

SOLID WIRE FOR GAS SHIELD ARC WELDING  
OF HIGH STRENGTH STEEL

[Technical Field]

[0001]

The present disclosure relates to a solid wire for gas shield arc welding of high-strength steel having tensile strength of 780 MPa class, and particularly relates to a solid wire for the welding of high-strength steel the welded portion of the metal (hereinafter simply referred to as the weld metal) of which is excellent in toughness at low temperature.

[Background]

[0002]

In recent years, 780MPa class steel has been used in general because the steel used in steel structures such as buildings, bridge constructions and marine structures has been substituted with high-strength steel to meet the increase in demand for increasing the size and decreasing the weight of such structures.

[0003]

Gas shield arc welding, excellent in resistance in cracking because of less amount of hydrogen and suitable for high efficiency in welding, is often used for the welding of the 780 MPa class high-strength steel.

[0004]

As a high-strength solid wire, a solid wire doped with Ni, Cr and Mo disclosed in Reference 1, has been used for the welding of high-strength steel by gas shield arc welding. However, a solid wire disclosed in Reference 1 is suitable for TIG type welding but is not suitable for MAG type welding which uses consumable electrode because a sufficient strength and an excellent toughness at low temperature of the weld metal cannot be obtained.

[0005]

Reference 2 discloses a method to improve the toughness by making the microstructure of the weld metal fine-grained by specifying contents and the ratio of the contents of acid-soluble component and acid-insoluble component such as Al and Ti in addition to the doping with Ni, Cr and Mo. However, even with the help of the method disclosed in Reference 2, the toughness at low temperature of the weld metal cannot be obtained.

[0006]

Reference 3 discloses a wire to ensure the toughness and strength of the weld metal even under the conditions of high electrical current, high heat input and high inter-pass temperature for the gas shield arc welding of 490 to 780 MPa class high strength steel. However, the wire disclosed in Reference 3 cannot ensure the toughness at low temperature of the weld metal when the wire is applied to the welding of 780 MPa class high strength steel plate.

[0007]

Reference 4 discloses a wire for gas shield arc welding for high strength steel by which the weld metal with the strength of 1200 MPa or more is obtainable. However, the wire disclosed in Reference 4 cannot ensure the toughness at low temperature since the carbon equivalent (Ceq) of the wire is so high that the tensile strength of the weld metal becomes too high to ensure the toughness of it.

[Patent - related references]

[0008]

[Reference 1] Japanese Published Unexamined Patent Application  
No. Shou 57-159293

[Reference 2] Japanese Published Examined Patent Application  
No. Shou 60-057953

[Reference 3] Japanese Published Unexamined Patent Application  
No. 2007-253163

[Reference 4] Japanese Published Unexamined Patent Application  
No. 2006-110581

[Summary]

[The problem to be solved]

[0009]

The present disclosure, which is to solve the above mentioned problem, is made to provide a solid wire for gas shield arc welding for high-strength steel, the wire can provide a weld metal having a suitable strength and an excellent and stable toughness at low temperature in the welding of 780 MPa class as well as an excellent workability of the welding.

[Measures to solve the problem]

[0010]

A first aspect of the present disclosure is a solid wire for the gas shield arc welding, said wire comprising by mass% to the whole

wire: C: 0.02 to 0.10%, Si: 0.20 to 0.55%, Mn: 1.50 to 1.95%, Cu: 0.15 to 0.45%, Ni: 2.7 to 3.2%, Cr: 0.35 to 0.65%, Mo: 0.15 to 0.40%, Ti: 0.02 to 0.10%, wherein Pts defined by EQ(1) is 0.73 to 0.95, Al: 0.010% or less, P: 0.020% or less, S: 0.020% or less, N: 0.007% or less, O: 0.010% or less, and the remnant is Fe and the unavoidable impurities,

$$\begin{aligned} \text{Pts} = & [\text{C}] + [\text{Si}]/7 + [\text{Mn}]/5 + [\text{Cu}]/7 + [\text{Ni}]/20 \\ & + [\text{Cr}]/8 + [\text{Mo}]/2 + [\text{Ti}]/5 \end{aligned} \quad \text{EQ(1)},$$

where [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [Ti] denote the contents of the elements by mass%.

[0011]

A second aspect of the present disclosure is the solid wire for the gas shield arc welding described in the first aspect above, wherein the solid wire has a lubrication oil of 0.3 to 1.0 g per 10 kg of the solid wire on the surface.

