

FLUX CORED WIRE FOR GAS-SHIELDED ARC WELDING OF HIGH TENSILE STEEL

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to a flux cored wire for gas-shielded arc welding of high tensile steel and, more particularly, to a flux cored wire for gas-shielded arc welding of high tensile steel having a proof stress higher than 620 MPa.

2. Description of the Related Art:

Recent steel structures require weight reduction as they become larger than before, and this requirement is met by the use of high tensile steel. There is an increasing demand for welding materials suitable for low-temperature toughness that is essential in the field of maritime structures and pressure vessels. Such welding materials are designed for shielded arc welding and submerged arc welding. These welding methods, however, have still problems with efficiency, operability, welding position, etc. This situation has aroused a demand for a flux cored wire that meets requirements for high efficiency, low-temperature toughness, and good operability.

Various kinds of flux cored wires have so far been developed. One of them is the flux cored wire for gas-shielded arc welding of high tensile steel (having a tensile strength of 690 MPa), which is disclosed in Japanese

Patent Laid-open No. H9-253886. It contains TiO_2 , metal fluoride, magnesium, and other alloying components in specific amounts, so that it provides not only good welding operability but also good high-temperature strength and low-temperature toughness after long PWHT (Post Weld Heat Treatment).

Another flux cored wire for gas-shielded arc welding of high tensile steel is disclosed in Japanese Patent Laid-open No. H3-47695. It has a titania-type flux composed mainly of TiO_2 , MgO , and MnO , with the ratio of TiO_2/MgO and the content of alloying components being adequately specified so that it provides good welding operability and toughness.

Yet another flux cored wire for gas-shielded arc welding of high tensile steel (with a tensile strength greater than 680 N/mm^2) is disclosed in Japanese Patent Laid-open No. H8-174275. Owing to its adequate content of alloying components and Ta, it permits efficient operation and provides good toughness and high strength equivalent to that of the base metal despite broadly ranging heat input.

OBJECT AND SUMMARY OF THE INVENTION

The welding wires disclosed in each of the above patent documents are tested for their low-temperature toughness in terms of Charpy impact value at -30 to -40°C . This testing temperature is not suitable for maritime structures and other structures which experience very low temperatures. Testing at much lower temperatures, say -60°C , is indispen-

sable. Nothing is mentioned in the above patent documents about toughness at low temperatures (about -60°C).

The welding wires disclosed in Japanese Patent Laid-open Nos. H9-253886 and H3-47695 contain such a large amount of slag forming agent that they give rise to slag in large amounts at the time of welding. This necessitates an additional step for slag removal and hence decreases the welding efficiency. Japanese Patent Laid-open No. H8-174275 specifies the amount of metal powder for improved welding efficiency but does not specify the content of Ti despite the fact that Ti is a component that results in slag at the time of welding and it plays an important role in welding efficiency.

No one has succeeded so far in the development of the flux cored wire for gas-shielded arc welding of high tensile steel which exhibits good toughness and cracking resistance at much lower temperatures and also permits improved welding operability.

The present invention was completed in view of the foregoing. It is an object of the present invention to provide a new flux cored wire for gas-shielded arc welding of high tensile steel with a proof stress higher than 620 MPa. Said cored flux wire gives weld metal with good cracking resistance and good low-temperature toughness at very low temperatures, say about -60°C , and it also excels in welding operability.

The present invention is directed to a flux cored wire

for gas-shielded arc welding of high tensile steel which comprises:

C : 0.04 to 0.11 mass%,

Si : 0.40 to 0.75 mass%,

Mn : 1.30 to 2.50 mass%,

Ni : 0.10 to 2.50 mass%,

Cr : 0.10 to 1.00 mass%,

Mo : 0.10 to 1.00 mass%,

Ti : 0.06 to 0.30 mass%,

Fe : no less than 90 mass%,

N : not more than 0.0150 mass%,

(based on the total amount of the wire),

the content in mass% of each component indicating the total amount in a sheath and a flux core, with each content of C, Si, Mn, Ni, Cr, Mo, and Ti, denoted respectively by [C], [Si], [Mn], [Ni], [Cr], [Mo], and [Ti], satisfying the formula below.

$$F(x) = -576.9[C] + 34.1[Si] + 80.1[Mn] + 1.5[Ni] - 22.8[Cr] - 6.8[Mo] - 83.1[Ti] \geq 100$$

The foregoing content represents the amount of the specified element constituting the compound added to the welding wire. For example, the content of Si is calculated from the amount of SiO₂ (or the like) added to the welding wire.

