Gas Shielded Arc Welding of High-Nitrogen Austenitic Stainless Steel (Report 1)†

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Abstract

The present paper summarizes the results of investigation on the gas shielded arc welding process on high-nitrogen austenitic stainless steels. High-nitrogen austenitic stainless steel plates (type 316N) were welded by using regular type 316 electrode wire and N_2, Ar, N_2-Ar, N_2-O_2 and N_2-CO_2 mixture shielding gas. The elevated temperature tensile and impact tests on deposited metal specimens were carried out. High-nitrogen austenitic stainless steel weld metals give a tensile strength of about 70 and about 30kg/mm² at room temperature and 700°C, respectively.

Elongation and reduction of area are not influenced by test temperature and about 15% and about 20% for temperature range room ∼ 700°C respectively.

At impact test, the absorbed energies were not affected by the test temperature and high-nitrogen austenitic stainless steel weld metals made in N_2-Ar mixture shielding gas heve the largest value of absorbed energy of about 16∼18kg-m at test temperature range for room∼700°C. Weld metals made in N_2-CO_2 mixture shielding gas have the smollest value of absorbed energy.

From view point of MIG process, high-nitrogen austenitic stainless steel plate is able to be welded by using regular type electrode wire due to using of N_2-Ar mixture shielding gas.

KEY WORDS: (Nitrogen) (Stainless Steel) (MIG Welding Process) (Tensile, Impact Test)

1. Introduction

The addition of nitrogen to austenitic stainless steel appers to be one means of improving on elevated temperature strength of type 316 austenitic stainless steel. This problem has been studied by many investigaters.[1)-3)] When these high-nitrogen austenitic stainless steel is welded by MIG process, prevention of the decreasing of nitrogen content in weld metal is one of the most important factor on the welding process. And then, MIG process with an electrode of the same composition that base metal and the spot welding process have been investigated[4)-7)].

Several years ago, the present authors published a report[8)] on the nitrogen absorption in weld metals of mild steel, stainless steel and Fe-Cr-Ni alloy when different welding atmosphere are used on MIG welding. Main results in this report are follows, (1) The enhancement of nitrogen absorption is increased by the coexistence of oxidizing gas such as oxygen or carbon dioxide with nitrogen in welding atmosphere, (2) The porosity of Fe-Cr-Ni alloy weld metal which is made in 1atm nitrogen welding atmosphere is reduced by increasing of the chromium content in the electrode wires. This suggest that the sound weld metal of Fe-Cr-Ni alloy can be obtained by MIG welding for the some ranges of alloying component on this alloy system.

This investigation bases on the such previous knowledges and plans; i.e. the high-nitrogen austenitic stainless steel is MIG welded in the atmospheres of the nitrogen-argon, nitrogen-carbon deoxide and nitrogen-oxygen mixture gas by using regular type austenitic stainless steel electrode wire. And then their results are discussed.
In this report, following factors were examined; effect of nitrogen volume percent in shielding gas on nitrogen content of weld metal, blow hole number of weld metal, bead shape, penetration depth.

Then welding variables ; ratio of nitrogen in shielding gas, welding current, arc voltage and welding speed etc, which are able to obtain a good weld metals were fixed.

All deposited metal tensile test specimen (6mmΦ, with screw) and charpy impact test specimen (JIS.No.4) were taken from 11mm thick 60° Vee butt joints which are made with multi pass welding.

Tests have been carried out at the temperature range from −196°C to 700°C.

This report includes in relation between nitrogen content of weld metal and shielding gas component, be-

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haviours of porosity in weld metal and mechanical property of elevated temperature on high-nitrogen austenitic stainless steel.

2. Experimental Methods

2.1 Materials used

The high-nitrogen type 316 stainless steel base metal (11x70x150mm) and regular type 316 stainless steel electrode wire (1.6mmΦ) are used in this investigation. And the chemical compositions of these metals are shown in **Table 1**.

2.2 Composition of shielding gas

The welding was parformed under the N_2-Ar, N_2-CO_2 and N_2-O_2 mixture gas shielding. These gases were flowing at 20 ℓ /min.