[The effect]

[0012]

The present disclosure provides a solid wire for gas shield arc welding of high-strength steel, the wire is capable of keeping the arc stable, ensuring 780 MPa class strength and providing a high quality weld metal with a stable high toughness at low temperature without defects.

[Brief Description of the Drawings]

[Fig.1] Fig.1 shows an image of steel plate to be welded, where the steel plate is 20 mm in thickness having a groove with 20-degree groove angle and 16 mm root gap backed by a backing.

[Fig.2] Fig.2 shows an image of specimen to be taken out from the center part of the base in thickness direction including the weld metal and the welded base plate.

[Description of the preferred embodiments]

[0013]

In order to solve the problem mentioned above, the inventors have studied carefully on the component composition of the solid wire for the gas shield arc welding which is capable of providing a weld metal having a suitable strength and a stable high toughness even at low temperature of -60°C in the welding of 780 MPa class high-strength steel as well as an excellent workability of the welding.

[0014]

As a result, the inventors have found that having a suitable amount of each component of C, Si, Mn, Cu, Ni, Cr, Mo and Ti in

the solid wire are effective to obtain both suitable strength and stable toughness at low temperature of the weld metal. The inventors have also found that having a suitable amount of each component of Si and Mn and a suitable amount of lubricating oil supplied to the wire surface is effective to obtain an excellent workability in the welding.

[0015]

The effect of the solid wire for gas shield arc welding of high strength steel of the present disclosure is derived from each component composition or synergetic effect by the combination of some components. The reason for doping each of the components and limiting the range of them is described below. Hereinafter the chemical components of the solid wire are expressed by mass% to the whole solid wire and the "mass%" is simply represented as "%"

[0016]

[C: 0.02 to 0.10%]

C is an element necessary to strengthen the weld metal by solid solution hardening. However, the effect of solid solution hardening is not obtainable if the content of C is less than 0.02%. If the content of C is more than 0.10%, the welding crack sensitivity in the weld metal increase. The preferable range of the C content is 0.03 to 0.09%.

[0017]

[Si: 0.20 to 0.55%]

Si is added in order to deoxidize the weld metal. If the Si content is less than 0.20%, the arc is not stable and the toughness of the weld metal decreases because of the insufficient deoxidization. If the content of Si is more than 0.55%, the toughness at low temperature cannot be obtainable stably. The preferable range of the Si content is 0.25 to 0.50%.

[0018]

[Mn: 1.50 to 1.95%]

Mn is added in order to deoxidize the weld metal as the same effect of Si. However, toughness of the weld metal cannot sufficiently be preserved if the content of Mn is less than 1.50%. If the content of Mn is more than 1.95%, the toughness at low temperature cannot be obtained stably. The preferable range of the of the Mn content is 1.50 to 1.90%.

[0019]

[Cu: 0.15 to 0.45%]

Cu has the effect of strengthening by precipitation

strengthening and lowers the transformation temperature to stabilise the toughness by making the weld metal structure fine-grained. However, the toughness at low temperature cannot be obtained stably if the Cu content is less than 0.15%. If the Cu content is more than 0.45%, the toughness of weld metal deteriorates because of the effect of embrittlement by precipitation of Cu. The preferable range of the Cu content is 0.20 to 0.40%. If the surface of the solid wire is plated with Cu for rust prevention, the amount of the Cu plating is included in the Cu content.

[0020]

[Ni: 2.7 to 3.2%]

Ni has the effects of making the structure fine-grained by lowering the transformation temperature and strengthening the weld metal by solid solution without deteriorating the toughness of the weld metal. However, the effect of preventing the deterioration of toughness is not sufficiently obtainable if the Ni content is less than 2.7%. If the Ni content is more than 3.2%, the toughness of the weld metal is deteriorated because of the embrittlement of grain boundary.

[0021]

[Cr: 0.35 to 0.65%]

Cr has the effect of increasing the toughness of the weld metal by making the structure fine-grained and by lowering the transformation temperature. However, the effect of increasing the toughness of the weld metal is not obtainable if the Cr content is less than 0.35%. If the Cr content is more than 0.65%, the toughness is deteriorated because the weld metal becomes hardened more.

[0022]

[Mo: 0.15 to 0.40%]

Mo has the effect of increasing the toughness of the weld metal by making the weld metal structure fine-grained and by lowering the transformation temperature. However, the effect of increasing the toughness is not sufficiently obtainable if the Mo content is less than 0.15%. If the Mo content is more than 0.40%, the toughness at low temperature cannot be obtainable stably.

