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# WELDABLE HIGH STRENGTH STEEL

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## ABSTRACT OF THE DISCLOSURE

A weldable high strength structural steel which consists of less than 0.25% carbon, from 0.10 to 0.75% silicon, from 0.5 to 1.5% manganese, from 0.3 to 1.5% chromium, from 0.1 to 0.6% molybdenum, from 0.02 to 0.2% vanadium, from 0.03 to 0.18% metallic nitride precipitate, and from 0.0005 to 0.005% boron, the metallic nitride being any one or any combination of aluminum nitride, beryllium nitride, columbium nitride, titanium nitride and zirconium nitride, the rest substantially all iron with incidental impurities, the steel being in martensitic condition.

This application is a continuation-in-part of application Ser. No. 674,015, filed Oct. 9, 1967, now abandoned, which in turn is a continuation of Ser. No. 326,387, filed Nov. 27, 1963, now abandoned.

This invention relates to a structural steel that is readily weldable yet having high tensile and yield strengths as well as superior ductility.

It is generally accepted that the strength and the ductility, or the strength and the weldability of a steel are characteristics that are mutually contradictory, in that any gain in one is inevitably accompanied by appreciable loss in the other. Namely, the strength may be elevated only at an expense of ductility or weldability or both, and therefore, it has been the main interest in the art of steelmaking how to produce steels with those three properties simultaneously maintained at a high level.

Thus, it is the primary purpose in this invention to provide a steel that possesses a tensile strength of 100 kg./mm.$^2$ level and is yet ductile and weldable enough to serve as material in welded structure construction.

In the existing methods of increasing the strength level of steel, the most common and the most economical means is to raise the carbon level. However, since the weldability of the steel is impaired as the carbon content is raised over a certain limit, the limit depending on other factors including the contents of coexisting alloying elements, the manufacture of steels with high strength and good weldability has to be accomplished by other means.

That is to say, in the existing methods of manufacturing high strength and weldable steel, as far as we are aware, there is one particular method that is generally followed, in which the strength is attained without impairing the weldability by adding one or several alloying elements, each in relatively small quantity, to the steel, and further subjecting the steel to proper heat treatment, such as quenching and tempering, when it is so desired to elevate the strength to yet higher level or in an attempt at economizing by reducing the content of expensive alloying elements.



Generally, one or several alloying elements are necessary for steels to gain tensile strengths over 60 kg./mm.$^2$ level, but in order that the tensile strength of over 80 kg./mm.$^2$ be assured, not only at least a few alloying elements are needed in varying kinds and proportions, but also a proper heat treatment is almost mandatory. Many a weldable high strength steel has been proposed to date, and some of them have been in commercial use, but it is generally believed today that in steels for welded structure, which can be handled with ease and safety at the shop and in industrial application, tensile strengths range of 80 to 90 kg./mm.$^2$ is the limit.

Apparently, there are two ways open to overcome this difficulty. The one is to add more alloying elements, while the other is to lower the tempering temperature in the course of the aforementioned heat treatment. However, the first method is disadvantageous in the economy and in the weldability, for many of the strength increasing alloy elements are unfavorable to the weldability, while in the latter, the aim is only attainable by sacrificing low temperature ductility and, furthermore, the welded structure would deteriorate at the welded joint in the post-welding annealing, which is often inevitable in practice to relieve the residual weld stress, and is necessarily carried out at a temperature close to or surpassing that of tempering.

Thus, the primary purpose of this invention resides in the provision of steels featuring the tensile strength of at least 90 to 100 kg./mm.$^2$ (which will be referred to as the 100 kg./mm.$^2$ level hereinafter for the sake of simplicity) and having ductility and weldability that are comparable to those of existing 80 kg./mm.$^2$ class tensile strength steels, by properly heat treating the stock, of which certain metallic alloying elements and certain metallic nitride precipitants are important and critical components.

More specifically, this invention relates to a steel comprising carbon less than 0.25%, silicon from 0.10 to 0.75%, manganese from 0.5 to 1.5%, chromium from 0.3 to 1.5%, molybdenum from 0.1 to 0.6%, vanadium from 0.02 to 0.2%, at least one of; aluminium nitride, beryllium nitride, columbium nitride, titanium nitride or zirconium nitride, from 0.03 to 0.18%, and boron from 0.0005 to 0.005%, copper from 0.2 to 0.7%, being an optional alloying element to be added according to the specific needs, the rest being substantially all iron with incidental or unavoidable impurities, the steel being rapidly cooled from a temperature above the $A_3$ transformation point, and preferably below 1200° C., namely a temperature range where the normal quench-hardening temperature range coincides with the fastest precipitation temperature range of nitrides of aluminium, beryllium or columbium, then tempered at a temperature between 550° C. and the $A_1$ transformation point.