Table 1 Chemical composition of base metal and electrode wire (wt%)

	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	N
Base Metal	0.02	0.76	1.59	0.028	0.007	13.28	17.02	2.62	0.24	0.144
Electrode Wire	0.02	0.31	1.97	0.025	0.016	12.33	19.20	2.30	—	0.022

2.3 Welding procedure

After setting the base metal and the electrode wire which were surface ground and cleaned, bead on plate specimens were made automatically in a flat position using a constant potential rectifier as the welding source with an electrode positive polarity.

Welding variables used are: arc voltage 27V, welding current 200A and 250A, welding speed of 30cm/min. By repeating the same procedure, two beads of a similar state were obtained.

Sampling of the weld metals for nitrogen analysis was carried out by turning after radiography. The chemical analysis of nitrogen in the weld metals was made by the Kjeldahl distillation method.

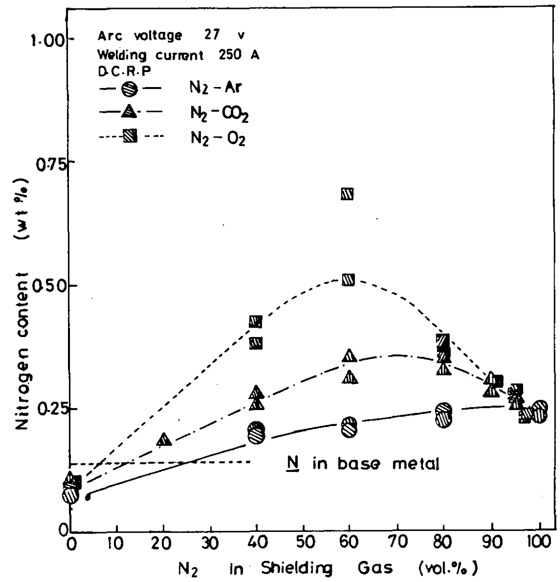

Fig. 1 Relation between nitrogen content of stainless steel weld metal and N_2 volume(%) in shielding gas

3. Experimental Results and Discussions

3.1 Nitrogen contents and blow hole number in weld metals

Figure 1 shows that the relation between nitrogen content of weld metals by bead on plate method and nitrogen volume percent in mixture shielding gases of N_2-Ar, N_2-CO_2 and N_2-O_2.

In N_2-Ar mixture gas system, nitrogen contents of weld metals increase considerably with increasing of N_2 volume percent in shielding gas, then at 100%N_2 shielding, nitrogen contents show the about 0.24wt%. In N_2-CO_2 system, nitrogen contents of weld metals increase with increasing of N_2 volume percent in shielding gas up to 60~70%, where the nitrogen contents of weld metal show the maximum value of about 0.32wt%. Results of N_2-O_2 system show a same tendency with N_2-CO_2 system. Then nitrogen contents show the maximum value of about 0.5wt% at N_2 volume percent of about 60% in the shielding gas. Those phenomena are similar results to previous papers.[8)]

It is kown that if addition of nitrogen is more than 20% in Ar shielding gas, nitrogen contents of weld metals is much more than that of base metal.

Surface of weld beads deposited in N_2-O_2 shielding gas was covered oxidized layer with many pits and defect. In N_2-CO_2 shielding gas, surface was not so much oxidized. Weld beads surface made in N_2-Ar shielding gas was generally smooth and fine.

In case of welding variables were changed into arc voltage 27V, welding current 200A, a similar results were obtained.

Figure 2 shows the relation between the blow hole number in weld metals and nitrogen content in various mixture shielding gas.

