chisel. It is a hot summer day; the smith is working over a huge fire with a large piece of work in the middle of the fire and a number of small pieces of steel stuck in the edge of the fire.

He is welding large iron frog-points, and in the interval he is filling a hurried order for four dozen track-chisels for which the trackmen are waiting. He is not merely forging the chisels, he is hardening and tempering them. The glare of the welding-work makes him color-blind, the hurry gives him no time for manipulation, and the trackmen have no chisels.

After a thorough expression of sympathy for the smith the steel-maker turns upon the foreman and master mechanic, and gives them such a tongue-lashing that they turn away silenced and ashamed.

Page after page of such cases could be written, but one should be enough.

A steel-maker has a thoroughly skilled and expert steel-worker; he rushes into the shop and says, "Mike, refine this right away, please; I want to know what it is."

Mike replies, "I will do that to-morrow; I am welding to-day."

That is entirely satisfactory; those men understand one another, and they know a little something about their business.

A temperer should do no other work when he is heating for hardening, and he should always be allowed to use as much time about it as he pleases, assuming that he is a decently honest man who prefers good work to bad; and as a rule such honest men are in the majority, if they are given a fair chance.

IX.

ON THE SURFACE.

THE condition of the surface of steel has much to do with its successful hardening and working.

A slight film adherent to the surface of steel will prevent its hardening properly; the steel may harden under such a film and not be hard upon the immediate surface, and, as in almost every case a hard, strong surface is necessary to good work, it is important that a piece of steel to harden well should have a clean surface of sound steel.

It has been stated already that all bars and forgings of steel have upon the surface a coat of oxide of iron, and immediately beneath this a thin film of decarbonized iron.

Neither of these substances will harden, and in every case where a hard-bearing surface or a keen-cutting edge is desired these coatings must be removed. Polished drill-wire and cold-rolled spring-steel for watches, clocks, etc., should have perfect surfaces, and it is the duty of steel-makers to turn them out in that condition. All black steel, or hot-finished steel, contains these coatings.

In the manufacture of railroad, wagon, and carriage springs it is not necessary or customary to pay any attention to these coatings; the body of the steel hardens well, giving the required resilience and elasticity, so that an unhardened coat of .01 to .001 inch thick does no harm. To all bearing-surfaces and cutting-edges such coatings are fatal.

The ordinary way of preparing steel is to cut the skin off, and this is sufficient if enough be take off; it happens often that a purchaser, in pursuit of economy and unaware of the importance of this skin, orders his bars or forgings so close to size that when they are finished the decarbonized skin is not all removed, and the result is an expensive tap, reamer, milling-cutter, or some tool of that sort with the points of the teeth soft and worthless.

In small tools $\frac{1}{16}$ inch, in medium-size tools, say up to two or three inches in diameter, $\frac{1}{8}$ inch cut off should be plenty; in large tools and dies, especially in shaped forgings, it would be wiser to cut away $\frac{3}{16}$ inch.

In many cases sufficient hardness can be obtained by pickling off the surface-scale, but this will not do where thorough hardening is required, because the acid does not remove the thin decarbonized surface. It seems to be impracticable to remove the decarbonized skin by the action of acid, for if the steel be left in the acid long enough to accomplish this the acid will penetrate deeper, oxidizing and ruining the steel as it advances.

Grinding is frequently resorted to, being quicker and cheaper than turning, planing, or milling.

When grinding is used, care must be taken not to glaze the surface of the steel, or if it should be glazed the glaze must be removed by filing or scraping.

In the manufacture of files it is customary to grind the blanks after they are forged and before the teeth are cut.

After the blanks are ground they are held up to the light and examined carefully for glaze. Every blank that shows by the flash of light that it is glazed is put to one side; then these glazed blanks are taken by other operatives and filed until all traces of glaze are removed. The file-maker will explain that if this be not done the files when hardened will be soft at the tips of the teeth over the whole of the glazed surface. This inspection and filing of blanks involves considerable expense, and it is certain that such an expense would not be incurred if it were not necessary.

This glaze does not appear to be due to burning, at least the stones are run in water; the blanks are handled by the bare hands of the grinders, and do not appear to be hot.

After pieces are hardened and tempered they frequently require grinding to bring them to exact dimensions. This is usually done on emery-wheels with an abundance of water, and as no temper colors are developed indicating heat it is assumed that no harm can be done.

