The Development of Welding Consumables for Modified 2.5 Cr-1Mo Steel

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1. ABSTRACT

Following on the investigation of optimum chemical compositions to improve creep rupture strengths of modified 2.5 Cr-1Mo weld metals which revealed that the decrease of C and Mn contents in weld metals was effective in improving creep rupture strength, the effects of N and Ni on mechanical properties were investigated. This investigation showed that an increase of N lowered creep rupture strength of weld metal, but Ni had not any clear effect on tensile properties of weld metal. According to these investigations, welding consumables were newly designed and tested: the mechanical properties of weld metals satisfied the requirements of V-modified 2.5 Cr-1Mo steel.

2. INTRODUCTION

Modified 2.5 Cr-1Mo steel, which is suitable for applications at high temperatures and high pressure hydrogen atmospheres such as in coal conversion plants, has been developed recently. Welding consumables are expected to be developed as an actual application for this type of steel.

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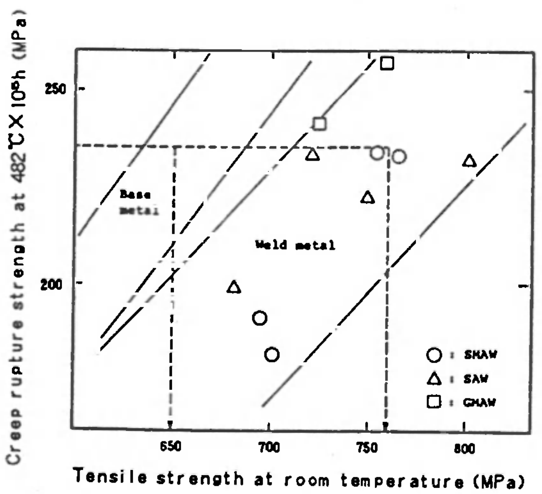


Fig. 1. *Tensile strength at room temperature vs. creep rupture strength*

One of the most serious problems with weld metals is that the creep rupture strengths of weld metals are lower for their tensile strengths than those of base metals. Fig. 1 shows the relations between tensile strengths at room temperature and creep rupture strengths of both weld metals and base metals. Higher tensile strengths of conventional and former Nb-V bearing weld metals are necessary to attain the same level of creep rupture strengths as base metals.

As the resistance to hydrogen embrittlement and toughness decrease with the increase of tensile strength, it is necessary to improve creep rupture strength without increasing tensile strength.

In this paper, the details of a solution to the problem and typical examples of test data of newly developed welding consumables are reported.

3. INVESTIGATION OF OPTIMUM CHEMICAL COMPOSITIONS

3.1 Experimental Procedure

An investigation on the effects of chemical composition on mechanical properties was carried out to find optimum chemical compositions which allow an increase in creep rupture strengths without increasing tensile strengths at room temperature. Chemical compositions of the SAW and SMAW weld metals tested are given in Table 1 and Table 2 respectively.

Table 1. Chemical composition of SMAW weld metals tested (wt%)

	C	Si	Mn	Cr	Mo	V	Nb
Range	0.10 / 0.13	0.20 / 0.40	0.48 / 0.81	2.20 / 2.51	0.97 / 1.04	0.23 / 0.44	- / 0.054

Table 2. Chemical composition of SAW weld metals tested (wt%)

	C	Si	Mn	Cr	Mo	V	Nb
Range	0.10 / 0.15	0.08 / 0.15	0.55 / 0.86	2.18 / 2.48	0.96 / 1.02	0.22 / 0.33	/ 0.015

Table 3. Welding conditions

Welding process	Dia. of electrode (mm)	Polarity	Welding current (Amp.)	Arc voltage (V)	Travel speed (cm/min)	Preheat & interpass temp
SAW	4.0 mm	A.C.	L. 520 T. 550	L. 31 T. 32	55	200~250°C
SMAW	4.0 mm	A.C.	170	23~26	10~14	

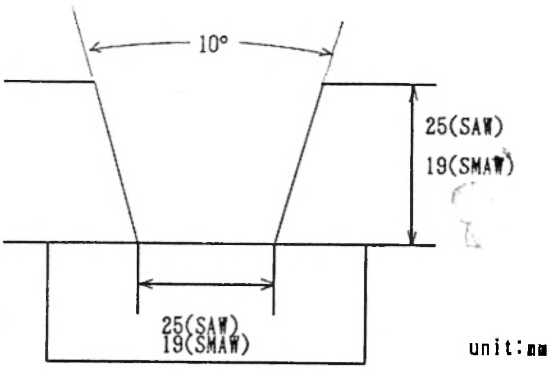


Fig. 2. *Groove configuration*

Welding conditions and the groove configuration are shown in Table 3 and Fig.2.