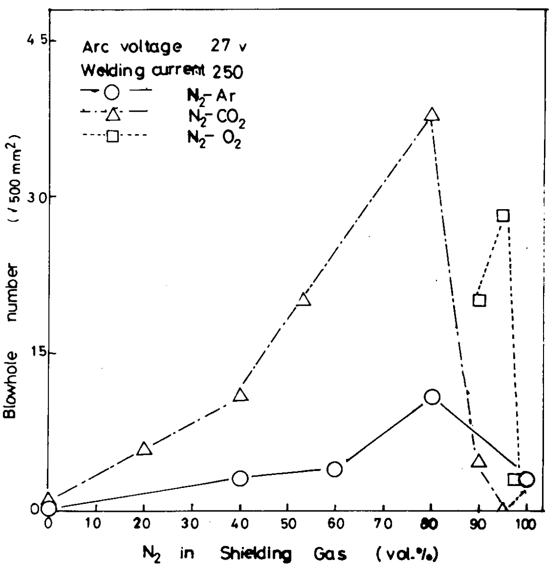

Fig. 2 Relation between blowhole number and N_2 volume(%) in shielding gas

Number of blow hole in weld metals made in 100%Ar, 100%N_2 and 100%CO_2 shielding gas is less than 5/500mm^2; i.e. the weld metals are comparatively sound. But weld metals made in N_2-CO_2 and N_2-O_2 mixture shielding gas have a large quantity of nitrogen or oxygen so that the weld metals are very porous.

From the nitrogen contents of weld metals and soundness of welds, the suitable welding variables were determined as shown **Table 2**.

Using the welding variables described in **Table 2**, 60° Vee butt welds were made by multi pass welding automatically. Welding variables used are : arc voltage 27V, welding current 250A, welding speed 30cm/min, shielding gas ; 100%N_2, 20%N_2-80%Ar and 20%N_2-80%CO_2 respectively.

As shown in **Fig. 3**, all deposited metal tensile test specimens and V notch charpy impact test specimens were taken from 11mm thick 60° Vee butt joints.

Table 2 Determined suitable welding variables

System	Conditions		Effective N_2 (vol%) in mixed shielding gas
N_2—Ar	27v	200A	> 30%
	27v	250A	> 25%
N_2—CO_2	27v	200A	10%~30% or >95%
	27v	250A	10%~40% or >90%
N_2—O_2	27v	200A	>97.5%
	27v	250A	>97.5%

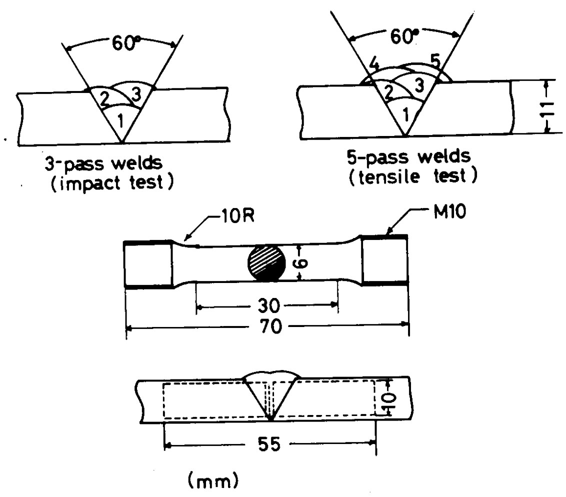

Fig. 3 Location of tensile and charpy impact test specimen(mm)

3.2 Mechanical properties of weld metals

3.2.1 Results of tensile test

Instron type universal testing machine with electric furnace was used for elevated temperature tensile test. The tensile test in the temperature range room temperature ~700°C were carried out in cross head speed 10mm/min. The specimen was heated in the furnace up to the test temperature then it was tested after holding for 30 min. at the test temperature. The results of tensile test on weld metals made in 100%Ar shielding gas are shown in **Fig. 4**. At room temperature, tensile strength of specimens have about 60kg/mm^2 then tensile strength decrease with increasing of test temperature as the result of them, it decrease to about 35kg/mm^2 at 700°C.

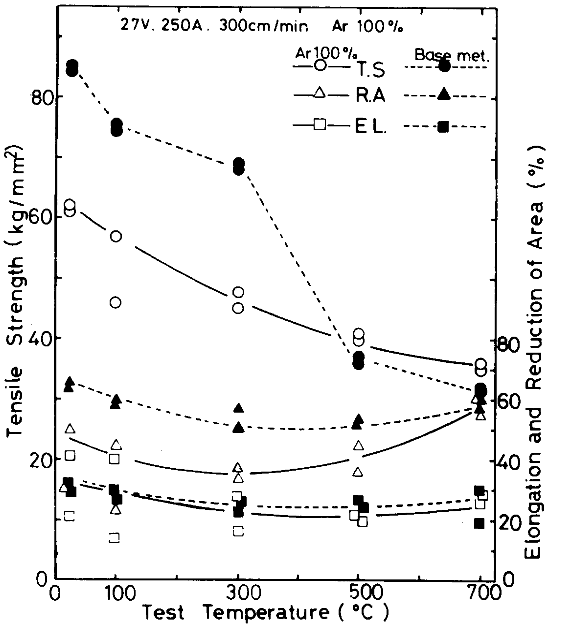

Fig. 4 Effect of temperature on the tensile strength, elongation and reduction area of base metal and weld metal made in Ar shielding gas

In the same figure, results of base metal are shown too. Strength of weld metal is slightly better than the base metal at the high temperature range more over 500°C.

