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[54] **HIGH TENSILE STRENGTH STEEL PLATE FOR COLD-FORMING**

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[58] **Field of Search**... 75/126 D, 126 F, 126 O, 124

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[57] **ABSTRACT**

A high tensile strength steel of low carbon Si-Cr series for use in frames of automobile which has a tensile strength of 50 to 65 kg/mm^2 and is particularly excellent in the cold press-formability and fatigue strength, containing Cr and Si in more amounts than conventional high tensile strength steels of this kind and further Cu, Ti, Nb and V besides said elements to obtain above-mentioned characteristics, said steel plate being applicable as hot-rolled.

2 Claims, No Drawings

HIGH TENSILE STRENGTH STEEL PLATE FOR COLD-FORMING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a low-carbon Si-Cr series steel plate which is weatherproof, high in the tensile strength and particularly excellent in the cold-formability and fatigue strength.

2. Description of the Prior Art

In general, steel plates have many uses, and for each of these uses there are produced various kinds of steels suitable therefor. Above all, for cold press-forming workings (deep-drawing, stretching, frame-forming, bending and the like) there are applied various kinds of steels, covering from very thin ones to relatively thick ones. There has recently been remarkably increased the demand for hot-rolled steel plates which are low in the manufacturing cost among steel plates. Particularly remarkable is the increase in the demand for strips which are continuously made in the coiled form with a strip rolling machine. Also for such strips the demand has increased for steel plates which have a higher strength than ever. In this case, however, as different from thick steel plates for ordinary uses, steel plates are required to be particularly excellent in the cold press-forming characteristics to meet requirements in forming final products and at the same time high in the strength. But, conventional high tensile strength steel plates are those which have been developed by taking into consideration only the uses of thick steel plates, in which the low temperature toughness and weldability are mainly required, without the cold press-forming characteristics being not considered. Therefore, it is a mattter of course that no satisfactory results could be always obtained, even by making such thick steel plates of various kinds as above-mentioned to thin ones and applying them, as they are, to uses, for which the cold press-forming characteristics are required.

It is comparatively easy to elevate the tensile strength or yield point of a steel plate up to a required level by adding alloying elements or by subjecting it to such heat-treatments as hardening and tempering. However, no satisfactory result could be obtained in harmonizing the strength and the cold formability with any combination or content range of alloying elements which have been heretofore used for harmonizing the strength and the weldability or notch toughness in known weldable high tensile strength steel.

Further, also any conventional high tensile strength steel to be used for cold workings has shown no satisfactory result in its repeated uses under high stresses, that is, to high value was shown to its fatigue limit.

SUMMARY OF THE INVENTION

In view of the above-mentioned facts, the present invention has for its object the provision of a high tensile strength steel plates which are endurable to such considerably severe cold press-forming as, for example, into frames for motor vehicles and are high in the yield point and tensile strength.

Another object of the present invention is to provide a high tensile strength steel for cold-forming which is high in the fatigue strength.

A further object of the present invention is to obtain cheaply a high tensile strength steel which has a tensile strength of about 50 to 65 kg/mm², and is high in the cold press-formability as rolled and is weatherproof.

Still further objects of the present invention will become clear from the following description.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The steel of the present invention is a steel cheap in the price and low in the carbon content, consisting of a main composition of 0.05 to 0.15 percent by weight carbon, 0.60 to 2.50 percent by weight silicon, 0.20 to 1.50 percent by weight manganese and 1.00 to 5.00 percent by weight chromium, and, as required 0.20 to 0.60 percent by weight copper and a total of 0.03 to 0.15 percent by weight of one, two or all of Ti, V and Nb, the rest being Fe and unavoidable impurities, which is characterized by properties of being weatherproof, high in the tensile strength and at the same time excellent in the cold formability.

The reasons for defining the respective constituent elements in the present invention to be as mentioned above are as follows.

Table 1 shows results of experiments in which the relations between each of alloying element (carbon, silicon, manganese and chromium) and characteristics of steel to be influenced by the addition of each of said elements, that is, the total elongation representing the elongation characteristic, the CCV (conical cup value) representing the drawability and stretchability, the minimum allowable bending radius representing the bending characteristic and the hole expansion height representing the hole expansibility, were determined by the method of multiple recurrent analysis and on the basis of the results obtained by said analysis the variation rates of each characteristic against an increase in the tensile strength due to the addition of said each of said elements were measured. By the way, for information, brief explanations of the respective characteristic values are given below Table 1. The chemical composition ranges of the steel plates subjected to the experiments were 0.05 to 0.20 percent carbon, 0.15 to 2.5 percent silicon, 0.15 to 2.0 percent manganese, 0.05 to 3.0 percent chromium, less than 0.020 percent phosphorus and sulphur respectively and less than 0.10 percent copper.

