about 100 carbon is all that iron will dissolve without extraneous force; and higher carbon must be forced into solution by the work of hammers, presses, or rolls.

This gives reason to the experienced tool-maker's well-known preference for well-hammered steel.

The hypothesis of tension, probably molecular, covers all of the phenomena of excessive hardness due to high heat, which means high molecular motion checked violently by sudden quenching. It accounts for the progressive softening due to every added degree of heat, and it accounts for rupture, cracking, due to excessive heat or to any unevenness of heat.

Without this hypothesis of tension it is difficult to understand why quenching should rupture a piece of steel, no matter what the degree of heat, or how uneven it might be.

Without it, too, it is hard to see how successive additions of heat can cause gradual changes from β to α iron, or from an unstable carbide to an imperfect solution. It would seem that the allotropic changes, or the decompositions of carbides, must be more marked than the gradual changes from hard to soft which we know to take place by slow and gentle accretions of heat.

There is no property of steel known to the author which is not covered by Langley's hypothesis, and therefore it is put forward with confidence for engineers and steel-users to work by until the scientists shall have completed their investigations, and after that it is believed that it will be a safe working hypothesis, because science does not change facts, it only collates them and reveals the laws of action.

Under this hypothesis of Langley's we may define *hardness* as *tension, softness* as absence of tension.

This is not stated as established fact; it is given as a simple definition to cover the known phenomena until the final solution of the problem shall lead to a better explanation.

Regarding steel as a solution of carbon in iron, one important fact may be set down as established thoroughly: that is, that the more perfect the solution under all circumstances the better the steel.

Continued application of heat in any part of the plastic condition allows carbon to separate out of solution into a condition of mere mixture; it converts the clear sea-water into muddy water; this is the reason why so much emphasis has been given in previous chapters to the harmfulness of long-continued heating.

In every case, when steel is hot enough for the purpose desired, it should be removed at once from the fire.

XII.

INSPECTION.

Careful and systematic inspection is of the utmost importance from the first operation of melting to the last act of the finisher.

Assuming that every operator is honest and conscientious in the performance of his work, the personal equation must be considered, as well as the exigencies of the many operations. The steel-maker must inspect his ingots to see that they are melted well and teemed properly, that they are sound and clean, and to determine their proper temper.

When work is finished, he must inspect it to see that it has been worked at proper, even heats, that it is correct in dimensions, and that all pipes and seams have been cut out. After all this has been done faithfully it were well that his work were done when it were well done. Such is not his happy lot; every successive manipulator may ruin the steel by carelessness or ignorance, and it is a gala day for a steel-maker when he does not receive some sample of stupid ignorance or gross carelessness, with an intimation that it would be well for him to learn how to make steel before he presumed to offend by sending out such worthless material. And sometimes, though not so often if he knows his business, he finds a complaint well founded; then he must regulate his own household and make his peace with his angry customer as best he can.

The engineer must inspect his steel to see that it is sound, and clean, and finished properly, as he has a right to expect that it should be.

It is not intended here to lay down rules for shop and field inspection,—that is an art in itself outside of the function or the experience of a steel-maker,—but some hints may be given as to the examination of steel as it comes from the mill, and it has been the aim in previous chapters to give such information as may enable an engineer to form a good judgment as to matters which are not likely to come to his knowledge in the course of ordinary practice.

Steel should be sound; it should be examined before it is oiled or painted. All pipe should be cut off; a pipe of any considerable size will show in the end of a sheared bar, and a careful observer will soon learn to detect it. If there is reason to suspect a pipe, file the place and the pipe will be revealed if it is there. Do not chip at it, for a chisel will often smooth a line which a file will bring out. In tool-steel there should not only be no pipe, there should be no star left in the bar. A "star" is a bright spot which shows the last of the pipe, not quite cut away; the steel is not solid in the star and it will not make a good cutting-edge; it may even cause a sledge to split.

SEAMS.

In tool-steel there should be no seams at all. Some makers declare that in high steel, seams are evidences of good quality; such a statement is the veriest fraud; it is hard to get any high steel free from seams, and therefore if the maker can get the user to believe that a seam is a good thing he can enhance his profit; that is, he can enhance it for a time until his fraud is understood.

Some seams are hard to see; when there is reason to suspect one, a little filing across the line will show it in a distinct black line if it is there. A file is an indispensable tool for an inspector, better than a chisel or a grindstone.

In machinery and structural steel a few small seams may be unobjectionable; too close inspection may lead to unnecessary cost without a compensating gain; still every engineer should reserve the right to determine what seams are allowable and what are not, for his own safety.

