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VANADIUM

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Its Services in
Automobile Manufacture

VANADIUM

ITS SERVICES
IN AUTOMOBILE MANUFACTURE

By J. KENT SMITH

BEING A REPORT OF AN ADDRESS AND DISCUSSION BEFORE THE ASSOCIATION OF LICENSED AUTOMOBILE MANUFACTURERS, IN NEW YORK CITY, MARCH 7, 1907, WITH FIVE TABLES OF TESTS APPENDED

AMERICAN VANADIUM CO.

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I-Beam Automobile Axle—Vanadium Steel—$3\frac{1}{2}$ twists in $24\frac{1}{2}$ inches. Elastic limit of torsion, 7,540 inch pounds.

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VANADIUM STEELS

By J. KENT SMITH

STEEL is a very complex body; to paraphrase a satirical remark of an eminent scientist, it is so complex that even the youngest may not form a fixed opinion regarding it.

Everybody will agree that during the past two decades the demands on steel applied to special purposes have changed greatly, and steels which satisfactorily met the engineering requirements of twenty years ago are unsuitable to-day. Then if a steel stretched nicely—had good elongation—it was supposed to be all right, provided it showed the required tensile strength. But although steel may have good static qualities, that is, it may have a high tensile strength, elongate greatly and bend well under a steady load, when it is subjected to repeated work, undergoing vibration accompanied by shocks, big or little, and strains which may perhaps be in the nature of alternating bends, it must possess other qualities to enable it to meet such entirely different conditions.

If we take a steel the elastic limit of which is represented by the figure 10 (use any unit desired), and this is subjected to a series of strains at regular intervals, fairly rapidly repeated, each equivalent in strength to, say, the figure 5, in due time that steel will break. Nicola Tesla puts forward an extreme in asserting that if a brick were to be placed on the roof of a high building and could be vibrated sufficiently rapidly, the building would fall to pieces and topple into the street. On the other hand, if the steel be subjected to strains to the same number and at the same intervals, the strength of each of which is represented only by the number 2½, it also will break, but in much more than double the time.

In effect, as these strains approach more nearly to the elastic limit, the deterioration of the steel is enormously hastened. This fact assumes supreme practical importance when it is noted that this deterioration does not take place at the same rate in all steels, those which best resist such deterioration being said to withstand "fatigue" best.

Vanadium has been proved to be an alloy so preëminent in conferring to steel resistance to fatigue that it practically stands alone among alloys.

It is true in the average mild steel,—though not in all mild steels,—that with a good static ductility, there is generally corresponding good behavior under dynamic strains, but this relation is by no means invariable, and it is in such cases as the latter that we have the so-called "mysterious failures."

In the course of about fifteen years, the author has seldom found a "mysterious" failure where the cause was not found to be dynamic (in the few cases where the cause was static the "dynamics" were, of course, bad). In many cases static tests showed good tensile figures, the chemical analysis was good, and yet the steel would not "stand" at all.

By way of illustration, an extreme case may be cited: Two bars of the same steel were taken; one was pulled in the tensile machine, the test figures obtained being very satisfactory; the other (and similar) piece was dropped on the floor and broke in two. In one case, the load was so applied that the material had time to adjust itself to the conditions; in the other case, a shock stress was applied and the material did *not* have time to adjust itself to conditions.

Let us take an every-day case somewhat analogous: In many stores may be noticed an advertisement of a cement, this advertisement taking the form of a tripod, hanging from which is a dinner plate broken across the middle, and held together with cement, a weight being suspended from the plate. If you should lift up the weight (even first having replaced it by a lesser one) for an inch or so and let it fall, the plate will break in two. Here we have a strain applied (1) steadily or (2) suddenly.

It is said, and advisedly, that automobile construction has to a much greater degree than any other industry forced the steel manufacturer to make a better product. It has done more for special steel than anything else in the world because its demands are so drastic that the only material suitable is the best; if a steel will make an automobile spring it will make very nearly any spring, likewise if a steel will make an automobile axle it should be excellent material for any kind of axle.

When automobiles were first made steel was not what it is to-day, but neither were automobiles what they are to-day, and if the steels which were available then were the only steels available now, there would certainly be dire trouble for all concerned. The manufacturers were put "on their mettle" when compelled to meet the severe requirements of modern engineering, and, in passing, it may be noted that the great majority lost themselves in taking it for granted that if they could improve the strength of steel and retain its ductility there would be a corresponding improvement in service. They were right only partially. In the high-speed steam engines of to-day, 85 to 90 per cent. of the strains and stresses put on the metal are dynamically applied, while only perhaps 10 or 15 per cent. are applied statically. It is not a common-sense view to confine attention to that 10 or 15 per cent. and to let the 85 per cent. take care of itself and "trust to luck." More attention should have been given to a study of the dynamic conditions in the past; however, everybody is now beginning to pay more heed to "dynamics."

Some steel makers might say that "the ordinary tests are quite good enough; there is enough work in them without introducing additional work." Now, it is not proposed to introduce any more work; what is desired is that materials should be subjected to tests having some relation to the life conditions which they are going to endure. It is not a logical proposal to test a steel that will make a crank-shaft for a gasoline engine running 1,000 or 1,200 revolutions a minute, receiving perhaps two impacts every revolution, and where also the question of journal wear has to be considered, by exactly the same formula as a steel for I-beams or bridge construction, where a large percentage of the work is static — in the latter case it is largely devoted to holding the structure's own weight.

The author's attention was first directed, many years ago, to vanadium through the investigation of a specimen of Swedish iron that had done marvels in work and had succeeded where everything else had been tried and failed. It gave excellent results on the static machine, though nothing wonderful; it also gave a pure analysis. Micro-analysis in those days was not what it is to-day, but the microscope revealed a normal appearance. That steel contained a considerable amount of vanadium. Most Swedish irons contain a little; one or two varieties contain quite an amount, but they are small in quantity. In one instance such an iron was in the hands of a comparatively few men who really did not know where the great benefit lay in this material; they knew it gave a good pure analysis, but that was all they knew about it chemically. It was observed by one or two makers in Sheffield who used it that they could get their best results only when they employed it. The point was investigated by the speaker, who determined, then and there, to make an exhaustive study of the application of vanadium to the steel industry, believing that it was all going to be done in a very short time. In this he was mistaken.

He began by reading up what work had been done, for several persons had spasmodically made various trials, but the reports were vague and contradictory. There may be many explanations of this outside of the personal equation. Here are two: first, vanadium is a very "elusive" element and it does not follow that if a certain quantity of vanadium is put into a batch of steel that that vanadium really goes into the steel. Vanadium *can* be added consistently and commercially, but it is by no means certain that if one throws a few pieces of vanadium haphazard into an open-hearth cast that the steel contains vanadium. The majority of the published steel tests alluded to above showed the effect of certain vanadium *additions*. The speaker was lucky enough to secure one which purported to show the effect of the addition of .5% of vanadium; as a matter of fact, the sample contained .17%; although .5% had been added, it had not been added properly. Secondly, there is enormous rearrangement in the static and dynamic properties of vanadium steels at the point of recalescence, in what is called in metallurgy "subsaturated" steel, that is, a steel which contains free ferrite.

In such steel the carbon exists in combination with a certain amount of iron and this compound of carbon and iron is alloyed with a certain amount of soft iron and forms what is called pearlite, this pearlite being distributed through the main "back-ground" of soft carbonless iron, called ferrite. If heat is applied to a bar of steel, after awhile it will reach a point where its pearlite is decomposed and the carbide goes into solid solution in the ferrite. While there is work done in changing the state of the carbon, the bar does not get any hotter; when this work is finished the temperature once more steadily rises. On cooling again, the carbon or carbide is thrown out of solution at a fixed temperature point and reforms pearlite, sensible cooling being delayed during this transformation. This is a very crude explanation of the phenomena of calescence and recalescence, which in subsaturated points take place generally in the cherry red zone of temperature.