[0023]

[Ti: 0.02 to 0.10%]

Ti has the effect of improving toughness of the weld metal by reducing the amount of the oxygen in the weld metal and by acting as a deoxidizing agent. Ti also has the effect of forming a fine-

grained oxidation products of Ti in the weld metal, which also improves the toughness of the weld metal. However, toughness at low temperature cannot be obtained stably if the Ti content is less than 0.02%. If the Ti content is more than 0.10%, toughness deteriorates because the content of the Ti existing as solid solution in the weld metal becomes too high.

[0024]

[Pts: 0.73 to 0.95%]

The coefficient of the EQ(1) defined below is derived by multiple linear regression analysis with variables of the contents of C, Mn, Cu, Ni, Cr, Mo and Ti as independent variables, the strength and toughness of the weld metal as dependent variables, however, the coefficient of [C] is set as 1 and the coefficients of the other elements are calculated by the multiple linear regression analysis. The Pts, calculated by the EQ(1), is the estimated value of the strength and toughness of the weld metal. If the Pts calculated by EQ(1) is within the range of 0.73 to 0.95, the contents of C, Mn, Cu, Ni, Cr, Mo and Ti is suitable to ensure both the strength and toughness at low temperature of the weld metal. However, the strength of the weld metal deteriorates if Pts is less than 0.73. If Pts is more than 0.95, the strength of the weld metal becomes too high to get stable toughness at low temperature.

$$\begin{aligned} \text{Pts} = & [\text{C}] + [\text{Si}]/7 + [\text{Mn}]/5 + [\text{Cu}]/7 + [\text{Ni}]/20 \\ & + [\text{Cr}]/8 + [\text{Mo}]/2 + [\text{Ti}]/5 \end{aligned} \quad \text{EQ(1).}$$

Al is contained inevitably at steel making, however, the less the Al content the better since Al forms non-metallic inclusion in the weld metal to lower the toughness, and thus the Al content is limited to less than 0.010%. S and P are the impurities that deteriorate the toughness of the weld metal. The content of S and P are preferably less than 0.020% respectively.

[0025]

N is an impurity and is inevitably contained. In order to improve the toughness of the weld metal, stably decreasing the solid solution of N is necessary. If the N content is more than 0.0070%, the toughness of the weld metal deteriorates.

O(oxygen) deteriorates the toughness of the weld metal by forming non-metallic inclusion with Si and Mn and so on.

The content of O is preferably less than 0.010%.

[0026]

[Rate of Lubrication Oil supplied: 0.3 to 1.0g / 10kg of solid wire]

Lubrication oil supplied to the surface of the solid wire to

cover the surface is not necessary, however, smooth wire feeding promoted by the oil supply, especially in semi-automatic welding, may keep the arc stable to reduce the amount of the sputter and it may prevent the generation of defects in weld metal. However if the rate of lubrication oil supplied to the surface of the wire becomes less than 0.3 g per 10 kg of the wire fed, the smooth wire feeding cannot be kept, which may cause an unstable arc and increase of the amount of the sputter, and also may cause a slag-inclusion defect easily. If the rate of lubrication oil supplied to the surface of the wire becomes more than 1.0 g per 10 kg of the wire fed, a slip between the fed wire and the wire feeding roll is caused, which leads to unstable arc and increase of the amount of the sputter. Furthermore, a blowhole may be easily formed in the weld metal portion. Accordingly, the amount of lubrication oil covering the surface is preferably 0.3 to 1.0g / 10kg of the solid wire.

[0027]

As a lubrication oil, any of animal oil, vegetable oil, mineral oil and synthetic oil can be used. As the animal oil and vegetable oil, palm oil, canola oil, castor oil (ricinus oil), pig oil, cow oil, fish oil and the like can be used. As the mineral oil, machine oil, turbine oil and spindle oil and the like can be used. As the synthetic oil, hydrocarbon type oil, ester type oil, polyglycol type oil, polyphenol type oil, silicone type oil, Frollo-carbon type oil can be used.

Furthermore, lubrication oil(s) containing Sulfur that comprise base oil(s) having one or more of fat(s) and ester(s) and Sulfur containing oil(s) having one or more of sulfurated-fat, sulfurated-ester, sulfurated-fat acid and sulfurated-olefin can be used.