The elongation is 20~30% at all range of test temperature. The reduction of area is about 40% up to 500°C then it slightly increase with increasing of test temperature. Percentage of reduction area of weld metals is less than that of base metal at under 500°C. The elongation of weld metals is allmost equal to that of base metal.

The testing results on weld metals made in 100%N_2 and 20%N_2-80%Ar mixture shielding gas are shown in **Fig. 5**. Tensile strength of weld metal made in 100%N_2 shielding gas decreased with increasing of test temperature, i.e. it decreased from about 65kg/mm^2 at room temperature to about 25kg/mm^2 at 700°C. And a similar tendency was obserbed in the weld metal specimens made in 20%N_2-80%Ar shielding gas. Reduction of area and elongation of specimens are not influenced by test temperature. When weld metals were made in 100%N_2 and 20%N_2-80%Ar shielding gas, reduction of area of specimens is about 55% and about 48% respectively. Elongation of specimens made in 100%N_2 and 20%N_2-80%Ar shielding gas show a same value of about 35%.

The tensile testing results on weld metals made in 20% N_2-80%CO_2 mixture shielding gas are shown in **Fig. 6**. Tensile strength of weld metal decrease with increasing of test temperature, i.e. it decreased from about 70kg/mm^2 at room temperature to about 25kg/mm^2 at 700°C. Reduction of area of specimen is about 40% and it has a

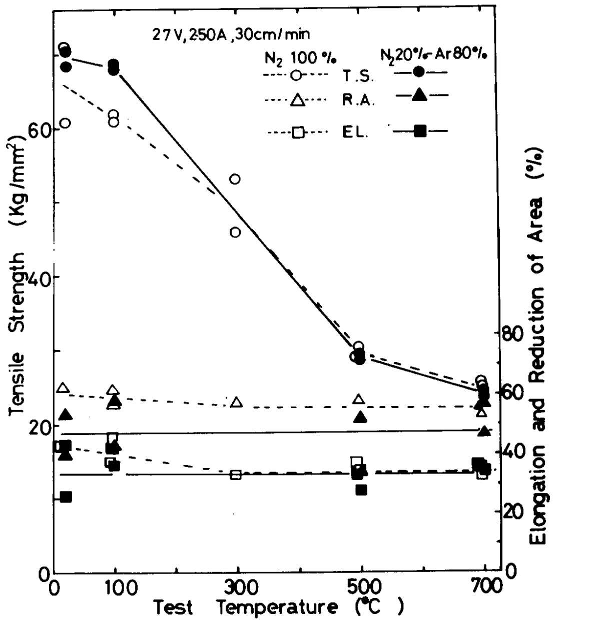

Fig. 5 Effect of temperature on the tensile strength, elongation and reduction area of weld metal made in N_2 or N_2-Ar shielding gas

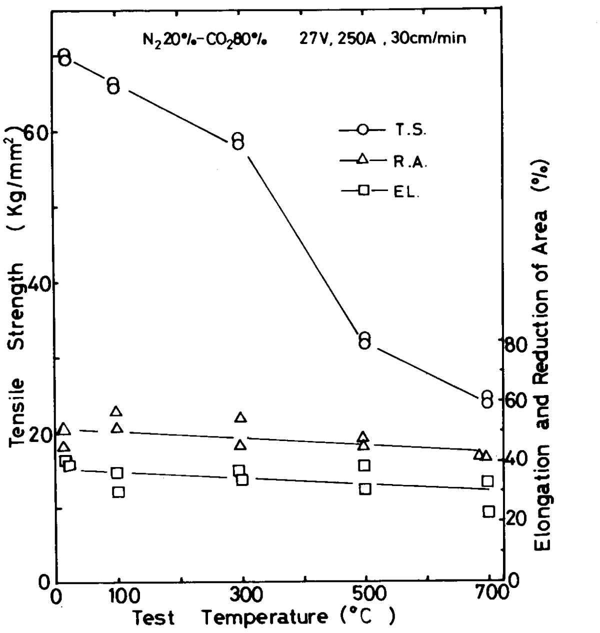

Fig. 6 Effect of temperature on the tensile strength, elongation and reduction area of weld metal made in N_2-CO_2 shielding gas

tendency to slightly decrease with increasing temperature.

