Title	Low Temperature Mechanical Properties of High-Nitrogen Type 316 Austenitic Stainless Steel Weld Metals : Gas Shielded Arc Welding of High-Nitrogen Type 316 Austenitic Stainless Steel (Report 2)
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Low Temperature Mechanical Properties of High-Nitrogen Type 316 Austenitic Stainless Steel Weld Metals†
– Gas Shielded Arc Welding of High-Nitrogen Type 316 Austenitic Stainless Steel (Report 2) –

Toshio ENJO*, Yasushi KIKUCHI**, Takuro KOBAYASHI*** and Takeshi KUWANA****

Abstract

High-nitrogen austenitic stainless steel weld metals were obtained by using regular type 316 electrode wire and N_2, Ar, N_2-Ar, N_2-CO_2 mixture shielding gas.

Low temperature tension and impact test on deposited metal specimens were carried out.

High-nitrogen austenitic stainless steel weld metals give a tensile strength of about 65 and about 130 kg/mm² at 0°C and –196°C respectively.

At impact test, high-nitrogen austenitic stainless steel weld metals made in pure N_2 shielding gas give an absorbed energy of about 17 and about 6 kg-m at 0°C and –196°C respectively. Weld metals made in N_2-CO_2 mixture shielding gas give a smaller absorbed energy than in N_2-Ar mixture shielding gas.

Oxygen free high-nitrogen austenitic stainless steel weld metals made in N_2, and N_2-Ar mixture shielding gas show a good mechanical property in the test temperature range from 0°C to –196°C.

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

1. Introduction

The high nitrogen austenitic stainless steel plates were welded by the MIG process as presented in previous paper[1]), which makes use of N_2, Ar, N_2-Ar and N_2-CO_2 mixture shielding gas and regular type austenitic stainless steel electrode wire. Mechanical properties of elevated temperature on high nitrogen austenitic stainless steel weld metals were tested by means of the similar process reported previous paper[1]).

This report includes in the results of low temperature tension and impact test on high nitrgen austenitic stainless steel weld metals.

2. Experimental Methods and Welding Procedure

Type 316 austenitic stainless steel base metal (11 x 70 x 150 mm) and electrode wire (1.6mmφ) are used in this investigation. The chemical composition of these materials are shown in Table 1.

Welding apparatus and welding variables described in previous paper[1]) are used, i.e. arc voltage 27V, welding current 250A, welding speed of 30 cm/min and an electrode positive polarity.

Table 1 Chemical composition of base metal and electrode wire.

	C	Si	Mn	P	S	Ni	Cr	Mo	N
Base metal	0.025	0.57	1.77	0.035	0.007	12.62	17.71	2.25	0.016
Electrode wire	0.019	0.31	1.97	0.025	0.016	12.33	19.20	2.30	0.022

60° Vee butt welds were made by multi pass welding automatically and all deposited metal tensile test specimen (6 mmφ, with screw) and charpy impact test specimen (JIS, type No.4) were taken from 11 mm thick Vee butt joints.

The mechanical tests have been carried out at the temperature range from 0°C to –196°C (liquefied nitrogen).

3. Experimental Results and Discussions

3.1 Results of tensile test

Instron type universal testing machine with low temperature chamber was used for low temperature tensile test. The specimen was cooled in the chamber up to

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test temperature, and then it was tested by cross head speed 10 mm/min. after holding for 30 min at test temperature. The results of tensile test on weld metals made in 100% Ar shielding gas are shown in Fig. 1. At 0°C, tensile strength of specimens have about 70 kg/mm^2 then