[0028]

A gas mixture of Ar and CO<sub>2</sub> is used as a shield gas, the volumetric percentage of CO<sub>2</sub> in the mixture gas is 5 to 20 volume % in order to reduce the O(oxygen) content in the weld metal. The flow rate of the shield gas is preferably 20 to 35 l/min in order to reduce the generation of defects and to avoid the interfusion of Nitrogen gas from the air.

[Examples]

[0029]

The effect of the present disclosure is explained in detail by the examples.

[0030]

Solid wires for testing are prepared of which chemical compositions are shown in TABLE 1, the diameter of the wires is 1.2mm, and the surface is covered with a palm oil. Steel plates of 780MPa class high-strength steel are prepared with the specification as shown in TABLE 2 and Fig.1 where the thickness of plate is 20 mm, the groove angle is 20 degrees and the root gap is 16 mm backed with a backing. In the test, Multi-layered welding is carried out under the welding condition in TABLE 3 and the solid wire for the welding is fed through a conduit cable of 6m in length.

[0031]

TABLE 1

| Type        | Wire | Wire Chemical Components (mass%) |             |             |       |       |             |             |             |             |             |       |        |        | Pts         | ROL<br>*1)  |
|-------------|------|----------------------------------|-------------|-------------|-------|-------|-------------|-------------|-------------|-------------|-------------|-------|--------|--------|-------------|-------------|
|             |      | C                                | Si          | Mn          | P     | S     | Cu          | Ni          | Cr          | Mo          | Ti          | Al    | N      | O      |             |             |
| Embodiments | W1   | 0.05                             | 0.51        | 1.67        | 0.007 | 0.008 | 0.26        | 2.95        | 0.41        | 0.22        | 0.06        | 0.002 | 0.0037 | 0.0025 | 0.81        | 0.33        |
|             | W2   | 0.03                             | 0.26        | 1.78        | 0.011 | 0.007 | 0.19        | 2.77        | 0.48        | 0.16        | 0.04        | 0.004 | 0.0041 | 0.0042 | 0.74        | 0.68        |
|             | W3   | 0.04                             | 0.53        | 1.72        | 0.006 | 0.009 | 0.29        | 3.03        | 0.63        | 0.19        | 0.02        | 0.006 | 0.0056 | 0.0038 | 0.83        | <u>0.27</u> |
|             | W4   | 0.07                             | 0.22        | 1.53        | 0.015 | 0.011 | 0.44        | 3.11        | 0.36        | 0.35        | 0.08        | 0.002 | 0.0033 | 0.0071 | 0.86        | 0.85        |
|             | W5   | 0.07                             | 0.49        | 1.93        | 0.009 | 0.007 | 0.31        | 2.96        | 0.55        | 0.29        | 0.05        | 0.004 | 0.0043 | 0.0034 | 0.94        | 0.46        |
|             | W6   | 0.08                             | 0.34        | 1.55        | 0.008 | 0.006 | 0.41        | 2.79        | 0.44        | 0.38        | 0.03        | 0.003 | 0.0054 | 0.0056 | 0.89        | 0.95        |
|             | W7   | 0.05                             | 0.49        | 1.84        | 0.014 | 0.012 | 0.16        | 3.16        | 0.54        | 0.26        | 0.04        | 0.005 | 0.0035 | 0.0049 | 0.87        | <u>1.04</u> |
|             | W8   | 0.09                             | 0.27        | 1.62        | 0.011 | 0.005 | 0.27        | 2.85        | 0.53        | 0.30        | 0.06        | 0.007 | 0.0028 | 0.0034 | 0.86        | 0.74        |
|             | W9   | 0.05                             | 0.41        | 1.76        | 0.007 | 0.007 | 0.18        | 2.73        | 0.39        | 0.18        | 0.09        | 0.002 | 0.0061 | 0.0065 | 0.78        | 0.38        |
|             | W10  | 0.04                             | 0.39        | 1.66        | 0.009 | 0.006 | 0.31        | 2.94        | 0.47        | 0.27        | 0.05        | 0.004 | 0.0052 | 0.0052 | 0.82        | 0.59        |