Transmission electron microscopy (TEM) and energy dispersive X-ray analysis (EDX) of carbon extraction replicas and X-ray diffraction analysis of non-aqueous electrolyte extraction residues were performed some of the SAW weld metals tested.

3.2 Experimental Results

3.2.1 Effects of chemical compositions on tensile properties

Fig. 3 shows the effects of chemical compositions on tensile properties. Nb and V were found to be effective in increasing creep rupture strength, but these elements also increase tensile strength to a level exceed-

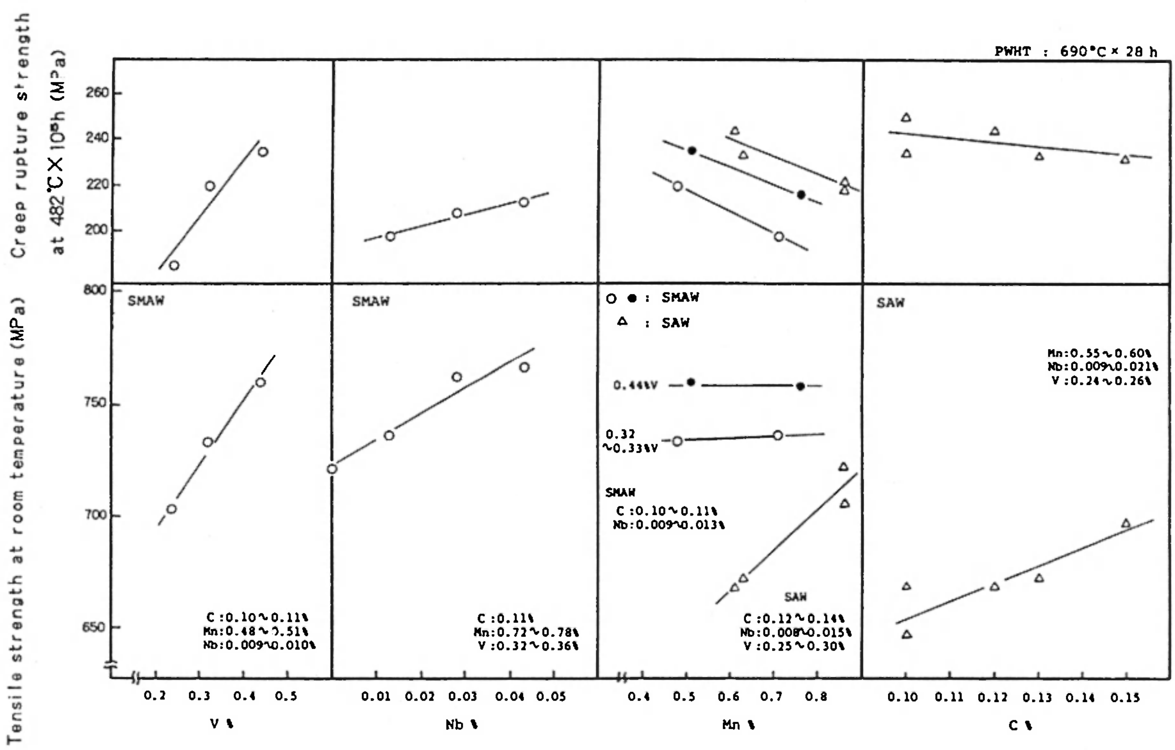
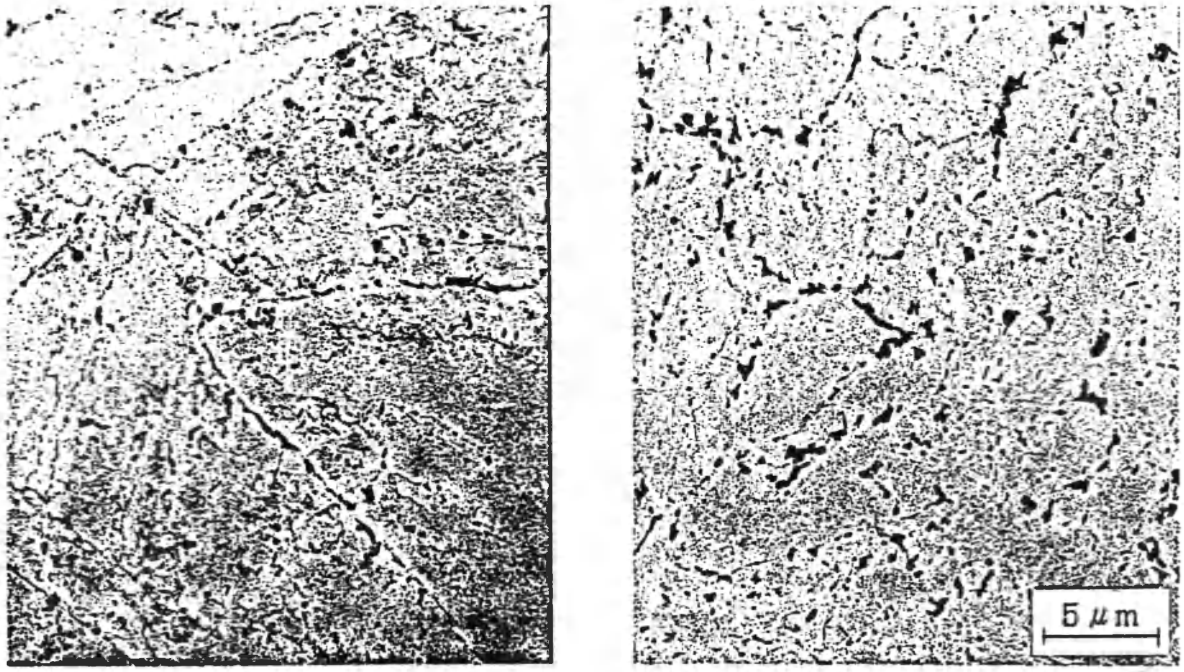