Elongation of weld metals decrease with increasing of test temperature and at 700°C it shows about 30%.

Summary on tensile test results of weld metal specimen made in various shielding gas is shown in **Fig. 7**. In the temperature range from room temperature up to 400°C, weld metals specimens made in mixed nitrogen shielding gas have a good quality comparing with specimens made in 100%Ar shielding gas.

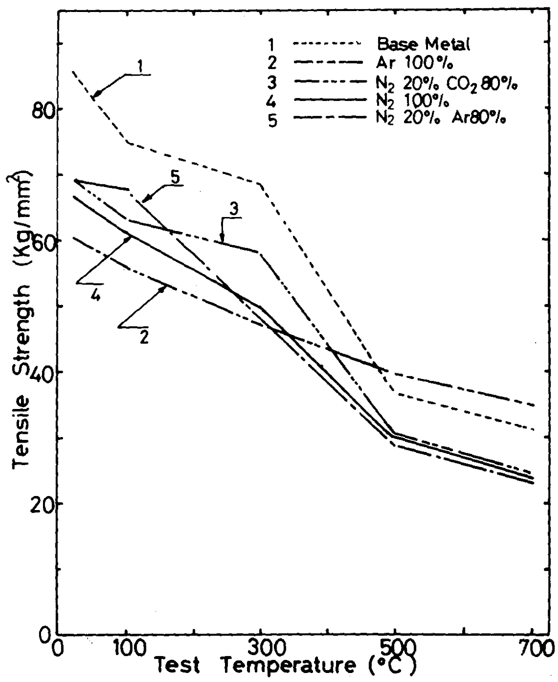

Fig. 7 Effect of temperature on the tensile strength of base metal and weld metals made in various shielding gas

On the other hand, nitrogen content of weld metals made in various shielding gas are not equal to each specimens so that influence of nitrogen on the tensile strength was studied.

It was known that at present test temperature, the tensile strength of weld metals was not changed by nitrogen content of specimens.

3.2.2 Results of charpy impact test

As shown in **Fig. 3**, Vee notch was machined at weld metals so as the fracture surface and longitudinal direction of bead become parallel to each other. The specimens were heated in the furnace up to test temperature then were tested after holding for 30min. at the test temperature. The impact test results on weld metals made in 100% Ar shielding gas are shown in **Fig. 8**. At room temperature, weld metals have absorbed energy of about 15kg-m, and test temperature range over 300°C, absorbed energy slightly decrease with increasing of test temperature. The results of base metal are shown in the same figure as compared with that of weld metals.

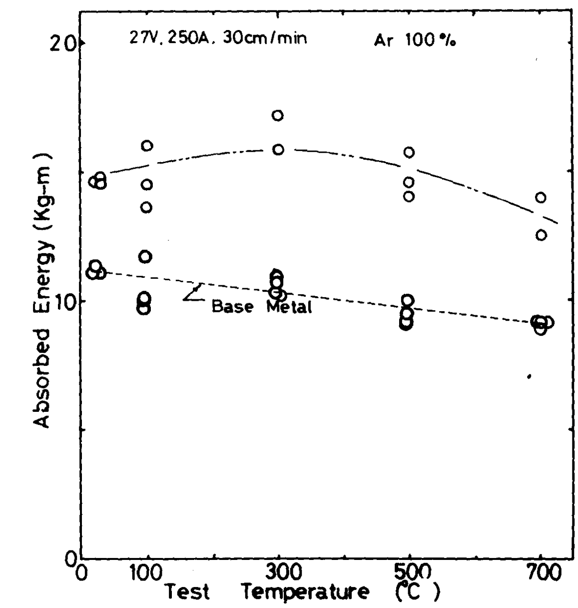

Fig. 8 Effect of temperature on the charpy impact value of base metal and weld metal made in Ar shielding gas

The results of weld metals made in 100%N_2 and 20%N_2-80%Ar, 20%N_2-80%CO_2 mixture shielding gas are shown in **Fig. 9**.