Laps should not be tolerated in any work.

Torn cracks on edges or surface indicate burned steel or red-short steel; they should not be allowed.

The grain of steel should be practically uniform, not too coarse, not with brilliant lustre, nor with a dark india-ink tint. With an even fine grain, a bright lustre may indicate a mild steel not worked badly. Inspectors must learn by practice what is tolerable and what is not, as it is impossible to lay down hard and fast rules; it is safe, however, to say that a fairly fine grain of even texture, not much lustre, and no india-ink shade, is indicative of good heating and proper working.

With these few general hints the subject must be left, for, like tempering, inspecting is an art in itself, and it cannot be taught in a book.

An expert inspector will see seams and pipes with his naked eye that a novice could not detect with an ordinary magnifying-glass.

It may do no harm to the inspector to suggest to him that amiability and good sense are the best ingredients to mix with sound judgment.

If he will cultivate these, and learn to distinguish between a mere blemish and a real defect, he will find his work made easy and pleasant; and he will be far less likely to have bad work thrust at him than he will if he makes it apparent that he regards himself as the only honest man.

XIII.

SPECIFICATIONS.

Specifications should cover three principal points:

Physical properties: Elastic limit; ultimate tensile strength; elongation; reduction of area.

Chemical constituents: Limiting silicon, phosphorus, sulphur, manganese, and copper; all other elements to be absent or mere traces in quantity, except carbon.

Finish and general condition: Fixing limit of variation in size from a given standard; conditions as to pipes, seams, laps, uniformity of grain, and other defects; no red-shortness.

PHYSICAL PROPERTIES.

It has been shown in Chap. V that tensile strength may be had from 46,800 lbs. per square inch to 248,700 lbs. per square inch.

There are published in many transactions and technical periodicals thousands of tests giving elastic and ultimate strength, ductility, etc., so that every engineer can find easily what has been done to guide him as to what he can get.

In almost every case the engineer must be the judge as to the requirements in each; therefore it would be useless to attempt to lay down any fixed rules or limits.

Many engineers adhere to low tenacity and high ductility in the belief that they are securing that material which will be safest against sudden shocks and violent accidental strains.

Theoretically this appears to be correct, but if the statements made in the preceding chapters are credible it is plain that the limit to such safety can be passed, and that in insisting upon too low tenacity and high ductility the engineer may be getting simply a rotten, microscopically unsound material, through no fault of the manufacturer, who has been compelled to overmelt or overblow his steel to meet the requirements, and so reducing the quality of otherwise good material at no saving in cost to himself, and at a considerable cost in quality to the consumer.

Any manufacturer would rather check his melt between 10 and 15 carbon, or stop his blow so as to be sure not to overblow, if he were asked to do so, because it would save him time and expense, and it would yield sounder, better, and easier working steel.

It may not be wise yet for an engineer to fix limits as to blowing or melting, for the reason that neither he nor his assistants would know how to insure compliance, and in attempting to do it they might interfere too far with manufacturing operations and so involve themselves in responsibilities which they ought not to assume.

On the other hand, if they will let the carbon and tensile strength run up a little and reduce ductility slightly, it is safe to say that any manufacturer will be glad of the chance to help them to get the best results, which involve no extra cost.

Boiler-steel and rivet-steel usually suffer the most in this respect. A boiler should be tough, yet it is the belief of the author that boilers made of the 46,800-lb. steel of which the analysis is given in Chap. V would not last half as long as boilers made of 65,000-lb. to 70,000-lb. steel when the increased strength was gained by added carbon and no overmelting was allowed.

In the same table the "Crucible-sheet" column gives a mean of 24 tests, and a mean analysis, of boiler-steel which has been in use in 12 boilers for nearly 16 years. The boilers are in perfectly good condition; they have been subjected to severe and very irregular usage, and they have been in every way satisfactory, Only one test-piece of the 24 was mild enough to stand the ordinary bending test after quenching.

That 46,800-lb. steel is remarkably pure chemically; it is unusually red-short. It would appear to some to be an ideal rivet-steel; it would stand a very high heat, it would head well and finish beautifully under a button-set. There is every probability that the majority of rivets driven of that steel would be cracked on the under side of the head, where the cracks would never be discovered until in service the heads flew off.

Rails are usually made of 40 to 45 carbon, tires from 65 up to 80 carbon, crank-pins as high as 70 carbon, with 85,000 lbs. to 95,000 lbs. tensile strength and 12% to 15% elongation.