| Comparative | W11  | <u>0.01</u>                      | 0.31        | 1.69        | 0.006 | 0.005 | 0.26        | 2.82        | 0.41        | 0.22        | <u>0.01</u> | 0.003 | 0.0047 | 0.0048 | 0.73        | 0.64        |
|             | W12  | <u>0.11</u>                      | 0.43        | 1.75        | 0.013 | 0.011 | 0.18        | 2.79        | 0.72        | 0.24        | 0.04        | 0.006 | 0.0039 | 0.0047 | 0.90        | 0.48        |
|             | W13  | 0.03                             | <u>0.16</u> | 1.65        | 0.011 | 0.010 | 0.31        | 2.84        | 0.39        | 0.25        | 0.05        | 0.008 | 0.0027 | 0.0038 | 0.75        | 0.91        |
|             | W14  | 0.06                             | <u>0.62</u> | 1.75        | 0.015 | 0.009 | 0.29        | 2.97        | 0.46        | 0.31        | 0.03        | 0.005 | 0.0052 | 0.0054 | 0.91        | <u>0.22</u> |
|             | W15  | 0.05                             | 0.36        | <u>1.44</u> | 0.011 | 0.007 | 0.25        | 2.94        | 0.41        | 0.21        | 0.04        | 0.002 | 0.0037 | 0.0081 | 0.74        | 0.42        |
|             | W16  | 0.04                             | 0.39        | <u>2.03</u> | 0.009 | 0.011 | 0.31        | 3.00        | 0.51        | 0.33        | 0.03        | 0.006 | 0.0045 | 0.0061 | 0.93        | <u>1.18</u> |
|             | W17  | 0.03                             | 0.22        | 1.65        | 0.008 | 0.012 | <u>0.11</u> | 2.88        | 0.39        | 0.18        | 0.05        | 0.008 | 0.0062 | 0.0047 | <u>0.70</u> | 0.55        |
|             | W18  | 0.05                             | 0.42        | 1.77        | 0.015 | 0.006 | <u>0.51</u> | 2.99        | 0.55        | 0.22        | 0.06        | 0.003 | 0.0031 | 0.0063 | 0.88        | 0.64        |
|             | W19  | 0.04                             | 0.38        | 1.74        | 0.013 | 0.014 | 0.21        | <u>2.62</u> | 0.39        | 0.21        | 0.04        | 0.004 | 0.0044 | 0.0055 | 0.77        | 0.39        |
|             | W20  | 0.06                             | 0.37        | 1.91        | 0.007 | 0.004 | 0.31        | <u>3.28</u> | 0.45        | 0.27        | 0.05        | 0.002 | 0.0029 | 0.0073 | 0.90        | 0.52        |
|             | W21  | 0.04                             | 0.31        | 1.68        | 0.012 | 0.007 | 0.28        | 2.79        | <u>0.29</u> | 0.25        | 0.03        | 0.008 | 0.0037 | 0.0049 | 0.77        | 0.61        |
|             | W22  | 0.05                             | 0.36        | 1.71        | 0.014 | 0.012 | 0.33        | 2.96        | 0.49        | <u>0.11</u> | 0.04        | 0.005 | 0.0048 | 0.0055 | 0.76        | 0.87        |
|             | W23  | 0.03                             | 0.42        | 1.84        | 0.016 | 0.013 | 0.35        | 2.92        | 0.39        | <u>0.47</u> | 0.03        | 0.003 | 0.0064 | 0.0064 | 0.94        | 0.69        |
|             | W24  | 0.04                             | 0.38        | 1.68        | 0.008 | 0.007 | 0.26        | 3.09        | 0.45        | 0.19        | <u>0.12</u> | 0.006 | 0.0028 | 0.0037 | 0.80        | 0.52        |
|             | W25  | 0.08                             | 0.41        | 1.87        | 0.011 | 0.009 | 0.34        | 3.02        | 0.58        | 0.36        | 0.05        | 0.007 | 0.0044 | 0.0084 | <u>0.97</u> | 0.84        |

\*1) ROL: Rate of Lubrication Oil supplied to the surface of solid wire fed (g of oil/10 kg of solid wire)

The lines under the components of comparison example in TABLE 1 show that the underlined components are outside the range of the

disclosure. The underlined ROL value in the example of W3 and W7 shows that the amount of lubrication oil on the surface of the wire is outside the range of 0.3 to 1.0g / 10 kg of solid wire.