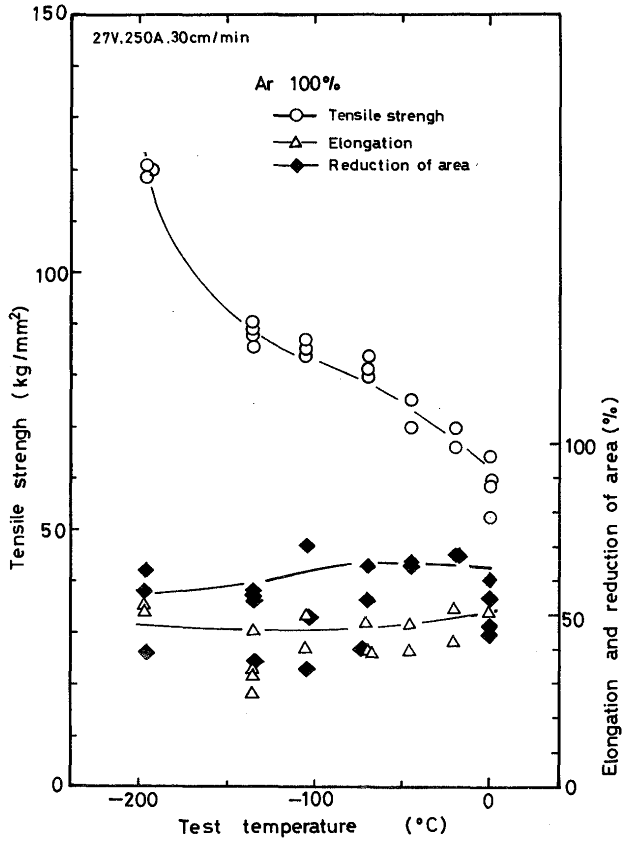

Fig. 1 Effect of temperature on the tensile strength, elongation and reduction of area of weld metals made in Ar shielding gas.

tensile strength increase with decreasing of test temperature as shown in Fig. 1.

And it increased to about 120 kg/mm^2 at –196°C. It is seemed that the mechnical properties of weld metal are affected by strain induced martensite and transformed martensite stracture at low test temperature.

The elongation is about 60% and the redution of area is about 50% at all range of test temperature.

The defects such as small blow holl or oxide inclusion were obserbed in the fractured surface. Then, the effect of defect on the tensile strength was considered. But the mutual relation between tensile strength and the defect in the fractured surface of specimens could not be detected and so it is seemed that decreasing of strength is slightly by reason of defect.

The testing result on weld metals made in 100% N_2 shielding gas is shown in Fig. 2. A similar tendency is

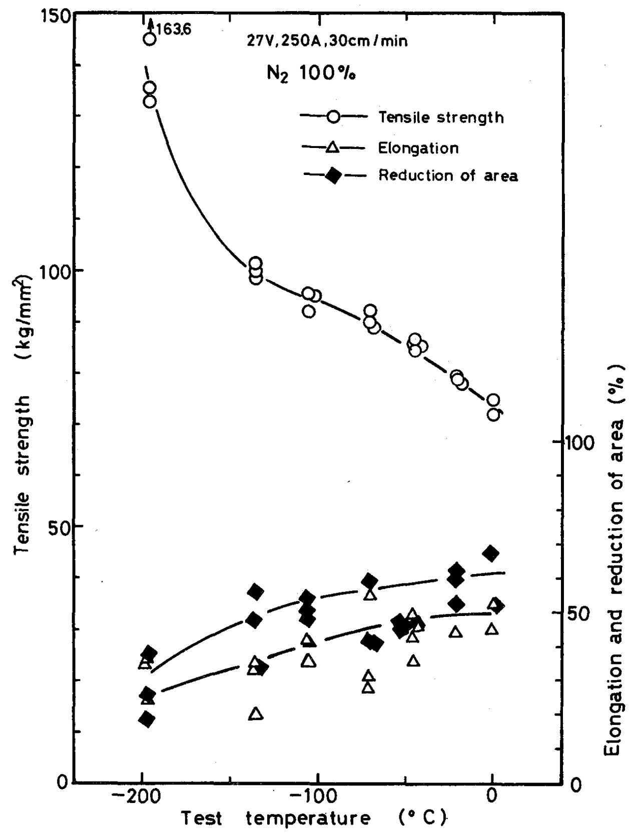

Fig. 2 Effect of temperature on the tensile strength, elongation and reduction of area of weld metals made in N_2 shielding gas.

obserbed in the weld metal specimens made in 100% Ar shielding gas. The tensile strength of weld metals have about 75 kg/mm^2 at 0°C, about 100 kg/mm^2 at –130°C and about 145 kg/mm^2 at –196°C respectively.

These values of weld metals are slightly better than of weld metals made in 100% Ar shielding gas.

Elongation and reduction of area of specimen decreased with decreasing of test temperature, that is to say, elongation decreased about 50% at 0°C to about 25% at –196°C and reduction of area of specimen similary decreased from about 60% to about 30% at –196°C respectively.

The result on weld metal made in 20%N_2-80%Ar mixture shielding gas is shown in Fig. 3. Tensile strength of weld metal increased with decreasing of test temperature, i.e. it increased from about 60 kg/mm^2 at 0°C to about 120 kg/mm^2 at –196°C.

Elongation and reduction of area of specimen decreased similarly from about 40% at 0°C to about 25% at –196°C and from about 60% at 0°C to about 40% at –196°C respectively.