It is difficult to see how a bridge or a boiler is to be subjected to any such violent usage as these receive daily; and while it is not advised that even 40 carbon should be used in boilers or bridges, although it would be perfectly safe, it does seem to be unreasonable to run to the other extreme to the injury of the material.

For steel for springs, and for all sorts of tools that are to

be tempered, there is no need of a specification of physical properties as they are indicated by testing-machines.

The requirement that they shall harden safely and do good work afterwards involves necessarily, high steel of suitable quality.

CHEMICAL CONSTITUENTS.

No engineer should, unless he be an expert steel-maker, attempt to specify an exact chemical formula and a corresponding physical requirement; in doing so he would probably make two requirements which could not be obtained in one piece of steel, and so subject himself to a back down or to ridicule, or both.

On the other hand, he may properly, and he should fix, a limit beyond which the hurtful elements would not be tolerated. Notwithstanding satisfactory machine tests, successful shop-work, and a liberal margin of safety, no steel can be relied upon that is overloaded with phosphorus, sulphur, manganese, oxygen, antimony, arsenic, or nitrogen.

In regard to silicon, it is common to have as much as 20 to 25 points in tire, with 55 to 80 carbon; such tires are made by the best manufacturers, and they endure well. But it is certain that good, sound steel can be made for any purpose with silicon not exceeding 10.

Structural steel can be made cheaply within the following limits:

Silicon	$< .10$
Phosphorus	$< .05$
Sulphur	$< .02$
Manganese	$< .50$ or even $< .30$
Copper	$< .03$

Carbon to meet the physical requirements

Steel made within these limits and not overblown or overmelted must be better in every way than steel of

Silicon	$> .20$
Phosphorus	$> .08$
Sulphur	$> .05$
Manganese	$> .60$

Carbon to meet the same requirements

A steel of the latter composition, or with no fixed limits, may be made cheaper than the first by a dollar or two a ton; but for any large lot it is believed that the first specification would be bid to at as low a price as if there were no specification; competition among manufacturers would fix that. At any rate there is no reason why an engineer should refuse to demand fairly pure material when he can do so at little or no extra cost.

Arsenic, antimony, or any other elements should be absent, or $< .005$.

FINISH AND GENERAL CONDITIONS.

As there can be no such thing as exact work done, there must be some tolerance as to variation in size. In standard sections, sheets, and plates this is usually covered by a percentage of weight; in forgings or any pieces that are to be machined the consumer should allow enough to insure a clean, sound surface. But it would be unwise to lay down any rule here, because conditions vary; a rolled round bar may finish nicely by a cut of from $\frac{1}{32}$ to $\frac{1}{16}$ of an inch, and so also a neatly dropped forging; an ordinary hammered forging might require a cut of $\frac{1}{4}$ or $\frac{3}{8}$ of an inch; such a forging might be made closer to size at a cost for extra time at the hammer far exceeding the saving of cost in the lathe. These are cases where common-sense and good judgment must govern.

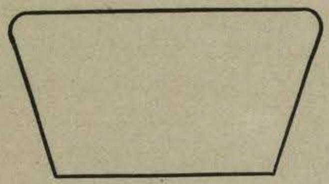
Pipes should not be tolerated if they can be discovered; because a pipe appears small in the end of a bar it is no evidence that it is not larger farther in.

Seams should not be allowed in any steel that is to be hardened; they should be a mininum in any steel, as they are of no possible use; small seams when not too numerous may do no harm in structural or machinery steel, and consumers should be reasonable in regard to them, or else they may have too high prices put upon their work, or too high heat used in efforts to close the last few harmless seams.

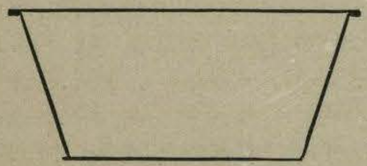
Burns, rough, ragged holes in the faces or on the corners, are inexcusable and should be rejected; the steel has been abused, or it is red-short; in either case the ragged breaks are good starting-points for final rupture.

Laps should not be permitted; they are evidences of carelessness; there can be no excuse for them.

Fins are sometimes unavoidable in a difficult shape; for instance, if a trapezoid is wanted, it may be rolled in this form:



or in this:



The consumer must decide which; if he wants sharp angles he must accept the fin and cut it off, or have it cut off by the manufacturer.

Rivet-steel should be tested rigidly for red-shortness, because red-short steel may crack under the head as the steel cools.

Emphasis is laid upon this because engineers will insist upon excessive ductility in rivet-steel, not realizing that they may be requiring the manufacturer to overdose his steel with oxygen to its serious injury.

No sharp re-entrant angles should be allowed under any circumstances where there is a possibility of vibrations running through the mass. All re-entrant angles should be filleted neatly.