Just here much valuable work is destroyed. The tempered piece is put on the wheel, in a "flood of water"; the work is rushed, and the piece comes out literally covered with little surface-cracks running in every direction, perfectly visible to the naked eye. Until the steel-worker learns better he blames and condemns the steel.

This result is very common in the manufacture of shear-knives, scissors, shear-blades, dies, etc.

Sometimes too a round bearing or expander-pin is hardened; examined by means of a file it appears perfectly hard; it is then ground, not quite heavily enough to produce surface-cracks, but still heavily, and on a glazed wheel. It is found now that the surface is soft; only a thousandth of an inch or so has been cut off, and the steel is condemned at once because it will harden only skin deep.

Let the file be drawn heavily over the surface and it will be found that the soft surface is only about a thousandth of an inch thick, and underneath the steel is perfectly hard.

Now grind slightly on a sharp, clean wheel and re-harden; the surface will be found to be perfectly hard. Ground heavily again on the glazed wheel, it will become soft, as before. These operations can be repeated with unvarying results until the whole piece is ground away.

These difficulties occur more with emery-wheels than with grindstones, either because emery-wheels glaze more easily than grindstones, or because, owing to their superior cutting powers under any circumstances, they are more neglected than grindstones.

Experience shows that these bad results occur almost invariably on glazed wheels. It is rare to find any bad work come off from a clean, sharp wheel, unless the pressure has been so excessive as to show that the operator is either foolish or stupid.

The remedy is simple: Keep the wheels *clean* and *sharp.*

Many grinders who understand this matter will not run any wheel more than one day without dressing, nor even a whole day if the work is continuous and they have reason to apprehend danger.

A FEW WORDS IN REGARD TO PICKLING.

Pickling is the placing of steel in a bath of dilute acid to remove the scale. It is a necessary operation in wire-making and for many other purposes, and it may be hastened by having the acid hot.

Sulphuric acid is used generally; it is efficient and cheap. When thin sheets are to be pickled, the acid should not be

too hot, or it will raise a rash all over the sheet in many cases. This indicates some unsoundness in the steel, the presence probably of innumerable little bubbles of occluded gases. This is possibly true, yet the same sheets pickled properly and brought out smooth will polish perfectly, or if cut up will make thousands of little tools that will show no evidence of unsoundness.

Steel should never be left in the pickling-bath any longer than is necessary to remove the scale; it seems unnecessary to warn readers that the acid will continue to act on the steel, eat the steel after the scale is removed. When taken from the pickle, the steel should be washed in limewater and plenty of clean running water; but this does not take out all of the acid. It should then be baked for several hours at a heat of 400° to 450° F. to decompose the remaining acid. This is just below a bluing heat, and it does not discolor or oxidize the surface. It is known as the sizzling-heat, the heat that the expert laundry-woman gets on her flat-iron which she tests with her moistened finger.

Acid if not taken off completely will continue to act upon and rot the steel; how far this will go on is not known exactly; for instance, it is not known whether if a block six inches cube were pickled and merely washed, the remaining acid would penetrate and rot the whole mass or not. There must be some relation between the mass of the steel and the power of a small amount of acid to penetrate.

The power of acid can be illustrated on the other extreme: A lot of watch-spring steel is finished in long coils and .010 inch thick; when last pickled, the baking was neglected; the steel is tough, it hardens well, an when tempered it is springy and strong; by all of the tests it is just right in every coil. It is shipped away and in three or four weeks the spring-maker begins work on it. He reports at once that it is rotten and worthless, it will not make a spring at all, and he is angry. The steel is returned to the maker and he finds the report true: the steel is rotten and worthless. Then by diligent inquiry he finds that the last baking was omitted, and he pockets his loss, sending an humble apology to the irate spring-maker.

Whether the residual acid can ruin a large piece of steel or not need not be considered when the simple operation of baking will remove the possibility of harm.

X.

IMPURITIES IN STEEL.

ANY elements in steel which reduce its strength or durability in any way may be classed as impurities.

A theoretical ideal of pure steel is a compound of iron and carbon; it is an ideal that is never reached in practice, but it is one that is aimed at by many manufacturers and consumers, because experience shows that, especially in high steels, the more nearly it is attained the more reliable and safe is the product.