The principle and the scope of this invention will be explained in the course of the disclosure which follows.

No special preference is given to the type of steelmaking furnace by which the steel of this invention is manufactured, though care must be taken as to the kind and the amount of alloying elements and the nitrides in regard to such factors of the steel as the thickness or the particulars of the end application, so that the featured tensile strength of 100 kg./mm.$^2$ level is assured without impairing the ductility or weldability when the steel is finished as product after heat treatment. In other words, emphasis is given in this invention not only on the deter-

mination of the proper composition range for alloy elements and nitride components but also on the proper method of heat treatment through which the tensile strength level aimed at is first attained.

The conditions necessary to achieve the objects of the invention have been found through many experiments and theoretical considerations, the results of which are now disclosed. In the first place, the carbon content is limited to less than 0.25% at which it was found that the rise in strength due to carbon is balanced by the deterioration in weldability. As for silicon, at least 0.10% is needed, for this kind of high tensile strength steels are necessarily killed, but not over 0.75%, above which the ductility of the steel tends to deteriorate. Manganese, one of the more economical alloying elements to improve the tensile strength, becomes effective at 0.5%, but beyond 1.5%, the weldability of the steel is adversely affected. Chromium is necessary for increase of the tensile strength at least by 0.3%, but not over 1.5%, for then the notch ductility and weldability of the steel are unfavorably affected. Molybdenum, which helps to improve the ductility along with the strength, is added in the range of 0.1% to 0.6%, without which limits the effect is either not apparent or saturated. Vanadium is prescribed for its grain refining and strength raising effect in a range of 0.02 to 0.2%, above which it is not only unnecessary, but often makes the steel tend to become brittle. In short, the basic composition of this steel is so designed that, with the cooperation of carbon, manganese, chromium, molybdenum and vanadium, that the strength of steel is elevated without damaging the ductility and the weldability.

However, it is to be noted that a tensile strength of over the 70 to 80 kg./mm.$^2$ range cannot be obtained even with proper heat treatment from a steel having the chemical composition listed above. Here resides the significance of the metallic nitride precipitate component, which therefore constitutes one necessary fundamental requisite in this invention.

It has been known that certain metallic nitride precipitates, for example aluminum nitride, work to refine the granular structure, and as a consequence, to improve the room temperature ductility as well as the low temperature notch-toughness of the steel. We have applied this principle to the cases of high tensile strength steels and were rewarded with expected result, i.e., the improved ductility. Not only that, we discovered for the particular case at hand that the strength of the steel, too, was markedly raised. However, it was seen at the same time that our nitride-containing low-alloy high strength steel is so fine-grained that its quench-hardenability is rather lowered, or a satisfactory quench-depth is obtained only with difficulty, particularly when the thickness of the stock is large, say over one inch. We then considered this difficulty to be surmountable by adding boron to correct for the loss in the quench-hardenability, which was duly substantiated by experiments. The effect of improving the quench-hardenability by boron is felt from a very small amount of 0.0005%, but when added in excess of 0.005%, the boron begins to precipitate as ferrous boride along the grain boundaries, which tends to act adversely on the ductility.

With regard to the kind and content of metallic nitride, the following should be taken into consideration. Of all the possible metallic nitride formers, we have ascertained that at least aluminum, beryllium, columbium, titanium and zirconium, particularly the former three, are effective. The content range for those metallic nitride precipitates to be effective is, taking the case of aluminum nitride, from 0.03 to 0.12%, for which formation metallic aluminum of at least 0.02 to 0.08% must be provided. Below this limit, the tensile strength level cannot be guaranteed, while above this range, the nitrogen that has to be contained in steel prior to aluminum nitride formation becomes too much for the ingot to finish in the killed state as required, where a lot of blow holes appear within the ingot. For the case where more nitride precipitates are needed, any combination of those nitrides, particularly one from the aluminum, beryllium and columbium group and another from the titanium and zirconium group, say a combination of aluminum and zirconium, may be used to raise the nitride content. However, no significant improvement is apparent beyond 0.18%.

Furthermore, it is possible to add copper to the basic composition described above. Copper is added by at least 0.2% when the corrosion resistivity of the steel is particularly specified. However, when present by more than 0.7%, it tends to limit the workability of the steel.