The results of tensile test on weld metals made in 20%N_2-80%CO_2 mixture shielding gas are shown in Fig. 4. Tensile strength of weld metals increase with

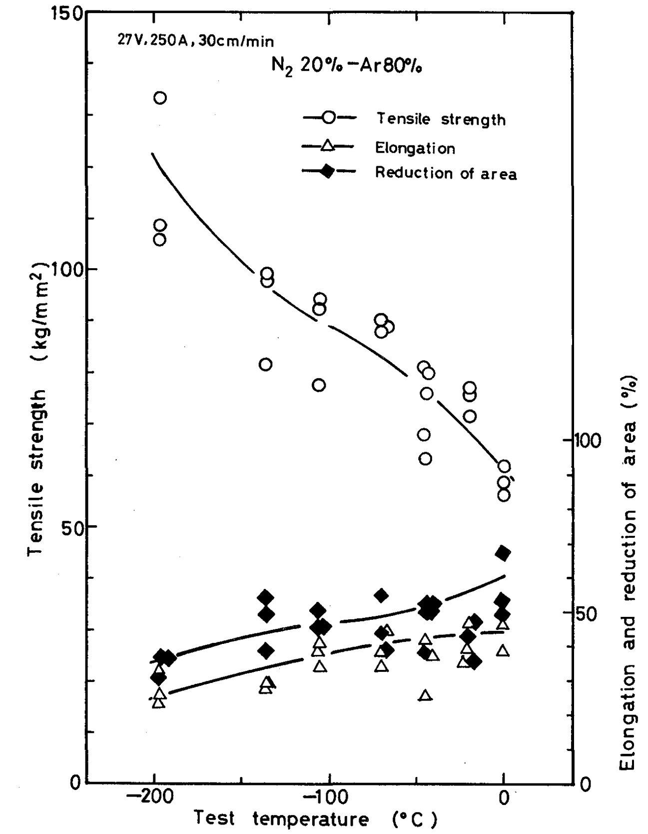

Fig. 3 Effect of temperature on the tensile strength, elongation and reduction of area of weld metals made in N_2-Ar shielding gas.

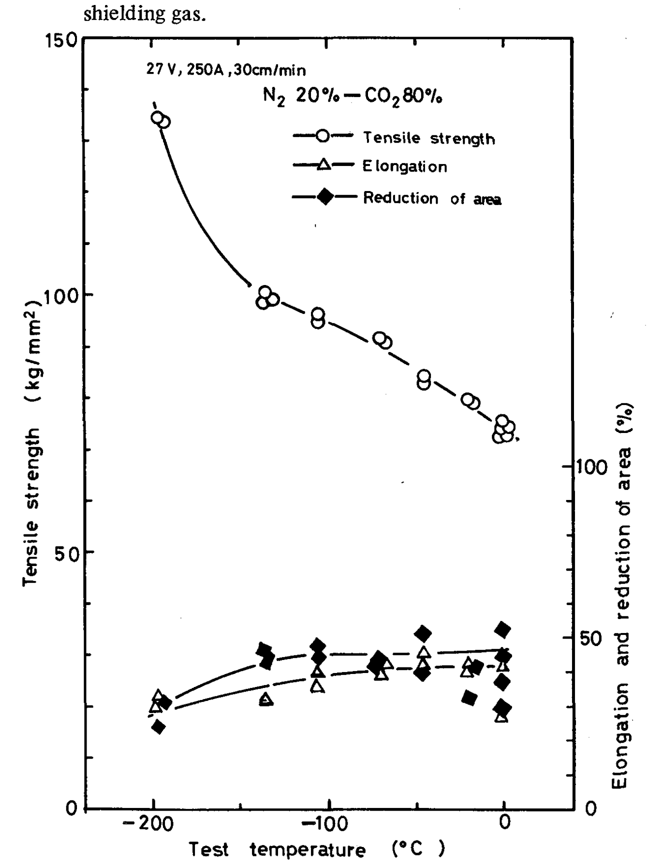

Fig. 4 Effect of temperature on the tensile strength, elongation and reduction of area of weld metals made in N_2-CO_2 shielding gas.

decreasing of test temperature, i.e. it increased from about 65 kg/mm² at 0°C to about 135 kg/mm² at –196°C. Elongation and reduction of area of specimen have similar tendency which was obserbed in the weld metals specimens made in another shielding gas. They decreased from 40 ~ 50% at 0°C to 20 ~ 30% at –196°C respectively.