Fig. 3. *Effects of chemical compositions in weld metals on tensile strength at room temperature and creep rupture strength*



(a) 0.10%C weld metal (b) 0.15%C weld metal

Fig. 4. *Transmission electron micrographs of carbon extraction replicas of SAW weld metals (PWHT : 690°C for 24 hours)*

ing the maximum required tensile strength, 758 MPa (110 ksi), as shown in Fig. 3

Consequently, only the addition of Nb and V for high creep rupture strength is not sufficient for this purpose. Fig. 3 also suggests that a decrease of Mn content in weld metal of both SAW and SMAW can improve creep rupture strength without increasing tensile strength at room temperature. Fig. 3 also shows the remarkable effect that C has on improving the creep rupture strength of weld metals.

3.2.2 X-ray diffraction analysis

Non-aqueous electrolyte extraction residues of weld metals were identified using X-ray diffraction analysis. According to the X-ray diffraction patterns of precipitates extracted from weld metals, in 0. 14%C-0.64%Mn weld metal, fine V-carbides decreased, and coarse massive carbides, M_6C, increased after thermal aging. Contrarily, in 0.09%C-0.62%Mn weld metal, V-carbides increased and MPV6PVC decreased after aging. These facts suggest that in low C weld metal, the growth of carbides will occur, which lessen creep rupture strength.

3.2.3 Morphology of carbides

Fig. 4 shows transmission electron micrographs of carbon extraction replicas of SAW weld metals. In both the grain boundary of 0.15%C weld metal as PWHT and also after the creep rupture test following PWHT, coarse grain precipitates were observed. But in 0.10%C weld metal, precipitates were smaller in both size and quantity than those of 0.15%C weld metals. Judging from the results, the effect of C on creep rupture strength may be explained by the size and distribution of carbides; that is to say, the distribution of fine carbides in weld metal of optimum C content may improve the ratio of creep rupture suengtn to tensile strength at room temperature.