As some of the bars of which results were recorded had been finished cool, some had been annealed at blood red heat, others annealed at bright cherry heat, and so on, the static results, which were the only ones noticed, were naturally contradictory.

The speaker determined to go through the whole investigation systematically and from the very beginning. He had early recognized the value of dynamics and found that while the strength of steel might be increased by means of some alloys without impairment of its ductility, still their introduction often caused a great deal of dynamic deterioration, and as the quantity of the alloy went up, the dynamic properties, as a general rule, went away down, so that what was given with one hand was unconsciously in a great measure taken back with the other.

A certain amount of information only is obtained with usual rotary vibration tests, due to variation in the elastic limit of the metals tested, so that the alternating strains which are put on by the simple vibration produce a fiber strain that is not equally removed from those elastic limits, the importance of which point in regard to rate of deterioration has already been noted; on the other hand, if there is a rapidly repeated alternating bend accompanied by impact, then the "fundamental" quality of the material to resist vibratory deterioration is obtained. In the speaker's opinion, it is a combination of these two tests — the test of simple vibration and the alternating vibratory impact — which is going to show a great deal. Something must be known about the static quality of the steel, what its strength is — and useful strength be it remembered is represented by the elastic limit, therefore the static elastic limit of the material must be ascertained.

The ordinary factor of safety based on the tensile strength of the material is certainly misleading, as the formula used in calculating it does not take any account of the proportion of the elastic limit. If the elastic limit were always exactly proportionate to the tensile strength, that would be quite in order, but such is not so; in some cases it is 50 per cent., in others 60, in others 80, some specimens even give 90 and yet show a big ductility. *Before it is possible to deduce a true factor of safety, it is necessary to know the elastic limit and the fundamental property of the material to resist what may be called molecular disintegration.*

One steel may prove almost infinitely better than another in service and at the same time the inferior steel may show an equally good factor of safety on the present accepted formula where the true limit of static strength is not considered and questions of fatigue resistance are entirely neglected.

It was the speaker's desire to go into all these points as fully as possible, and he worked without intermission from the spring of 1901 until Christmas, 1904, when some of his results were communicated to the Institution of Mechanical Engineers of England. These figures were practical as well as academic, as he then had the privilege of being in a works composed of three divisions: a special steel, a hydraulic, and a boiler department.

After making the original carbon crucible steels, he worked steadily on the alloy steels and many types of vanadium steel, after which he made them by the open-hearth process on a small scale, then on a larger scale, trying them in the works referred to for the better part of a year (where there were several difficult propositions in hydraulic work to contend with); when the first figures were published, he had learned enough to be convinced of the absolute superiority of vanadium steels over all other steels.

In the course of these experiments he found that vanadium not only imparted extra dynamic qualities to pure steel, but had a static intensifying action on another alloy, such as chrome or nickel. A great deal of the work was done with chrome, and *for automobile construction, he has worked almost entirely with chrome-vanadium.*

Broadly speaking, as before stated, it was found that if another alloy be added so as to greatly increase strength, the "dynamics" suffer severely; but by making use of the static intensifying property of vanadium among its other qualities, one is able to use a much *smaller* proportion of these alloys, which are in themselves in *large quantity* mischievous dynamically, while at the same time the original dynamic value of the carbonless iron base is greatly enhanced.

The author has no hesitation whatever in saying that chrome-vanadium steel is the finest steel the world has ever seen for moving-machinery parts, and believes he has well named it: "Anti-fatigue steel."

There is *no one* vanadium steel that does *all* things. It is necessary to make all kinds and grades of vanadium steel for different purposes. Before the speaker are samples of some of these types. One of these, a knotted sample, is an open-hearth chrome-vanadium steel of the type used for springs; its extreme ductility is apparent by the cold knotting of the annealed bar. The sharp end was quenched from about 900 deg. C. in ordinary water; it scratches glass. That is a combination of softness and hardness in one material which is difficult to beat. With regard to alternating tests on that type of steel: when any steel is tempered, its dynamic resistance beyond its elastic limit goes down. A piece of the best carbon spring steel made in the crucible was selected, one piece annealed; a sample of vanadium spring steel was tempered as for a spring; and the tempered vanadium steel was superior dynamically to the annealed carbon steel. In the English conditions of alternating stress test where the free length is perhaps four inches, the specimen 3/8″ square and a permanent set of about 1/4″ a side is given, the carbon steel annealed stood 250, the carbon steel tempered stood about 40; the vanadium steel annealed stood over 500 and the vanadium steel tempered stood between 350 and 400. Now, under this test, be it noted, it is not that because one stands double the number of alternating impacts it is only twice as good steel. We have the question of alternating impact under life conditions and under them (though we hope the steel will never break) it may break at the end of 6 or 12 months. In this machine the steel is broken by fatigue in a minute or so;

the test has been most drastic as regards the stresses applied and the material has no time to readjust itself in the slightest degree. There can be no factor of comparison in test and life conditions unless the life conditions are constant. In automobiling, for instance, no one can tell what stones are going to be hit on the road, while each stone hit means a shock. The life conditions must vary considerably and therefore it is not possible to get an absolute comparison figure, but the probability is that taking the average life conditions the comparison of the two would be on a curve of high degree, so that two to one under testing conditions would mean something like one thousand to one if the tenth power represented life conditions.

The speaker believes that vanadium steels of all grades have been subjected to nearly all tests known, and everybody who has tested them has spoken well of them.

This roughly is a brief general history of what vanadium can do in steel. The different grades of steel have not been touched upon. The grades suited to automobile work principally made are:

1st. A grade suitable for crankshafts, transmission shafts, and driving axles;

2d. Another grade for connecting rods and very often for light axles;

3d. Another for stub axles;

4th. Another for springs;

5th. Another for mesh gears;

6th. Another for case hardening, etc., etc.

Very thorough microscopic study has been given by the speaker to the conditions of case hardening. In case hardening there are five scientific principles which must be considered to assure success. Everyone will assuredly agree that no tempering steel should be case hardened; the core of the bar must be strong and tough *after* it is quenched. Therefore, begin low and finish high, rather than begin high at first and then fall over the top. The idea is to have the core approach in quality as nearly as possible to the material that is put in crank shafts, but it must be after the bar is carburized and *quenched* that the conditions inside are analogous to the *tempered* shaft, thus it is necessary to start from two different points of view in order to arrive at the one final goal.

Here are two practical instances which demonstrate the dynamic superiority of vanadium. One automobile manufacturer could not get a steel to stand certain work, and the trouble was diagnosed by the author as a question entirely of alternating impact. In March, 1904, this manufacturer was given six vanadium steel axles of a type best fitted to resist such conditions, the understanding being that they were to be put on trial cars and punished severely, so as to form a fairly quick opinion of the nature of the steel. He was of the opinion they would break, as the tensile strength, elongation, and reduction of area were practically similar to those in the steel he was unsuccessfully using. The vanadium steel chosen succeeded triumphantly and that man has never built a car since with any other kind of axle steel. Another illustration is that of a friend who desired shafts for a three engine launch, the shafts to transmit 80 h. p. at 1,200 revolutions a minute, through 17′ 6″. Carefully checked designs of these shafts in vanadium steel, showing an ample factor of safety, only came out at 1 1/8″ diameter, and, despite most pessimistic remarks from "practical" men, these shafts behaved perfectly under the most exigent trials. The boat in which they were used won the race (I do not say because the shafts were made of vanadium steel), and the builder stated he was designing a lot more launches and had specified vanadium steel for all. The steel he had been using before had higher static ultimate strength, good ductility and was apparently first-class steel, he was using a bigger shaft and yet he had been getting breakages.

