VANADIUM STEELS

THEIR CLASSIFICATION AND HEAT TREATMENT WITH DIRECTIONS FOR APPLICATION OF VANADIUM TO STEEL AND IRON

BY J. KENT SMITH

AMERICAN VANADIUM COMPANY

FRICK BUILDING PITTSBURGH. U. S. A.

VANADIUM STEELS

THEIR CLASSIFICATION AND HEAT TREATMENT WITH DIRECTIONS FOR APPLICATION OF VANADIUM TO IRON AND STEEL ⚜ ⚜ ⚜ ⚜ ⚜ ⚜ ⚜

By J. KENT SMITH

1909

AMERICAN VANADIUM COMPANY
FRICK BUILDING PITTSBURGH, U. S. A.

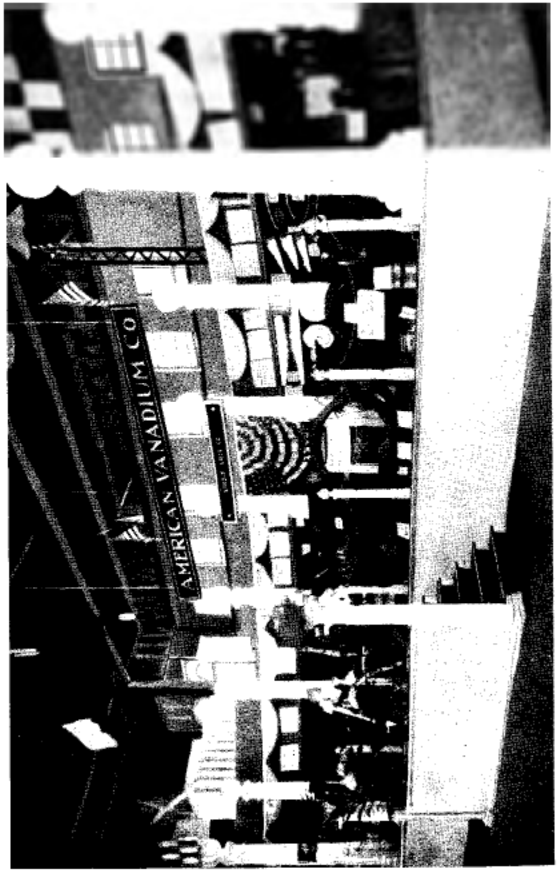


EXHIBIT OF VANADIUM STEEL PRODUCTS
At Convention of Master Mechanics and Master Car Builders, Atlantic City, June, 1908.
By American Vanadium Company

FOREWORD

THE uses of Vanadium are multitudinous, embracing practically the entire metal trades—iron and steel, copper, brass and bronze, aluminum and lead. The triple effect of vanadium in cleansing, strengthening and toughening follows its introduction into each, thus conferring superlative power and tenacity, with ready yielding to the skill of the artisan.

Vanadium has wrought wonders in crucible steel and produced magic transformations in open-hearth steel. Endowed with it, cast iron assumes added strength and fourfold endurance, copper annexes some of the properties of steel while retaining its pristine virtues, aluminum is wonderfully improved, especially in ease of machining, while even lead is strengthened and toughened.

Contemplation of the latent power, revolutionary changes, and marvelous possibilities, in the lightening of parts, lengthening of service, increased safety, and the vitalizing of inventions heretofore impossible of practical operation, due to an extremely small addition of vanadium, inevitably lead to the conclusion that this indeed is the "Master Weapon of the Metallurgist" where-with a vast expanse of troublous difficulties will be overcome and made to bring forth newer triumphs of art and science.

And what is the nature of this element destined to work these changes, whence comes it, and why its meteoric appearance during the past few years? The story, fascinating and true, of discouragement and triumph, luck and toil, so interwoven as to both charm and instruct, cannot be told here. The cold, bare facts must suffice.

Vanadium is one of the seventy odd elements making up the crust of this old earth. It is widely distributed, though only in minute quantities. Some of it is found in the lead vanadates of Northern Spain and in Swedish iron ores, while it is scattered here and there in the vanadates and sandstones of our Western States. Its initial use was confined to the making of aniline dyes and to some extent in glass-tinting. The discovery that the extraordinary properties of Swedish iron were due to the presence of vanadium attracted the attention of metallurgists, who patiently and with unremitting zeal, despite the scanty commercial supply of vanadium, evolved a series of steels having strength and life far beyond their most sanguine expectations.

Vanadium would have remained of academic interest only had not a vast and immensely rich deposit of the ore, sufficient to provide for the world's needs for many years, been found three years ago near the top of the lofty Andes in Peru by engineers of the American Vanadium Company.

With this discovery came the commercialization of vanadium, the utilization of its potent power in the world's service, the destruction of the steel idols of the past, with their attendant false rules and doctrines, and the adoption of a newer, better and scientific code, making for more orderly and hopeful progress

It must not be expected, however, that under the new dispensation every manufacturer will produce an equally high grade steel, nor that every fabricator will obtain its maximum efficiency, for the more powerful the instrument employed, the more is the personal equation intensified. Caprice has brought as many men to the forge as training and aptitude.

Just as a draft horse is unfit for racing, so the composition and heat treatment of a steel giving marvelous results in a piston rod or crankshaft would be wholly unsuited for a razor blade or a watch spring. Fortunately, years of experiment, research and investigation, amplified by voluminous actual service records have definitely determined the proper method of making vanadium steels, and the special type and treatment giving most efficacious results for a specific requirement.

The intent of this treatise is to guide the consumer in the selection of the type of vanadium steel best adapted to his particular purpose and direct him in the proper heat treatment of such steel, to the end that he may realize the promise that vanadium steel is the nearest approach ever made to the ideal of perfect steel.

Inasmuch as the instructor should always furnish credentials of his learning and experience, a word as to J. Kent Smith, author of the treatise, is in order. Mr. Kent Smith is a trained analyst and metallurgist and a practical steel maker; he has devoted thirteen years to the study of vanadium; he has lectured on his favorite theme before many scientific and trade societies in Europe and America; he has made hundreds of successful heats of various types of vanadium steel in the mills of both worlds, and is universally accorded recognition as the Court of Last Resort in all questions appertaining to vanadium.

AMERICAN VANADIUM COMPANY.

VANADIUM STEELS

Their Classification and Heat Treatment with Directions for Application of Vanadium to Iron and Steel

By J. KENT SMITH

The element Vanadium has within the past few years sprung from the position of a scientific curiosity to that of a metal which, suitably harnessed, has marked an epoch in the history of the steel trade.

The existence of the element was first recognized in 1801, by Del Rio, of Mexico, who named it erythronium. His observations were generally discredited by contemporaneous chemists. Thirty years later Sefström of Sweden found the element in his native iron ores and in honor of one of the Scandanavian deities called it Vanadium.

Several decades passed before the element was isolated by Sir Henry Roscoe, who made a study of its compounds, which were used to a small extent in dyeing, tinting glass, etc., though such use was necessarily costly.

The pure metal is silvery white in appearance and of very high melting point, its value being almost entirely academic. It was observed, however, that an alloy of vanadium and iron in the respective proportions of one to two had a comparatively low melting point and that the judicious use of the element *in small quantity* conferred marvelous properties upon steel. This at once opened the door to its probable utility in the service of man.

A demand having been indicated, a supply was soon forthcoming, owing to the discovery and development of an immense deposit of very high-grade vanadium ore of a type unique even to mineralogists, so that ferro-vanadium is now available as a market article in any quantity. From having a value many times that of gold, vanadium is now, mainly owing to increased production and to improvements in the processes of manufacture of the alloy, procurable at a price (reckoned on its net weight), about half that of silver.

Of necessity, therefore, Vanadium Steels cannot be low-priced in first cost, but in view of the facts that to obtain the best effects it is only necessary to use vanadium in proper combination in "homeopathic" doses, and that vanadium steels are meant to meet requirements with which admittedly the best classes of ordinary steel are powerless to cope—and which even the highest classes of pre-

viously known steels of the most expensive character were unable to successfully meet in many directions—it is evident that owing to the greatly increased demands made by modern engineers, a wide scope is opened out for its use and that this field is daily growing wider.

Useful Strength in Steel

It had been the custom for many years to form an opinion of the qualities of steel by its behavior when subjected to a steady load or a slowly applied bending action, that being considered the best metal which was strong and ductile, stretching greatly before breaking under a steady pull, and bending without breaking. Ductility could be maintained in steels of ordinary composition up to a certain strength, but beyond this the metal became brittle.

Steels were next prepared in which much higher resistance to load could be attained before brittleness was reached, through the use of various alloys. But it soon became apparent that in many cases the ductility thus attained did not necessarily imply a certainty that the metal would behave well under stresses applied in a different manner. Statically ductile steel fractured some-times like glass under the influence of shock, whether so severe as to be termed "overwhelming" in nature, or much lighter and continually repeated, or even under the influence of constant vibration.

The needs of the engineer of to-day demand, with increasing force, strong steel which shall be enduring under such conditions as the latter, and it has become obvious that the same basis of judgment should not be taken literally in indicating the suitability of materials for such widely different purposes as—to take two typical examples—the manufacture of (1) bridges and (2) locomotive connecting rods.

In modern machine construction, especially in those parts which are liable to failure in service, *it is after all "dynamic" superiority that is the essential consideration*, namely, resistance to repeated stresses, to alternating stresses, to simple or repeated alternating impacts, and to fatigue (which latter is the outward visible sign of molecular disintegration). Thus a new field has been opened out and in this field vanadium was found by extended experiment and prolonged practical experience to be preëminent, in fact to stand alone.

Vanadium statically intensifies tremendously the strengthening power of another ingredient, enabling such a small quantity of that ingredient to be used as to not dynamically poison the metal; in itself, it confers remarkable dynamic properties to steel; it retards "segregation," and so renders steel particularly susceptible to the highly important improvements due to tempering; utilizing this same characteristic, steels can be prepared by natural means which are very resistant to wear and erosion; it toughens steel, and confers to it great powers of resistance to torsional rupture; in a word, it endows it with the quality of "life" in practical work.

"Dynamic" Testing of Steel

In the table on pages 40 and 41, dynamic figures shown under the heading of "alternations" were obtained by means of the alternating impact test performed on the Turner-Landgraf machine under strictly standard conditions.

In this form of test, the test piece, held securely at one end in a vise, is moved backwards and forwards by means of a slotted arm which communicates to the piece successive permanent distortions in each direction, such distortion having been produced by means of an impact followed immediately by a pushing motion. As a result, the test piece is fractured finally on the line of the vise, at which point the severest stresses are created. The slotted arm moves on a crank, so that the pushing motion is performed without the interfering factor of "rub," as the slotted arm describes the same arc as the distorted test piece.

It has been objected by some engineers that, as in commercial work they never anticipate the stresses on metal parts to even approach the elastic limit of the metal, this test has no bearing on service conditions. On the other hand, it is universally conceded that the great majority of

service fractures are caused by strains which are repeatedly applied, thus resulting in the molecular deterioration of the metal. Furthermore, it is allowed that the nearer such repeated stresses individually approach in degree the elastic limit, the rate of deterioration is enormously increased. Hence, by submitting a metal to rotary vibration against an overhanging weight, unless the fibre stress thus communicated in each case bears a strict relation to the elastic limit of the metal under investigation, the figures obtained are so obscured as to render the results valueless for purposes of comparison. In addition, many other factors influence the results of a rotary test, such as fluctuation in the rate of rotation, "whipping" of the sample, deviation from true alignment, swinging motion of the overhanging weight, and the method of the initial application of the same, which all tend to further render the results of the test non-comparable.