4. THE EFFECTS OF N AND Ni

In addition to the above investigation, the effects of N and Ni on the mechanical properties of V-modified 2.5 Cr-1Mo weld metals by SAW were observed. Besides C and Mn, N and Ni have important effects on the mechanical properties of 2.5 Cr-1Mo weld metals. For example, a N-added(0.027%) 2.5 Cr-1Mo weld metal has been reported to have displayed better Charpy characteristics than conventional weld metal [1]. It is useful, therefore, to investigate the effects of N and Ni on V-modified 2.5 Cr-1Mo weld metals for the better design of weld consumables.

4.1 Materials Tested

Table 4 shows the chemical composition of the weld metals tested. The addition of N was determined

Table 4. Chemical composition of weld metals(wt%)

	C	Si	Mn	Ni	Cr	Mo	V	Nb	N
HL	0.11	0.18	0.70	0.13	2.28	1.00	0.27	0.020	0.0062
HH	0.10	0.17	0.67	0.14	2.31	1.01	0.29	0.022	0.024
LL	0.11	0.17	0.65	0.02	2.28	0.99	0.27	0.019	0.0068
LH	0.10	0.16	0.61	0.02	2.27	0.98	0.27	0.021	0.026

Note: P:0.007~0.008 S:0.005~0.006

according to a previous paper [1] on the effect of N addition. Ni was added so that the specification of base metal, ASME code case 1960, was satisfied. The weld metals were made by tandem submerged arc welding using ASTM A387 Gr. 22 Cl.2 as a base metal. The welding condition and the groove configuration for SAW were the same as Table 3 and Fig. 2 respectively.

4.2 Mechanical Test

All-weld-metal tension tests were performed after SR at room temperature on round specimens with a 12.5mm gage diameter and a gage length of 50mm. All-weld-metal creep rupture tests were also performed at 550°C after SR on round specimens with a 6mm gage diameter and a gage length of 30mm. The location of the specimens is shown in Fig.5.

4.3 X-ray Diffraction Analysis

Non-aqueous electrolyte extraction residues of weld metals were identified using X-ray diffraction analysis.

4.4 Test Results and Discussion

The tensile properties at room temperature of all-weld-metal are shown in Table 5. This table shows these four weld metals had almost the same 0.2% yield strength and tensile strength which satisfy the specification of base metal, ASME code case 1960, although they differed in N and Ni content.

On the other hand, the creep rupture strengths of these four weld metals were quite different as indicated in Fig. 6. The figure shown the creep rupture strengths of N-added weld metals, HH and LH, were lower than those of the two others, HL and LL. But the diagram can not show clearly the effect of Ni on creep rupture strength of weld metals.

Table 5. Tensile properties of all-weld-metals

	0.2%YS (MPa)	TS (NPa)	El (%)	RA (%)
HL	606	707	22	63
HH	596	703	20	62
LL	597	700	22	58
LH	608	702	21	60

A bulk carbide extraction was employed to investigate the role of N in carbide precipitation. Fig. 7 shows the quantity of extracted residues of weld metals as a result of three different heat treatment conditions. On the whole, extracted residues of weld metals increased in quantity after SR, but did not increase or decreased slightly after thermal aging. A detailed analysis shows that more residues were extracted from the N-added weld metals, HH and LH, in all heat treatments than from the two others, HL and LL. However, the effect of Ni is not clear, resembling the results of the creep rupture test mentioned above. A chemical analysis of the extracted residues was also carried out. The results of analysis did not show any distinct difference among them.