All steel contains silicon, phosphorus, sulphur, oxygen, hydrogen, and nitrogen, none of which add any useful property to the material. It is admitted that, starting with very small quantities of silicon or phosphorus in mild steel, small additions of either element will increase the tensile strength of the steel perceptibly up to a given amount, and that then the addition of more of either one will cause a reduction of strength. The same increase of strength can be obtained by the addition of a little carbon, producing a much more reliable material. It is not known that even such slight apparent gain in strength can be made by using oxygen, nitrogen, or hydrogen.

Manganese is present in all steel as a necessary ingredient, it gives an increase in strength in the same way as phosphorus, and when increased beyond a small limit it causes brittleness. Hadfield's manganese steel is a unique material, not to be considered in connection with the ordinary steel of commerce.

Webster's experiments are perhaps the most complete of any that show the effects of small increases of silicon, phosphorus, sulphur, and manganese, but as these are not completed they are not quoted here, because Mr. Webster may reach additional and different results before these pages are printed.

The chief bad qualities of steel that are caused by these impurities are known as "red-shortness," "cold-shortness," and "hot-shortness."

A steel is called red-short when it is brittle and friable at what is known commonly as a low red heat—"cherry red," "orange red."

Red-shortness is caused chiefly by sulphur or by oxygen; many other elements may produce the same effects; it seems probable that nitrogen may be one of these, but the real action of nitrogen is as yet obscure.

A red-short steel is difficult to work; it must be worked at a high heat—from bright orange up to near the heat of granulation—or it will crack. When hardened, it is almost certain to crack. When red-short steel is worked with care into a sound condition, it may when cold be reasonably strong, but hardly any engineer of experience would be willing to trust it.

Hot-short steel is that which cannot be worked at a high heat, say above a medium to light orange, but which is generally malleable and works soundly at medium orange down to dark orange, or almost black.

This is a characteristic of most of the so-called alloy steels, or steels containing considerable quantities of tungsten, manganese, or silicon. It is claimed that chrome steel may be worked at high heats and that it is less easily injured in the fire than carbon steel. This is not within the author's experience. It is this property of hot-shortness that makes the alloy steels so expensive; the ingots cannot be heated hot enough nor worked heavily enough to close up porosities, and therefore, there is a heavy loss from seams.

The range of heat at which they can be worked is so small that many re-heatings are required, increasing greatly the cost of working.

As compared to good carbon steel they are liable to crack in hardening, and when hardened they are friable, although they may be excessively hard.

Cold-short steel is steel which is weak and brittle when cold, either hardened or unhardened. Of those which are always found in steel, phosphorus is the one well-known element which produces cold-shortness.

It is clear that no one can have any use for cold-short steel.

Red-short or hot short steel may be of some use when worked successfully into a cold condition, but cold-short steel is to be avoided in all cases where the steel is used ultimately cold.

If the theoretically perfect steel is a compound of iron and carbon, it cannot be obtained in practice, and the only safeguard is to fix a maximum above which other elements are not to be tolerated.

In tool-steel of ordinary standard excellence such maximum should be .02 of one per cent; it may be worked to easily and economically, except perhaps in silicon, which element is generally given off to some extent by the crucible; it should be kept as low as possible, however, say well under 10, one tenth of one per cent. Some people claim that a little higher silicon makes steel sounder and better; but any expert temperer will soon observe the difference between steels of .10 and .01 silicon. For the highest and best grade of tool-steel the maximum should be the least attainable. Every one hundredth of one per cent of phosphorus, silicon, or sulphur will show itself in fine tool-steel when it is hardened. It is assumed, of course, that such impurities as copper, antimony, arsenic, etc., exist only as mere traces, or not at all.

As oxygen must be at a minimum, no one has yet succeeded in making a really fine tool-steel from the products of the Bessemer or of the open-hearth process.

The removal of the last fractions of these impurities is difficult and expensive; for instance, a steel melting iron of

Silicon	.03 to .06
Phosphorus	.03 " .02
Sulphur	.002 or less

may be bought for 2 cents a pound or less, whereas an iron of

Silicon	< .02
Phosphorus	< .01
Sulphur	trace

can hardly be bought for less than 5 cents a pound.