The function of the alternating impact test is to rapidly tear apart both from each other and in themselves the constituent "crystals" of the metal of the test piece, and as a result, the inherent value of the metal, in resisting molecular deterioration, is obtained. Thus, although the alternating impact test would at first sight appear to have nothing in common with practical conditions, the identical results required for successful service performance are obtained. Without elaborating further on this matter, it will be sufficient to refer any interested persons to the prolific work of Professor Arnold, Professor MacWilliam, Mr. J. T. Milton, Mr. W. L. Turner and many others, on the service value of the test.

It has already been said that the rate of deterioration advances enormously as the conditions are more drastic, and therefore direct readings of the alternation machine should be taken in some measure of geometrical proportion, rather than in arithmetical proportion, in deducing "life" value, as a progressive or detailed fracture is produced in the course of a couple of minutes on the testing machine in question.

Effect of Vanadium

Vanadium steels of numerous types are being made regularly by the progressive steel mills of the world and the properties of the steels obtained fully substantiate the published tests.

Vanadium exerts its power in at least three ways:

1. It indirectly toughens steel owing to its powerful scavenging action, removing oxides, nitrides, etc., in a fusible form easily carried away to the slag. In this respect, it differs markedly from some other deoxidizing alloys.

2. It directly toughens steel mainly by its solid solution, under normal conditions, in the carbonless portion known as ferrite. To succeed in this respect, the alloy must either contain free vanadium, or vanadium combined with some other element which also goes into solid solution in ferrite under normal conditions, such as silicon.

3. It forms complex carbides of such nature as to statically greatly strengthen the steel containing them. These carbides are proved to add more strength to steel when they contain chromium or nickel.

There is no one type of vanadium steel that does all things. It is necessary to make various kinds and grades for different purposes and hereinafter will be found a list of the purposes for which different vanadium steels have been successfully applied, with instructions as to their proper heat treatment to meet specified requirements.

In the tables presented, with regard to composition and heat-treatment, the results have been *mainly* deduced from experience with basic open-hearth Chrome-Vanadium steels and are corroborated by service records and by exhaustive microscopic investigation.

"Atmosphere" Influence in Steel Making

It has long been known that steels of the same analysis but made by different processes, vary considerably in their mechanical properties. No attempt to form any correlation on this point had been made until Prof. F. W. Harbord of London, England, in the latter half of 1907, published carefully observed data on the tensile and hardness investigations of acid Bessemer, basic Bessemer, acid open-hearth and basic open-hearth steels, without, however, attempting any explanation of the observed phenomena. In the ensuing discussion, two suggestions were made: First, that oxidation, and second, that heat of refining, were the cause of the differences. But both suggestions are untenable, as forming the basis of complete explanation in the light of our present knowledge.

Two other possible—and probable—causes of difference are (1) the nature of the atmosphere in which the steel was refined, and (2) the nature of the slag covering the steel bath, and of the material forming the container of the molten steel, with the consequent extent of such atmosphere

being transmitted to the steel bath in radiation or conduction processes.

It is generally admitted that some of the finest possible steels are the product of the coke fired "white" pot. The latter, as has been abundantly proved, is porous to gases, and the atmosphere surrounding the steel must in this case be one of nitrogen and carbonic oxide. The product of a gas fired crucible furnace in which *black-lead* pots are used should be identical in nature, provided the analysis of the material coincides.

In the electric furnace, a somewhat similar atmosphere prevails, and its product is comparable in all ways with the best crucible steel of similar composition, while its units are of much greater dimensions. It is almost entirely the questions of this atmosphere and of complete deoxidation that endow the steel made in the electric furnace with such high attributes, and these are in no way due to the imparting of any especial virtue by the electricity, per se, which is used only as a heating agent. It will thus be seen that the electric furnace is preëminently suited to the production of the highest grades of alloy steel, in which it is a *sine qua non* that a most excellent base be used.

Whatever be the *cause* of difference, however, for given tenacity with regard to similar composition, the writer would place steels made by different processes in the following order of stiffness:

1. Coke fired crucible ("white" or "black lead" pot).
   Gas fired crucible ("black lead" pot).
   Electric Furnace.
2. Bessemer acid.
3. Bessemer basic.
4. Open-hearth acid.
5. Open-hearth basic.

While the product of the Tropenas converter, acid lined, very strongly resembles in nature that of the acid Bessemer, it differs from it in some respects. If there is anything in the question of atmosphere, this is exactly as would be expected.

The production of special steels may practically be limited to the output of the open-hearth and crucible processes.

Heat-Treatment of Vanadium Steel

The term "heat-treatment" is of comparatively recent origin. Strictly, however, it covers processes which have been practiced for many years, namely

Annealing, and
Tempering.

The extension of the term to include such manipulation by heat as will either wholly or partially restore a steel which, owing to mechanical, thermal, or service conditions, has become dangerously crystalline and brittle—a question full of controversy at the moment—should not really enter into the heat-treatment of newly-made or of unused steels.

Before dwelling on the commercial phase of the subject, the ultimate structure of a piece of constructional (or "subsaturated") steel, under normal conditions, will be considered in as elementary and non-technical manner as possible. Such steel consists primarily of iron, with more or less carbon, some sulphur, phosphorus and manganese, and possibly, silicon, nickel, chromium or vanadium, in addition.

The carbon therein contained is combined chemically with a molecular proportion of iron. A molecule of this chemical compound alloys itself with twenty-one atoms of carbonless iron and the resultant alloy is distributed in lumps, or in mesh form, through the main background of carbonless iron. The alloy, or eutectoid, is known technically as pearlite, and the free carbonless iron as ferrite. The precise manner in which this pearlite is arranged in respect to size, plate-like form, regular or irregular distribution, etc., depends to a considerable degree on the nature and amount of "hot work" put on the steel, the rate of cooling, and so on.

Part of the manganese unites chemically with the sulphur (also possibly with some of the silicon) of the steel, the resultant compound forming striae, or globules throughout the mass.

The phosphorus and the remainder of the silicon, and, if used, a large part of the nickel, are dissolved in the ferrite, in the form known as "solid solution."

Chromium is found as a constituent of the pearlite.

Vanadium is found partly in solid solution in the ferrite, (free and constituent in the pearlite), which it toughens, and partly in the carbide portion of the pearlite, which it strengthens.

If heat be applied to a bar of normal steel, it will become sensibly hotter with each successive increment of heat up to a given point. Thereupon further application of heat causes a molecular rearrangement instead of increasing the sensible temperature of the steel; the pearlite becomes broken up, its carbides going into solid solution in the ferrite. When such decomposition and solution are complete, sensible temperature of the steel again rises as heat is applied.

In cooling the steel, the converse takes place. To a certain point, the steel cools regularly; then it apparently ceases to cool, its dissolved carbides being thrown out of solution, and alloying themselves with ferrite to reform pearlite. When the carbides are completely thrown out of solution, sensible cooling again regularly proceeds.

Such is a brief explanation of the phenomena of calescence and recalescence.

The object of annealing is to break up the carbide areas and distribute the same in small colonies. Wherefore, the steel should be heated above the calescence point, this temperature being maintained long enough to thoroughly decompose the pearlite, as well as to remove any strains that may have been locked up in the mass during mechanical operations; it should then be allowed to cool slowly through the recalescence point, due precautions being taken to prevent chilling, etc. The less sandwich-like the formation of the pearlite thus reformed, and the more granular (or "sorbitic") the colonized carbide areas, the better the annealing.

The general appearance of pearlite in worked, but unannealed steel will be seen in microphotograph No. 1 (the white portion of the photograph represents carbonless iron, or ferrite), while the result of excellent annealing of such steel will be seen in microphotograph No. 2, page 39.

A vanadium ferrite does not permit of the ready passage through it of the carbides precipitated at the recalescence point; therefore the colonization of carbides in such steel is much less complete and their distribution better; consequently, the toughness and tenacity of the steel is increased, irrespective of the added toughness of the background of vanadium ferrite. Exemplification of this is shown in microphotograph No. 3, page 42.

If the steel heated above the calescence point (when it contains all its carbides in solid solution), be subjected to very quick cooling, so that no chance is given for the deposition or reprecipitation of its dissolved carbide, a new body is formed known by the generic term "martensite"; in

other words, martensite may be said to consist of a frozen solution of carbides in ferrite. In its nature, this body is brittle and intensely hard. The intensity of its hardness, however, naturally varies both with regard to the nature and amount of carbides contained in the frozen solid solution, and to their rate of freezing.

For most machinery purposes, it is better to make this sudden abstraction of heat by quenching in an oil bath. Quenching in water certainly results in the quicker abstraction of heat and in the formation of a more intense martensite, but water quenching is very apt to give rise to the formation of small (they may be microscopically small) cracks, which militate severely against the useful performance in service of the steel which has undergone this process of quenching.

Under certain conditions, oil may be replaced, with more or less advantage, by different aqueous solutions; this course is resorted to when it is desired to impart a more intense hardness to the material than can be attained by quenching in oil and at the same time to avoid the formation of the minute cracks due to ordinary water-quenching.

In passing, it should be noted that steels containing considerable quantities of chromium and manganese together are particularly liable to give rise to cracks when quenched in water.

The typical martensitic structure obtained by quenching Type A Chrome-Vanadium steel in oil from 900 degrees Centigrade, is illustrated in microphotograph No. 4, page 42.

Martensite is not a stable "body," its equilibrium being destroyed very much below the calescence point; when subjected to a temperature of about 360 degrees Centigrade, for a period of time sufficient to thoroughly soak through the mass, it is decomposed, its carbides being deposited in situ and soft ferrite liberated as a background. As the temperature applied in this tempering (or "letting down") heat is increased, the carbides begin to flock together, the rate increasing much more rapidly as the tempering heat is augmented.

Microphotograph No. 5, page 43, illustrates the tempering of the steel illustrated in microphotograph No. 4, by the immersion at 550 degrees Centigrade, for fifteen minutes, of a 1¼ inch round bar.

Microphotograph No. 6, page 43, shows the flocking together of the carbides on increasing the temperature, this being precisely the same steel shown in microphotographs Nos. 4 and 5, except that the tempering heat was continued to 630 degrees Centigrade.

At the calescence point the deposited carbides once more go into solid solution, and are again precipitated on cooling the steel; if such cooling be slow, the phenomena of an annealed steel are obtained. Hence, it will be seen, that the oil tempering operation, which consists essentially of the two processes of quenching and of letting down (or drawing back), must be practiced so that the letting down is never performed at or above the calescence point, otherwise the virtues due to the oil tempering are entirely lost.

It would be well to observe in connection with this drawing back, or letting down, process, that it can be accomplished elegantly at low temperatures in an oil bath kept at the requisite temperature by means of a fire or gas burner.

An excellent way of drawing back small quenched articles, which are required to be let down at a higher temperature than is consistent with the use of hot oil, is to immerse same in a bath of molten lead, which latter is kept at the desired heat by means of a fire.