Table 1 – Increase or decrease in the respective characteristic values in case the tensile strength was increased by 5 kg./mm.² by each of the constituent elements alone

Characteristic values / Elements	Tensile strength kg/mm²	Total elongation %	CCV mm	Minimum allowable bending radius in direction C mm	Hole expansion height mm	Amount of increase of tensile strength against the addition of 1% of each element kg/mm²
C	+5	−2.12	+0.59	+2.00	−2.31	+78.1
Si	+5	−2.04	+0.15	+0.20	−0.79	+ 9.20

Table 1.—Continued

Characteristic values / Elements	Tensile strength kg/mm²	Total elongation %	CCV mm	Minimum allowable bending radius in direction C mm	Hole expansion height mm	Amount of increase of tensile strength against the addition of 1% of each element kg/mm²
Mn	+5	−3.16	+0.25	+1.34	−2.02	+ 5.61
Cr	+5	+0.26	+0.13	−0.39	+0.39	+ 2.53

Note: Explanation of the respective characteristic values

Tensile strength: Measured with a tensile test piece of JIS Z 2201

Total elongation: Measured with a tensile test piece of JIS Z 2201

CCV value: This means a conical cup value. In this test, a blank having a diameter of 108mm. was drawn-in by using a ball having a diameter of 36.51mm. on a conical die of an angle of 60 degrees. The outside diameter of the blank at the time of its rupture was made a CCV. The smaller this value, the better the drawability and stretchability.

Minimum allowable bending radius: A test piece 3.0mm. thick x 80mm. wide x 160mm. long was bent by 180 degrees. The bending radius at which no crack was produced at all was made the minimum allowable bending radius. The smaller the value, the higher the bendability.

Hole expansion height: A hole having a diameter of 25mm. was made and finished in the center of a blank of an outside diameter of 250mm. with a lathe. A force of 60 tons for pressing the blank was applied to the hole in the central part of the blank, expanded with a spherical-bottomed punch having a diameter of 100mm. until the hole was cracked. The height of the punch pressed-in at the time of the hole being cracked was made a hole expansion height. The larger this value, the higher the hole expansibility.

It is known since long ago that carbon is an element most convenient and effective to elevate the strength of steel. However, as understood from Table 1, carbon remarkably deteriorates the cold-pressibility, and it is also well known that carbon is an element not desirable in regard to the weldability. As a result of the qualitative determination tests of the steel of the present invention, it has been confirmed that particularly when carbon is more than 0.15 percent, the pearlite area rate becomes large, a pearlite layer structure is likely to be formed and the cold-pressibility, particularly the bendability, is remarkably reduced. Therefore, the upper limit is kept at 0.15 percent, and the lower limit is made 0.05 percent due to the restriction in the steel-making operation and to the fact that the steel of the present invention having a tensile strength of more than 50 kg/mm² should preferably contain at least 0.05 percent carbon. The carbon content range most desirable to the steel of the present invention is 0.07 to 0.11 percent.

Silicon is one of elements to be added, by which the steel of the present invention is characterized. As understood from Table 1, silicon does not reduce the workability of the steel so much in spite of the strength being elevated thereby. Among carbon, silicon, manganese and chromium, that is, elements effective in elevating the strength of steel, silicon is next to carbon in the effectiveness. Therefore, in the steel of the present invention, silicon is added in a particularly large amount. In an ordinary high tensile strength steel, however, silicon is used to be added in an amount less than 0.60 percent for deoxidation of steel or for elevating the tensile strength. Even in a very specific case, silicon is limited to be less than 1.00 percent. On the other hand, in the steel of the present invention the lower limit of silicon is made 0.60 percent and its upper limit 2.50 percent. According to the results of experiments, it has been confirmed that in regard to disadvantages accompanied by the advantageous effect of silicon of elevating the strength of steel the degree of deteriorating the press-formability of steel by the addition of silicon is in general lower than that by the addition of carbon and manganese, but if the addition of silicon exceeds 2.5 percent, it is no more practically effective, because such an addition of silicon makes it difficult to add alloying elements in the steel-making operation and further elevates the minimum finishing outlet temperature necessary for obtaining a proper rolling structure in rolling a strip on account of the A_3 transformation point being elevated by silicon. Thus, the optinum content range of silicon is 0.70 to 2.00 percent. Further, silicon of an amount lying within the range specified by the present invention elevates the fatigue strength of the steel plate. Particularly, when it is made to coexist with Cr, its effect is high.

Manganese is also an element added since long ago to elevate the strength of steel like carbon and silicon. The same as carbon, manganese considerably reduces the cold press-formability. Therefore, in the steel of the present invention, the upper limit of manganese is specified to be 1.50 percent and its lower limit is made 0.20 percent from the view point of preventing the hot-rolling brittleness due to sulfur contained as an impurity in the steel. According to the results of experiments, manganese elevates the pearlite area rate the same as carbon, and if the content of manganese exceeds about 0.8 percent, a pearlite layer structure detrimental to the workability is produced. Therefore, the most preferable content range of manganese is 0.20 to 0.80 percent.