<Effect of the invention>

According to the present invention, the flux cored wire for gas-shielded arc welding of high tensile steel

gives weld metal excelling in low-temperature toughness and crack resistance even at very low temperatures, say about -60°C. It is also superior in welding operability and working efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph showing the relation between the value of F(x) and the Charpy impact value (vE -60°C (J)) at -60°C.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In what follows the invention will be described in more detail. In order to address the above-mentioned problems, the present inventors investigated alloying components of flux cored welding wires effective in improving the low-temperature toughness. As the result, they found that there exists a relationship between the amount of alloying components in the wire and the low-temperature toughness of the weld metal. Apparently, the low-temperature toughness of weld metal depends on the mutual action of alloying components. The effect of individual alloying components on the low-temperature toughness was examined and formalized experimentally. The results are shown below.

In other words, the relationship between the amount of alloying components in the wire and the low-temperature toughness of the weld metal is represented by the formula below.

$$F(x) = -576.9[C] + 34.1[Si] + 80.1[Mn] + 1.5[Ni] - 22.8[Cr]$$

$$-6.8[\text{Mo}] - 83.1[\text{Ti}] \geq 100$$

where [C], [Si], [Mn], [Ni], [Cr], [Mo], and [Ti] denote respectively the content of C, Si, Mn, Ni, Cr, Mo, and Ti in the welding wire. Only if the value of $F(x)$ is no smaller than 100, the welding wire gives weld metal excelling in low-temperature toughness at very low temperatures, say about -60°C .

Weld metal resulting from the welding of high-tensile steel (with a proof stress higher than 620 MPa) tends to decrease in toughness as the content of C, Cr, Ti, and Mo (particularly the content of C and Ti) increases in the welding wire.

The increase in Ti content results in an increase in the content of solid solution Ti in weld metal, which in turn results in precipitation of TiC in the reheated part (or that part of weld metal which is heated by the following pass). The precipitation of TiC aggravates the nucleus forming ability, thereby making coarse lath-like bainite dominant, which leads to a remarkable decrease in toughness. An increase in C content yields island martensite to deteriorate toughness.

By contrast, Si, Mn, and Ni tend to increase toughness. Particularly, Si and Mn reduce the oxygen content in weld metal, thereby contributing to toughness.

The present invention produces its effect only when the welding wire contains properly selected alloying components in adequate quantities according to the above-

mentioned findings. The alloying components were selected and quantified for the following reasons. The content of each component given below is based on the total amount (in mass%) of the welding wire. The flux cored welding wire according to the present invention consists of a steel sheath and a flux core therein, and either or both of the sheath and core will contain any of the following components.

C : 0.04 to 0.11 mass%

C is a component that greatly affects the strength of weld metal. With an amount less than 0.04 mass%, it does not provide a proof stress higher than 620 MPa. Therefore, the amount of C should be no less than 0.04 mass%, more preferably no less than 0.06 mass%. With an amount more than 0.11 mass%, it makes weld metal greatly sensitive to cold cracking. Therefore, the amount of C should be no more than 0.11 mass%, more preferably no more than 0.10 mass%.

Si : 0.40 to 0.75 mass%

Si functions as a deoxidizer which lowers the oxygen content in weld metal and retains the strength of weld metal. With an amount less than 0.40 mass%, it does not perform deoxidation completely, which results in blow hole and poor toughness. Therefore, the amount of Si should be no less than 0.40 mass%, more preferably no less than 0.50 mass%. With an amount more than 0.75 mass%, it gives rise to viscous weld metal, which is incompatible with base metal, and hence aggravates welding operability. Therefore,

the amount of Si should be no more than 0.75 mass%, more preferably no more than 0.60.