Drawing back may also be accomplished, for both large and small articles, by immersion in a furnace which is *already at the desired temperature, maintaining such heat during the prescribed period.* The recalescence points of similar steels, made by the different processes hereinbefore mentioned, being substantially the same, the annealing treatment recommended is applicable in all cases. When it comes to temper, however, three facts must be considered:

1. That the stiffer steels when quenched form more intense martensites.

2. That some quenching liquids are more drastic than others.

3. That the more intense the martensite, the more decomposing it takes, other things being equal.

In the treatments hereinafter recommended, the figures given are with respect to quenching in lard oil, or a mixture of lard and fish oils, which mixture will be found very satisfactory.

The oil is generally contained in a tank which is water cooled, so that the temperature of the bath is usually about 50 or 60°C, or in some cases, possibly a little higher. It is not absolutely necessary that lard and fish oils be used alone, as it is admissible to add a considerable quantity of cotton seed oil, etc., but the characteristics of such mixture of lard and fish oil should be adhered to as much as possible; for example, the admixture of any class of medium-thin paraffin oil would not be recommended.

A more drastic quenching liquid than the above, would be cold water, which, however, for reasons already explained, is not recommended for structural steels, while iced brine and quicksilver are still more drastic in their cooling action. Even in the case of cold water, the temperature from which the steel is quenched must be about 50°C to 150°C less (always keeping it above the calescence point, of course) than if the quenching were done in oil, in order to obtain the same degree of martensitic formation.

It is apparent that if absolutely the same composition be followed irrespective of the process of manufacture, as the stiffer steels form martensites which require more breaking up, the drawing-back temperatures in tempering should be correspondingly somewhat higher, or the quenching temperatures somewhat lower, or both, so that the final results may in each case be equal. Similar remarks apply if two steels be made by the same process, one of which is somewhat stiffer than the other owing to composition.

Conversely, if quenching and drawing-back temperatures are kept constant, then the figures on the table which apply to the composition of basic open-hearth steels must be modified somewhat in their stiffening elements, according to the process of manufacture, so that the final results be the same.

Such modifications in composition are approximately given in tabular form.

The stiffening elements may be said to be Carbon, Manganese, Chromium, and part of the Vanadium. It is assumed that the Phosphorus and Sulphur, the former especially, remain reasonably low in every case.

Taking an example: If acid Type D Chrome-Vanadium spring steel be made, and is to be subjected to the heat-treatment indicated in the table, the carbon should be kept in the neighborhood of .40%, the chromium should be kept down to but little over 1%, while the manganese content should be about .80%. If on the other hand, the Type D composition shown on the table for basic open-hearth steel be used in the case of acid steel, the quenching in oil of the resultant spring bar should be done from a temperature of about 850°C and the drawing-back performed between 450°C and 550°C.

Comparative Compositions
(Approximate)

	ACID	BASIC	CRUCIBLE
TYPE "A," REGULAR			
Carbon	.23%	.27%	.21%
Manganese	.40%	.45%	.40%
Chromium	1.00%	1.00%	1.00%
Vanadium (contained)	.16%	.16%	.16%
TYPE "A," MILD			
Carbon	.20%	.23%	.18%
Manganese	.35%	.40%	.35%
Chromium	.90%	.90%	.90%
Vanadium (contained)	.14%	.14%	.14%
TYPE "A," FULL			
Carbon	.26%	.30%	.24%
Manganese	.48%	.50%	.48%
Chromium	1.00%	1.00%	1.00%
Vanadium (contained)	.18%	.18%	.18%
TYPE "B"			
Carbon	.15%	.18%	.13%
Manganese	.27%	.30%	.25%
Chromium	.50%	.50%	.50%
Vanadium (contained)	.12%	.12%	.12%
TYPE "C"			
Carbon	.17%	.20%	.15%
Manganese	.35%	.40%	.35%
Chromium	.80%	.80%	.80%
Vanadium (contained)	.16%	.16%	.16%
TYPE "D," REGULAR			
Carbon	.41%	.47%	.38%
Manganese	.80%	.90%	.80%
Chromium	1.10%	1.25%	1.10%
Vanadium (contained)	.18%	.18%	.18%
TYPE "D," MILD			
Carbon	.35%	.40%	.33%
Manganese	.75%	.85%	.75%
Chromium	1.00%	1.10%	1.00%
Vanadium (contained)	.16%	.16%	.16%

Comparative Compositions—Continued

	ACID	BASIC	CRUCIBLE
TYPE "E"			
Carbon	.09%	.13%	......
Manganese	.20%	.25%	......
Chromium	.30%	.30%	......
Vanadium (contained)	.12%	.12%	......
TYPE "F"			
Carbon	......	.09%	......
Manganese	......	.20%	......
Vanadium (contained)	......	.12%	......
TYPE "G"			
Carbon	.55%	.60%	......
Manganese	.60%	.65%	......
Chromium	1.00%	1.10%	......
Vanadium (contained)	.18%	.18%	......
TYPE "H"*			
Carbon	......	.....	.85%
Manganese	......	.....	.45%
Chromium	......	.....	1.00%
Vanadium (contained)	......	.....	.25%
TYPE "J" (STEEL CASTINGS)			
Carbon	.25 to .30%	.....	......
Silicon	.25%	.....	......
Manganese	.50 to .60%	.....	......
Vanadium (contained)	.20%	.....	......
TYPE "K"			
Carbon	......	.....	.45%
Manganese	......	.....	.30%
Chromium	......	.....	1.00%
Vanadium (contained)	......	.....	.20%

Remarks

*Type "H" is specially intended for cutter work and would be modified, mainly as to its carbon percentage, in order to make it suitable for other work, such as saws, etc., while in some cases its Manganese content would be also lowered.

All steels to be as pure as possible from sulphur and phosphorus. The sulphur percentage may go to .035% without detriment.

With phosphorus at .02% the silicon may be .1% in types "A," "B," "C," and "E," and .15% in type "D."

With phosphorus at .03% the silicon should not exceed .07% in types "A," "B," "C," and "E," and .1% in type "D."

In type "F" the silicon should be as low as possible. In type "G" it may go up to .2% and in type "H" to .15% under normal conditions.

In these compositions the vanadium given in each case is that which should be contained in the steel.

From the earlier remarks it will be seen that an extra amount of vanadium must be *added* in order to cleanse the steel; this vanadium vanishes to slag in combination with the constituents from which it purges the steel.

Under normal conditions of good melting, it would be safe to assume that the finished metal in the furnace would contain rather less than .01% of nitrogen and about .02% of oxygen. To provide for this amount of nitrogen and oxygen, about .07% of vanadium (reckoned on the weight of the steel) would be required, but .10% of vanadium is quite commonly wanted to scavenge openhearth steel which has been well deoxidized by ordinary means.

In a steel of ideal properties it is a certainty that composition must play the leading "rôle," for though it is possible to manipulate a steel of bad composition so that it fulfils a few of the requirements of a good steel, it is impossible by simple (or complex) "faking"—to use the term of Professor Arnold in this connection—to attain them all. Given the necessary composition, both the processes of manufacture and treatment of the product must be carefully carried out to ensure success, and in a steel of new composition these may deviate somewhat from routine practice as applied to ordinary steel. Hence something further is required after the matter of composition is settled.

Heat Treatments

Based on Compositions given on page 29, etc.

No. 1. Anneal at 800°C for one or two hours, cooling slowly in air, in ashes, or even in the furnace, according to the nature of the piece, the cooling process being made to take place more slowly with smaller pieces, as such small pieces do not contain any body of heat.

No. 2. Quench from 900°C in oil and anneal ("let down" or "draw back") the quenched piece at 550°C for one-half to two hours according to size of piece. Cool in air.

No. 3. Quench from 900 to 950°C in oil and anneal at 360°C for one-quarter to one-half hour. Cool in air.

No. 4. Quench from 875°C in oil and draw back at 400 to 450°C. Cool in air.

No. 5. Quench from 850°C and draw back at 550°C. Cool in air.

No. 6. This number represents the special tool tempering treatment which is applied in ordinary circumstances to the nature of the same tool when made from ordinary steel.

No. 7. Case Hardening Process: The essential feature of case-hardening involves not only the production of a body having a hard outside, but of one which at the same time has a strong and tough core. Thus it will be seen that no tempering steel should be case hardened, for as the practically final process of case hardening involves a quenching treatment, such steel would become hard right through. Taking advantage of the comparatively slow transition of carbides through a vanadium ferrite, and of the strong nature of vanadium ferrite interspersed with well emulsified vanadium sorbite, and further of the comparatively tough nature of vanadium martensite, the type "E" Chrome-Vanadium steel is particularly suited to the case-hardening process. The raw steel is essentially a mild steel and is illustrated in microphotograph No. 7, page 44, while a piece cut from the core of the cased and quenched article made from this steel is structurally illustrated in microphotograph No. 8, page 44. The strong similarity of microphotographs No. 6 and 8 show that by quenching this type "E" steel a physical result is obtained which is almost exactly comparable with slightly over-tempered type "A" Chrome-Vanadium steel, and this similarity is further evidenced by the results of many tests made in the mechanical laboratory.

The best case-hardening process will be found by proceeding on the following lines:

The rough machined material is annealed, *irrespective of its softness*, in order to remove all strains imprisoned therein through the mechanical processes of forging or rolling. This is a very important item, as the first time the article is subjected to sufficient heat, these strains are liberated, and distortion ensues; consequently, if the piece has already been machined to dead size and the strains are liberated by means of the casing heat, the quenching process fixes this distortion permanently. After such annealing, the

article is machined to finished size and is packed in the carburizing material. Many good carburizing materials are to be found: bone, bone-dust, hydro-carbonated bone, good charred leather, and a mixture of charcoal and carbonate of baryta all being suitable. Great things are claimed for the last named, especially in France, on account of its declared regularity of penetration, but it would seem that its use is principally in the direction of the cementing of large articles, such as plates, etc. It is the consensus of opinion that the best carburizing agents are nitrogenous; nitrogen compounds probably assist the carburizing either by the promotion of secondary reactions, or as some contend, through their lowering action on the transformation point of iron. Small amounts of nitrogen, pure and simple, are absorbed or occluded from them by the iron to be cased but such nitrogen is expelled by the reheating preceding quenching. It is important that the carburizing material should be thoroughly dried, evenly sized and free from all admixture of earthy or metallic impurities. The luting of the box containing the packed articles should be done with *clay which is absolutely free from grease*. The box and its contents are then heated to 1000°C and kept there as long as may be necessary; it is impossible to *fix* any given time, as naturally this must be regulated from practical experience, taking into consideration the contour of the article to be cased, its size, and the depth of casing desired.

The box and its contents are allowed to cool, the articles removed, brushed and reheated in an atmosphere as non-oxidizing as possible, to 850°C, when they are plunged in clean cool water. The article thus quenched is thrown into hot oil and kept at a temperature of about 200°C to 250°C for some time in order to release some of the strains caused by quenching. This oil warming does not appreciably interfere with the surface hardness of case hardened machinery steels, but it relieves imprisoned strains very considerably.

Trials made on test bars of open-hearth basic steel of the type above shown showed the following typical figures—in the soft condition:

Elastic limit, lbs. per sq. in...	43,650
Tensile strength, lbs. per sq. in.	70,780
Elongation in 2″	31%
Reduction of area	74.8%

Bars of 1⅛ and 1¼″ diameter were cleaned and cased as recommended. The case-hardened bars were subjected to load until the outer surface was cracked; the bars had then taken a very appreciable bend, although the case hardening had

penetrated at least one millimeter. The bars were then broken; sharp corners of the case would easily scratch glass. The hard casing was next ground away and as soon as a portion was obtained sufficiently soft to be machined were turned down to the ordinary shaped tensile test-piece, and also to round rods about one-half inch diameter. Tensile test of the actual cores showed the following figures:

Elastic limit, lbs. per sq. in...	81,000
Tensile strength, lbs. per sq. in.	103,000
Elongation in 2″	20%
Reduction of area	60%

In each case the machined half-inch rounds from the core bent double cold.