These two instances are typical of dozens.

The author does not advocate absolutely lowering tensile strength, but in many cases a steel possesses all the tensile strength required, and perhaps a little more, and it would be folly to further increase tensile strength which is not required at the expense of something essential. The dynamic qualities of the material must be maintained to insure life in service, and a steel of the same ductility, but of improved dynamic qualities though of comparatively low "strength" might succeed where a

Steel of merely higher tensile qualities would fail. *Dynamic properties are not given sufficient consideration in too many cases.*

The following may be taken as showing the static power of vanadium: A type of open hearth vanadium steel, tempered in the ordinary shop, gave an elastic limit of 224,000 pounds to the square inch, ultimate tensile strength 232,000 pounds, elongation 11 per cent., and reduction of area 39 per cent. This type of steel is recommended for certain purposes, but it would not be suitable in the highest degree for a chain shaft or driving axle, because it would not possess the best dynamic qualities, while a steel of lower static strength is amply able to meet all requirements for such purposes.

Vanadium is a most satisfactory alloy because it can be employed so universally. It works in more than one direction and the direction can be determined at will. If the compounding of steels is considered with regard to the particular service they are required to perform, vanadium has placed a master weapon in the hands of the steel-makers.

The history of vanadium has not been touched upon, because that probably will not interest this assembly; nor has anything been said as to the natural occurrence of vanadium, as this latter is a question of more interest to the steel-maker.

CHAIRMAN: Gentlemen, you have heard Mr. Kent Smith's very interesting remarks on vanadium steel. The subject is now open for discussion. This seems to be a kind of *ultima thule* that we have been looking for.

MR. MAXIM: I would like to ask Mr. Kent Smith what that alternating impact test is? How it differs from what we call the *alternating stress test,* where we rotate the piece.

MR. KENT SMITH: In the test I use the test piece is held vertically. When the "tool" moves forward it hits the specimen, deflects it and moves it beyond its elastic limit. It is really an alternate bending — very rapidly performed — partly by impact. I have a few bars here that were run through on a machine that I fitted up temporarily. There is one thing I ought to say about the tests; in this system of testing the bar ought to be polished with a glassy surface; with rough samples, you get widely discordant results, the tool marks being miniature notches. These were run through in a hurry (showing samples) and almost exactly follow work previously done by me, though I never publish figures obtained on specimens like these, because I do not think it would be fair information for anybody. The deflection is done by a combination of impact and push.

MR. MAXIM: How did the vanadium steel compare with a very good high-carbon steel?

MR. KENT SMITH: Taking a sub-saturated steel and a super-saturated carbon steel, my experience is that the latter goes very quickly — comparatively.

Mr. Maxim: By very quickly, what do you mean?

Mr. Kent Smith: It soon breaks.

Mr. Maxim: How many alternations?

Mr. Kent Smith: A high-carbon steel (super-saturated) might run perhaps 100. As regards vanadium, I made some tests in Sheffield for demonstration to a high official; the samples were tested against carbon steel that was supplied by him — samples of acid open-hearth steel, officially recommended as of the very best kind for axles and connecting-rod bolts and giving most excellent static results. That of course was a sub-saturated steel; it ran about 290 alternations before it fractured. An excellent quality of nickel steel went about 270. A sample of vanadium steel, which was statically comparable with the nickel steel, instead of going 290 went 570. That is a test ratio of practically two to one; in life it would be enormously greater as before stated. Tempered vanadium steel alternated under the same conditions, with a static strength which is double that of the vanadium steel already quoted and with practically the same ductility, instead of 570 ran 480.

Mr. Maxim: Can you give us an idea, if you should use a piece of wrought iron in that test what the result would be?

Mr. Kent Smith: A piece of wrought iron on the same machine went about 270, almost exactly the same as the nickel steel. You have a different condition from the pure vibration test in the test I am speaking of, because there is a serious deflection accompanied by shock. The "power" goes on all of a sudden.

Mr. Maxim: Does it make any difference whether it is very quick or very slow?

Mr. Kent Smith: Yes, a very big difference. You must adopt standard conditions as to rate, size of test piece, and way of gripping (being careful not to cut the specimen). You must have the same length of bar under test. Prof. Arnold is now, I believe, working out an elaborate series of tests, getting at the different co-efficients of time and deflection. He has taken several thousand pieces of the steel which is so strongly recommended as giving excellent results, and he has treated them all in the same way.

Mr. Maxim: Results are obtained very quickly?

Mr. Kent Smith: Yes. I use round specimens, as I have found the results were absolutely concordant amongst themselves, though you cannot compare them exactly with results obtained on square specimens. The round specimen is easier to prepare; a round piece six inches long does not take long to turn on the lathe, nor does it take long to polish it with a fine emery powder. If you have the conditions I was speaking of just now, it is a good steel that goes a minute under test. Giving half a minute for fixing in the grip and half a minute for putting down the results, etc., does not make it a very long test.

Mr. Maxim: Can you get those testing machines on the market?

Mr. Kent Smith: Prof. Arnold is making them in England. The tests I have made here were done on a temporary machine. I hope Mr. Souther will use one of those machines, so that we can all get comparable results.

Mr. Wilkinson: I would like to know how these results would compare if, instead of carrying the strain beyond the elastic limit, you carried the strain inside the elastic limit.

Mr. Kent Smith: There can be no absolute comparison, for in one case you have a very variable factor, and in the other case you are getting at the fundamental quality of the metal to resist intermolecular disintegration. It is the combination of those two tests that, in my opinion, is very important. For an axle or a connecting-rod I believe strongly in the test I have just described.

Mr. Wilkinson: I think you did not quite understand my question. You strain the material beyond the elastic limit, and then perhaps your piece of vanadium steel will stand quite as many alternations as a piece of nickel steel with equal tensile strength.

Mr. Kent Smith: It stands far more.

Mr. Wilkinson: Now, if you put them both in and strain them only to one-half the elastic limit, will the vanadium show up more than twice?

Mr. Kent Smith: Certainly it will. I

worked with Prof. Stead for some time on vibration tests; his test is different from that of Mr. Souther; he uses a small cylindrical test piece filleted. There we have had perhaps three or four different steels giving practically the same rotary vibration results. They had not the same elastic limit; and when we put them on the alternating impact machine they showed quite different figures. As I said, there can be no absolute comparison between the results, the two conditions being so fundamentally different. It would almost be like trying to deduce dynamic qualities from a static test.

Mr. Souther: Mr. Chairman, I think I reflect the feeling of the others present when I say it is a great pleasure to have a man come here from the other side of the water and confirm some of our notions. Mr. Kent Smith has brought out the great value of the dynamic test as compared with the static test. He has grown up in about the same era and generation that I have in the steel business apparently, and with very much the same results. In the old days, when the government inspected the steel at the steel works, the static test — the plain tensile test or torsion or bend — was considered final by everybody. That notion I came to New England with, and lived with a while before I discovered that a rapidly moving machine, a machine subjected to shock, was different from a bridge or the rivets in a ship. I was put up against the bicycle problem, and next against the automobile problem. As Mr. Kent Smith has made plain, here is required the greatest resistance to shock. Consequently, the idea of a dynamic test, alternations of load combined with shock, was brought forcibly to my attention, and I hunted around to find an endurance or alternating stress machine. I found that one existed at Watertown, and I equipped one and obtained results; and recently, as you all know, another one has been developed which is very much easier to use. It has, however, the drawback of being slow in its results.