[0032]

TABLE 2

| thickness<br>(mm) | Chemical Components (mass%) |      |      |       |       |      |      |      |
|-------------------|-----------------------------|------|------|-------|-------|------|------|------|
|                   | C                           | Si   | Mn   | P     | S     | Ni   | Cr   | Mo   |
| 20                | 0.12                        | 0.25 | 1.12 | 0.009 | 0.002 | 0.04 | 0.76 | 0.17 |

[0033]

TABLE 3

| Welding Condition |                |                   |                                                      |                                    |                                  |
|-------------------|----------------|-------------------|------------------------------------------------------|------------------------------------|----------------------------------|
| Current<br>(A)    | Voltage<br>(V) | Speed<br>(cm/min) | Shield Gas                                           | Pre-heating<br>Temperature<br>(°C) | Interpass<br>Temperature<br>(°C) |
| 300               | 30             | 30                | Ar + 10% CO <sub>2</sub><br>flow rate:<br>25 (l/min) | 100                                | 150                              |

[0034]

For the total evaluation of the tested wires, a stability of arc at welding is examined, defect detection by X-ray permeation test as in JIS Z 3106 is carried out and mechanical property of the weld metal is measured. As for the mechanical property of the weld metal, the specimens as shown in Fig.2, which are taken out from the center part of the base in the thickness direction including the weld metal and the welded base plate so that in the thickness direction, the center of the specimen to be taken out is coincident with the center at the depth of 1/2 thickness of the base plate according to JIS Z 2241 10 and Charpy specimen as in JIS Z 2242 V notch specimen, are used. As for the stability of arc, "stable" or "slightly unstable" is graded as "good". As for the defect detection by X-ray permeation test, "No defect" is graded as "good".

[0035]

As for the tensile strength, the tensile strength of 800 to 920 MPa is graded as "good". As for the toughness, Absorbed Energy of 5 of Charpy impact tests for every example is evaluated. The average of the Absorbed Energy is graded "good" if the average of the Absorbed Energy is 89 J or more, the minimum of the Absorbed Energy is graded "good" if the minimum of the Absorbed Energy is

70J or more. As for total evaluation, if the stability of arc, X-ray permeation test, tensile strength, average and minimum of Absorbed Energy are all "good", total evaluation is "passable" represented by small circles (symbol: o). On the other hand, total evaluation is "failure" represented by crosses (symbol: X) if any one of the stability of arc, X-ray permeation test, tensile strength, average and minimum of Absorbed Energy is "not good". The results of the evaluation are shown in TABLE 4.

[0036]

TABLE 4

| type        | Wire | Stability of Arc             | X-ray Permeation Test Result | Tensile Strength (MPa) | Absorbed Energy (J) |         | Total Evaluation |
|-------------|------|------------------------------|------------------------------|------------------------|---------------------|---------|------------------|
|             |      |                              |                              |                        | Average             | Minimum |                  |
| Embodiments | W1   | Stable                       | No defect                    | 858                    | 104                 | 98      | o                |
|             | W2   | Stable                       | No defect                    | 812                    | 127                 | 106     | o                |
|             | W3   | Slightly Unstable            | No defect                    | 866                    | 108                 | 92      | o                |
|             | W4   | Stable                       | No defect                    | 882                    | 95                  | 90      | o                |
|             | W5   | Stable                       | No defect                    | 915                    | 89                  | 78      | o                |
|             | W6   | Stable                       | No defect                    | 901                    | 92                  | 81      | o                |
|             | W7   | Slightly Unstable            | No defect                    | 892                    | 98                  | 81      | o                |
|             | W8   | Stable                       | No defect                    | 883                    | 103                 | 98      | o                |
|             | W9   | Stable                       | No defect                    | 835                    | 108                 | 93      | o                |
|             | W10  | Stable                       | No defect                    | 859                    | 113                 | 98      | o                |
| comparative | W11  | Stable                       | No defect                    | 781                    | 91                  | 67      | X                |
|             | W12  | Stable                       | Crater                       | 925                    | 67                  | 56      | X                |
|             | W13  | Arc Unstable                 | No defect                    | 819                    | 81                  | 58      | X                |
|             | W14  | Arc Unstable<br>Much Sputter | Slag Inclusion               | 911                    | 93                  | 48      | X                |
|             | W15  | Arc Unstable                 | No defect                    | 812                    | 85                  | 61      | X                |
|             | W16  | Arc Unstable<br>Much Sputter | Blowhole                     | 918                    | 93                  | 52      | X                |
|             | W17  | Stable                       | No defect                    | 779                    | 103                 | 64      | X                |
|             | W18  | Stable                       | Crater                       | 892                    | 73                  | 53      | X                |
|             | W19  | Stable                       | No defect                    | 825                    | 78                  | 58      | X                |
|             | W20  | Stable                       | No defect                    | 902                    | 72                  | 54      | X                |
|             | W21  | Stable                       | No defect                    | 828                    | 80                  | 55      | X                |
|             | W22  | Stable                       | No defect                    | 817                    | 84                  | 65      | X                |
|             | W23  | Stable                       | No defect                    | 916                    | 96                  | 46      | X                |
|             | W24  | Stable                       | No defect                    | 843                    | 82                  | 56      | X                |
|             | W25  | Stable                       | No defect                    | 955                    | 92                  | 47      | X                |