Other bars were deeply cased and a photograph (three times natural size) of such a bar, fractured, is shown on page 61.

Rounds were also case-hardened and were beaten out cold to rectangular shape. The casing, although shattered, adhered to the soft core. The photograph on page 62 (three times natural size) shows a piece treated in this way.

The dynamic figure under alternating impact was exceptionally high when the steel was in the soft condition; quality figures deduced from the static tests and the alternating impact tests on the Turner formula gave the high quality figure of approximately 6000, while the "core" gave a correspondingly high quality figure.

In the foregoing, all temperatures quoted were determined by the electric pyrometer. The appended table gives the approximate color valuations of these temperatures in the diffused daylight of the ordinary shop. The temperatures generally enunciated in the pocketbooks as corresponding to various color shades should on no account be taken, as they are based on the fallacy that the specific heat of iron is constant for all temperatures, which is now known to be a grossly mistaken view.

Approximate Correlation of Color Temperature

As Viewed in the Diffused Daylight of the Ordinary Shop, with the Reading of the Electric Resistance Pyrometer

Black red (just visible)	About 500°C
Dull blood red	" 550°C
Warm blood red	" 600°C
Cherry red	" 700°C
Very full cherry red	" 800°C
Light red, merging from very clear cherry	850 to 900°C
Orange to light yellow	1000 to 1100°C
White	1200°C
Throwing off sparks, i.e., scintillating heat of fairly mild steel	" 1300°C
Melting point of mild steel	" 1520°C
Not determined by electric resistance.	

PLATE 1. All microphotographs from etched transverse sections, vertically illuminated and magnified 360 diameters

Fig. 1

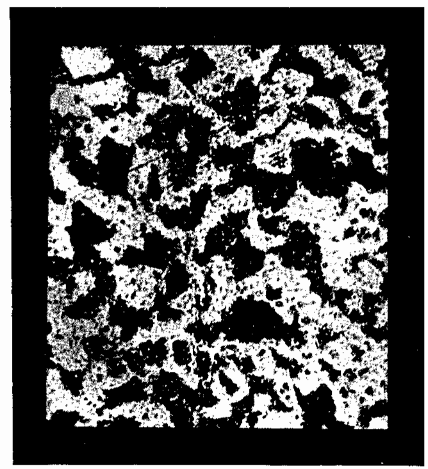


Fig. 2

OFFICE OF THE

American Vanadium Company

Frick Building, Pittsburg, Pennsylvania

Results of some comparative tests made on all grades of Steel to determine relative strengths and properties of fatigue resistance

The results on each Steel are collectively combined into a "Quality Figure"

No.	Steel	Heat Treatment	Approximate Chemical Analysis C.	Mn	Cr.	Ni.	V.	Static Figures Elas'c Limit (E)	T'sile Stress	Ratio El/TS %	El'g %	Red Ar. % (R)	Dynamic Figs. Alternations (A)	Quality Figs. E x R x A / 10^6	Process of Manufacture	Remarks
	ELASTIC LIMITS—30,000—60,000															
1	Mild Vanadium Steel	Annealed	.11	.31	...	....	.19	32,120	54,400	59.0	44.0	60.1	1111	2143	Open Hearth	
2	Old Boiler Plate	Raw	.24	.42	...	....	....	58,160	70,840	82.1	25.5	53.4	612	1901	Open Hearth	Scrapped After Service
3	Mild Carbon Steel	Annealed	.18	.40	...	....	....	39,460	60,650	65.1	35.0	62.6	871	2152	Open Hearth	
4	" " "	O.T. 900/425	.18	.40	...	....	....	45,390	70,030	64.6	33.0	64.0	777	2258	Open Hearth	Shafting Steel
5	Carbon Forging Steel	Annealed	.26	.28	...	....	....	43,010	61,850	69.5	34.0	63.4	1415	3858	Open Hearth	Specially Selected
6	" " "	O.T. 900/550	.26	.28	...	....	....	52,230	77,310	67.5	28.0	65.3	1175	4008	Open Hearth	
7	Vanadium Case Hardening Steel	Annealed	.15	.25	.30	....	.12	44,790	51,990	80.0	45.0	69.0	1958	6051	Open Hearth	Sliding Gear Steel
8	Chrome-Nickel Steel	Annealed	.36	.34	.95	1.70	....	56,520	81,370	69.5	32.0	68.5	978	3787	Crucible	
9	Carbon Steel Casting	Annealed	.18	.65	...	....	....	34,690	58,800	57.0	28.0	44.9	269	419	Acid Open Hearth	
10	Vanadium Steel Casting	Annealed	.19	.60	...	....	.076	44,340	70,250	63.0	25.5	44.9	850	1671	Acid Open Hearth	{ Used for Car Wheels
11	Cr-Va.-Steel Casting	Annealed	.57	.68	.75	....	.16	52,330	92,900	56.3	16.0	20.5	656	704	Basic Open Hearth	{ (NB—High Carbon Steel)
	ELASTIC LIMITS—60,000—100,000															
12	Nickel Forging Steel	Annealed	.21	.45	....	3.70	....	61,140	79,700	76.7	30.0	62.5	746	2851	Basic Open Hearth	
13	" "	O.T. 900/550	.21	.45	....	3.70	....	77,140	98,470	78.3	25.0	65.3	664	3345	Basic Open Hearth	
14	Chrome-Vanadium F'ging Steel	Annealed	.26	.50	1.00	....	.16	61,920	92,900	66.6	25.0	57.3	1608	5706	Basic Open Hearth	Known as Type "A"
15	Carbon Spring Steel	Annealed	1.00	.30	....	....	....	63,800	125,000	51.0	8.5	15.2	1260	1222	Open Hearth	
16	Chrome-Vanadium Spring Steel	Annealed	.40	.77	1.22	....	.19	67,520	100,600	67.1	26.0	61.7	1406	5858	Crucible	Known as Type "D"
17	Chrome-Nickel-Vanadium Steel	Annealed	.30	.27	1.51	3.45	.085	69,140	96,880	71.3	28.5	68.5	507	2402	Crucible	Imported Automobile Steel
18	Nickel-Vanadium Steel	Annealed	.24	.72	....	3.40	.15	79,260	99,700	79.5	25.0	64.0	798	4048	Basic Open Hearth	
19	Chrome-Nickel Vanadium Steel	Annealed	.57	.27	.93	2.04	.07	95,150	129,100	73.7	21.0	49.8	983	4659	Crucible	
20	Chrome-Nickel Steel	Tempered	.37	.34	.89	1.70	....	86,080	102,700	83.8	22.0	63.8	702	3855	Crucible	
	ELASTIC LIMITS—100,000 and over															
21	Carbon Spring Steel	O.T. 900/450	1.00	.30	....	....	....	101,000	185,300	54.2	9.5	16.1	561	912	Open Hearth	Spring Temper
22	Chrome-Vanadium Spring Steel	O.T. 900/450	.40	.77	1.22	....	.19	195,300	208,500	93.7	10.0	36.3	480	3403	Acid Open Hearth	Spring Temper Type "D"
23	Chrome-Vanadium F'ging Steel	O.T. 900/550	.30	.50	1.00	....	.16	141,600	151,750	93.0	16.0	56.2	717	5705	Basic Open Hearth	Type "A" Crankshaft Temper
24	Nickel-Vanadium Steel	O.T. 900/550	.24	.72	....	3.4	.15	129,900	134,600	96.4	18.0	64.8	626	5270	Basic Open Hearth	
25	Chrome-Nickel-Vanadium Steel	O.T. 900/550	.30	.27	1.51	3.45	.085	152,300	159,900	95.2	17.0	58.9	487	4369	Crucible	Imported Automobile Steel
26	Chrome-Vanadium Spring Steel	O.T. 900/550	.40	.77	1.22	....	.19	183,400	187,600	97.7	14.0	50.6	634	5883	Crucible	Type "D"
27	Chrome-Nickel Steel	Tempered	.36	.34	.95	1.70	....	134,500	150,300	89.5	15.5	53.5	579	4166	Crucible	

O.T.=OIL TEMPERED

NOTES

STATIC TESTS MADE ON SAMPLES ½″ DIA. X 2″ LONG.
DYNAMIC TESTS MADE ON LANDGRAF-TURNER ALTERNATING IMPACT MACHINE. (OLD FORM)

QUALITY FIGURE IS PRODUCT OF:

ELASTIC LIMIT .... REPRESENTING USEFUL STRENGTH
REDUCTION OF AREA .... REPRESENTING STATIC DUCTILITY
DYNAMIC FIGURE .... REPRESENTING FATIGUE-RESISTING PROPERTY

DIVIDED BY ONE MILLION, OR $\frac{E \times R \times A}{10^6}$ = QUALITY FIGURE

DATA CORRECT. W. L. TURNER, ENG'R OF TESTS. JUNE, 1908

PLATE 2. All microphotographs from etched transverse sections, vertically illuminated and magnified 360 diameters

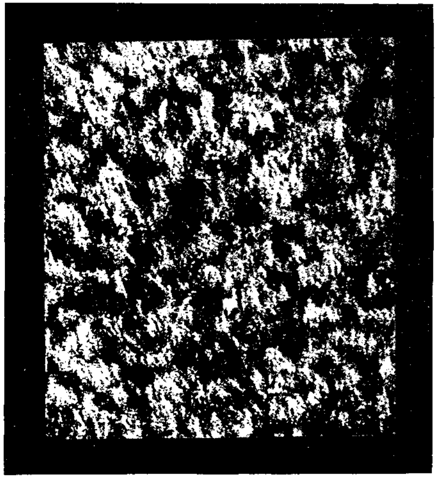


Fig. 3

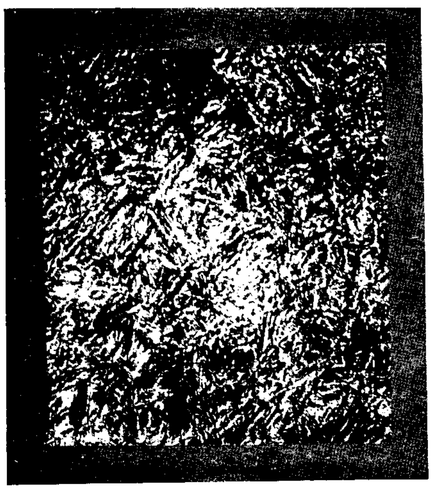


Fig. 4

PLATE 3. All microphotographs from etched transverse sections, vertically illuminated and magnified 360 diameters

Fig. 5

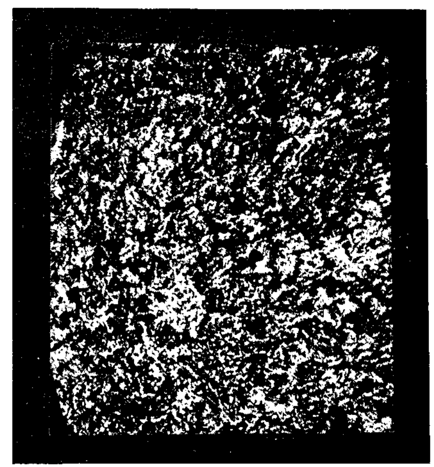


Fig. 6

PLATE 4. All microphotographs from etched transverse sections, vertically illuminated and magnified 360 diameters