I had known of these alternating bending tests; that is what they amount to, for you bend the steel beyond its elastic limit and bend it back again. Horseshoe people use it and axle people use it to bend axles backward and forward under a drop; and I, of course, had read of this Arnold machine. I cannot help thinking that its greatest merit is in its quick results. I have not been able to feel that a test could be of greatest value that bent a specimen beyond its elastic limit. Suppose we bend an axle on an automobile. If we bend it much, we are out of business. We do not go over another rock and bend it back again. What we actually do is to bend it within its elastic limit an immense number of times. That is the result that we get from the endurance machine. I believe it reproduces as nearly as possible what we do on the road. Nevertheless, I think that if this bending test is a quick measure of the same thing, we want to use it frequently.

Mr. Kent Smith has given to the old idea of crystallization a name which, I think, is a fine one. It is "intermolecular disintegration." It exactly conveys to my mind what happens when an axle drops off on a smooth piece of road; as we all know it does. It drops off more often, according to my observance, when it is running quietly along a decent piece of road than it does going over a hump. I had various experiences of the same kind in connection with bicycles, for I have been riding a bicycle and something has dropped off when there was absolutely no cause for it.

What I would like to know, and it cannot be answered yet — I think Mr. Kent Smith will bear me out — is if there is any *relation* existing between the bending and endurance tests, the endurance test within the elastic limit and the endurance test where there is an actual bending. I hardly think the results are well enough known to draw a conclusion.

Also I want to ask one or two practical questions. I know some of the members have them in their mind. Does the addition of a small amount of vanadium and the existence of it in the steel increase the life of a plain carbon steel? Next, does it increase the life of nickel steel? Does it increase the life and endurance of chrome-nickel or silico-manganese, and so on?—all of which interests us. Further, does the addition of vanadium to a carbon steel increase the difficulty of machining or forging the steel? And, similarly, does it increase the ductility and ease of machining or forging the other steels?

In conclusion, I should add that we have just now finished a test on some vanadium specimens in our laboratory at Hartford and the results bear out what Mr. Kent Smith has said about endurance. The vanadium specimen has run one hundred million revolutions. I did not succeed in breaking it under the fiber stress adopted as our stress. Mr. Kent Smith and I talked over various modifications of the test and there is one, I think, should be tried, to hasten the result. It is to take the fiber stress, which we have now adopted as being standard, 53,000 pounds to the square inch, and run a specimen, say, ten thousand revolutions. If it does not break, increase the fiber stress 10,000 pounds and run it another ten thousand revolutions; and so on, increasing *the fiber stress every ten thousand revolutions.* We are driven to this by exactly what Mr. Kent Smith stated: that maybe the steel has gone "beyond its life" and the ordinary fiber stress will not break these steels within a reasonable length of time.

MR. KENT SMITH: With regard to the tests, Mr. Souther has brought out a point which I am very glad to have the opportunity of saying a few words upon. Mr. Souther asked about the relation between the Arnold test and the pure vibration test. As I said before, I did not quite see how there could be any relation between the two because of the absolutely different conditions. But with the modified form of rotary vibration tests Mr. Souther speaks of, namely, keeping on increasing the load, it is likely there will be some interesting relationship established between some of the various forms of dynamic tests. Of course, the great value that is attached to this Arnold test is that the distortion of the metal is practically accomplished, one-half by steady push and one-half by shock; and my own notion has always been that in practice we had to study the combination of the two, especially, I take it, in the trade in which the gentlemen here assembled are interested, because you all have to study the question of pure vibration accompanied by shock. Say you have an axle rotating: it is rotating against counter-weight, and there are shocks which shift the moment of fiber stress on the axle with regard to the elastic limit, some shocks applied having practically the effect of shifting the point of fiber stress much nearer the elastic limit according to their greater magnitude.

As regards the addition of vanadium to carbon steel, I say if the carbon steel is pure and of a good grade, that vanadium will increase the life very much. It is impossible to give actual "life" figures, but in some tests that were made with plain carbon steel under practically the same conditions as I have stated — the thirty carbon steel, already quoted — ran 290. A lower carbon steel ran about 280. Wrought iron ran 270. A sample of steel of the same carbon as that which had run 280 with the addition of vanadium showed about 450. The effect of the simple addition of vanadium to a low carbon steel raises the tensile strength and elastic limit of that steel somewhat, but still not so considerably as if it had another element to act through.

Now, in regard to the action of vanadium on nickel steel as to increasing life. I have not yet found any intensified nickel steel — whether it was intensified by vanadium or chrome — to have really a considerable measure of longer "life" when tested beyond its elastic limit. I believe in the intensifying of chrome by vanadium where "dynamics" are in question. Where the requirements are much more static than dynamic, or in equal proportion of both, then I consider the vanadium-nickel steel is superior. I am speaking now of the experience I had in vanadium-nickel steel over a few years; but I have not had any such experience in it as I have in vanadium-chrome steel. *The results that have been obtained in the automobile trade have been almost entirely in regard to vanadium-chrome.*

(A few of the properties of the different types of vanadium steel are shown in the appended tables.)

There is one point that Mr. Souther asked that has a very great bearing, I think, to the practical man, the question of machining.

Vanadium steel machines nicely, a vanadium-chrome steel machining almost like a carbon steel. There is no difference practically observable in machining a carbon axle and a vanadium-chrome axle. It is almost the same in a crankshaft; a vanadium-chrome steel shaft is a little stiffer to machine than an ordinary carbon crankshaft, but it is certainly no more difficult to machine than the ordinary nickel crankshaft, and it is nothing like as difficult as the nickel-chrome crankshaft.

In forging and hot working, the vanadium steels, *like all other steels of high temper*, must be treated carefully in the first heating. High carbon steel cannot be heated in the first stage with the same drastic procedure that a low carbon steel can be heated; the heat is applied at first reasonably slowly. In a continuous billet furnace, where you begin fairly cool and finish hot, you have the ideal conditions for heating any class of steel. I do not mean that you should treat billets by "hand warming," but put them into the reasonably hot furnace and then raise the furnace heat. One should not put a billet of any kind of steel into a really hot furnace, otherwise you get the bursting effect; and the high-temper steels are more susceptible to disintegration by such heating than the low-temper. In actual forging and drop forging the vanadium steels are almost as easily worked as plain carbon steels of the same types.

There is not as much difficulty in hammer-forging vanadium-chrome steel as there is in forging ordinary nickel steel; if you add vanadium to nickel it makes it no more difficult to forge than plain nickel steel, but, on the contrary, easier. I have always regarded the most useful field for vanadium as in the quaternary steels.

MR. SOUTHER: Have you any reason to believe that the addition of vanadium would injure chrome-nickel or the other alloys that you have mentioned?

MR. KENT SMITH: No. It certainly will not.

MR. SOUTHER: Have you any reason to believe that it would help them?

MR. KENT SMITH: I think it would help them.

MR. SOUTHER: You have no evidence to be able to state that vanadium nickel is bad?

MR. KENT SMITH: Certainly not, but that I find, when it comes to a combination of static and dynamic qualities that vanadium-chrome is the best combination; where the conditions to be considered are practically half one and half the other, or even more static than dynamic, I have found vanadium and nickel a good combination without a doubt. No man has a higher opinion of nickel steel than I have. Nickel steel is a splendid thing; but the chief fault about it is that too much has been claimed for it. When it comes to be a question of dynamics, then we have a special question.

Mr. Souther: Have you successfully used or seen used chrome-vanadium steel for gears, and, if so, what was the effect as to case-hardening; or could it be hardened in the ordinary way?