No deep tool-marks should be allowed; a fine line scored around a piece by a lathe-tool, or a sharp line cut in a surface by a planing-tool will fix a line of fracture as neatly as a diamond-scratch will do it on a piece of glass.

Indentations by hammers or sledges should be avoided; they may not be as dangerous as lathe-cuts, but they can do no good, and therefore they are of no use.

XIV.

HUMBUGS.

Steel is of such universal use and interest in all of the arts that it attracts the attention of would-be inventors perhaps more than any other one material.

Half-informed, or wholly uninformed, men get a smattering of knowledge of some one or more of the well-known properties of steel, make an experiment which produces a result that is new and startling to them, and at once imagine that they have made a discovery; this they proceed to patent and then offer it to the world with a great flourish of trumpets.

Many steel-workers, even men of skill, who know something of the difficulties that follow irregular work, or who are not quite fully informed as to the properties of steel, seize upon these discoveries in the hope that they have found a royal road to success where all old pitfalls are removed and their path is made easy.

Not wishing to discourage pioneers in legitimate efforts to improve, it is the object of this chapter to warn them against being too ready to spend their money because of flaming circulars or glib tongues. It is the duty and the interest of a steel-maker to examine and test every apparently new suggestion, for the reason that there is still room for improvement, and he should let no opportunity for a betterment slip past him.

As a rule the steel-maker does test every claim that is laid before him, unless it be a repetition of some old plan long since tried and found worthless. This is the bane of the steel-maker's life, and yet he must keep at this work so that he may know for himself whether anything of value has been discovered, and also that he may advise his clientage properly.

Inventions relating to the manufacture of steel have no interest for steel-users except as lively manufacturers may adopt the mistaken plan of flourishing trumpets to attract trade, not always giving a corresponding benefit to the consumer.

Examples of this sort of thing may be illustrated by so-called phosphorus steel, silicon steel, and aluminum steel; also the case mentioned before of parties recommending seams as evidences of excellence in high steel. Such efforts are sometimes costly to consumers until active competitive manufacturers expose the humbug.

Among the most absurd of such claims are those where a nostrum is used to convert ordinary Bessemer or open-hearth steel into the finest of tool-steel, equal to the best crucible-steel; for example, a patent to convert mild Bessemer steel into the finest tool-steel by merely carbonizing it by the old cementation process; this takes no account of the silicon, manganese, oxygen, and nitrogen in the mild Bessemer, makes no provision for their removal, and involves a costly method of putting carbon into poor stock in face of the fact that a Bessemer-steel maker can put the same amount of carbon there at practically no cost, and so produce a better material.

Among the humbugs that do not involve the manufacturer, the pet one is a nostrum for restoring burnt steel; these have been evolved by the dozen, in face of the fact that burned steel cannot be restored except by smelting, and that overheated steel, coarse-grained steel, can be restored by merely heating it to the right temperature, a process which has been explained fully in Chapter VI.

Another pet is some greasy compound for toughening high steel so as to make it do more work. This is done by heating the steel to about recalescence and plunging it into the grease, perhaps once, or possibly two or three times; then working it into a tool and proceeding in the ordinary way. This will make a good tool; it is the partial annealing plan explained in a previous chapter. Now take a similar piece of steel, heat it the same way, lay it down in a warm, dry place alongside the forge-fire, and let it cool; then heat it and work it into a tool and it will beat the greased tool.

When all of these operations of restoring, partial annealing, annealing, etc., depend merely upon temperature and rate of cooling, why spend money for nostrums that add no possible benefit?

There is room for improvement in steel, great room for great improvements; they will come in time as science and knowledge advance, and great benefits to the consumers will come with them.

This chapter is not written to place difficulties in the way of legitimate improvement, but to warn unsuspecting people against quackery. Some of the humbugs are honest productions of well-meaning ignorance, and some that come from designing manufacturers are not entitled to such charitable designation. A knowledge of the simplest properties of steel will enable a thoughtful man to judge as to whether a proposed improvement is likely to be of any value or not, and the warnings given are intended as a protection to the unsuspecting and credulous.

XV.

CONCLUSIONS.

After perusal of the preceding chapters the reader may form a hasty conclusion that if steel be so sensitive as it is stated to be its use may be difficult and precarious, and that it must be handled in fear and trembling, lest the result should be a dangerous structure, and the builder must be in doubt as to its safety.

The conveyance of any such impressions is not intended at all; emphasis has been laid upon practices that are hurtful in order that every steel-user may know what to avoid, solely that he may then be sure that he has the best, the most reliable, and most useful material that is known to man.