This difference of three cents a pound is justifiable when the highest grade of tool-steel is to be made; and it would be silly to require any such material in any spring, machinery, or structural steel.

In addition to these impurities there are other difficulties to be guarded against, chief among which is an uneven distribution of elements.

In all steel there is some *segregation;* that is to say, as the liquid metal freezes, the elements are to some extent squeezed out and collected in that part of the ingot which congeals last. It is claimed that in the Bessemer and Open-hearth processes any ferro-silicon added to quiet a heat, or any ferro-manganese added to remove oxygen, are at once absorbed and distributed through the mass, and so when any serious irregularity is discovered it is charged to *segregation.*

A heat may produce billets of 75 carbon and 120 carbon, and again it is called segregation.

As a rule, inertia has more to do with such differences than segregation. One crucible of steel may produce an ingot containing 90 carbon and 130 carbon. Segregation has nothing to do with this: a careless mixer has put a heavy lump of 140- or 150-carbon steel in the bottom of the pot and covered it up with iron. The steel melted first and settled in the bottom of the pot, the iron melted later and settled on top of the steel, and they did not mix. The teeming was not sufficient to cause a thorough mixing.

Segregation covers a multitude of sins.

Exactly how much is sin and how much is segregation will not be known until analyses are made of the top, middle, and bottom of the bath, and of the contents of the ladle, these to be compared to analyses of the top, bottom, and middle of the ingots. There is certainly an unavoidable amount of segregration, and as equally certain an amount of curable irregularity due to inertia.

WILD HEATS.

After steel is melted, whether in a crucible, an open hearth, or a Bessemer vessel, it boils with more or less violence. This boiling is caused by ebullition of gases, and if steel be poured into moulds while it is boiling the resulting ingot will be found to be honeycombed to an extent that is governed by the degree of the boiling.

If a heat boils violently and persistently, it is said to be "wild," and if a wild heat be teemed the ingots will be honeycombed completely; such ingots cannot be worked into thoroughly sound steel, and no melter who has any regard for his work will teem a wild heat if he knows it.

To stop the boiling is called "dead-melting," "killing" the steel, so that it shall be quiet in the furnace and in the moulds.

A crucible-steel maker who knows his business can, and he will, always dead-melt his steel. It only requires a few minutes of application of a heat a little above melting temperature, and this can be applied by a skilled melter without burning his crucible or cutting down his furnace; this is indeed about all of the art there is in crucible-melting, the remaining operations being easy and simple.

Dead-melting in the Bessemer vessel is not possible by increase of time; wild heats are managed differently, probably by adding manganese or silicon, or both, but exactly how is not within the author's experience.

Dead-melting in the open hearth would appear at first sight to be always possible, but there are more difficulties in the way than in the case of crucible-melting.

The heat may be wild when the right carbon is reached, and then the melter must use a little ferro-silicon, or silico-spiegel, or highly silicious pig, or aluminum, and he must use good judgment so as not to have his steel overdosed with any of these. From half an ounce to an ounce of aluminum to a ton of steel is usually sufficient, and although any considerable content of aluminum is injurious to steel there is little danger of its being added, because of its cost, and because a little too much aluminum will cause the ingots to pipe from top to bottom.

Silicon seems to be the most kindly element to use, and it is claimed that a content of silicon as high as 20 is not injurious; some people claim that it is beneficial. That it does help materially in the production of sound steel there can be no doubt, and if such steel meets all of the requirements of the engineer and of practice it would seem to be wise not to place the upper limit for silicon so low as to prevent its sufficient use in securing soundness. But the author cannot concede that as much as 20 silicon is necessary. In crucible practice high silicon is not necessary; in "melting-iron," or iron to be melted, it means so much dirt, indicating careless workmanship; but there will always be a little silicon present which the steel has absorbed from the walls of the crucible during the operation of melting. In high tool-steel silicon should be at the lowest minimum that is attainable.

This discussion of wild heats may appear to be outside of the scope of this work, and to belong exclusively to the art of manufacturing steel, of which this book does not pretend to treat. This is true so far that it is not recommended that the engineer shall meddle in any way with the manufacturer in the management of his work; on the other hand, it is vital to the engineer that he should know about it, because wild steel may hammer or roll perfectly well, it may appear to be sound, but the author cannot believe that it is ever sound and reliable.