Mr. Kent Smith: I can answer that question almost absolutely by instances. I have used chrome-vanadium steel both hardened and case-hardened. For gears in continual mesh I use hardened steel (something between crankshaft composition and spring composition as far as actual chemical composition goes) with excellent results. Several auto-makers in England are using it very largely. Vanadium case-hardened steel is very largely used over the water. One gentleman, who is in absolute charge of the building of a very high-grade car there, will not use any other kind of case-hardening steel. He says he gets results out of the case-hardening type of chrome-vanadium steel that he cannot duplicate with any other case-hardening steel he has. I am a strong advocate of case-hardening sliding gears.

Chairman: Do you draw the temper of the case-hardened gear?

Mr. Kent Smith: No. I carburize a mild vanadium steel, the carburized article being allowed to cool slowly. Crystalline fractures are very noticeable at this stage. (I have followed the crystalline fracture microscopically in another place.) I then reheat the cased article to 850 or 900 degrees Centigrade in a non-oxidizing atmosphere as far as possible, and quench it in warm water. Some people want absolute glass-hardness, but I personally have not found that to give such excellent wearing results in case-hardening; I do not say I want the article soft, but just "rough" to a smooth file. Therefore I quench in warm water. If I want glass-hardness I quench in cold water, salt and water, or potash and water.

MR. ELWOOD HAYNES: I would like to ask Mr. Kent Smith one or two questions. First, whether he has ever noticed any increase in the rigidity or what is usually termed modulus of elasticity in the vanadium steel or any of its combinations; or whether he has ever observed any increase in this property in any steel over the ordinary carbon steel? Secondly, whether it is essential for any of the vanadium to remain in the vanadium steel, in order to give the special properties of vanadium steel; or whether it acts the same as magnesium does on impure nickel? for if you introduce a little magnesium into nickel it totally changes the property of the nickel, and renders it plastic instead of brittle. Thirdly, what is the composition of the steels that are exhibited here, as to their carbon, chrome, and vanadium?

MR. KENT SMITH. I have no absolute figures on the modulus of elasticity as yet—I recently supplied a large number of vanadium samples to one of the colleges in London, England, and am expecting the results in by any mail. As regards rigidity, the vanadium-chrome steels are more rigid than the carbon steels used for the same purpose. You get a greater rigidity and therefore you can use a slightly less area. But I cannot put this into figures until I have those modulus of elasticity results in front of me; the moment I receive them a copy shall be mailed to you. I had no apparatus for determining accurately the modulus of elasticity, nor the time to go very deeply into that question. That part of the vanadium study was by no means overlooked, but, unfortunately, the man that took it up was unable to finish it, his health breaking down, so I had to go all over it again. It is an extensive series of investigations and the ordinary engineering college is not famed for working exceedingly quickly; its work is accurate rather than quick, as a general rule. I am expecting those results in time; in the meantime, as the result of shop figures, I can positively say that you will find vanadium steel more rigid than carbon steel for the same purpose.

With regard to the question as to whether it is necessary for vanadium to remain in the steel, I answer that strongly in the affirmative. Vanadium is an "elusive" element. If there is any oxide left in the steel the vanadium will scavenge it out; but vanadium is an expensive scavenger. You want your vanadium left in to both statically intensify and to give dynamic quality to the metal. It will do the scavenging in preference to anything else, because it is the easiest work. Hence there is little use in adding vanadium to an oxidized steel, because you will not find the vanadium in the steel. I have said already that it does not follow that because you put a certain amount of vanadium in the steel that vanadium is there. That is why so many of the old results went wrong, because vanadium was just put into the steel, no consideration being given to the oxidation of the steel itself or the oxidizing conditions that were the concomitants of the vanadium addition. The vanadium did its easiest work first, and its easiest work was to combine with oxygen. Commercial nickel contains a considerable quantity of oxides. There are probably many people who have more extensive sources of information on that point than I have; one should not base an opinion on just a few spasmodic trials, but I found that by the very careful use of aluminum in the oxidized metal I could get practically as good results as with magnesium, though if I used a little too much aluminum the nickel alloy remaining had nothing like the properties of the pure nickel.

As regards the composition of these steels before us I am glad to say anything I can. The steels are basic steels. This is an oil-tempered crankshaft steel (producing samples). This is a cold bend of the same. It contains about .25% carbon, 1.0% chromium, and .18% vanadium. Its elastic limit is about 110,000 to 120,000 pounds to the square inch, its ultimate strength about 140,000; the elongation on two inches about 21 or 22%, and the contraction of area between 56 and 60%. I may here say that I have invariably, as the result of twelve years' pretty close watching, found the bend to follow the contraction of area and not the elongation. The average elongation, I take it, is very largely a measure of longitudinal flow; if the metal flows inward the elongation will be very much less, but it does not follow that the steel is any less ductile. I do not bother my head about the elongation unless I know both the general and local elongations, and as a measure of strength I always look at the elastic limit pure and simple. We used to judge steel by tensile strength and elongation, but those things are in the far-away now. I always run my carbon a little higher in basic steel than I do in acid steel. D (spring type) will run nearly .50% carbon; manganese from .8% to 1%, with 1.25% of chrome, while I use about the same amount of vanadium as before. I use the vanadium as a "master." In the case-hardening type, with perhaps .12 to .15% carbon, very low manganese, and about 0.3% chrome, the vanadium will run .12 to .15%. Vanadium steel is very susceptible to quenching as I think that sample that I showed you demonstrated, and the finished article in case-hardening is a quenched article, be it remembered, therefore, for case-hardening we must use an initially "dead mild" vanadium steel.

Vanadium is a very powerful weapon;

indeed, vanadium in steel is comparable to strychnine in medicine. A little is a splendid tonic, but if you give too much you kill your patient. I look on vanadium to metallurgy as strychnine to medicine, for I defeat my own ends if I use too much, though if I use in ordinary case-hardening steel only .02% or .04% vanadium I will not get as good a result as by using .15%.

MR. SOUTHER: That is remaining in the steel?

MR. KENT SMITH: That is remaining in the steel. The question of how much remains in the steel and how much goes out, is, of course, a steel-maker's question; but I never had any difficulty in adding vanadium with about 10 per cent. loss. There is no difficulty whatever from a technical steel-making point of view in adding vanadium. It practically accompanies the addition of silicon. The thing is adding it properly and at the right time. It is simply a question of an intelligent interpretation of the higher principles of steel-making.

When I was connected with vanadium steel-making we used to run a lot of grades for different purposes. We varied the grades slightly according to the conditions to be met; some typical grades of steel for automobiles are shown in tables 1, 2, 3, 4, and 5. We would run a separate grade for railway tire-work and so on, as we would also run a grade for connecting-rod bolts. There was a difference in each, and the difference was not so much in the vanadium as in the relation of the other constituents; that is, the carbon, manganese, and chrome — it being taken for granted, of course, that sulphur and phosphorus were low.

MR. SOUTHER: How low do you regard it necessary to have phosphorus?

MR. KENT SMITH: The lower the better. We made it .02% and .03%, and I would not care to go above .03% of each. Of course, in acid steel you must run a lower carbon comparatively. I prefer a carefully-refined basic steel; that is, I think, the highest grade of steel that we can get out of the open hearth. I think the prejudice against basic steel is dying out, maybe slowly, but dying out all the same; and I think that prejudice largely arose through absolute misapprehension, since it was known that basic steel can be made from almost any kind of inferior stuff. In my mind the real trouble lay in the fact that basic steel is much more prone to oxidize than is acid steel in the furnace; if it is carefully worked down and good stock used, and at the end you have a good non-oxidized pure bath, I think you will have to go a long way to beat steel made by the basic process. Of course, it is no use adding any alloy, I do not care whether nickel, nickel-chrome, tungsten, or vanadium, to impure steel; if you start with a bad foundation you will never get good results.