Summary on tensile test results of weld metals specimen made in various shielding gas is shown in Fig. 5. The tendency of change due to test temperature was similarly

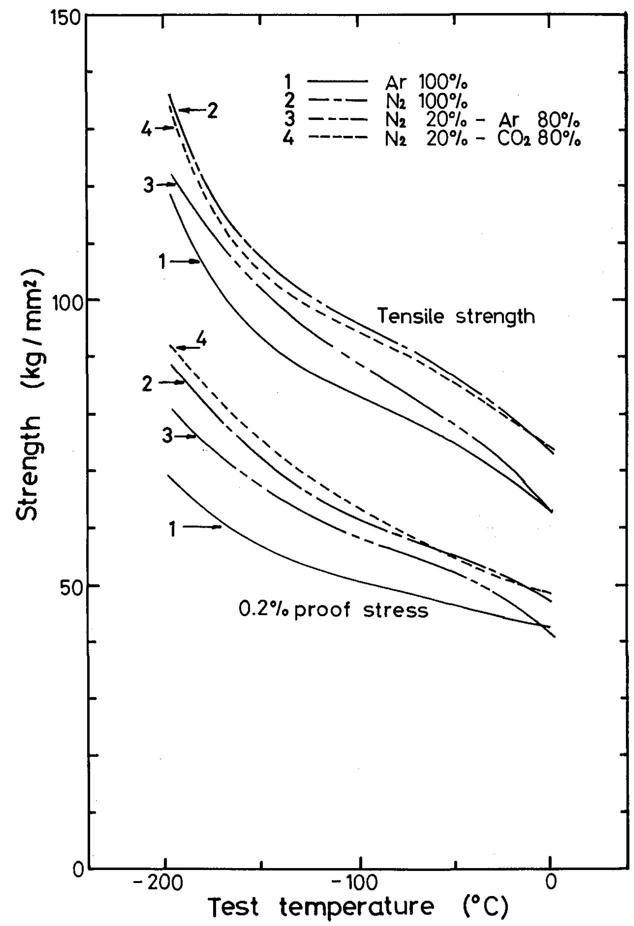

Fig. 5 Effect of temperature on the tensile strength and 0.2% proof stress of weld metals made in various shielding gas.

in tensile strength of weld metals made in various shilding gas. The strengthes of weld metals made in N_2 100% and N_2 20%-CO_2 80% shielding gas are the similar value which are the highest value at every test temperature. After, strength of weld metals made in N_2 20%-Ar80% is higher than that of weld metals made in Ar100% shielding gas.

0.2% proof stress of weld metals is shown in the same figure. Compared with the change of tensile strength, a similar tendency is obserbed in change of 0.2% proof stress of weld metals too.

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

The result was summerized in Fig. 6. It was known that at present test temperature, tensile strength of weld metals was increased by the addition of nitrogen to weld metal.

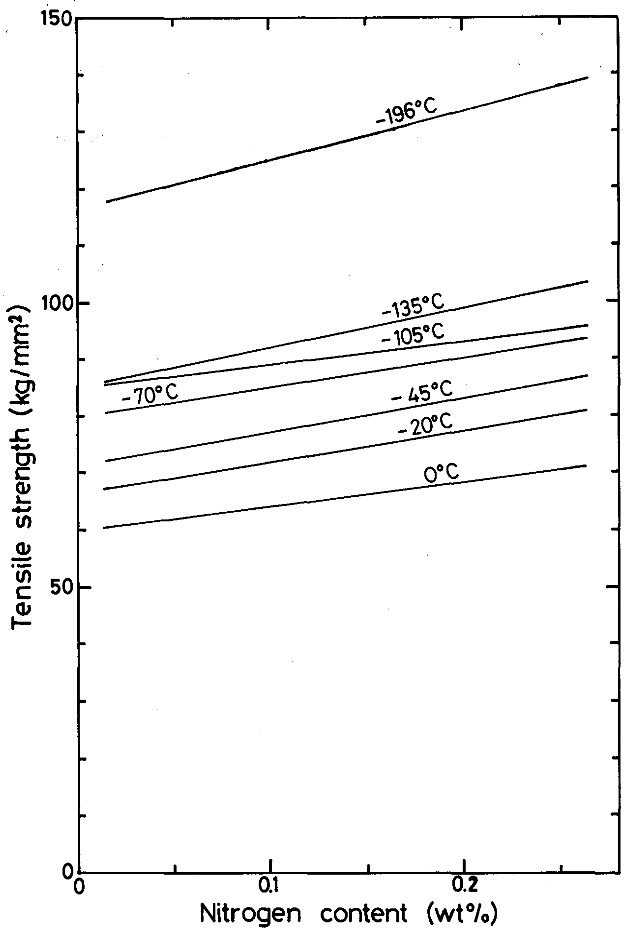

Fig. 6 Influence of nitrogen content of weld metals on the tensile strength of weld metals.

3.2 Results of charpy impact test

Vee notch was machined at weld metals so as the fracture surface and logitudinal direction of bead became parallel to each other. The specimens[1] (JIS, No.4 type) were cooled in the vacuum bottle up to the test temperature then were tested after holding for 30 min. at the test temperature.

The results of impact test on the weld metals made in 100%N_2 and 100%Ar shielding gas are shown in Fig. 7 respectively.