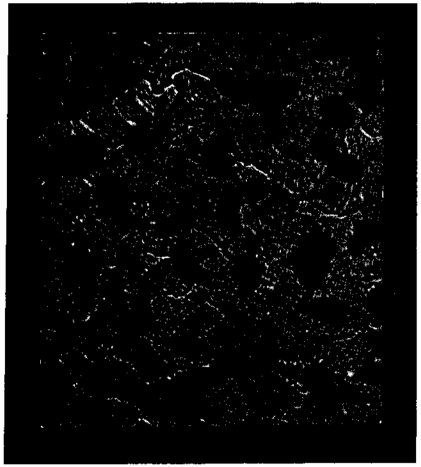


Fig. 7

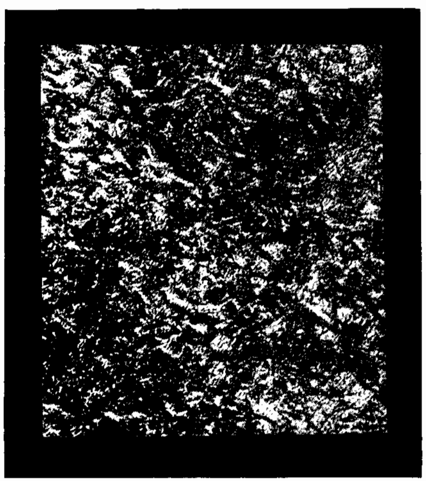


Fig. 8

Some Applications of Vanadium Steel, and the Type and Treatment Recommended for each case

	TYPE	HEAT TREATMENT NO.
A		
Air Reservoirs	A	2
Ammunition Hoists	A	
Ammunition Wagons	A	
Anchors	F	Normal
Angles	A, B, C	"
Armature Shafts	A	2
Armor Plate	Special	
Armor Plate Bolts	A	1
Automobile Boiler Tubes	B or E	Annealed
Automobile Castings	J	Annealed
Automobile Forgings	A, D, E	1, 2, 5 and 7
Axes	H	6
Automobile Axles	A	1 and 2
Electric Car Axles	A	1 and 2
Field Gun Carriage Axles	A	1 and 2
Freight Car Axles	A	1 and 2
"Light" Axles	A	1
Locomotive Axles	A	1 and 2
Passenger Car Axles	A	1 and 2
Tender Truck Axles	A	1 and 2
B		
Ball Mill Plates	H	6
Ball Mill Shafts	A	1
Bars	All types	
Beams	A, B, C	Normal
Bicycle Chains (part)	A	2
Bicycle Tubes	A, B, C	1 and 2
Billets	All types	
Blooms	All types	
Bolts	A, B, C	1
Bridge Pins	A, D	1 and 2
Bulb Angles	A, B, C	Normal
Ball Races	E, H	7 and 6

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
C		
Cables, Wire	A, D	1 and 2
Cam Shafts	E	7
Channels	A, B, C	Normal
Columns, Rolled	A, B, C	"
Condenser Tubes	B, E	1
Couplers	J	Annealed
Crank Pins	A, D	2 and 1
Crank Shafts	A	1 and 2
Crank Webs	A	1 and 2
Cross Heads (Locomotive)	J	Annealed
Yacht Plates	C, A	Normal
Cutlery	H	6
Case Hardening Steel	E	
CASTINGS		
Automobile Castings	J	Annealed
Couplers	J	"
Crank Webs	J	"
Cylinders	J	"
Dredge Bucket Lips	Special	
Frogs and Switches	Special	
Gearing and Gear Wheel Blanks	Special	
Knuckles	Special	
LOCOMOTIVE CASTINGS		
Air Brake Cylinder Levers	J or modified J, annealed	
Bell Cranks		
Brake Beams		
Brake Brackets		
Boiler Pads		
Buffers		
Cross Heads		
Cross Head Shoes		
Cross Head Arms		
Cross Braces		
Cab Brackets		
Cylinder Heads		
Centre Plates		
Driver Brake Levers		
Driving Boxes		

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
LOCOMOTIVE CASTINGS, Con.		
Driving Box Beams	J or modified J, annealed	
Driving Wheel Centres		
Draw Heads		
Engine Frames		
Engine Truck Frames		
Engine Truck Centre Pin Guides		
Engine Truck Swing Bolsters		
Engine Truck Swing Links		
Equalizer Beams		
Eccentrics		
Eccentric Straps		
Fire Box Mud Rings		
Foot Plates		
Frame Stiffening Pieces		
Frame Braces		
Fulcrum Shaft Bearings		
Fulcrum Castings		
Guide Yokes		
Guide Yoke Knees		
Grate Shaft Bearings		
Link Motion Supports		
Lift Shafts		
Pilot Frame Ends		
Pilot Frame Tops and Bottoms		
Pedestals		
Pistons		
Rocker Arms		
Rocker Boxes		
Reverse Shafts		
Runboard Brackets		
Rubbing or Chafing Irons		
Radial Bar Cross Tie Caps		
Side Bearings		
Spring Rigging Posts		
Spring Saddles		
Spring Seats		
Spring Hanger Plates		
Scoop Levers		

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
LOCOMOTIVE CASTINGS, Con.		
Steam Chests	J or modified J, annealed	
Transmission Bars	J or modified J, annealed	
Trailing Truck Brakes	J or modified J, annealed	
Levers	J or modified J, annealed	
Pan Bottom Segments	J or modified J, annealed	
Pan Scapers	J or modified J, annealed	
D		
Deck Plate	Special	
Die Rings	K	6
Dies	K	6
Discs	All types	
Dredge Bucket Lips	Special	
Drop Forgings	All types	
Driving Axles	A, D	2 and 1
E		
Eccentric Rods	A	1
Eccentric Shafts	A	1
Electric Car Axles	A	1 and 2
Electric Car Construction	All types	
Eye Bars	A	2
F		
File Steel	H	6
Feedwater Heater Tubes	A, B	1
Field Gun Carriage Axles	A	2 and 1
Fire Box Plate	E (mild)	Normal or Annealed
Flats	All types	
Freight Car Axles	A	1 and 2
Frogs and Switches	Special	
FORGINGS		
Automobile Forgings	All types	
Drop Forgings	"	
Locomotive Forgings	"	
Stationary Engine Forgings	"	
Marine Engine Forgings and Pins	"	

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
G		
Gas Engine Construction	All types	
Gearing and Gear Wheel Blanks	A, D, E	2, 3, 5, 6, 7
Girders	A, B, C	Normal
Grinding Mill Tires	G	6
Gudgeon Pins	E	7
Guns	A, D	1, 2 and 5
Gears—Clash	E	7
Gun Barrels	A, D	1, 2 and 5
Gun Forgings	A, D	As required
Gun Hoops	A or D	"
Gun Shield	Special	
H		
Hammer Piston and Hammer Piston Rods	A	1
Holding Down Bolts for Gun Mounts	B	Normal
Hollow Piston Rods	A	1
Hollow Shafting	A, B, C	1 and 2
Hydraulic Cylinders	Special	
I-K		
I-Beams	A, B, C	Normal
Keys	A, D	As required
Knuckles	Special	
L		
Locomotive Axles	A	1
Locomotive Boiler Plate	B, E	Normal
Locomotive Castings	J	Annealed
Locomotive Piston Rods	A	1
Locomotive Stay Bolts	F	Normal
Locomotive Tires	G	As required
LOCOMOTIVE FORGINGS		
Axles	A	1 and 2
Connecting Rods	A	1
Crank Pins	A, D	2 and 1
Cross Heads	J	Annealed
Guides	J	Annealed

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
LOCOMOTIVE FORGINGS, Con.		
Pedestal Cap Bolts	B	Normal
Piston Rods	A	1
M		
Marine Boiler Plate	B, E	Normal
Marine Boiler Tubes	A, B, C, E	Annealed
Marine Engine Piston Rods	A	1
Magnet Steel	Special	
MARINE ENGINE FORGINGS AND SHAFTING		
Connecting Rods	A	1
Crank Pins	D, A	1 and 2
Crank Shafts	A	1 and 2
ORDNANCE		
Gun Forgings	A, D	2 and 1
Gun Shields	Special	
Projectiles	Special	
Rifle Barrels and Small Arms	A, D	2 and 1
P		
Passenger Car Axles	A	1
Pedestal Cap Bolts	B	Normal
Pinions	A, D, E, G	As required
Pneumatic Tools	Special	"
Projectiles	Special	
Propeller Shafts	A	1 and 2
Punches	K	6
PISTON RODS		
Locomotive Piston Rods	A	1
Marine Engine Piston Rods	A	1
Stationary Engine Piston Rods	A	1
Steam Hammer and Rock Drill Piston Rods	A	1
PLATE		
Artillery Plate	Special	

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
PLATE, Con.		
Boiler (Marine, Locomotive and Stationary) Plates	B, E	As required
Deck, Hull and Ship Plates	A, B, C	Normal
Fire Box Plates	E	Normal
Protective Deck Plates	Special	
Armor Plate	Special	
R		
Rails	Special	
Rail Frogs and Switches	"	
Rifle Barrels and Small Arms	A, D	2 and 1
Rivets	A, B, C	Normal
Rods	All types	
Rope	A, D	As required
Rounds	All types	
Rotary Rock Cutters	H	6
ROLLED MATERIAL		
Bars	All types	
Billets	"	
Blooms	"	
Flats	"	
Rounds	"	
Slabs	"	
Squares	"	
Safe Deposit Vaults	Special	
Sheets	All types	
Shells	Special	
Ship Plate	A, B, C	Normal
Side Rods	A	1
Spindles	D or K	6
Springs and Spring Steel	D	4
Squares	All types	
Stationary Boiler Plate	A, B, C	Normal
Stationary Engine Forgings	All types	As required
Stationary Engine Piston Rods	A	1
Stay Bolts	F	Normal
Steam Hammer and Rock Drill Piston Rods	A	1

Some Applications of Vanadium Steels—Continued

	TYPE	HEAT TREATMENT NO.
ROLLED MATERIAL, Con.		
Stern Wheel Shafting	A, D	2 and 1
Structural Steel	All types	
Superheater Tubes	B, E	1
Shear Knife Steel	D, K, H	6
Saw Steel	H	6
Switches	D and Special	
T		
T-Bars	All types	
Tanks for Compressed Oxygen, Carbonic Acid, Hydrogen, Etc.	A	1 and 2
Tender Truck Axles	A	1 and 2
Tie Rods	A	1
Tires (Locomotive and Grinding Mill)	G	As required
Tool Steels and Tools	H, K	6
	Special	6
Transmission Parts	A	2
TUBING		
Automobile Boiler Tubing	B or E	Annealed
Bicycle Tubing	A, B, C	1 and 2
Condenser Tubing	B, E	1
Feedwater Heater Tubing	B, E	1
Torpedo Tubes	Special	
Marine Boiler Tubing	A, B, C, E	Annealed
V		
Valve Stem Forgings	A	1 and 2
W		
Watch Springs	D, Special	4
Wheels	D, Special	As required
WIRE		
Cables	A, D	As required
Springs and Spring Steel	D	4
Z		
Z-Bars	All types	

NOTE. In all cases where normal steel is recommended, the product of the mill should preferably be annealed at a dull red heat to remove rolling strains.