As mentioned briefly above, a proper heat treatment is another requisite for the steel of this invention to possess a tensile strength of 100 kg./mm.$^2$ level even if all those constitutents are chosen in most appropriate composition. In other words, the highly ductile and weldable steel with a tensile strength of 100 kg./mm.$^2$ level cannot be obtained by simply cooling the steel from the hot working temperature.

In order to achieve this end, the following heat treatment is mandatory. Firstly, the steel is heated to a temperature above the $A_3$ transformation point but below 1200° C., where the steel is austenitized and the metallic nitride precipitates out in the steel matrix finely and dispersedly. Secondly, after holding the steel at this temperature for sufficiently long time until the austenitization and nitride precipitation is completed, the steel is quenched in water, or rapidly cooled at a rate that is comparable to what is gained in the water quenching, so that most of the steel becomes martensite. Thirdly, the steel is tempered at a temperature between 550° C. and the $A_1$ transformation point so that the desired ductility is gained at an expense of strength, for the martensitic steel, even with the basic or modified composition of this invention, is too low in ductility, though the strength level can become very high. Here, the lower limit of the tempering temperature of 550° C. is rather critical, for tempering below this temperature leaves the steel susceptible to season cracking or other unfavorable phenomena that often occur in the steel after welding. In the heat treatment described above, care should be exercized to ascertain that substantially all the metallic nitride available has been precipitated.

## Example

In Table 1, an embodiment of a steel of this invention called steel A, is shown in terms of the chemical composition where the balance is substantially all iron with incidental impurities. The mechanical properties and the weldability of steel A is shown in Tables 2 and 3, respectively. In the Table 3, the weldability test A is in accordance with the Japanese National Railways (M. Otani, Journal of the Japan Welding Society, volume 25, November 5, 1956, pages 277 to 281) and the weldability test B is in accordance with the Lehigh University (R. D. Stout et al. Welding Journal, volume 25, 1946, pages 522–S to 531–S). The steel was first hot rolled to 25 mm. thickness, then quenched from 930° C. then tempered at 640° C., a particular heat treatment of this invention.

TABLE 1.—CHEMICAL COMPOSITION, WT. PERCENT

| Steel: | A |
|---|---|
| C | 0.13 |
| Si | 0.31 |
| Mn | 0.92 |
| Cr | 0.93 |
| Mo | 0.40 |
| V | 0.07 |
| B | 0.002 |
| Al | 0.076 |
| N | 0.016 |
| AlN | 0.044 |

TABLE 2.—MECHANICAL PROPERTIES

| Steel: | A |
|---|---|
| Yield point kg./mm.$^2$ | 102.9 |
| Tensile strength kg./mm.$^2$ | 108.2 |
| Elongation percent [1] | 19.6 |
| 15 ft./lb. transition temperature— | |
| ° C.[2] | −88 |
| ° C.[3] | <−120 |

[1] 14 mmϕ. 50 mm. gauge length.
[2] 2 mm. V-notch Charpy.
[3] 5 mm. V-notch Charpy.

TABLE 3.—WELDABILITY

| Steel: | A |
|---|---|
| Maximum hardness Vickers No. | 431. |
| Weldability Test A | No cracking with preheating at 120° C. |
| Weldability Test B | No cracking with preheating at 120° C. |

Thus, the steel of this invention possesses a tensile strength of 100 kg./mm.$^2$ level after the heat treatment and excellent room or low temperature ductility as well as a weldability which is quite comparable with that of known 80 kg./mm.$^2$ class high tensile strength steel.

What is claimed is:

1. A weldable high strength structural steel which consists of less than 0.25% carbon, from 0.10 to 0.75% silicon, from 0.5 to 1.5% manganese, from 0.3 to 1.5% chromium, from 0.1 to 0.6% molybdenum, from 0.02 to 0.2% vanadium, from 0.03 to 0.18% metallic nitride precipitate, and from 0.0005 to 0.005% boron, the metallic nitride being any one or any combination of aluminum nitride, beryllium nitride, columbium nitride, titanium nitride and zirconium nitride, the rest substantally all iron with incidental impurities, said steel being in martensitic condition.



2. A weldable high strength structural steel which consists of less than 0.25% carbon, from 0.10 to 0.75% silicon, from 0.5 to 1.5% manganese, from 0.3 to 1.5% chromium, from 0.1 to 0.6% molybdenum, from 0.02 to 0.2% vanadium, from 0.2 to 0.7% copper, from 0.03 to 0.18% metallic nitride precipitate, and from 0.0005 to 0.005% boron, the metallic nitride being any one or any combination of aluminum nitride, beryllium nitride, colubium nitride, titanium nitride and zirconum nitride, the rest substantially all iron with incidental impurties, said steel being in martensitic condition.


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