At using of 100%Ar shielding gas, weld metals have absorbed energy value of about 12 kg-m at 0°C. With decreasing of the test temperature, the absorbed energy

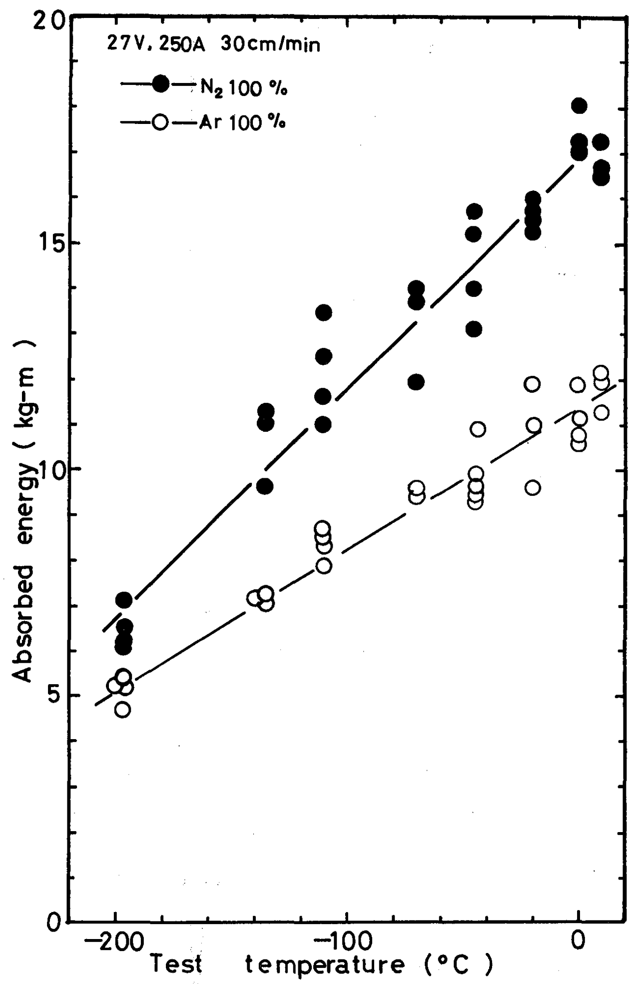

Fig. 7 Effect of temperature on the charpy impact value of weld metals made in N_2 or Ar shielding gas.

values linerly decrease and have about 5 kg-m at –196°C. At using of $N_2$100% shielding gas, weld metals have the absorbed energy value of about 17 kg-m at 0°C and about 6 kg-m at –196°C respectively.

Generally, absorbed energy values obtained by means of nitrogen shielding gas are better than that of weld metals obtained by means of Ar shielding gas.

But with decreasing test temperature, the difference between the absorbed energy value of weld metal made in N_2 shielding gas and that of weld metals made in Ar shielding gas becomes smaller.

The results of impact test for weld metals made in 20% N_2-80%Ar and 20%N_2-80%CO_2 mixture shielding gas are showen in Fig. 8.

The weld metals made in N_2-Ar shielding gas have an absorbed energy value of about 12 kg-m at 0°C and about 4 kg-m at –196°C respectively. Then, these results become the smaller values as comparing with results of weld metals made in 100%Ar shielding gas with decreasing of test temperature.

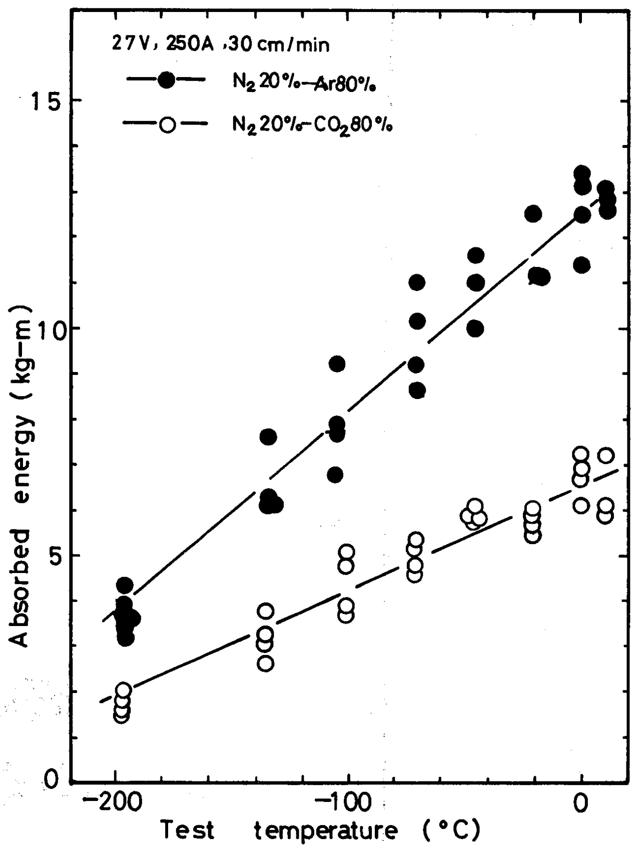

Fig. 8 Effect of temperature on the charpy impact value of weld metals made in N_2-Ar or N_2-CO_2 shielding gas.