The results very widely but it seems that the absorbed energy are hardly influenced by test temperature. The weld metals made in 100%N_2 shielding gas have a absorbed energy value of about 17kg-m and this is the largest value of them. And the absorbed energy values of which are made in 20%N_2-80%Ar and 20%N_2-80%CO_2 mixture shielding gas show similarly about 10kg-m in either case.

Summary on impact test results of weld metals made in various shielding gas is shown in **Fig. 10**. It seems that weld metals made in 100%N_2 shielding gas which have the highest nitrogen content have the very large absorbed energy. After, absorbed energies of weld metals made in N_2-Ar, Ar and N_2-CO_2 shielding gas decrease in sequence of order described.

At using N_2-CO_2 mixture shieling gas, weld metals take a smaller value of absorbed energy as comparing others. For a reason, it is seemed that the mechanical properties of welds are affected by absorbed oxygen (and small amount of carbon) in the weld metals.

Relation between nitrogen content of weld metals and absorbed energy of weld metals are shown in **Fig. 11**. As described previously, impact test temperature have not an effect on absorbed energy of weld metals so that the

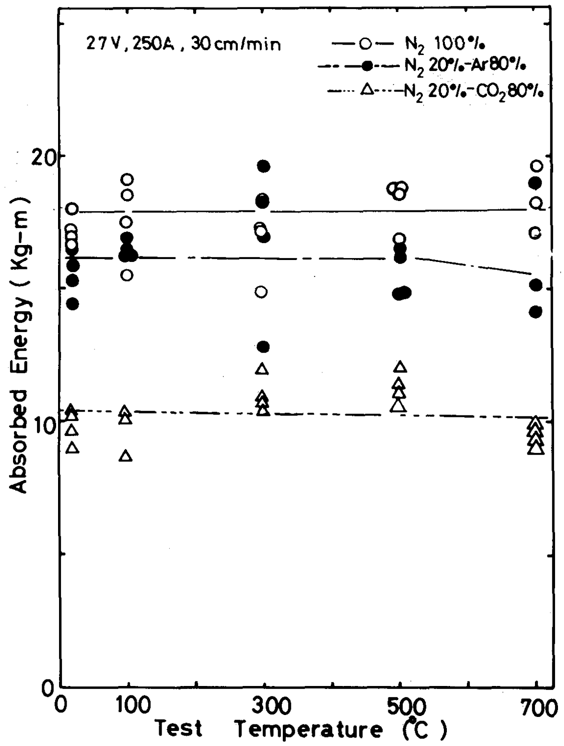

Fig. 9 Effect of temperature on the charpy impact value of weld metal made in N_2, N_2-Ar and N_2-CO_2 shielding gas

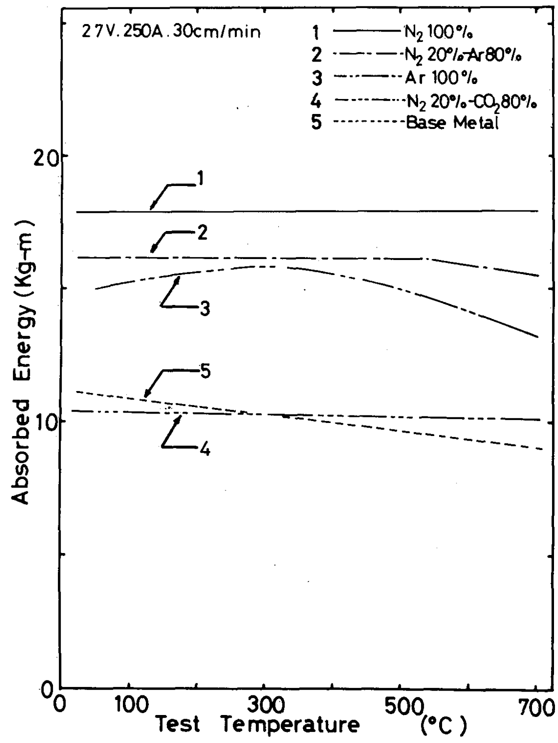

Fig. 10 Effect of temperature on the charpy impact value of weld metal made in verious shielding gas