MR. MAXIM: There is one more question I would like to ask Mr. Kent Smith. He spoke about a transmission shaft which was very alarming when he first saw it, it being an inch and an eighth in diameter. When you make that of vanadium and it stands up and does not break, it does not necessarily mean, does it, that it does not spring more than the old shaft?

MR. KENT SMITH: No.

MR. MAXIM: In building automobiles we frequently meet those two conditions: a condition in which a part is not strong enough, and also a condition where it might spring if it was made of a better material; and springing in some of our work is very serious. Is it a fact that vanadium steel, although it is stronger, springs just as much, and therefore when it is made smaller it springs more than our ordinary steel? For instance, take a small crankshaft, although it would not break, it would be liable to spring more, would it not, and possibly give bearing difficulty?

MR. KENT SMITH: Possibly, but the shaft would have to be very light indeed. In the particular work I was speaking of, the bearing easily took care of any difference, as the old shaft was very well supported all the way down.

CHAIRMAN: What would be the cost of vanadium steel in comparison to nickel-chrome or nickel steel?

MR. KENT SMITH: There is no question of the cost being prohibitive. *Vanadium steel can be furnished* — we are not steel-makers — *at a price which does not exceed the price of special steels to-day.*

Mr. Elwood Haynes: In regard to the supply of vanadium — I would like to know whether its use is fully warranted. It is a very rare substance, unless it has been discovered in greater quantity and very widely diffused and in very large deposits. A man who started in to use vanadium steel would not want to quit before the year was over.

Mr. Kent Smith: Mr. Haynes alludes to vanadium as a rare element. I want that impression to be somewhat modified. Vanadium is not a rare element. It may surprise many in this room to hear that ordinary soap generally contains a quantity of vanadium, because it is found in caustic soda, but the quantity is microscopical. The quantities we have been talking of are huge in comparison. The average percentage of vanadium that I have found in caustic soda has been .004%, and I found it by working on a pound or so. Most fire clays also contain vanadium. But vanadium is comparatively a rare element, or was at least a short time ago, when it came to the question of finding it in sufficiently concentrated deposits to repay extraction. The extraction of vanadium is a difficult problem in itself. Although there is a great deal of vanadium distributed over the world in odd places, I do not think it is likely we shall ever find another vanadium deposit like that which the American Vanadium Company has secured in Peru. I have here a sample from one of the main veins (exhibiting). I think that if one-half of the steel production of the United States to-day was vanadium steel, we could take care of it as far as Mother Nature goes, though we might have to build a very large factory to extract the necessary amount of vanadium alloy. As far as ordinary conditions go there is no earthly likelihood of there ever being a shortage of vanadium. Vanadium is an unique thing in metallurgy, since only a few years ago vanadium alloys and salts had only been prepared as "curiosities." Now the whole subject is on a commercial footing; we have any quantity of vanadium ore and we are building a factory that is reasonably big enough to take care of all the vanadium alloy that is likely to be wanted for a long time to come, while there is no difficulty in doubling or trebling the size of that factory. We can do that in a short time, and will warrant the supply at any time. There is no danger of automobile manufacturers starting out to use vanadium steel and then finding that there is no more vanadium to be had.

CHAIRMAN: Can vanadium be welded easily, heated by the ordinary process or the electric process? There has been difficulty in welding nickel steel and chrome-nickel steel. Does vanadium increase the difficulty or decrease it?

MR. KENT SMITH: The presence of vanadium, as far as welding goes, is beneficial rather than the reverse, because, as I said before, it forms a fusible oxide and thus promotes the welding action of the iron itself. If taken in conjunction with chrome, the vanadium being a static intensifying element, one is able to use very much less chrome, and therefore vanadium-chrome steels are more easily welded than ordinary chrome and nickel steels. The welding of vanadium-chrome steel does not present any difficulty. One can take a bar of steel containing about .25% or .30% carbon, cut the bar in two, weld it, and twist it cold so that it shows several twists, or take another piece, weld it, pull it, and it will not break at the weld.

CHAIRMAN: How do you weld it?

MR. KENT SMITH: I weld it in an ordinary blacksmith shop or by any good method.

MR. ROBERT JARDINE: At what heat?

MR. KENT SMITH: About the same heat that you weld an ordinary .20 carbon steel. I do not push the "A" type of steel (see table) as *welding steel*, but I do say that steel containing vanadium with mild carbon is as good a welding metal as the best wrought iron you can get. That is a very big statement to make, but it is backed by fact. As I said before, the influence of vanadium itself on the welding is beneficial, and on account of its static intensifying effect you can use very much less of the "obstinate" alloys, therefore vanadium steels for all purposes are much more easily welded than analogous chrome-nickel steels or nickel steel.

CHAIRMAN: If there are no further questions you would like to ask I will call for a vote of thanks to the American Vanadium Company and also to Mr. Kent Smith for the very interesting talk that he has given us on vanadium steel.

Mr. Maxim: I so move.

The motion was seconded and carried.

Mr. Kent Smith: Mr. Chairman and Gentlemen, will you allow me to thank you once more for the very kind invitation you have given me. Vanadium is not only my business, it has been my hobby for years. I am delighted to talk on the subject, and I am more than delighted to talk about it when I have so kind and patient a set of listeners as I have had this morning.

FROM THE OFFICE OF THE AMERICAN VANADIUM COMPANY 302 FRICK BUILDING, PITTSBURGH, PA. U.S.A.

COMPARATIVE FIGURES CARBON NICKEL & VANADIUM STEELS PHYSICAL TESTS

A DESCRIPTION OF MATERIAL	CHEMICAL COMPOSITION					PHYSICAL TESTS												REMARKS
	CARBON	MANGANESE	CHROMIUM	VANADIUM	NICKEL	ELASTIC LIMIT LBS. PER □"	TENSILE STRENGTH LBS. PER □"	RATIO %	ELONGATION IN 2" %	CONTRACTION OF AREA %	PENDULUM IMPACT FT. LBS.	IMPACT BLOWS	ALTERNATION OF STRESS	RIGHT ANGLE BENDS	⦿ TORSION TWISTS	ROTARY TEST STEAD-SOUTHER		
CARBON STEELS SWEDISH QUALITY MILD.	.12	.30				31,350	50,400	62	50	60	15		100	18	3.5	6,500	20,000	FULFILS THE MOST SEVERE CRUSHING, BENDING, BULGING AND EXPANDING TESTS.
FORGING QUALITY	.30	.50				38,080	69,440	54.9	32	47	8	25	120	12	2.8			EQUAL TO BEST SWEDISH MILD STEEL. EASILY STANDS PLATE BEND, D=2 T
NICKEL STEELS FORGING QUALITY	.25/.30	.50			3.2	49,270 57,300	87,360 77,800	56.4 73.6	34 31.5	58 62	14	35	100	12	3.1			BENDS, ETC. AS FORGING STEEL.
VANADIUM STEELS TYPE, "A". ANNEALED. 800° C.	25/.30	.50	1.0	.17		63,570 64,400 71,110	96,080 87,640 92,230	66.2 73.5 77.1	33 29 22	61 58 65	16.5		215		4.2	67,500		
OIL TEMPERED.						103,000	125,000	82.4	21	56	12	76	160	10				
VARIATION IN QUENCHING TEMPERATURES.						110,100 124,000 127,500 140,750 200,000 224,000	127,800 130,500 138,000 147,000 212,000 232,750	86.9 95 92 95 94 96	20 17 18 17 12 11	58 62 65 57 51 39							100 MILLION UN-BROKEN	.75" ROUND BENDS DOUBLE COLD D=2T
TYPE, "C". ANNEALED. 800° C.	.20	.35	.80	.15		47,030	87,360	53.8	34	53	16	69	190	18	4.56			5/8" SQ. & 1" ROUND BARS BEND CLOSE DOUBLE.
TYPE, "D". SPRING STEEL NORMAL ANNEALED. 800° C. OIL TEMPERED.	.45	.90	1.25	.18		101,900 82,060 221,000	162,400 114,800 235,000	62.7 71.5 93.8	13 30 10	44 63 39	4							TWISTS IN FLAT TIGHT UP. 9/16" RD BENDS DOUBLE. AFTER TEMPERING A SPRING OF IT COEFFICIENT OF SAFE WORKING LOAD=40000 WITH EXCELLENT CARBON STEEL THE COEFFICIENT OF SAFE WORKING LOAD =20000.
TYPE, "E". CASE HARDENING STEEL.	.15	.25	.30	.12		44,790	55,990	80.0	45	69	17		240		5.0			BENDS CLOSE DOUBLE COLD.
SOFT CORE OF SAME AFTER CASE HARDENING AND STRIPPING CASE						78,390	100,800	77,8	22	60	10							