The lower level values of absorbed energy were obtained at using of N_2-CO_2 mixture shielding gas, i.e. weld metals made in this shielding gas have an absorbed energy value of about 7 kg-m at 0°C and about 2 kg-m at –196°C respectively.

It is seemed that the weld metal are affected by absorbed oxygen in the weld metals.

Summary on impact test results of weld metals made in various shielding gas are shown in Fig. 9. As shown in Fig. 9, absorbed energy of the weld metals made in 100% N_2 shielding gas are the highest clearly in the all weld metals.

And using of N_2-CO_2 mixture shielding gas, weld metals take the smallest values of absorbed energy as comparing others.

Nitrogen content of weld metals made in various shielding gas are not equal to each specimens, so that effect of nitrogen on the absorbed energy was studied. For an example, in case of test temperatures of –135°C and –20°C mutual relation between absorbed energy and nitrogen content are shown in Fig. 10.

It be shown in Fig. 10 that the absorbed energy of weld metals slightly increasess with increasing of nitrogen content of weld metal. But at using of N_2-CO_2 mixture

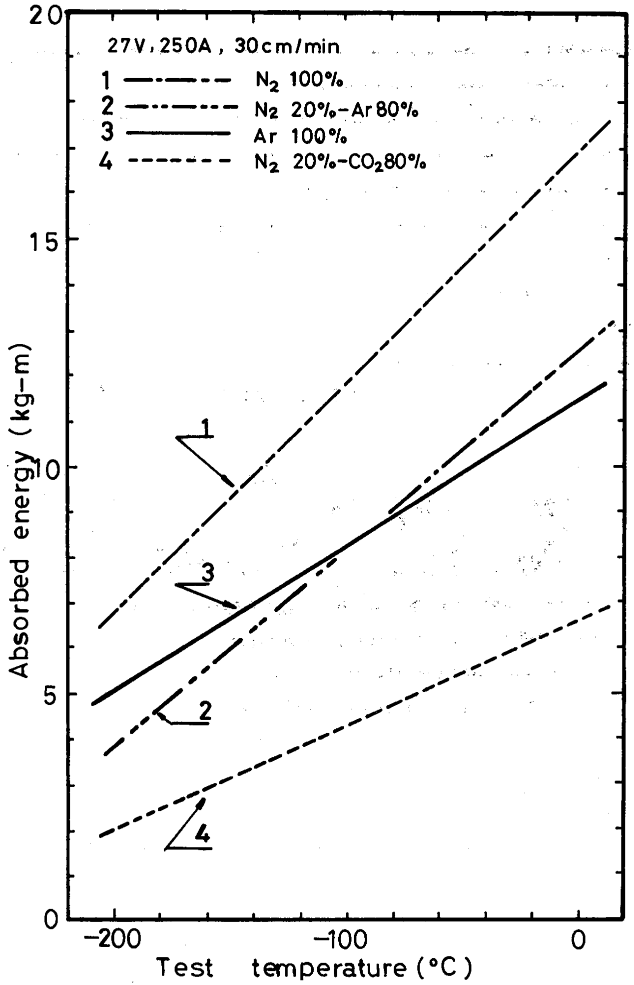

Fig. 9 Effect of temperature on the charpy impact value of weld metals made in various shielding gas.

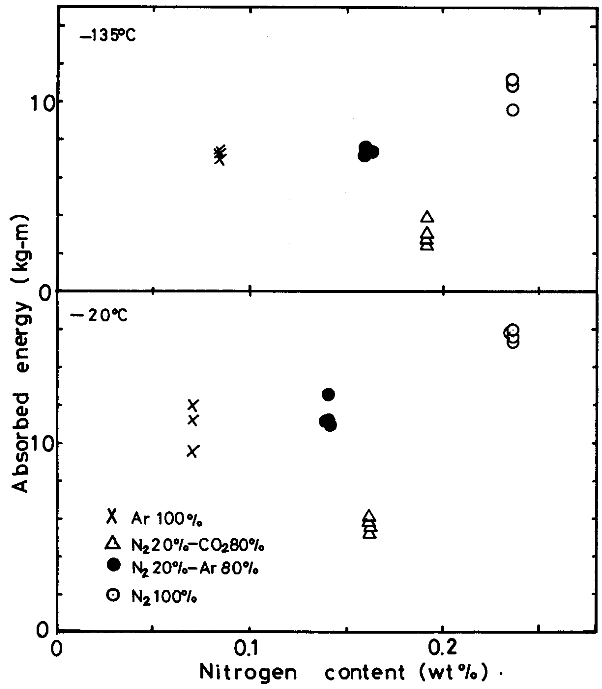

Fig. 10 Influence of nitrogen content of weld metals on the chrapy impact value of weld metals made in various shielding gas.

shielding gas, the large drop of abosrbed energy is obserbed at every testing temperature.