Type "A"

This is perhaps the most adaptable of all types of vanadium steel. It has great static strength and ductility, with stupendous resistance to shock and fatigue.

Under trip hammer dies or drawing dies, it works comparably with soft open-hearth steel.

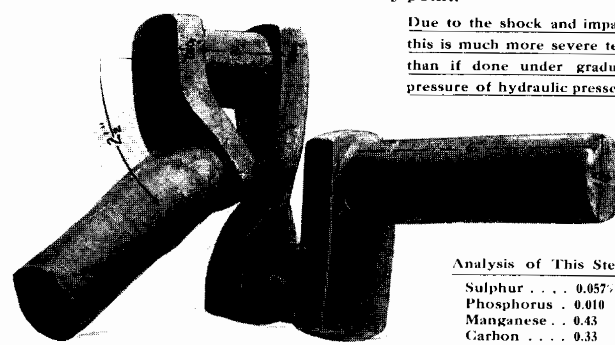
In drop forging, it flows readily in the die, withstands high temperatures without deterioration and takes a high finish.

It is easily machined.

Drop Forged Type "A" Vanadium Steel Crankshaft

Distorted by repeated blows under 2500 lb. Steam Hammer with no sign of a fracture at any point.

Due to the shock and impact this is much more severe test than if done under gradual pressure of hydraulic presses.



Analysis of This Steel

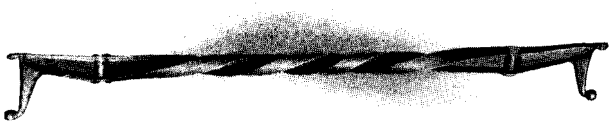
Sulphur	0.057%
Phosphorus	0.010
Manganese	0.43
Carbon	0.33
Chromium	0.96
Vanadium	0.18

An excellent .35% Carbon Steel shaft was subjected to like test but could not be distorted to the same extent without fracture, the force exerted to an equal number of blows being only one-fourth that required to distort the Type "A" Vanadium Steel shaft.

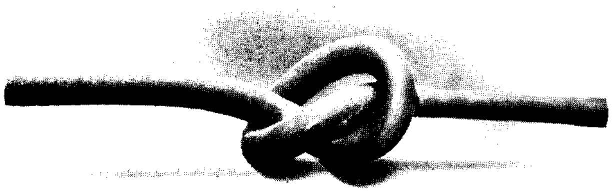
Statically, an untreated bar of Type "A" steel gave the following figures:

Elastic limit, lbs. per sq. inch	106,233
Tensile Strength "	123,070
Elongation in 2", per cent	23.8
Reduction of area, "	49.4

Type "A" Vanadium Steel



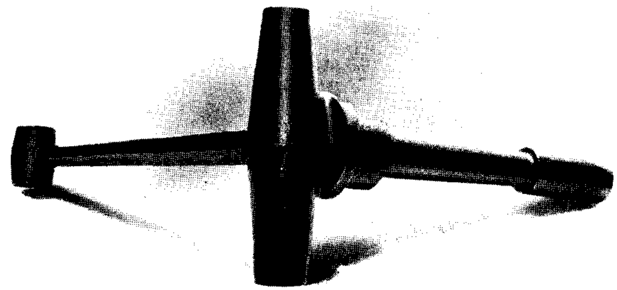
Drop Forged Automobile Axle—Twisted Cold



Knot Tied Cold 1" Diameter Bar

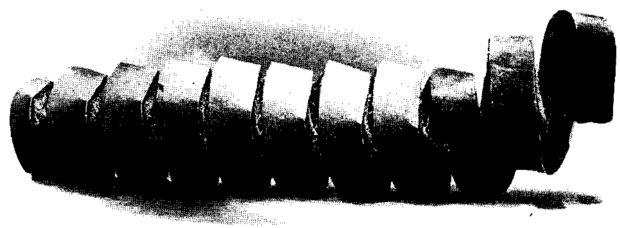
100,000 per square inch *elastic limit*

Type "A" Vanadium Steel



Drop Forged Automobile Steering Knuckle

Maximum diameter of barrel 1⅜", minimum diameter ⅞". Diameter of collar 1⅞". Maximum diameter of shank 1", minimum ⅝". Diameter of shank boss ⅞". Arm length 6½"



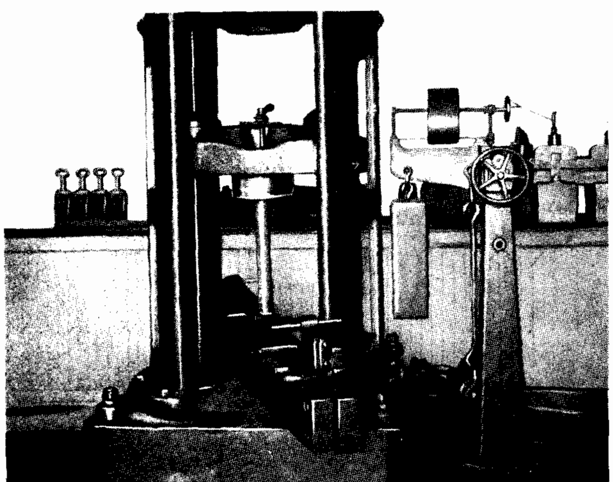
Spring Coil

Steel 9-16"x 7-16"; was hardened in oil and then subjected to crushing test in hydraulic press. It required 210,000 lbs. to distort and over 400,000 lbs. final pressure to bend to present condition. This test was repeated on opposite end of coil without sign of fracture

Type "D"

This type is essentially suited for manufacture of springs, and is also used for gears in constant mesh, rifle barrels, high tensile wire and similar work.

In springs it has double the co-efficient of safe working load of Carbon Spring Steel; it is easily "welded" and in service can be repeatedly over-loaded without serious deterioration; it has an elastic limit of from 180,000 to 225,000 lbs. per sq. in., with tensile strength ranging from 190,000 to 250,000 lbs. Spring makers guarantee it to have three times the life of Carbon Steel springs.



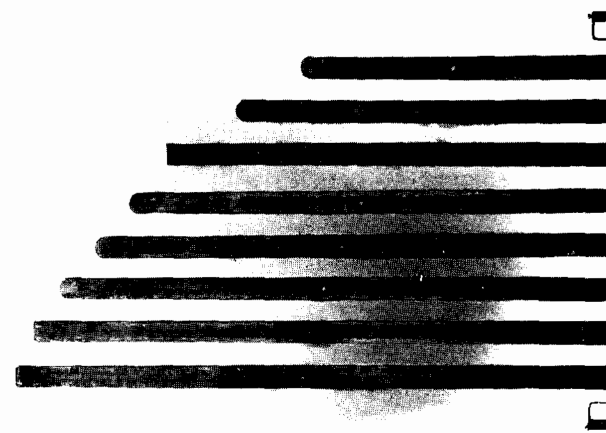
Test of Short Seven-leaf Automobile Spring, showing elastic limit at fibre stress of 214,000 lbs. per square inch

A comparative test of Type "D" vs. Chrome-Nickel Spring Steel:

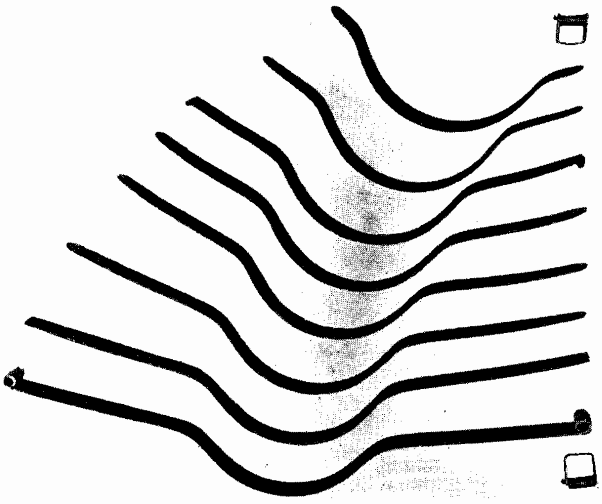
Both test pieces 25″ long, of same width and gauge, with a 4″ arc. In six plunges flat against the face of testing machine—

Type "D" Steel took permanent set of $\frac{3}{16}$″.

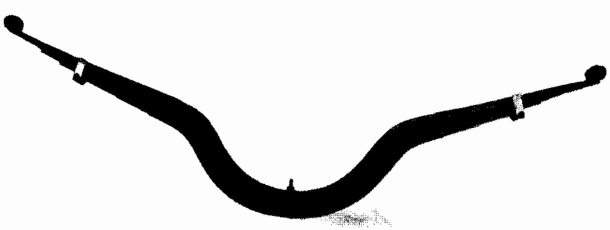
Chrome-Nickel Steel took permanent set of ¾″.



Type "D" Automobile Spring Flats forged ready to form and temper



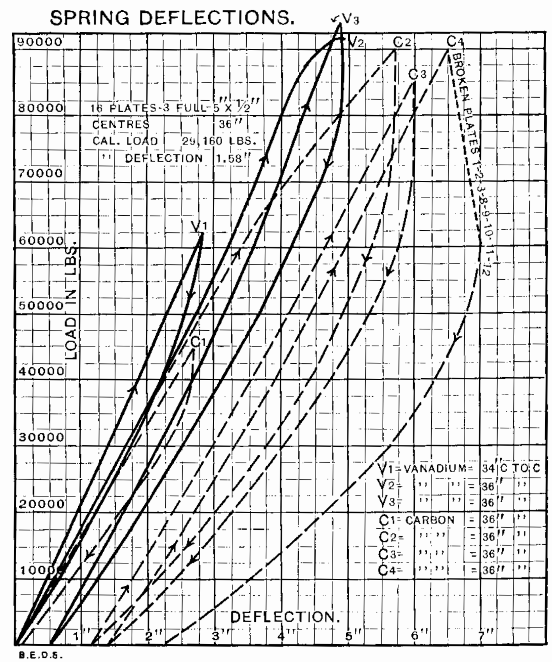
Type "D" Automobile Spring Leaves, formed, tempered and ready to assemble



Type "D" Automobile Spring, finished

Type "D" Vanadium Steel Locomotive Driving Spring

Under load corresponding to stress of 110,000 lbs. per sq. inch, this spring withstood 23,620 compressions.
Under load corresponding to stress of somewhat less than 90,000 lbs. per sq. inch, a Carbon Steel Spring has either broken or the steel became "dead" and lost its camber before reaching 10,000 deflections



Comparative tests of Vanadium and Carbon Steel Locomotive Springs
(Tested by American Locomotive Company)

(See next page)

Spring Tests

(See Curves on page 59).

The Vanadium Spring was Tested:

1. To 62,700 lbs. with 34 inch centres.
2. To 92,000 " " 36 " "
3. To 94,000 " " 36 " "

On Second Test, Elastic Limit was reached at 85,000 pounds, or 234,500 pounds Fibre Stress with Permanent Set of .48 inches.

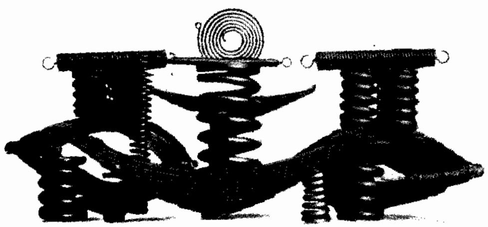
The third test was repeated three times without the least variation from recorded heights.