⦿ NASH TORSION TEST. LENGTH 6" DIA. .75"

DATA CORRECT J. Kent Smith CHIEF METALLURGIST. [signature] ENGINEER OF TESTS

B:E:D:S:

DATE *May 1, 1907*

PRINT NO. 1

FROM THE OFFICE OF THE

AMERICAN VANADIUM COMPANY

302 FRICK BUILDING, PITTSBURGH, PA. U.S.A.

TYPES OF VANADIUM STEEL

COMPOSITION

TYPE. A. NO. 1.	TYPE. A. NO. 2.	TYPE. A. NO. 3	TYPE. B.	TYPE. C.	TYPE. D. NO. 1.	TYPE. D. NO. 2	TYPE. E.
CARBON %.25-.30 MANCANESE %.40-.50 CHROMIUM % 1.0 VANADIUM %.16-.18	CARBON %.25-.30 MANGANESE %.40-.50 CHROMIUM % 1.0 VANADIUM %.16-.18	CARBON %.25-.30 MANGANESE %.40-.50 CHROMIUM % 1.0 VANADIUM %.16-.18	CARBON %.20 MANGANESE %.30-.40 CHROMIUM %.50 VANADIUM %.12	CARBON %.20 MANGANESE %.40 CHROMIUM %.80 VANADIUM %.16	CARBON %.45-.55 MANGANESE %.80-1.0 CHROMIUM % 1.25 VANADIUM % .18	CARBON %.45-.55 MANGANESE %.80-1.0 CHROMIUM % 1.25 VANADIUM % .18	CARBON %.12-.15 MANGANESE % .20 CHROMIUM % .30 VANADIUM % .12

APPLICATIONS

TYPE. A. NO. 1.	TYPE. A. NO. 2.	TYPE. A. NO. 3	TYPE. B.	TYPE. C.	TYPE. D. NO. 1.	TYPE. D. NO. 2	TYPE. E.
"LIGHT" AXLES. CONNECTING RODS. SIDE AND MAIN RODS. DRIVING AXLES. PISTON RODS.	CRANK SHAFTS. TRANSMISSION PARTS. CRANK PINS.	GEARS IN CONSTANT MESH. NOT UNDULY PRESSED	AXLE WORK, HAMMER RODS AND WHERE TORSION IS OF GREAT MOMENT. BOLT STEEL.	INTERMEDIATE STEEL VERY USEFUL FOR CAR AXLES. HOLDING BOLTS ETC.	SOLID WHEELS FOR RAILWAY USE. GUN BARRELS. CRANK PINS.	SPRINGS FOR AUTOMOBILE, CARRIAGE AND LOCOMOTIVE WORK.	CASE HARDENING STEEL FOR ALL ENGINE AND MACHINE PARTS.

HEAT TREATMENTS

TYPE. A. NO. 1.	TYPE. A. NO. 2.	TYPE. A. NO. 3	TYPE. B.	TYPE. C.	TYPE. D. NO. 1.	TYPE. D. NO. 2	TYPE. E.
ANNEAL AT 800°C. FOR ONE OR TWO HOURS. COOL IN AIR OR ASHES ACCORDING TO NATURE OF PIECE.	QUENCH FROM 900°C. IN LARD OR FISH OIL & ANNEAL AT 550°C. FOR 1/2 TO 2 HOURS ACCORDING TO SIZE IN AIR	QUENCH FROM 950°C. IN LARD OIL AND LET DOWN AT 360°C. FOR 1/4 TO 1/2 HOURS PREFERABLY IN LEAD BATH. COOL IN AIR.	NORMAL	NORMAL	ANNEAL AT 800°C. FOR ONE HOUR. COOL SLOWLY TAKING GREAT CARE NOT TO CHILL OR TO PASS FROM 800°C. TO 600°C. TOO QUICK	QUENCH IN OIL FROM 900°C. AND DRAW BACK AT 400°C. TO 450°C. IN LEAD BATH PREFERRED COOL IN AIR.	REGULAR CASE HARDENING PROCESS.

REMARKS

ALL STEELS TO BE AS PURE AS POSSIBLE FROM SULPHUR & PHOSPHORUS. SULPHUR MAY GO TO .035% WITHOUT DETRIMENT.
WITH PHOSPHORUS AT 0.02% THE SILICON MAY BE .15% IN "D" AND .10% IN "A" "B" & "C"
WITH PHOSPHORUS AT 0.03% THE SILICON SHOULD NOT EXCEED .05% TO .06% IN "A" "B" & "C", OR .10% IN "D"

DATA CORRECT. *J. Kent Smith* CHIEF METALLURGIST.

ENGINEER OF TESTS. *May 1, 1907*
DATE

PRINT NO. 2

B.E.D.S.

FROM THE OFFICE OF THE **AMERICAN VANADIUM COMPANY** 302 FRICK BUILDING, PITTSBURGH, PA. U.S.A.

RESULTS OF MECHANICAL TESTS OF TYPICAL VANADIUM & OTHER STEELS

SHOWING HOW THE ALLOY VANADIUM CAN BE USED TO ATTAIN STATIC SUPER-EXCELLENCE, DYNAMIC-SUPER EXCELLENCE, OR COMBINATIONS OF BOTH. **AUTOMOBILE PURPOSES** ARE TAKEN OWING TO REQUIREMENTS OF SAME BEING OF THE MOST EXIGENT NATURE.

TEST	#1 CARBON "AXLE" STEEL	#2 NICKEL "AXLE" STEEL	#3 VANADIUM "AXLE" STEEL TYPE A NO.1	#4 VANADIUM CRANKSHAFT STEEL TYPE A NO.2	#5 VANADIUM GEAR STEEL CONTINUAL MESH. TYPE A NO.3	NATURE
YIELD POINT LBS. PER SQ. IN.	41,330	49,270	63,570	110,100	224,000	STATIC
ULTIMATE STRESS TENSILE STRENGTH IN LBS. PER SQ. IN.	65,840	87,360	96,080	127,800	232,750	STATIC
RATIO	62%	56%	66%	87%	96%	STATIC
ELONGATION ON 2"	42%	34%	33%	20%	11%	STATIC
CONTRACTION OF AREA	61%	58%	61%	58%	39%	STATIC
TORSIONAL TWISTS	2.6	3.2	4.2	2.5	1.8	STATIC
ALTERNATING BENDS	10	12	18	10	6	INTERMEDIATE
PENDULUM IMPACT FOOT POUNDS	12.3	14	16.5	12	6	DYNAMIC
ALTERNATING IMPACT NUMBER OF STRESSES	960	800	2,700	1850	800	DYNAMIC
FALLING WEIGHT ON NOTCHED BAR NUMBER OF BLOWS	25	35	69	76		DYNAMIC
ROTARY VIBRATIONS NUMBER OF REVOLUTIONS	6,200	10,000	67,500			DYNAMIC

ALL FIGURES OBTAINED UNDER COMPARATIVE CONDITIONS.