WHAT TO AVOID.

He should avoid uneven heat, excessive heat, or too low heat. The range between orange red and the heat that will granulate is so great that no one who is not a bungler or indifferent need ever get outside of it.

The uniformity of temperature that is insisted upon is so easily seen that any person who is not color-blind should have no trouble in securing it by the simplest manipulations of the furnace.

Practical uniformity of the work put on a piece is readily secured by any mechanic of ordinary skill.

Red-short, cold-short, or honeycombed steel are easily detected, and, under reasonable specifications, the steel-makers can as easily avoid them.

Steel a little higher than most engineers favor in their specifications is certainly as safe as, and likely to be sounder than, extremely ductile steel.

Wild steel, resulting almost certainly in micro-honeycombs, if not worse, can only be avoided by the co-operation of the manufacturer, and engineers should impress this point with energy.

Such micro-unsoundness as is shown in Mr. Andrews's report upon a broken rail and propeller-shaft can be reduced to a minimum by insisting upon reasonably pure steel.

If sulphur, phosphorus, silicon, and oxygen are kept at a reasonable minimum, sulphides, phosphides, silicides or silicates, and oxides must be at a corresponding minimum.

That there is much room for improvement in the manufacture of steel is evident, and when means of getting rid of oxygen, nitrogen, and all other undesirable elements have been found the steel of the future will be very different in kindliness of working and in endurance of strains than that with which we are familiar.

It is believed, however, that no matter how perfect the manufacture may become, nor what the final theories of hardening, etc., may be, the properties stated in these pages will remain the same as long as steel continues to be essentially a union of iron and carbon.

Some other alloy or compound may displace carbon steel, and present an entirely new set of properties, but there is nothing of the kind in sight now, and engineers need have no fear of having a new art to learn very soon.

To one who has spent an ordinary business lifetime in making steel, studying it, and working with it it becomes a subject of absorbing interest, if not of love; and steel when handled reasonably is so true that "true as steel" ceases to be a metaphor, it is then a fact which fills him with the most entire confidence.

Once more, steel highly charged with sulphur, phosphorus, arsenic, oxygen, and nitrogen is certainly highly charged with so many elements of disintegration; it takes more serious harm from ordinary deviations from good practice, such little irregularities as occur inevitably in daily working, than steel does which is more free from these elements.

Reasonably pure, sound, reliable steel can be had at moderate cost, and all consumers should insist upon having it.

Regular, uniform, reliable working can be had where it is required, and there should be no excuse for irregular grain, overheated work, uneven work, or any other bungling. Where skill is required and reasonable discipline is enforced, good work will not cost any more than bad work.

Many people still hold to the idea that there are many mysteries connected with steel, and that many unaccountable breaks occur which make it an unreliable material. It is hoped that what has been set down in these pages will go far to dissipate these supposed mysteries, and to give confidence to steel-users.

Many breaks are unaccounted for, but it is not within the author's experience that any fracture ever occurred that could not have been explained if it had been examined thoroughly in the light of what we know now. There is much to be learned, but there are no mysteries.

GLOSSARY.

THERE are many shop terms used in this book which may not be familiar to all steel-users.

They are in common use in steel-manufactories, and definitions of them will enable a steel-user to understand more clearly the common talk he will hear in the shops.

Blow-holes.—Blow-holes are the small cavities, usually spherical, which are formed in ingots as the steel congeals by bubbles of gas which cannot escape through the already frozen surface.

Burned.—Burned steel is steel that is reduced to oxide in part by excessive heating.

Check.—A check is a small rupture caused by water; it may run in any direction; it is usually not visible until steel is ruptured.

Chemical Numeration.—Chemical quantities are almost universally expressed in hundredths of one per cent, as explained in the body of the work. It is a very convenient numeration; any steel-worker, melter, hammerman, etc., will talk of 20, or 50, or 130 carbon; or 8 phosphorus; or 10, 15, or 25 silicon, etc.; and will talk intelligently, although he may not know the exact mathematical value of these points.

Dead-melting; synonym, killing.—Dead-melting—killing—means melting steel in the crucible or open hearth until it ceases to boil or evolve gases; it is then dead, it lies quiet in the furnace, and killed properly it will set in the moulds without rising or boiling.

Dry.—Steel is called *dry* when its fracture is sandy-looking, without lustre or sheen, and without a proper blue cast. There is more of a shade of yellowish sandstone. It is an evidence of impurity and weakness.

Fiery.—Fiery steel has a brilliant lustre; it is an evidence of high heat.