The Carbon Spring was Tested:

1. To 44,000 lbs. with 36 inch centres.
2. To 89,280 " " 36 " "
3. To 84,520 " " 36 " "
4. To 89,280 " " 36 " "

On Second Test, Elastic Limit was reached at 65,000 pounds, or 180,000 pounds Fibre Stress with Permanent Set of 1.12 inches.

On Third Test it took an additional set of .26 inches, and on Fourth Test, plates 1, 2, 3, 8, 9, 10, 11 and 12 failed at the Centre.

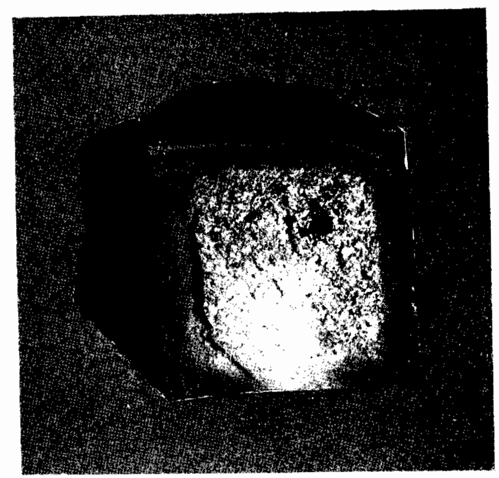


These tests indicate that Vanadium Steel is far superior to Carbon Steel and is particularly to be recommended where the severest service conditions are encountered.

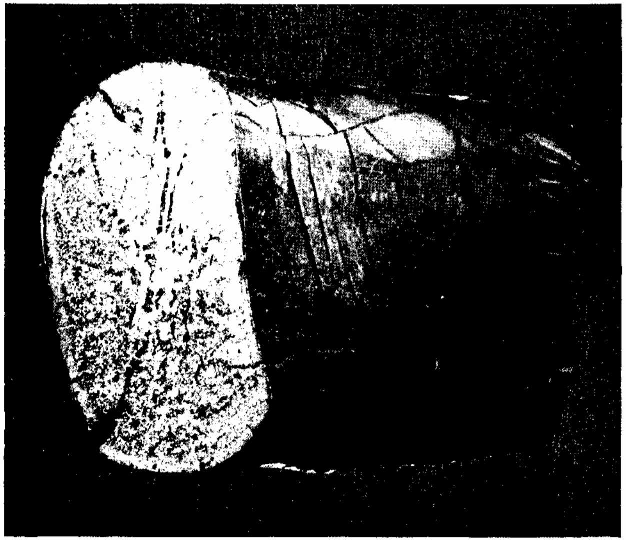
Type "E"

This type of steel is especially designed for case hardening. The essential features of good case hardening steel, the results obtainable from Type "E" case-hardened vanadium steel and the logical reasons involved, have already been fully dealt with on page 33 et seq:

Briefly epitomized, the advantages of Type "E" steel comprise (1) strong case, (2) powerful resistance to abrasion of such case, (3) close cohesion of such case to the softer core, (4) absence of "flaking away" or powdering away of such case, (5) a core which is exceedingly ductile and at the same time has great strength and resistance to disintegration.



Type "E" Vanadium Case Hardened Steel
(3 times natural size)
½" bar case hardened by the process detailed on page 37
Note the tough break of the soft core, in conjunction with the depth of casing for such a small article



Type "E" Case-Hardened Vanadium Steel
(3 times natural size)

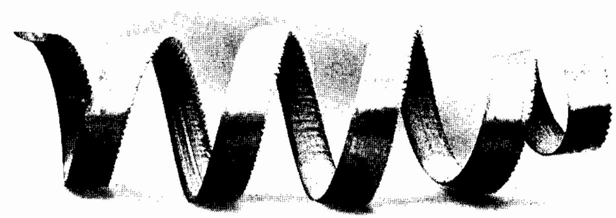
This steel was case-hardened in the perfect round section and after quenching, was beaten out COLD to the shape shown, under a heavy power hammer

Note strong adhesion of the case to the core and the ductile nature of the core

Type "G"

This type is designed for locomotive tires. It has high static strength, and withstands 1260 alternations before fracture under the alternating impact test, or more than double the number withstood by the regular grade of tire steel.

It is very homogeneous and machines quite readily; it combines superlative resistance to wear with an excellent adhesive surface--qualities of the utmost importance in a tire.



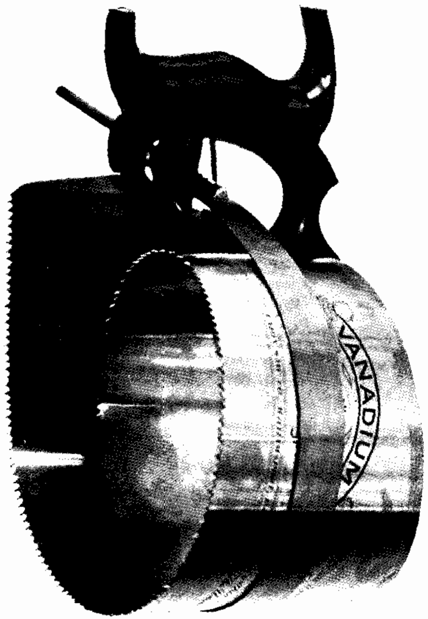
Cutting from Type "G" Vanadium Steel Tire

21″ in length over all; diametrically measured 5½″; width of turning 1¼″ thickness 5-16″ Cut with Rex AA Vanadium High Speed Tool Steel

Type "G" Vanadium Steel

Type "H"

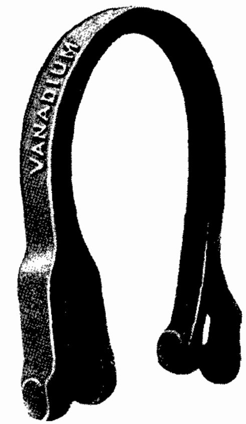
This type of steel is intended especially for cutting tools, such as rotary cutters, etc. With some slight modifications as to Carbon and Manganese content, it is admirably adapted for use in manufacture of saw blades. It tempers accurately and evenly and although hard is extremely tough. Its especial advantages for saws is that the latter will not cramp in the cut; will not develop kinks; can be easily set without danger of fracturing the teeth; will retain the cutting edge more than twice as long as saws made from the regular Carbon Steel; and will hold the set and cut faster than any other saws.



Type "H" Vanadium Steel Saw with blade coiled

After remaining thus for thirty days, the blade was released, and returned to perfect alignment

Steel Castings



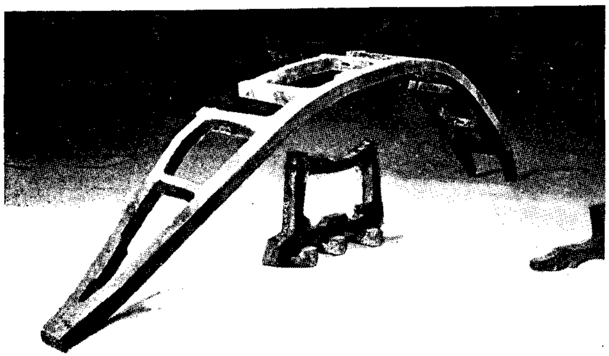
Type "J" Vanadium Steel Locomotive Transmission Bar, *Bent Cold*

Type "J"

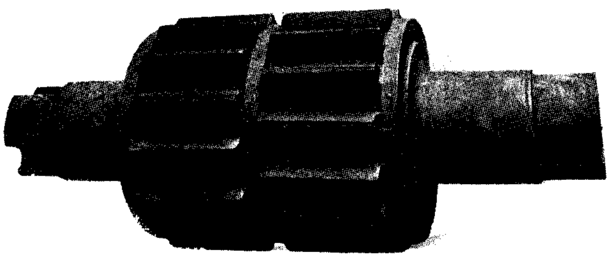
This type of steel is designed expressly for castings, which are thereby rendered solid and more nearly perfect. It pours quietly and freely and is readily welded; it has approximately 25 per cent. increased elastic limit and 15 per cent. greater tensile strength than the regular Carbon steel casting; the ductility is maintained and there is no impairment of the machining qualities.

Type "J" steel is extremely tough and close in structure. It withstands under the Turner formula about the same number of alternations as ordinary forged Steel of the same carbon content, *and twice that of the regular steel casting.*

This latter point is of supreme importance. Almost invariably the service failure of a casting is not traceable to any lack of original static strength and ductility but rather to the fact that it has deteriorated rapidly under the vibration and repeated stresses incidental to its practical usage. It is not claiming too much to say that vanadium steel castings approximate *in "life" quality to forged Carbon Steel.*



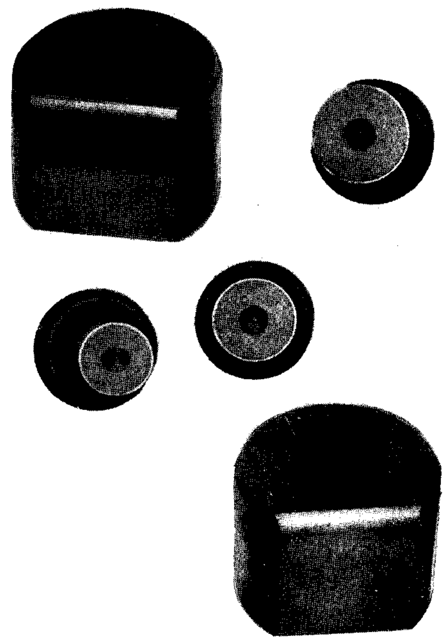
Type "J" Vanadium Steel Engine Frame Section
Subjected to 20 blows from a 5000-lb. tup dropping from a height of 18 ft. in the clear; supports four feet apart
Regular steel frame section invariably breaks on either the first or the second blow



Type "J"–45″ dia. Vanadium Steel Mill Pinion
After working four months under drastic conditions
A 3½% Nickel Steel Pinion, made by the same firm to same pattern, and into companion service in same rolling mill, was worn out completely, while the Vanadium Steel pinion had suffered only to the extent shown in the cut

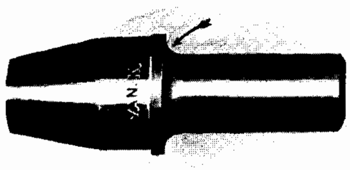
Type "K"

This type of steel is intended for the making of punches and dies, etc. It will not upset, is hard and tough and offers the ultimate resistance to crystallization attainable in steel of this "temper."



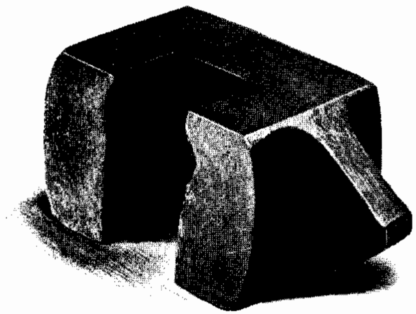
Type "K" Vanadium Steel Punches and Dies

5-16 V Holes	13-19 V 4402 Holes	13-16 V Spl Die 5253 Holes



Pneumatic Hammer Riveting Die

sed in shipbuilding work, in continuous service fourteen months. Requirements drastic, as many of the ⅞" rivets are redriven cold against large flat bottom rivetter. A large American shipbuilding concern reports the normal life of the tool steel dies they formerly used was ten hours, the main trouble being that the constant vibration crystallized the shank of the dies and they broke at point indicated by arrow



Reddington Flue Cutter Tool

Removed after cutting 3627 flues. Highest comparative record by other steel tested by same railway, 1000 flues

Machining Forging and Welding Qualities

The vanadium steels are readily forged and give no trouble in the fire. It is of course to be noted that the same precautions are to be observed in their initial heating as are accorded to any high-grade steel. With regard to drop-forging, all the vanadium steels flow readily in the dies and no trouble is experienced in the process, a fact which in this respect brings them into sharp contrast with some other alloy steels for which great merit is claimed as to mechanical attributes.