It is seemed that the drop of absorbed energy is due to effect of oxygen absorbed with nitrogen into weld metals from the arc atmosphere. The effect of oxygen content of weld metals on the absorbed energy of weld metals is investigated.

The relation between absorbed energy and oxygen content at −110°C are shown in Fig. 11. The absorbed energy decrease hardly with increasing oxygen content of weld metal.

Therefore, it is anticipated that the brittleness of weld metals made in N_2-CO_2 shielding gas is due to the oxygen content of welds. In addition to this fact, it is considered that the carbon and oxide inclusion content in weld metal have influence upon the brittlness.

The tensile strength and 0.2% proof stress of weld metals at the test temperature range from −196°C to 700°C are summarized in Fig. 12. And beside, the Fig. 12 shows the previous results[1]) with the present results.

The effect of nitrogen on the tensile strength of weld metals which are made in nitrogen mixtured shielding gas is recognized clearly at low test temperature range.

The charpy impact test results of weld metals at test temperature range from −196°C to 700°C are summarized in Fig. 13.

The absorbed energy of weld metal decrease hardly below 0°C but at the test temperature range above 300°C, impact test values are not changed by test temperature,

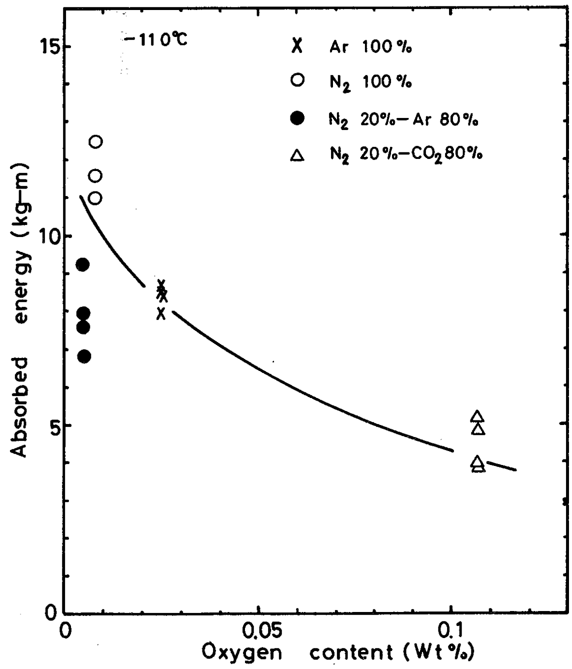

Fig. 11 Influence of oxygen content of weld metals on the charpy impact value of weld metals made in various shielding gas.

without Ar100% shielding gas. In the all testing temperature range, weld metals specimens made in N_2 100% shielding gas have the highest absorbed energy value.

It is noticed that the high-nitrogen austenitic stainless steel weld metal shows the good toughness in spite of for the high tensile strength below 0°C.