Mn : 1.30 to 2.50 mass%

Mn functions as a deoxidizer like Si. It also improves the toughness of weld metal. With an amount less than 1.20 mass%, it does not perform deoxidation completely, which results in blow hole and poor toughness. Therefore, the amount of Mn should be no less than 1.30 mass%, more preferably no less than 1.80 mass%. With an amount more than 2.50 mass%, it increases strength but makes weld metal more sensitive to cold cracking. Therefore, the amount of Mn should be no more than 2.50 mass%, more preferably no more than 2.10 mass%.

Ni : 0.10 to 2.50 mass%

Ni is a component that greatly affects the strength and toughness of weld metal. With an amount less than 0.10 mass%, it does not help improve toughness sufficiently. Therefore, the amount of Ni should be no less than 0.10 mass%, more preferably no less than 0.50 mass%. With an amount more than 2.50 mass%, it is liable to cause hot cracking. Therefore, the amount of Ni should be no more than 2.50 mass%, more preferably no more than 2.00 mass%.

Cr : 0.10 to 1.00 mass%

Cr invariably contributes to strength. With an amount less than 0.10 mass%, it does not provide adequate strength. Therefore, the amount of Cr should be no less than 0.10 mass%. With an amount more than 1.00 mass%, it greatly

increases strength but deteriorates toughness and causes cold cracking. Therefore, the amount of Cr should be no more than 1.00 mass%, more preferably no more than 0.60 mass%.

Mo : 0.10 to 1.00 mass%

Mo invariably contributes to strength, reduces grain size, and improves low-temperature toughness. With an amount less than 0.10 mass%, it does not provide adequate strength, nor does it produce the effect of grain refinement, which leads to low toughness. Therefore, the amount of Mo should be no less than 0.10 mass%, more preferably no less than 0.20 mass%. With an amount more than 1.00 mass%, it causes remarkable hardening, which deteriorates toughness. Therefore, the amount of Mo should be no more than 1.00 mass%, more preferably no more than 0.60 mass%.

Ti : 0.06 to 0.30 mass%

Ti reduces grain size, but it gives rise to slag when it exists in excess amount. With an amount less than 0.06 mass%, it does not reduce grain size as desired, which leads to poor low-temperature toughness. Therefore, the amount of Ti should be no less than 0.06 mass%, more preferably no less than 0.10 mass%. With an amount more than 0.30 mass%, it gives rise to slag, necessitating additional steps to remove slag, which lowers manufacturing efficiency. Therefore, the amount of Ti should be no more than 0.30 mass%, more preferably no more than 0.25 mass%.

Incidentally, Ti should preferably be added in the

form of metal or alloy (such as Fe-Ti). Ti added in oxide form gives rise to a large amount of slag, which necessitates additional steps for its removal, thereby decreasing the manufacturing efficiency. By contrast, Ti added in metal or alloy form gives rise to very little slag, which permits efficient flat or horizontal position welding.

N : not more than 0.015 mass%

N is not positively added in the present invention. However, a flux cored wire contains N to some extent, which comes from a raw material of a flux. With an amount more than 0.015 mass%, blow holes tend to be generated. Therefore, the amount of N should be not more than 0.015 mass%, more preferably not more than 0.010 mass%.

The remainder of the above-mentioned constituents of the flux cored welding wire according to the present invention is composed mainly of Fe alloys (such as Fe-Si, Fe-Mn, Fe-Cr, Fe-Mo, and Fe-Ti), which exist in the steel sheath and the flux therein, and Fe originating from iron powder. Fe accounts for more than 90 mass% in the total amount of the wire, more preferably more than 93 mass%. Fe content of more than 90 mass% provides high deposition rate. Moreover, the flux cored welding wire according to the present invention may additionally contain alkali metal fluoride and oxide, alkaline earth metal fluoride and oxide, B, Al, Mg, etc.