Again, it has a scientific interest; that wildness is due to too much gas, and probably to carbon-gas, may be shown by an illustration.

It has its parallel in the rising of the iron in a puddling-furnace at the close of the boil, a phenomenon with which every one is familiar who has watched a heat being boiled or puddled. That all of the iron does not run out of the puddling-furnace at this stage is owing to the fact that there is not heat enough in the puddling-furnace to keep the iron liquid after it has been decarbonized.

During the running of a basic open-hearth furnace an apparently dead heat was tapped; before the steel reached the ladle there was a sort of explosion; the steel was blown all over the shop, the men had to run for their lives, and not one tenth of the steel reached the ladle. The manager was rated roundly for carelessness in not having dried his spout, and the incident closed. A few days later another quiet heat was tapped and it ran into the ladle; about the time the ladle was full the steel rose rapidly, like a beaten egg or whipped cream, and ran out on to the floor, cutting the sides of the ladle, the ladle-chains, and the crane-beams as it flowed. The men ran, and there was no injury to the person.

Again the manager was blamed, this time for having a damp ladle, and he was notified of an impending dismissal if such a thing occurred again. He protested that he knew the ladle and the stopper were red-hot, that he had examined them personally and carefully, and knew he stated the truth.

There were several reasons for looking into the matter farther: first, the man in charge was known to be truthful and careful, so that there was no reason for doubting his word; second, if the vessel and rod were red-hot, there could be no aqueous moisture there ; and, finally, such an ebullition from dampness was contrary to experience, as a small quantity of water *under* a mass of molten iron, or slag, results almost invariably in a violent explosion, like that of gunpowder or dynamite.

Upon inquiry it was found that prior to both ebullitions there had been a large hole in the furnace-bottom, requiring about a peck of material to fill it in each case. Magnesite was used; the magnesite was bought raw, and burned in the place. It is well known that it takes a long time and high heat to drive carbonic acid out of magnesite, and it was surmised that insufficient roasting might have caused the trouble. Samples of burned and of raw magnesite were sent to the laboratory, and the burned was found to contain about as much carbonic acid as the raw magnesite. Then the case seemed clear: This heavily charged magnesite was packed into the hole; the heat was charged and melted. The magnesite held the carbonic acid until near the close of the operation; then the intense heat of the steel forced the release of the gas, which was at once absorbed by the steel. Owing to the superincumbent weight of the steel the gas was absorbed quietly, and when the weight was removed the gas escaped, exactly as it does at the close of puddling or in the frothing of yeast.

Whether the carbonic acid remained such, or whether it took up an equivalent of carbon and became carbonic oxide, and then again took up oxygen from the bath, and so kept on increasing in volume, is not known.

The facts seem clear, and the collateral proof is that thorough burning of the magnesite, and of any dolomite that was used, prevented a recurrence of any such accidents.

Such ebullitions have occurred and caused the burning to death of pitmen, and the statement of the above case may be of use to melters in the future who have not met such an experience.

OXYGEN AND NITROGEN.

Oxygen and nitrogen are present in all steel and both are injurious, probably the most so of all impurities.

The oxides of iron are too well known to need discussion or description; they are the iron ores mixed with gangue. They are brittle, friable, hard, and weak, like sandstones. Mixed in steel they can be nothing but weakeners, elements of disintegration. Let any one take a handful of scale—or rust—oxide of iron, in his fingers and crumble it, and it will be difficult for him to imagine how such material could be anything but harmful when incorporated in steel. Langley has shown, and other scientists have confirmed him, that oxygen may exist in iron in solution, and not as oxide; the discovery was attended with the assertion that such dissolved oxygen produced excessive red-shortness. The proof that red-shortness was caused in this way was completed by the removal of the oxygen from some extremely red-short steel; the red-shortness disappeared with the oxygen and the steel worked perfectly.

When steel is melted very low in carbon, by any process, it is certain to be red-short and rotten unless the greatest care be used to prevent the introduction of oxygen. Crucible-steel of 15 carbon or less will as a rule be red-short and cold-short; it will not weld, and is generally thoroughly worthless. The same material melted to contain 18 to 25 carbon will be tough and waxlike, hot or cold. It will weld easily into tubes, and may be stamped cold into almost any desired shape.