Chromium as well as silicon is an element characterizing the steel of the present invention. According to the results of experiments, it has been made clear that chromium is an element which improves the bendability and hole expansibility, in spite of the strength of steel being elevated by chromium as is shown in Table 1. Further, among carbon, silicon, manganese and chromium, chromium is the lowest in the degree of lowering the drawability of steel and further has a function of elevating the fatigue strength, which particularly effective in case it is made to coexist with Si. In this sense, the lower limit of chromium is made 1.0 percent and its upper limit 5.0 percent. On the other hand, chromium is the lowest among four elements abovementioned in the effect of elevating the strength of steel. Therefore, in view of the actual steel-making operation and cost considerations, the optimum chromium content is 1.0 to 2.5 percent. It is also well known that chromium is an important element for obtaining an improvement of the weatherproofness of steel, which is, of course, achieved by the addition of such amount of chromium as is specified in the present invention. Further, it is also one of the features of the steel of the present invention that on account of nitrogen in the steel being fixed as a nitride due to sufficient contents of chromium and silicon the steel of the present invention is nonageing.

From Table 2 showing the example 1 of the present invention it can be observed that, as compared with reference materials consisting predominantly of carbon and manganese, the steel of the present invention has substantially the same strength but is far superior to the reference materials in the cold press-formability. Further, as is evidently seen from the ageing indices, the steel of the present invention is perfectly nonageing.

Table 3

Fatigue limits in kg/mm² of surface-ground materials containing Si and Cr. The numbers in the parentheses represent fatigue limit ratios

Cr (%) / Si(%)	0.5	0.1	1.5
0.2	23 (0.51)	22 (0.50)	23 (0.50)
0.5	25 (0.50)	26 (0.41)	—
1.0	32 (0.60)	32 (0.58)	35 (0.62)
1.5	34 (0.61)	35 (0.60)	38 (0.63)
1.7	35 (0.61)	37 (0.63)	38 (0.64)

Note: There was used a steel based on the composition of 0.09 to 0.11% C, 0.40 to 0.60% Mn, 0.009 to 0.020% P, 0.005 to 0.010% S, 0.00 to 0.08% Cu and about 0.02% Al, the rest being substantially Fe.

In the steel material of 1.5% Si and 1.5% Cr black-skinned as it was, the fatigue limit was 29 kg/mm² and

Table 2

a) Chemical composition

	Chemical analysis values (%) C	Si	Mn	Cr	P	S	Cu	Al
Present invention steel A	0.10	0.93	0.50	1.02	0.016	0.015	0.04	0.028
Reference material B	0.16	0.36	1.13	—	0.015	0.017	0.03	0.025
Present i invention steel C	0.09	1.54	0.75	1.48	0.018	0.022	0.05	0.037
Reference material D	0.18	0.49	1.36	—	0.017	0.019	0.04	0.025

b) Mechanical properties and cold press-formability (Plate thickness: 3.0mm)

	Direction	Lower yield point kg/mm²	Tensile strength kg/mm²	Uniform elongation %	Total elongation %	CCV mm	Erichsen value mm	Minimum allowable bending radius in direction C mm	Hole expansion height mm	Ageing index kg/mm²
Present invention steel A	L	37.1	52.0	21.9	35.5	86.9	15.0	0.75	48.5	0.2
	C	38.0	52.6	21.9	34.0					
Reference material B	L	34.5	50.2	21.4	34.7	87.8	14.7	2.5	44.0	4.0
	C	36.2	51.2	21.0	32.6					
Present invention steel C	L	44.0	58.7	20.5	34.5	87.2	14.8	1.00	45.0	0.1
	C	45.0	59.0	20.0	33.0					
Reference material D	L	41.5	57.5	17.4	32.4	88.4	14.0	3.0	42.0	4.0
	C	43.0	58.2	17.0	30.1					

In regard to the fatigue strength a test of the mother material was carried out by a both-end swinging plane bending method, and in Table 3 the results of the test are shown in a Schenck type bending fatigue test value. The tests were made with surface-ground materials (to eliminate the influences of fine flaws and scales on the surfaces) and black-skinned materials. That is, in the surface-ground materials with the exception of those low in Si and Cr beyond the composition range of the steel of the present invention, the fatigue limit was 32 to 38 kg/mm² and the fatugue limit ratio was so high as 0.58 to 0.64. That is to say, the higher the Si content, the higher the fatigue limit. It was recognized that, with Cr, too, the fatigue limit was increased but that, with its coexistence with Si, the fatigue limit became higher.

the fatigue limit ratio was 0.48, that is, about 20 percent lower than the fatigue limit of 38 kg/mm² and fatigue limit ration of 0.63 shown in the surface-ground material.