The content of alloying elements is specified by the following formula.

$$F(x) = -576.9[C] + 34.1[Si] + 80.1[Mn] + 1.5[Ni] - 22.8[Cr] - 6.8[Mo] - 83.1[Ti] \geq 100$$

This formula indicates how the low-temperature toughness of weld metal depends on the content of alloying elements. It was obtained statistically by performing Charpy impact test (at -60°C) on weld metal resulting from tens of wire samples each containing C, Si, Mn, Ni, Cr, Mo, Ti, Fe, N, and others as specified below.

C : 0.03 to 0.15 mass%,

Si : 0.32 to 0.89 mass%,

Mn : 1.18 to 2.65 mass%,

Ni : 0.04 to 2.75 mass%,

Cr : 0.05 to 1.20 mass%,

Mo : 0.04 to 1.21 mass%,

Ti : 0.03 to 0.36 mass%,

Fe : 92.1 to 96.1 mass%,

N : 0.0010 to 0.0150 mass%,

Others : 0.10 to 3.25 mass%

(Others including B, Na, F, K, Li, Al, Ca, Mg, P, and S)

The value of $F(x)$ is proportional to the low-temperature toughness of weld metal. The factor before the content of each alloying element denotes the effect of each alloying element on the low-temperature toughness of weld metal. In other words, the larger the factor, the greater the effect of alloying element on the low-temperature toughness, and vice versa. The negative factor means that the alloying element relating to it has an adverse effect

on low-temperature toughness. The factors in the formula $F(x)$ were determined according to how much the alloying elements contribute to the improvement of low-temperature toughness in proportion to their amount in the experiments with tens of wire samples.

The value of $F(x)$, as the index of the low-temperature toughness which is achieved when the amount of each alloying element is properly adjusted, was obtained for each wire sample, and the thus obtained values were plotted against the Charpy impact value at -60°C (abbreviated as $vE -60^{\circ}\text{C}$) of the samples. The result is shown in Fig. 1. It is noted from Fig. 1 that there is a linear relationship between $F(x)$ and $vE -60^{\circ}\text{C}$. The values of $vE -60^{\circ}\text{C} \geq 50 \text{ J}$ in the region of $F(x) \geq 100$ suggest good low-temperature toughness. Thus it was proved that the value of $F(x)$ permits an accurate prediction about the relation between the composition of the flux cored wire for gas-shielded arc welding for high-strength steel and the low-temperature toughness of the weld metal resulting from it.

The flux cored wire according to the present invention should contain flux in an amount of 10 to 30%, which is adequate for ordinary flux cored wires. An amount less than 10% is too small for the flux to supply necessary alloying elements by itself. Addition of alloying elements from the sheath leads to an increase in raw material cost. More over, incorporation with alloying elements increases the sheath strength, thereby aggravating the wire drawability, which

is unfavorable to production cost. Conversely, the wire with excess flux more than 30% has a thin sheath and hence is poor in drawability (with frequent breakage), which is unfavorable to production cost.

EXAMPLES

The invention will be described in more detail with reference to the following examples and comparative examples. Welding in these examples was carried out under the conditions shown in Table 1 below. The composition and the F(x) value of the sample wires are shown in Table 2. The composition of the sheath of the sample wires is shown in Table 3. The sample wires shown in Table 2 have any of the two kinds (A and B) of sheath as shown in Table 4. The compositions of the sheath (A and B) are shown in Table 3. Weld metal of HT780 steel was prepared under the welding conditions shown in Table 1. The weld metal was cut to prepare specimens for tensile test and Charpy impact test according to JIS Z3111 No. A1 and No. A4, respectively. Table 5 below shows the results of test for proof stress (at 0.2%), Charpy impact strength, and welding operability.

The sample wires were regarded as satisfactory if the weld metal resulting from them has a proof stress higher than 620 MPa and a Charpy impact value (at -60°C) higher than 50 J.