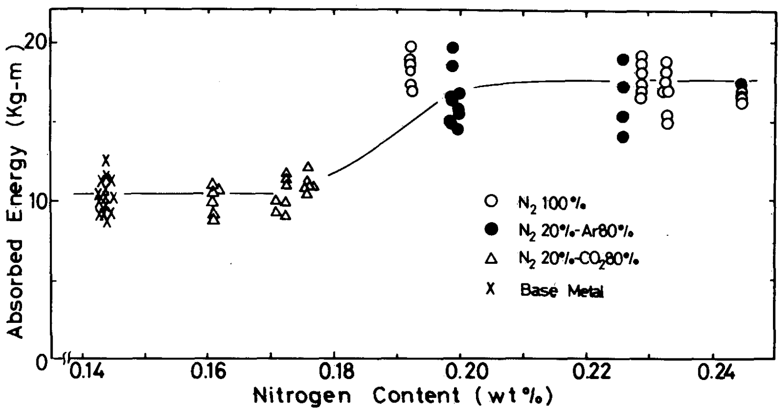

Fig. 11 Effect of nitrogen content on the charpy impact value

results of impact test are plotted without regard to test temperature specially in this figure. **Figure 11** shows that in the limit of this experiment, the absorbed energy of weld metals is not affected by nitrogen content but by oxygen content which is ascribed to difference of sheilding gas.

The influence of nitrogen content on the hardness of metals slightly increases with increasing of nitrogen content. The hardness test carried out at room temperature in this investigations, the authors are going to examin the hardness test at high temperature. At present paper, microscopical and fractographical observation, strengthening mechanism by nitrogen have not studied.

In future, the discussion on these problems have to carry out.

3.2.3 The behavior of nitrogen in austenitic stainless steels

It is well known that nitrogen dissolve interstitially in austenite and it is the strong austenite stabilizer. And then

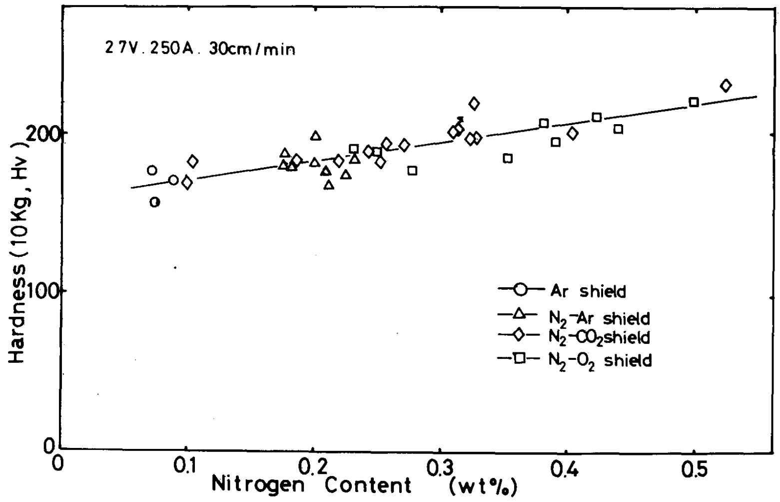

Fig. 12 Relation between nitrogen content of base metal, weld metal and vickers hardness number

many investigators have examined into using of nitrogen as an alloying element to the steels.

As shown in report already, the stabilizing force of nitrogen for austenite was 20~30 times that of Ni[9]. So that nitrogen is remarkable element which is used as substitute of the regular Ni.

Nitrogen content of stainless steels (type 304 or 316) does not standardize yet, but generally it is contained about value of 0.01~0.05wt% in stainless steels.

On the other hand, stainless steels with about ~ 0.5 wt% nitrogen are now produced commercially in case of that nitrogen is used as an alloying element.

The effect of nitrogen addition on stainless steels are following items; grain refining, prevention of grain growth, increasing of toughness and progress of yield strength and so on.

If the elements which form relatively stable nitride and carbide, are contained in stainless steel, crasters of nitride and carbide readily precipitate in matrix and these crasters fixed dislocation as known already.