Further, as shown in the below-mentioned Table 4, as compared with conventional SA 45 and SAE 50, the Cr series steel of the present invention was higher by about 6 to 9 kg/mm² in the fatigue limit and about 20% in the fatigue limit ratio.

The main constituent elements of the present invention have been detailed in the foregoing. However, when adding further copper, titanium, vanadium and niobium as required, the excellent cold press-formability of the present steel plate can be maintained, and at the same time the weatherproofness can be improved

Table 4

	Chemical composition and fatigue strength							
	C	Si	Mn	P	S	Cu	Fatigue limit of black-skinned material	Fatigue limit ratio
SA 45	0.16	0.25	0.71	0.017	0.020	0.05	19	0.40
SAE 50	0.18	0.40	1.17	0.031	0.028	—	21	0.42

by the addition of Cu and the strength can be easily increased by the addition of titanium, vanadium and niobium.

It is a well known fact that copper is an element which increases the weatherproofness, and copper is generally well used in manufacturing weatherproof steel plates. However, as it has a disadvantage of causing surface cracks when hot-rolled, the addition of copper is limited to be 0.20 to 0.60 percent and is to be selectively contained in the steel of the present invention.

It is also well known that titanium, vanadium and niobium are elements which are recently much used to elevate the tensile strength of steel plates. From the results of the experiments it has been confirmed that by the addition of these elements the yeild point and tensile strength were remarkably elevated, but corresponding thereto the cold press-formability was remarkably deteriorated, if the carbon content was more than 0.15 percent. This is, however, thought to be natural in view of the mechanism of elevating the strength to be caused by the addition of these elements. However, it has been discovered through the experiments that, if the carbon content is limited to less than 0.15 percent in the steel of the present invention, which contains silicon and chromium added and to which further titanium, vanadium and niobium are added, there is scarcely seen a deterioration in the press-formability, in spite of the strength being elevated, as shown in Table 4 and further when compared with a steel, in which the strength is developed by means of carbon and manganese or the steel of the present invention which is mainly composed of silicon and chromium, but to which a large amount of carbon is added, the cold press-formability, particularly the bendability, is far superior to that of said reference steels, though they show all substantially the same strength. The reasons therefor seem to reside in that on account of the pearlite area rate being reduced and silicon and chromium being added in such amounts as specified in the steel of the present invention the formation of a pearlite layer structure is restrained, the anisotropy in the directions L and C is reduced and a deterioration of the ductility in the direction C as a general defect inherent to hot-rolled steel plates is prevented.

Further, the amounts of addition of titanium, vanadium and niobium are limited to be 0.03 to 0.15 percent as alone or combined, as generally practiced.

Table 5

a) Chemical composition

	Chemical analysis values (%)								
	C	Si	Mn	Cr	P	S	Cu	Al	Others
Present invention steel E	0.08	1.04	0.33	1.40	0.011	0.014	0.05	0.018	0.04 Nb
Reference material F	0.16	1.04	0.50	1.40	0.007	0.013	0.04	0.020	—
Reference material D	0.18	0.49	1.36	—	0.017	0.019	0.04	0.025	—

b) Mechanical properties and cold press-formability (Plate thickness: 3.0mm)

	Direction	Lower yield point	Tensile strength kg/mm²	Uniform elongation %	Total elongation %	CCV mm	Erichsen value mm	Minimum allowable bending radius in direction C mm	Hole expansion height mm
Present invention steel E	L	46.4	57.1	18.7	32.2	87.8	14.6	1.0	44.0
	C	46.4	57.2	17.9	30.9				
Reference material F	L	42.6	58.4	17.0	32.1	88.0	14.4	2.5	43.0
	C	42.5	58.9	17.8	31.1				
Reference material D	L	41.5	57.5	17.4	32.4	88.4	14.0	3.0	42.0
	C	43.0	58.2	17.0	30.1				

As in the above, the present invention is to provide economically a high tensile strength steel plate as hot-rolled, which is distinguished from any conventional high tensile strength steel by that it has not only a good weatherproofness but also simultaneously an excellent cold press-formability.

What is claimed is:

1. A weatherproof high tensile strength steel strip having a tensile strength of more than 50kg/mm^2 and having the properties of excellent cold-formability and high fatigue strength, consisting of 0.05 to 0.15 percent by weight carbon, 0.60 to 2.50 percent by weight silicon, 0.20 to 1.50 percent by weight manganese, 0.20 to 0.60 percent by weight copper, and a quantity by weight of chromium of more than 1.00 percent and up to 5.00 percent, the rest being iron and unavoidable impurities.

2. A steel plate according to claim 1 produced as hot-rolled.

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