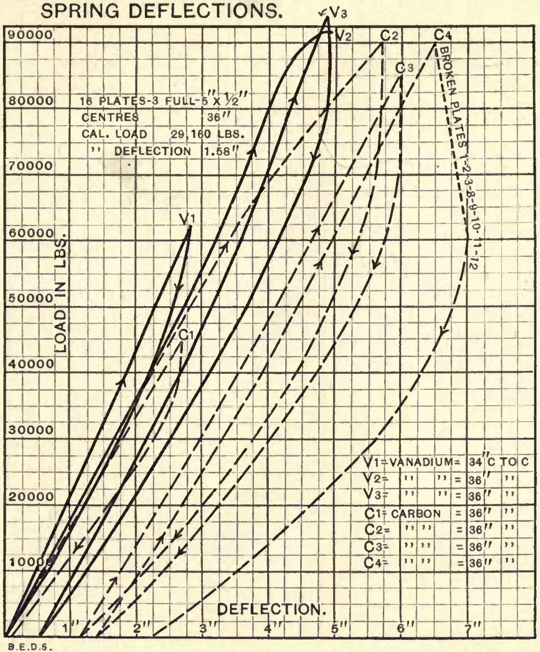
DATA CORRECT. J. Kent Smith CHIEF METALLURGIST.

ENGINEER OF TESTS.

DATE *May 1, 1907*

B.E.D.S.

PRINT NO. 3



THE AMERICAN VANADIUM COMPANY

GENERAL OFFICES SUITE 302 FRICK BUILDING
PITTSBURGH, PENN., U. S. A.

COMPARATIVE TESTS ON VANADIUM & CARBON STEEL SPRINGS

TESTED BY THE AMERICAN LOCOMOTIVE COMPANY.

THE VANADIUM SPRING WAS TESTED:

1. TO 82,700 LBS. WITH 84" CENTRES
2. TO 92,000 LBS. WITH 36" CENTRES
3. TO 94,000 LBS. WITH 36" CENTRES

ON SECOND TEST, ELASTIC LIMIT WAS REACHED AT 86,000 LBS. OR 234,500 LBS. FIBRE STRESS WITH PERMANENT SET OF .48"
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" CENTRES
2. TO 89,280 LBS. WITH 35" CENTRES
3. TO 84,520 LBS. WITH 36" CENTRES
4. TO 89,280 LBS. WITH 36" CENTRES

ON SECOND TEST, ELASTIC LIMIT WAS REACHED AT 65,000 LBS. OR 180,000 LBS. FIBRE STRESS WITH PERMANENT SET OF 1.12"
ON THIRD TEST, IT TOOK AN ADDITIONAL SET OF .26" AND ON FORTH TEST, PLATES 1-2-3-8-9-10-11-12 FAILED AT THE CENTRE.

THESE TESTS INDICATE THAT VANADIUM SPRING STEEL IS FAR SUPERIOR TO CARBON STEEL AND IS PARTICULARLY TO BE RECOMMENDED WHERE THE SEVEREST SERVICE CONDITIONS ARE ENCOUNTERED.

STATIC TEST ON PIECE CUT FROM LEAF OF SPRING.

ELASTIC LIMIT	227.100
ULTIMATE STRENGTH	237.500
RATIO	.96 PER CENT
ELONGATION 2"	.10 PER CENT
CONTRACTION OF AREA	.35 PER CENT

TYPE "D" VANADIUM SPRING STEEL.

PRINT NO.4

VANADIUM STEEL CASTINGS
FOR LOCOMOTIVE PARTS.

FERRO-VANADIUM, AS AN ALLOY, WHEN ADDED TO STEEL IN THE PROCESS OF CASTING, HAS A MARKED INFLUENCE ON THE GENERAL QUALITY THROUGHOUT, CLEANSING, BINDING TOGETHER THE MOLECULAR STRUCTURE AND IMPARTING TO THE FINISHED PRODUCT VITALITY WHICH OTHERWISE WOULD BE LACKING, RENDERING RESULTS MORE EFFICIENT IN SERVICE WHERE SHOCK, STRAIN AND VIBRATION ARE CONSTANT, YIELDING PROPORTIONATELY A HIGHER ELASTIC STRENGTH, AND AFFORDING A MARGIN OF SAFETY ABOVE THE ORDINARY STEEL CASTING.

COMPARATIVE AVERAGE TENSILE & VIBRATION TEST. ORDINARY AND VANADIUM STEEL CASTINGS.
TEST PIECES TAKEN FROM CAST STEEL LOCOMOTIVE FRAMES.

STEEL.	ELASTIC LIMIT.	ULT. TEN. STRENGTH.	RATIO.	8″ ELONGATION.	VIBRATIONS.
ORDINARY.	36.290	68.520	52.9%	20%	4206
VANADIUM.	45.620	77.800	58.6%	23%	12776

VIBRATION TEST ON ALTERNATING BENDING MACHINE. BAR HELD RIGID ONE END, OTHER END DEFLECTED 1/8″ FROM EACH SIDE OF CENTRE.

USE VANADIUM STEEL CASTINGS FOR THE FOLLOWING PARTS.

A
- AIR BRAKE CYLINDER LEVERS.

B
- BELL CRANKS.
- BRAKE BEAMS.
- BRAKE BRACKETS.
- BOILER PADS.
- BUFFERS.

C
- CROSS HEADS.
- CROSS HEAD SHOES.
- CROSS HEAD ARM.
- CROSS BRACES.
- CAB BRACKETS.
- CYLINDER HEADS.
- CENTRE PLATES.

D
- DRIVER BRAKE LEVERS.
- DRIVING BOXES.
- DRIVING BOX BEAM.
- DRIVING WHEEL CENTRES.
- DRAW HEADS.

E
- ENGINE FRAMES.
- ENGINE TRUCK FRAMES.
- ENGINE TRUCK CENT. PIN GUIDE.
- ENGINE TRUCK SWING BOLSTER.
- ENGINE TRUCK SWING LINKS.
- EQUALIZER BEAMS.
- ECCENTRICS.
- ECCENTRIC STRAPS.

F
- FIRE BOX MUD RINGS.
- FOOT PLATES.
- FRAME STIFFENING PIECE.
- FRAME BRACES.
- FULCRUM SHAFT BEARINGS.
- FULCRUM CASTING.

G
- GUIDE YOKES.
- GUIDE YOKE KNEES.
- GRATE SHAFT BEARINGS.

L
- LINK MOTION SUPPORTS.
- LIFT SHAFTS.

P
- PILOT FRAME ENDS.
- PILOT FRAME TOPS AND BOTTOM.
- PEDESTALS.
- PISTONS.

R
- ROCKER ARMS.
- ROCKER BOX.
- REVERSE SHAFTS.
- RUNBOARD BRACKETS.
- RUBBING OR CHAFING IRONS.
- RADIAL BAR CROSS TIE CAPS.

S
- SIDE BEARINGS.
- SPRING RIGGING POSTS.
- SPRING SADDLES.
- SPRING SEATS.
- SPRING HANGER PLATES.
- SCOOP LEVERS.
- STEAM CHEST.

T
- TRANSMISSION BAR.
- TRAILING TRUCK BRAKE LEVERS.

AMERICAN VANADIUM COMPANY
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