Bessemer or open-hearth steel of less than 8 carbon is almost certain to be equally worthless, whereas the same material blown or melted not below 10 or 12 carbon, and re-carbonized not above 20, will be tough and good at any heat under granulation, and equally good and tough when cold.

As to Bessemer steel, the author cannot say whether it would be possible to stop the blow between 10 and 15 carbon or not, but it seems certain that if there be no overblowing red-shortness and cold-shortness may be avoided by carbonizing back to about 15 by the use of manganese or silicon, or both together.

In the open hearth it is always possible to stop the melt at 10 carbon, and to deoxidize the heat so as to avoid shortness, and not to go above 20 carbon. Such steel will be sound and tough; it will weld and stamp perfectly, and will be satisfactory for all reasonable requirements.

The reason of this seems to be simple and plain: In melting or blowing out the last fractions of carbon below 10 to 15 the same quantity of air per second or minute must be used as when burning out the higher quantities, and now there is so little carbon to be attacked that the oxygen necessarily attacks the iron in greater and greater force as the carbon decreases.

This leaves an excess of oxygen in the steel which cannot be removed by the ordinary quantities of silicon, or manganese, or aluminum.

If more manganese or silicon be used, the red-shortness and weakness can be cured largely; but then the carbon is raised considerably, and thus the steel is brought up to where it would have been without this excessive decarbonizing, with the difference that it is not quite so strong.

What good is there, then, in extremely low melting?

It must be admitted that there are tough, good-working steels in the market of carbon < 5, manganese < 20. They are made in small furnaces, worked with great care; the product is expensive, and, unless it is wanted to be welded in place of common wrought iron, it is in no case as good as well-made steel of 12 to 20 carbon; even for welding the latter is superior if the worker will only be satisfied to work at a lemon instead of a scintillating heat.

These special cases do not militate against the general fact that extremely low steel is usually red-short and weak.

The above is written for the consideration of those engineers who think they are going safe when they prescribe low tensile strength and excessive ductility. If these requirements meant the reception of pure, or nearly pure, iron, indicated by the low tenacity and high stretch, then they would be wise; but if they result, as they almost certainly do, in initially good material rotted by overdoses of oxygen the wisdom may not be so apparent.

NITROGEN.

The real influence of nitrogen is not known to the author. Percy shows that nitrogenized iron is hard, exceedingly friable, and causes a brilliant, brassy lustre. He also says nitrogen is driven out at a yellow heat; doubtless this is true of the excess of nitrogen, but it has been shown in Chapter II that melting in a crucible will not drive the nitrogen out of Bessemer steel.

When crucible-steel not made from Bessemer scrap and Bessemer steel of equal analysis are compared in the tempered condition, there is almost invariably a yellowish tinge over the fresh Bessemer fracture which distinguishes it from the crucible-steel. The Bessemer steel is also the weaker. These differences are believed to be due to nitrogen.

Langley maintains his belief that oxygen is still the chief mischief-maker; the author believes nitrogen to be the more potent of the two; there is no known way to remove the nitrogen, and there the question stands.

ELEMENTS OF DISINTEGRATION.

It has been stated time and again that these impurities are elements of disintegration, and that it would be wise in every case to restrict the quantities allowable within reasonable limits, giving the steel-maker sufficient leeway to enable him to work efficiently and economically, and at the same time to keep the quantities of these impurities as low as possible.

On the other hand, able, successful, and conservative engineers have claimed that if the steel-maker meets their physical requirements as shown by prescribed tests they, the engineers, should be satisfied; that they should not interfere with chemical composition, as they had no fear of subsequent disintegrations.

This argument was answered by the statement that skilled steel-workers could manipulate poor steel so as to bring it up to the requirements; that the well-trained workers in the bridge-shops would not abuse the steel; that the inherent deficiencies would not be developed; the work would go out apparently satisfactory; and that it might remain so for a long time, in the absence of unusual shocks or strains, but that in an emergency such material might fail because of deterioration where a purer material would have held on. In the absence of proofs such statements have been met with a smile of incredulity.

Fortunately some proofs are now at hand, and as the method of getting them has been obtained, more will follow from time to time.

In *Engineering*, Jan. 17, 1896, Mr. Thomas Andrews, F.R.S., M.Inst.C.E., gives the following cases:

A fracture of a rail into many pieces, causing a serious accident.