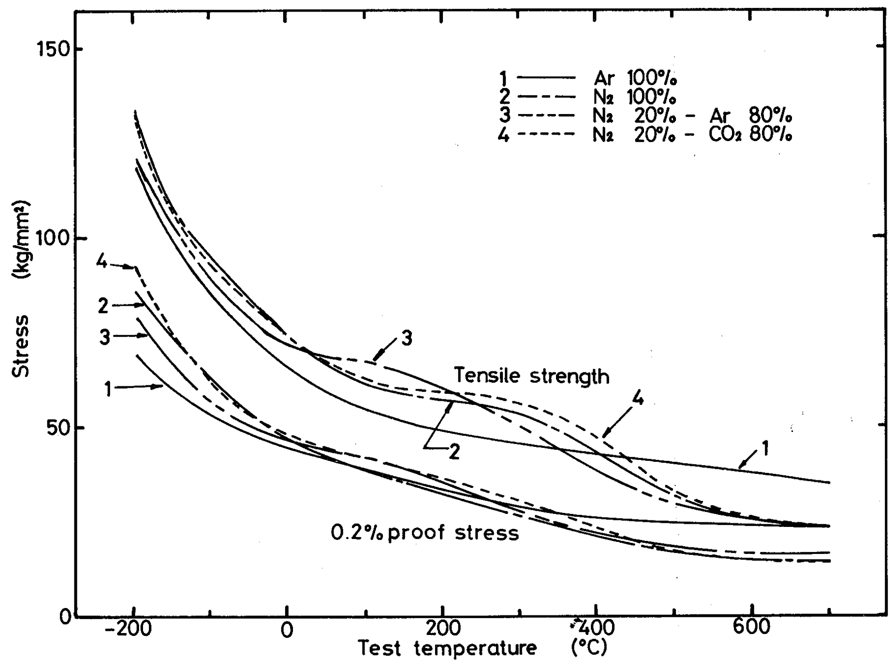

Fig. 12 Tensile strength and 0.2% proof stress of weld metals for test temperature range from −196°C to 700°C.

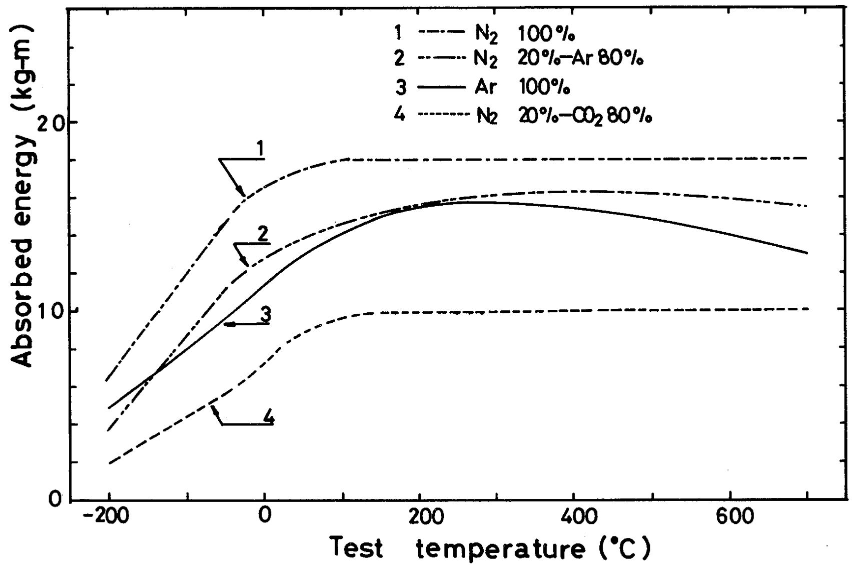

Fig. 13 Charpy impact value of weld metals for test temperature range from −196°C to 700°C.

3.3 The behavior of nitrogen in austenitic stainless steels

As discribed in the previous paper[1], it appear that the addition of nitrogen to austenitic stainless steel take effect to improvement of the high temperature strength on type 316 stainless steel[1]. Then, the effect of nitrogen on the low temperature mechanical properties of stainless steel does not determined yet.

In the present investigation, the mechanical properties of high-nitrogen austenitic stainless steel weld metals are studied by tensile and charpy impact test at low test temperature.

As shown in these test results, it is appeared that addition of nitrogen on weld metal is efficiency to tensile strength.

And moreover it has to be noted that this increasing of strength occures without decreasing of the toughness.

On the other hand, it is well known that strain-induced martensitic structure is formed when austenitic steel is deformed at low temperature. The strengthening of weld metal due to addition of nitrogen and atrain-induced martensite have much something to do with the present results.

At in this paper, microscopical and fractgraphical observation, strengthening mechanism by nitrogen have not studied.

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

4. Conclusions

High-nitrogen austenitic stainless steel weld metals were obtained by using regular type 316 electrode wire and N_2-Ar or N_2-CO_2 mixture shielding gas. Low temperature tension and impact test on deposited metal specimens were carried out.

Main results obtained as follows.

1) Tensile strength of high-nitrogen austenitic stainless steel weld metals increased with decreasing of test temperature, i.e. it changed from 60 ~ 70 kg/mm^2 at 0°C to 120 ~ 140 kg/mm^2 at −196°C.
2) It was known that oxygen free high-nitrogen austenitic stainless steel weld metals held a high tensile strength without decreasing of the toughness at low test temperature.
3) At impact test, high-nitrogen austenitic stainless steel weld metals made in pure N_2 shielding gas gave an absorbed energy of about 17 and 6 kg-m at 0°C and −196°C respectively.
4) Weld metals made in N_2-CO_2 mixture shielding gas gave a smaller absorbed energy than in N_2-Ar mixture shielding gas.
5) From a point of view in MIG welding process, it was distincted that the high-nitrogen austenitic stainless steel plates are able to be welded by using regular type electrode wire and N_2-Ar mixture shielding gas.

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