The samples were tested for cold cracking by ultrasonic flaw detection (according to JIS Z3060) and magnetic particle inspection (according to JIS G0565), with their

backing metal cut off after standing for 96 hours subsequent to welding. This test was followed by observation of fracture surface under an SEM. The samples were also tested for hot cracking by ultrasonic flaw detection (according to JIS Z3060) and radiographic examination (according to JIS Z3104), with their backing metal cut off. This test was followed by observation of fracture surface under an SEM. Incidentally, the tensile test and Charpy impact test were carried out according to JIS Z3111 for testing weld metal.

The welding operability is rated as "poor" if welding with the sample wire is apparently inefficient.

Table 1 (Conditions of welding)

Welding current (A)	Arc voltage (V)	Welding speed (mm/min)	Preheat and interpass temperature (°C)	Heat input (kJ/mm)
280	31	300	150	1.7
Composition of shielding gas (vol%)	Flow rate of shielding gas (L/min)	Wire diameter (mm)	Welding position	Steel plate for welding
Ar/CO ₂ = 80/20	25	1.2	downhand	JIS G312 8SHY685
Thickness of welded steel plate (mm)	Groove shape	Groove gap (mm)	--	--
20	V, 45°	12	--	--

Table 2 (Constituents of wire)

	No.	Constituents of wire (mass%)										F(x)
		C	Si	Mn	Ni	Cr	Mo	Ti	Fe	N	Rest	
Examples	1	0.04	0.54	1.80	1.20	0.50	0.20	0.20	94.15	0.0014	1.4	112
	2	0.11	0.56	2.10	1.40	0.10	0.50	0.21	94.73	0.0025	0.3	103
	3	0.07	0.42	1.82	1.66	0.22	0.48	0.10	94.34	0.0020	0.9	106
	4	0.07	0.74	1.81	1.20	0.19	0.49	0.22	94.25	0.0012	1.0	106
	5	0.05	0.74	1.34	2.49	0.11	0.11	0.06	94.22	0.0040	0.9	100
	6	0.10	0.51	2.48	1.04	0.23	0.48	0.10	94.78	0.0028	0.3	143
	7	0.08	0.51	1.90	0.14	0.20	0.45	0.10	94.22	0.0010	2.4	108
	8	0.08	0.50	1.88	2.51	0.32	0.28	0.11	93.11	0.0087	1.2	107
	9	0.08	0.49	2.01	0.82	0.13	0.55	0.25	93.57	0.0021	2.1	105
	10	0.06	0.66	2.05	1.80	1.00	0.33	0.25	93.22	0.0050	0.6	109
	11	0.08	0.52	1.95	1.55	0.20	0.12	0.29	94.44	0.0034	0.8	101
	12	0.08	0.61	1.88	1.15	0.21	1.01	0.12	94.55	0.0150	0.4	105
	13	0.09	0.48	1.88	1.34	0.35	0.43	0.06	93.94	0.0043	1.4	101
	14	0.08	0.46	2.20	1.93	0.20	0.42	0.31	94.12	0.0029	0.3	118
Comparative Examples	15	0.03	0.51	1.50	1.01	0.21	0.49	0.15	94.21	0.0024	1.9	101
	16	0.13	0.67	2.02	1.80	0.32	0.61	0.15	93.84	0.0057	0.5	86
	17	0.07	0.33	2.10	0.97	0.67	0.55	0.15	93.22	0.0068	1.9	109
	18	0.08	0.82	1.84	1.49	0.19	0.42	0.11	93.16	0.0020	1.9	115
	19	0.08	0.50	1.21	1.04	0.25	0.48	0.12	93.22	0.0015	3.1	50
	20	0.07	0.55	2.54	1.45	0.67	0.76	0.25	93.25	0.0028	0.5	143
	21	0.09	0.42	1.80	0.05	0.29	0.59	0.22	95.00	0.0020	1.5	75
	22	0.08	0.49	1.99	2.62	0.32	0.28	0.18	93.87	0.0054	0.2	110
	23	0.07	0.72	1.58	1.11	0.07	0.21	0.14	95.11	0.0025	1.0	101
	24	0.09	0.65	1.71	1.04	1.10	0.73	0.25	94.02	0.0058	0.4	58
	25	0.07	0.44	1.61	0.89	0.47	0.09	0.14	95.22	0.0101	1.1	82
	26	0.09	0.62	1.90	0.87	0.58	1.11	0.25	94.12	0.0040	0.5	81
	27	0.09	0.43	1.85	1.10	0.50	0.82	0.04	94.57	0.0042	0.6	90
	28	0.07	0.45	2.10	2.10	0.22	0.14	0.37	94.10	0.0050	0.4	110
	29	0.08	0.43	1.55	1.85	0.21	0.28	0.11	94.98	0.0025	0.5	80
	30	0.07	0.45	1.50	2.10	0.22	0.25	0.15	95.01	0.0103	0.2	79
	31	0.09	0.53	1.80	1.81	0.22	0.34	0.22	94.45	0.0045	0.5	87
	32	0.08	0.55	1.74	2.20	0.25	0.32	0.21	93.38	0.0032	1.3	90
	33	0.10	0.70	2.40	1.20	0.50	0.40	0.10	89.00	0.0059	5.6	138
	34	0.11	0.74	1.35	0.80	0.13	0.32	0.11	94.20	0.0160	2.2	57