The ease with which the vanadium steels can be machined is a matter of deep interest to the practical engineer. Broadly speaking it will be sufficient to say that they are machined as easily as carbon steels of the same "temper."

Vanadium itself helps the welding qualities of iron, and this fact, coupled with its intensifying strengthening action (already alluded to), on such ingredients as are themselves inimical to successful welding (thereby greatly decreasing the amounts of such ingredients necessary to be used), makes the vanadium steels the most weldable of all the alloy steels.

Uniformity of Vanadium Steel

Vanadium steels, *properly made by means of the right description of alloy* (this point is dealt with fully on page 72) are absolutely uniform.

In considering this question of uniformity it should not be overlooked that: (1) As vanadium will perform its scavenging function first, the amount of vanadium that will *remain* in the steel will necessarily depend upon the degree to which the metal has been deoxidized before the vanadium has been added; (2) As detailed hereinbefore at some length, an enormous readjustment of static and dynamic equilibrium takes place at the calescence point and therefore the *static* properties of two identical vanadium steels, one of which has been finished or annealed above the calescence point and the other finished or annealed below the calescence point, must necessarily differ considerably. From this it is obvious that a conclusion of non-uniformity must not be hastily reached as the result of a simple test in one direction.

To these must be added the personal equation and those differences of shop practice which must exist in all steel making, so that degrees of limitation must necessarily be introduced.

Recapitulating

It may be said that the marvelous results in steel hereinbefore instanced which follow from the proper application of carbonless ferro-vanadium are caused by its expelling the poisonous oxygen and nitrogen contents, by its toughening the carbonless portion of the iron, rendering it more impervious to the passage of carbides through it, (thus ensuring a generally sorbitic distribution of those carbides in annealed steel, and a perfect distribution of emulsified carbides in tempered steel) and by its greatly intensifying the static strengthening action of those carbides.

Ferro-Vanadium Alloy

The Ferro-Vanadium made by the American Vanadium Company is produced chemically, has a low fusing point, contains practically no carbon and ranges in vanadium content from 30 to 40%—quality, quantities and deliveries being guaranteed absolutely.

As vanadium produces its divers effects through its action on totally different components of the steel, it will readily be seen that:

1. Two vanadium alloys may easily be of the same ultimate composition analytically and yet give widely differing properties to steel on account of their elements being differently combined. The laboratory determination of this would be tedious and commercially impossible, though the microscope helps much, but manufacturing precautions can assure the reaching of the desired end.

2. The greater the degree of fusibility and solubility possessed by the ferro-vanadium, the more satisfactorily it should behave, other things being equal. Certain definite alloys, containing iron, silicon, and vanadium are much more fusible and soluble in molten steel than plain alloys of iron and vanadium, and their use is advantageous in many cases.

3. Owing to the powerful affinity of vanadium for oxygen and to the fact that the major portion of it is required for other purposes, vanadium alloys should only be added under deoxidizing conditions to metal that has previously been as well deoxidized as possible in the ordinary circumstances under the control of the steel maker.

4. Lastly, it must be remembered that, chemically speaking, vanadium is the radicle of a powerful acid, and therefore it must be kept from contact at a high heat with any material of a basic nature, such as calcareous slag.

Before closing, it may be of interest to touch briefly on the various simple courses of procedure which should be followed for the successful manufacture of vanadium steel by the different commercial processes in common use.

The Crucible Process

In the crucible process the charge is made up of such ordinary stock as the specifications may call for; any chrome or nickel may be included in the initial charge. When the same is thoroughly dead melted or "killed," the vanadium alloy should be introduced, avoiding contact with the slag as far as possible, together with such extra manganese, in the form of ferro-manganese, as the special circumstances of the case may dictate. After the expiration of 20 to 30 minutes the contents of the crucible are to be skimmed and poured as usual.

Acid Open-Hearth Process

In acid open-hearth practice, the furnace charge should be melted as usual, worked down with ore to a Carbon percentage at least thirty points above the percentage of Carbon to which it is desired to work down the bath, and preferably "shaken down" for the remainder of the way. At the finish, the slag should be "supersilicated," that is, it should contain at least 52% of silica, and should not contain excess of oxide of iron; in other words, in melter's parlance it should be "neutral." The fracture of the slag, and its "thickness" in proportion to the heat present, will tell the story to the practical eye. Any necessary proportion of ferro-chrome, warmed on the breast of the furnace is next added, and a few minutes later the ferro-manganese and "warmed" silicon pig. After their incorporation the flame is "blanketed" and the vanadium alloy added in large pieces; three minutes will suffice for its working through the bath, which is meanwhile rabbled. Tapping and teeming are then performed as usual. Any nickel may be charged at the outset.

Basic Open-Hearth Process

In basic open-hearth practice the furnace is charged with good stock and limestone, any required nickel being also added. The charge is melted and worked down to about the same point as in acid practice, then "shaken down" to the necessary degree of decarburization. The slag must be in good condition and free from excess of cutting oxides. The necessary ferro-chrome is now charged, due allowance being made for loss; in good practice a charge of 1.3% of chromium (in ferro chromium) should give 1% of chromium in the residual steel. It may be necessary to closely follow this addition with a little fluorspar in order to keep the slag sufficiently open. Ferro-manganese is then added in lump form to the bath, and when the metal additions are incorporated the furnace is tapped. After a small quantity of steel has run into the ladle, the ferro-vanadium and any further high grade ferro-silicon required, both broken up small and preferably preheated, are added, all additions being completed before slag appears. Rabbling the contents of the ladle greatly assists matters.

Bessemer and Tropenas Practice

In Tropenas practice the converter is charged and blown as usual, and "deoxidation" performed in the converter with manganese and silicon. The ferro-vanadium is added in the ladle as in basic practice, the metal being "skimmed" as it issues from the converter. Nickel would be added with the charge and chrome before or with the deoxidants.

The same remarks would apply to Bessemer practice as to Tropenas practice. The preparation of high grade alloy steels is not usually attempted in the Bessemer converter.

"Loss" in Addition

The percentage of "loss" concomitant with the addition of vanadium has often been asked. For obvious reasons it is impossible to give a simple answer on this point, as that portion of vanadium used up in doing scavenging work passes into slag. This point has been dealt with on page 31.

Vanadium in Cast Iron

In cast iron, in addition to the constituents present in normal steel, another constituent in comparatively large quantity is present in the form of graphite, which, of course, cannot from its nature be in itself influenced by any alloy. Steel in its normal state is a non-homogeneous body, but in comparison with gray cast iron it is very homogeneous. Nevertheless, the benefits which accrue from the proper incorporation of a judicious amount of vanadium with cast iron, especially in chill and cylinder castings, are very great, even if they are not so spectacular in their nature as those which are conferred to steel. But strength, rigidity and resistance to wear are all increased by the addition of vanadium to gray iron, while vanadium martensites are much tougher than ordinary martensites. Chilled rolls containing vanadium have shown a truly remarkable increased resistance to wear in service.

In applying vanadium to cast iron, it must be remembered that nothing like the heat of molten steel is at hand, consequently the metal is not in such state of molecular activity; therefore, one should use a finely divided alloy of low melting point. If the air furnace be used in preparing the molten iron the proposition is a very simple one; when the charge is melted, a little lump ferro-manganese is added to clean it, then the vanadium alloy is added to the furnace and rabbled well through at intervals during the 20 minutes or half hour which intervenes before pouring the metal. Where the iron is melted in the cupola, the fact of the ready oxidability of vanadium at once precludes its addition to the charge, and the ordinary alloy, non-molten, does not too readily dissolve in the comparatively cold ladle contents, for the reasons before stated. If such alloy be used, molten pig iron in weight about five times that of the alloy to be used is introduced on to the finely broken vanadium alloy contained in a crucible or Schwartz furnace. The mixture is heated for about half an hour for incorporation and is poured into the foundry ladle at the same time as the molten cupola metal, the whole being well rabbled. If, however, a special ferro-silico-vanadium be used, which alloy has a very high degree of solubility, the vanadium addition, non-molten, can be made to the ladle direct. The alloy is pulverized and is added, together with about 25 to 50% of ferro-manganese (reckoned on the iron to be vanadized in the ladle) direct to the molten stream of iron as it leaves the cupola spout, distributing the addition as well as possible

The contents of the ladle should be well rabbled before pouring, or preferably emptied into a second ladle of the same capacity to ensure thorough mixation.

The same procedure applies in the case of malleable iron, a product made by suitably annealing white cast iron of a definite composition in oxide of iron, or other "packing." The carbon in the exterior layer is oxidized, the temperature required to effect this not being sufficiently high, however, to bring about the complete oxidation of the dissolved vanadium, while the combined carbon in the interior is changed to the graphitic or temper form, the ferrite liberated being toughened as before described. Hence vanadium adds increased toughness to malleable iron in greater measure than it adds increased strength, for the reasons already enumerated.

Vanadium in Wrought Iron

The incorporation of vanadium in wrought or puddled iron is theoretically much more difficult, because wrought iron is essentially a precipitated metal, permeated more or less by frozen mother liquor of iron, (in which latter the vanadium is more especially contained), and also because the slag of the puddling furnace is strongly basic in its nature and removes vanadium from the bath much as it removes phosphorus. The writer has never met with a Swedish puddled iron containing much over 0.02% of vanadium, while the acid open-hearth steel made from pig iron smelted from the same ore frequently contains 0.08% of vanadium and upwards.

It will thus be seen that in no case but the last does the correct addition of vanadium present any difficulty, and results follow with certainty as long as due cognizance be taken of the simple facts concerning its properties and attributes, as detailed in the foregoing.

Conclusion

In fact, vanadium has placed in the hands of the thinking metallurgist a weapon whose power can hardly at present be estimated.

Broken railway axles and engine frames should soon be placed in the history of the past; an amount of energy can be transmitted by or stored up in a shaft of incredible lightness; springs may be made nearly half the weight of the best now existing and yet possess better tenacity and longer life; ships can be driven at increased speeds with safety; the flying-machine problem comes a step nearer solution; while the questions of the submarine, torpedoes, armorplate, big guns and their carriages, projectiles and the like enter on a new phase, and in bridge building spans become possible that were not contemplated in the most sanguine moments of the designer of a few years ago. These are all rendered possible by the judicious harnessing of an element which, with its compounds, was looked upon up to a few years ago almost as a chemical curiosity.

The application of vanadium to steel manufacture constitutes perhaps its most important employment. Very promising results have been obtained by means of its adaptation to copper and to some of the other metallic alloys, but here a totally different set of conditions is encountered and much work is now being done in this direction. In cast iron too, changes little short of revolutionary are daily being wrought by the truly wonderful element Vanadium.

INDEX

AMERICAN BANK NOTE COMPANY, N. Y.