A broken propeller-shaft which nearly caused a disastrous accident.

Analysis of the rail:

Carbon	0.440
Silicon	0.040
Manganese	0.800
Sulphur	0.100
Phosphorus	0.064

It is clear that the sulphur is excessive, and that it was neutralized so as to make the steel workable by an excess of manganese.

Of the propeller-shaft Mr. Andrews says chemical analysis of outside and central portions of the shaft showed serious segregation.

"The percentage of combined carbon was nearly 50 per cent greater in the inside of the shaft than on the outside; the manganese was also in excess in the inside of the shaft; the phosphorus and sulphur had also segregated in the interior of the shaft to nearly three times the percentage of these elements found near the outside of the shaft."

Unfortunately Mr. Andrews does not give the analysis of the shaft.

A number of micro-sections of the rail and of the shaft were made and examined.

"Numerous micro-sulphur flaws were found, varying in size from 0.015 inch downward, interspersed or segregated in the intercrystalline junctions of the ultimate crystals of the steel, and being located in such a manner as to prevent metallic cohesion between the facets of the crystals, thus inducing lines of internal weakness liable to be acted upon by the stress and strain of actual wear."

The dimensions of these flaws in the rail varied from .0150 × .0012 to .0010 × .0004 parts of an inch.

In the shaft from .0160 × .0030 to .0020 × .0016 parts of an inch.

In the rail he found as many as 14 flaws in an area of only 0.00018 square inch, equal to nearly 60,000 flaws per square inch.

In the shaft he found as many as 34 flaws in an area of only 0.00018 square inch, equal to nearly 190,000 per square inch.

In speaking of the shaft he says: "In addition to blow-holes, air-cavities, etc., the interior of the shaft was literally honeycombed with micro-sulphide of iron flaws, which were meshed about and around the primary crystals of the metal in every direction." "The deleterious effects of an excess of manganese in interfering with the normal crystallization of the normal carbide of iron areas were also perceptible."

As the number of micro-sulphur flaws in the shaft were about three times as many as in the rail, we may assume that the shaft contained at least as large a percentage of sulphur as the rail, and, owing to the general honey-combed structure, it would not be a far guess to assume that the steel was teemed wild.

"The deleterious effect of these treacherous sulphur areas and other microscopic flaws, with their prolonged ramifications spreading along the intercrystalline spaces of the ultimate crystals of the metal and destroying metallic cohesion, will be easily understood."

"Constant vibration gradually loosens the metallic adherence of the crystals, especially in areas where these micro-flaws exist. Cankering by internal corrosion and disintegration is induced whenever the terminations of any of the sulphide areas or other flaws in any way become exposed at the surface of the metal, either to the action of sea-water, or atmospheric or other oxidizing influences. In many other ways, also, it will be seen how deleterious is their presence."

"Internal micro-flaws of various character are nevertheless almost invariably present in masses of steel, and constitute sources of initial weakness which not unfrequently produce those mysterious and sudden fractures of steel axles, rails, tires, and shafts productive of such calamitous results. A fracture once commencing at one of these micro-flaws (started probably by some sudden shock or vibration, or owing to the deterioration caused by fatigue in the metal) runs straight through a steel forging on the line of least resistance, in a similar manner to the fracture of glass or ice."

It is understood that similar investigations are being carried out on an extensive scale by Prof. Arnold; in the meantime the above cases should satisfy any one that these impurities are elements of disintegration, and that the less there are of them in any steel the better for the steel.

It seems clear that if 10 sulphur will cause 60,000 flaws per square inch, 01 sulphur ought not to cause more than one tenth of that number; or, if an equal number, then they could only be one tenth of the size.

The segregation found in the shaft is so excessive that it would seen probable that there was a good deal of sin there also; but, even if it were unavoidable segregation, the harm would have been just so much the less if there had been less of total impurities present to segregate.

ARSENIC.

Arsenic is known to be very harmful in tool-steel, and it is proper to assume that it can do no good in structural steel. In any case where the properties of steel do not come up to the standard to be expected from the regular analysis examination should be made for arsenic, antimony, copper, etc. These are not as universal constitutents of steel as silicon, phosphorus, sulphur, and manganese, but they are present frequently, and in any appreciable amount they are bad.