[0037]

Wires W1 to W10 are the examples of the present disclosure and wires W11 to W25 are the comparable examples. The total evaluation of the wires W1 to W2, W4 to W6 and W8 to W10, examples of the present disclosure, are graded as passable(o) because the stability of arc, X-ray permeation test, tensile strength, average and minimum of Absorbed Energy are all "good", a very good result, where the contents of C, Si, Mn, Cu, Ni, Cr, Mo and Ti are suitable and the rate of supplying lubrication oil to the surface of the solid wire is adequate.

[0038]

Total evaluation of wires W3 and W7 are described as follows. As for wire W3, the rate of supplying the lubrication oil to the surface of the solid wire is lower than the minimum of the oil rate range. As for wire W7, the rate of supplying the lubrication oil to the surface of the solid wire is higher than the maximum of the oil rate range, therefore the arc is "slightly unstable", but any practical problem does not occur as a result. No defect is detected by the X-ray permeation test, tensile strength is within the targeted range, and average and minimum of Absorbed Energy are within the targeted range. Accordingly, the total evaluation is graded passable(o).

[0039]

Total evaluation of wire W11 is explained. As for W11, tensile strength of weld metal, which is 781 MPa (less than 800 MPa), is "not good" because C content is lower than the minimum of the C range. Absorbed Energy for W11, where the minimum Absorbed Energy is 67J (less than 70J), is "not good" because Ti content is lower than the minimum of the Ti range. Total evaluation of wire W11 is "failure".

[0040]

Total evaluation of wire W12 is explained. As for W12, X-ray permeation test, where cracks in the crater portion are detected, is "not good" because C content is higher than the maximum of the C range. Absorbed Energy for W12, where the average of the Absorbed Energy is 67J (less than 89J) and the minimum of the Absorbed Energy is 56J (less than 70J), is "not good" because Cr content is lower than the minimum of the Cr range. Total evaluation of wire W12 is "failure".

[0041]

Total evaluation of wire W13 is explained. As for W13, arc stability, where the arc is not stable, is "not good" because Si content is lower than the minimum of the Si range. Absorbed Energy for W13, where the average of the Absorbed Energy is 81J (less than 89J) and the minimum of the Absorbed Energy is 58J (less than 70J), is "not good". Total evaluation of wire W13 is "failure".

[0042]

Total evaluation of wire W14 is explained. As for W14, arc stability, where the arc is not stable and much sputtering is generated, is "not good" because the rate of supplying the lubrication oil to the surface of the solid wire is lower than the minimum of the oil rate range. X-ray permeation test, where the defect by slag inclusion is detected, is "not good". Furthermore, Absorbed Energy for W14, where the minimum of the Absorbed Energy is 48J (less than 70J), is "not good" because Si content is higher than the maximum of the Si range. Total evaluation of wire W14 is "failure".

[0043]

Total evaluation of wire W15 is explained. As for W15, arc stability, where the arc is not stable, is "not good" because Mn content is lower than the minimum of the Mn range. Absorbed Energy for W15, where the average of the Absorbed Energy is 85J (less than 89J) and the minimum of the Absorbed Energy is 61J (less than 70J), is "not good". Total evaluation of wire W15 is "failure".

[0044]

Total evaluation of wire W16 is explained. As for W16, arc stability, where the arc is not stable and much sputtering is generated, is "not good" because the rate of supplying the lubrication oil to the surface of the solid wire is higher than the maximum of the oil rate range. X-ray permeation test, where the blowhole is detected, is "not good". Absorbed Energy for W16, where the minimum of the Absorbed Energy is 52J (less than 70J), is "not good" because Mn content is higher than the maximum of the Mn range. Total evaluation of wire W16 is "failure".