Table 3

Type	C	Si	Mn	Ni	Cr	Mo	Ti	Fe	N	Rest
A	0.05	0.05	0.50	0.00	0.00	0.00	0.02	99.3	0.0020	0.1
B	0.03	0.02	0.70	0.50	0.10	0.10	0.00	98.4	0.0100	0.1
"Rest" includes P, S, Al, Nb, and V. Unit in mass%.										

Table 4

Examples		Comparative Examples	
No.	Type of sheath	No.	Type of sheath
1	A	15	A
2	A	16	A
3	A	17	A
4	A	18	A
5	A	19	A
6	A	20	A
7	A	21	A
8	B	22	A
9	A	23	A
10	A	24	A
11	A	25	B
12	B	26	A
13	A	27	A
14	A	28	A
--		29	A
--		30	B
--		31	A
--		32	A
--		33	A
--		34	B

Table 5 (Results of test)

	No.	Proof stress at 0.2% (MPa)	vE -60°C (J)	Welding operability	Others
Examples	1	659	72	○	—
	2	791	67	○	—
	3	705	84	○	—
	4	745	88	○	—
	5	621	57	○	—
	6	792	111	○	—
	7	647	73	○	—
	8	766	75	○	—
	9	712	89	○	—
	10	925	81	○	—
	11	670	82	○	—
	12	861	81	○	—
	13	752	79	○	—
	14	766	77	○	—
Comparative Examples	15	598	89	○	—
	16	942	48	○	Cold cracking
	17	801	58	Blow hole	—
	18	768	76	Incompatible	—
	19	662	41	Blow hole	—
	20	965	78	○	Cold cracking
	21	707	39	○	—
	22	786	55	○	Hot cracking
	23	605	52	○	—
	24	1024	27	○	Cold cracking
	25	618	32	○	—
	26	990	35	○	—
	27	862	44	○	—
	28	700	59	Excess slag	Low efficiency
	29	663	35	○	—
	30	659	33	○	—
	31	743	24	○	—
	32	749	42	○	—
	33	876	63	Excess slag	Low efficiency
	34	686	32	Blow hole	—

As shown in Table 2, sample wires in Examples Nos. 1 to 14 accord with the present invention, and sample wires in Comparative Examples 15 to 32 are outside the scope of the present invention.

It is noted from Table 5 that the sample wires in Examples Nos. 1 to 14 have a proof stress (at 0.2%) higher than 620 MPa and the value of $vE_{-60^{\circ}C}$ larger than 50 J, which are an indication of adequate strength and outstanding low-temperature toughness, and that they also excel in welding operability and cracking resistance.