It is known that the diffusion rate of carbon in steel get slower by nitrogen so that growth of carbides are prevented. But according to holding for longer time at elevated temperature, nitride precipitate remarkably at grain boundary and so the nitrogen content in the matrix decreases. Consequently, an effect of nitrogen addition on stainless steels is decreased.

The effect of carbon on intergranular corrosion in the weld heat affected zone is injurious but nitrogen not influence for intergranular corrosion. It is shown that nitrogen decreases the quantity of δ ferrite in austenite so that the pitting corrosion resistance increases by nitrogen. The corrosion resistance of austenitic stainless steels increases by decreasing of carbon content in stainless steels. But the decreasing carbon content introduce to loss of strength of austenitic stainless steels.

The interstitial solution hardening and precipitation hardening due to nitrogen make use of strengthening of austenitic stainless steel. On the other hand, it have been taken care that nitrogen has a injurious effect on stress corrosion cracking of stainless steels. The present investigation is based on the authors previous study about gas absorbtion in weld metal during arc welding.

High-nitrogen austenitic stainless steel weld metals are obtained by reaction between shielding gas and molten weld metals under the arc welding process. Nitrogen contents of sound weld metals can be controlled easily by changing of nitrogen volume percent in shielding gas. The mechanical property of high nitrogen austenitic stainless steel weld metals are studied by tensile test and charpy impact test at various temperature. The result of tensile test shows that high-nitrogen austenitic steel weld metals have a better tensile strength than that of base metal or reguler type stainless steel below the test temperature range 300°C. And the result of impact test shows that high-nitrogen stainless steel weld metals are better toughness than that of base metal or regular type stainless steel at all test temperature range.

The effects of nitrogen on mechanical preperty which are previously described are the results of investigated on warm and cold worked austenitic steels mainly.

The specimens in this investigation are made from multipass weld metals and then they have cast structure. Consequently, it is estimated that the effects of nitrogen on the weld metals are not quite similar to worked stainless steels.

The authors estimate that the mechanical properties of high-nitrogen austenitic stainless steel are changed by the situation of nitrogen in a stainless steel, so that the following problem on high-nitrogen austenitic stainless steel weld metals, must be studied : i.e. an effect of nitrides on the mechanical properties, stress corrosion cracking and hydrogen embrittlement and so on.

On the point of view from of welding process, when the 304 or 316 type austenitic stainless steels are welded by MIG process, it is expected that nitrogen takes place of argon ordinary used as the shielding gas. In this investigation, maximum nitrogen content of weld metal is about 0.25wt%. But nitrogen content of weld metals can be increased by increasing of the nitrogen pressure in shielding gas. So that it is expected to diminish the Ni content in stainless steel for weld metal with increasing of nitrogen content.

4. Conclusions

High-nitrogen austenitic stainless steel plates were welded by using type 316 electrode wire and N_2, Ar, N_2-O_2, N_2-Ar and N_2-CO_2 mixture shielding gas. Welding variables which give sound weld metal with high-nitrogen contents are determined. The weld metals welded by using suitable welding conditions are tested at elevated test temperature by tensile and charpy impact machines.

Main results obtained as follows;

1) Tensile strength of high-nitrogen austenitic stainless steel weld metals decreased with increasing of test temperature ; i.e. from about 70kg/mm^2 at room temperature to about 25kg/mm^2 at 700°C.
2) Absorbed energies were not affected by the test temperature from room temperature to 700°C. Weld metals made in 100%N_2 shielding gas have the largest value of absorbed energy about 17kg-m and weld metals in 20%N_2-80%Ar show about 16kg-m and made in 20%N_2-80%CO_2 show about 10kg-m respectively. In the case of using N_2-CO_2 mixture shielding gas, weld metals have the smallest value of absorbed energy, in spite of weld metals contain much more nitrogen. It is considered that this fact is due to effect of oxygen which is absorbed with nitrogen by welding.
3) It is seemed that the nitrogen in the weld metals are not influenced in tensile strength of them but the absorbed energies of them increases with increasing of nitrogen content of weld metals.
4) Judging from the results in this investigation, it is distinct that the high-nitrogen austenitic stainless steel plates are able to be welded by using regular type electrode wire due to using of N_2-Ar mixture shielding gas.

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