[0045]

Total evaluation of wire W17 is explained. As for W17, strength of the weld metal, which is 779 MPa (less than 800 MPa), is "not good" because Pts is lower than the minimum of the Pts range. Absorbed Energy for W17, where the minimum of the Absorbed Energy is 64J (less than 70J), is "not good" because Cu content is lower than the minimum of the Cu range. Total evaluation of wire W17 is

"failure".

[0046]

Total evaluation of wire W18 is explained. As for W18, X-ray permeation test, where a crack in the crater portion is detected, is "not good" because Cu content is higher than the maximum of the Cu range. Absorbed Energy for W18, where the average of the Absorbed Energy is 73J (less than 89J) and the minimum of the Absorbed Energy is 53J (less than 70J), is "not good" . Total evaluation of wire W18 is "failure".

[0047]

Total evaluation of wire W19 is explained. As for W19, Absorbed Energy for W19, where the average of the Absorbed Energy is 78J (less than 89J) and the minimum of the Absorbed Energy is 58J (less than 70J), is "not good" because Ni content is lower than the minimum of the Ni range.

[0048]

Total evaluation of wire W20 is explained. As for W20, Absorbed Energy for W20, where the average of the Absorbed Energy is 72J (less than 89J) and the minimum of the Absorbed Energy is 54J (less than 70J), is "not good" because Ni content is higher than the maximum of the Ni range. Total evaluation of wire W20 is "failure".

[0049]

Total evaluation of wire W21 is explained. As for W21, Absorbed Energy for W21, where the average of the Absorbed Energy is 80J (less than 89J) and the minimum of the Absorbed Energy is 55J (less than 70J), is "not good" because Cr content is lower than the minimum of the Cr range. Total evaluation of wire W21 is "failure".

[0050]

Total evaluation of wire W22 is explained. As for W22, Absorbed Energy for W22, where the average of the Absorbed Energy is 84J (less than 89J) and the minimum of the Absorbed Energy is 65J (less than 70J), is "not good" because Mo content is lower than the minimum of the Mo range. Total evaluation of wire W22 is "failure".

[0051]

Total evaluation of wire W23 is explained. As for W23, Absorbed Energy for W23, where the minimum of the Absorbed Energy is 46J

(less than 70J), is "not good" because Mo content is higher than the maximum of the Mo range. Total evaluation of wire W23 is "failure".

[0052]

Total evaluation of wire W24 is explained. As for W24, Absorbed Energy for W24, where the average of the Absorbed Energy is 82J (less than 89J) and the minimum of the Absorbed Energy is 56J (less than 70J), is "not good" because Ti content is higher than the maximum of the Ti range.

Total evaluation of wire W24 is "failure".

[0053]

Total evaluation of wire W25 is explained. As for W25, the strength of the weld metal, which is 955 MPa (more than 920 MPa), is "not good" because Pts is higher than the maximum of the Pts range. Absorbed Energy for W25, where the minimum of the Absorbed Energy is 47J (less than 70J), is "not good".

Total evaluation of wire W25 is "failure".

[0054]

[Explanation of Numerical Reference]

- 1 steel plate
- 2 backing
- 3 welding bead
- 4 specimen

[CLAIMS]

What is claim is

1. The solid wire for the gas shield arc welding,  
said wire comprising by mass% to the whole wire

C: 0.02 to 0.10%,

Si: 0.20 to 0.55%,

Mn: 1.50 to 1.95%,

Cu: 0.15 to 0.45%,

Ni: 2.7 to 3.2%,

Cr: 0.35 to 0.65%,

Mo: 0.15 to 0.40%,

Ti: 0.02 to 0.10%,

wherein Pts defined by EQ(1) is 0.73 to 0.95,

Al: 0.010% or less,

P: 0.020% or less,

S: 0.020% or less,

N: 0.007% or less,

O: 0.010% or less, and

the remnant is Fe and the unavoidable impurities,

$$\text{Pts} = [\text{C}] + [\text{Si}]/7 + [\text{Mn}]/5 + [\text{Cu}]/7 + [\text{Ni}]/20$$

$$+ [\text{Cr}]/8 + [\text{Mo}]/2 + [\text{Ti}]/5 \quad \text{EQ(1)},$$

where [C], [Si], [Mn], [Cu], [Ni], [Cr], [Mo], [Ti] denote the contents of the elements in mass%.

2. The solid wire for the gas shield arc welding of claim 1,

wherein the solid wire has a lubrication oil of 0.3 to 1.0 g per 10 kg of the solid wire on its surface.