Incidentally, Table 5 includes a column "others" to note only those sample wires which suffered cold-cracking or hot-cracking among all the sample wires (Example Nos. 1 to 32) tested.

By contrast, it is noted that the sample wires in Comparative Example No. 15 (in which the content of C is less than 0.04 mass%) and Comparative Example No. 23 (in which the content of Cr is less than 0.10 mass%) have a proof stress (at 0.2%) lower than 620 MPa, which is an indication of insufficient strength. It is also noted that the sample wires in Comparative Example No. 16 (in which the content of C is more than 0.11 mass%) and Comparative Example No. 24 (in which the content of Cr is more than 1.00 mass%) have excessive strength and reduced toughness and suffer cold cracking.

It is noted that the sample wires in Comparative Example No. 17 (in which the content of Si is less than 0.40

mass%) and Comparative Example No. 19 (in which the content of Mn is less than 1.30 mass%) have many blow holes due to insufficient deoxidation. It is also noted that the sample wire in Comparative Example No. 18 (in which the content of Si is more than 0.75 mass%) is incompatible with the base metal, which leads to poor welding operability.

It is noted that the sample wire in Comparative Example No. 20 (in which the content of Mn is more than 2.50 mass%) has excessive strength and suffer cold cracking.

It is noted that the sample wire in Comparative Example No. 21 (in which the content of Ni is less than 0.10 mass%) or the sample wire in Comparative Example No. 27 (in which the content of Ti is less than 0.06 mass%) has low toughness due to insufficient grain refinement. By contrast, it is noted that the sample wire in Comparative Example No. 22 (in which the content of Ni is more than 2.50 mass%) suffers hot-cracking.

It is noted that the sample wire in Comparative Example No. 25 (in which the content of Mo is less than 0.10 mass%) has low strength (with the proof stress at 0.02% being less than 620 MPa) and low toughness due to insufficient grain refinement.

It is noted that the sample wire in Comparative Example No. 26 (in which the content of Mo is more than 1.00 mass%) has low toughness due to extreme hardening of weld metal.

It is noted that the sample wire in Comparative Exam-

ple No. 28 (in which the content of Ti is more than 0.30 mass%) is poor in welding operability due to a large amount of slag resulting therefrom, which takes a long time to remove.

It is noted that the sample wires in Comparative Examples Nos. 29 to 32 (in which the value of $F(x)$ is smaller than 100) are poor in low-temperature toughness (with the Charpy impact value at -60°C being smaller than 50 J).

It is noted that the sample wire in Comparative Example No. 33 (in which the amount of elements other than Fe is large and the amount of Fe is less than 90 mass%) is poor in welding operability due to a large amount of slag and due to decreasing of deposited metal amount resulting therefrom.

It is noted that the sample wire in Comparative Example No. 34 (in which the amount of N is more than 0.015 mass%) has blow holes.

As mentioned above, the sample wires in Examples Nos. 1 to 14, which accord with the present invention, exhibit good low-temperature toughness, welding operability, and cracking resistance.

WHAT IS CLAIMED IS:

1. A flux cored wire for gas-shielded arc welding of high tensile steel which comprises:

C : 0.04 to 0.11 mass%,

Si : 0.40 to 0.75 mass%,

Mn : 1.30 to 2.50 mass%,

Ni : 0.10 to 2.50 mass%,

Cr : 0.10 to 1.00 mass%,

Mo : 0.10 to 1.00 mass%,

Ti : 0.06 to 0.30 mass%,

Fe : no less than 90 mass%,

N : not more than 0.0150 mass%,

(based on the total amount of the wire),

with each content of C, Si, Mn, Ni, Cr, Mo, and Ti, denoted respectively by [C], [Si], [Mn], [Ni], [Cr], [Mo], and [Ti], satisfying the formula below:

$$F(x) = -576.9[C] + 34.1[Si] + 80.1[Mn] + 1.5[Ni] - 22.8[Cr] - 6.8[Mo] - 83.1[Ti] \geq 100$$