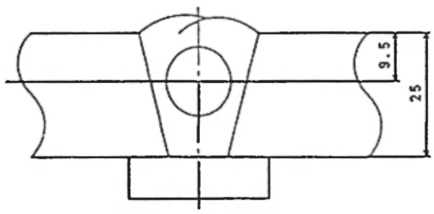


Fig. 5. *Location of all-weld-metal tension and creep rupture specimens*

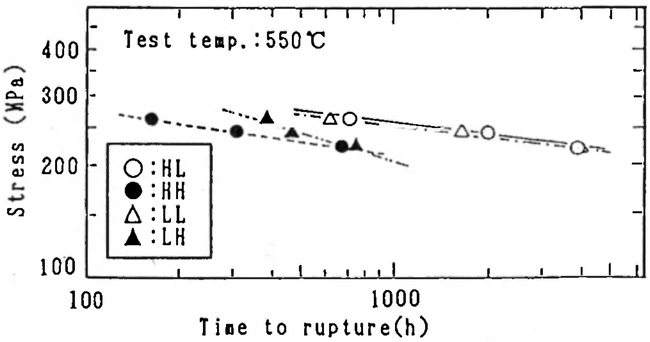


Fig. 6. *Creep rupture test result*

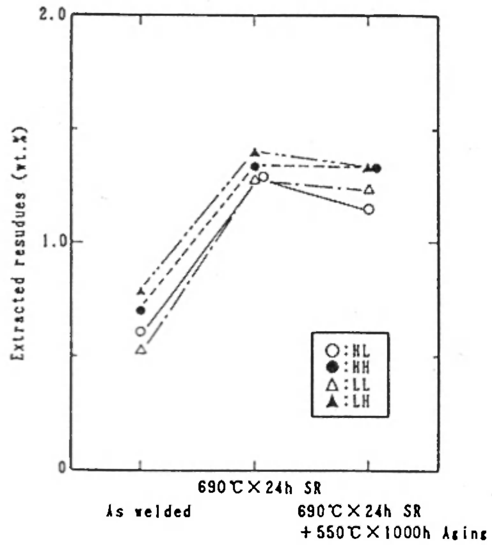


Fig. 7. *Change in amount of extracted residues*

According to X-ray diffraction analysis, although a clear change of precipitates in residue extracted from the weld metal, LL, was not observed after thermal aging, a remarkable increase of M_6C and M_2C in residue extracted from the N-added weld metal, LH, was observed. Very similar results were obtained from tests on the weld metals HL and HH: in HL there was little change in precipitation, but in HH there was a remarkable increase of M_6C and M_2C. The effects of N and Ni on creep rupture strength can be explained by analyzing the behaviour of precipitates in residues extracted from the weld metals. That is, in this experiment N activated the precipitation and growth of massive carbides, such as M_6C, but Ni had no clear effect on the behaviour of carbides.

5. MECHANICAL PROPERTIES OF NEWLY DEVELOPED WELD METALS

5.1 Welding Procedure

According to the test results, the chemical composition of welding Consumables was designed. C and Mn contents of newly developed welding consumables were lower than those of conventional ones. N content was also restricted as low as possible.

SAW and SMAW electrodes were produced, welded in accordance with the welding condition in Table 3 and Fig. 2 and tested. Chemical compositions are shown in Table 6.

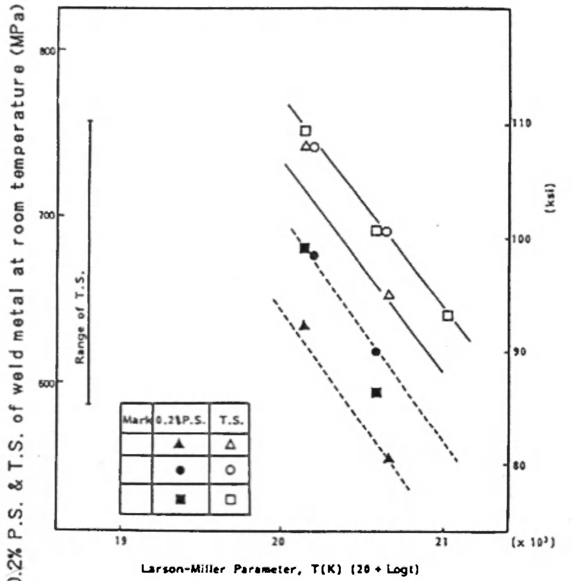


Fig. 8. *Tensile properties of SAW weld metal vs. LMP on PWHT*

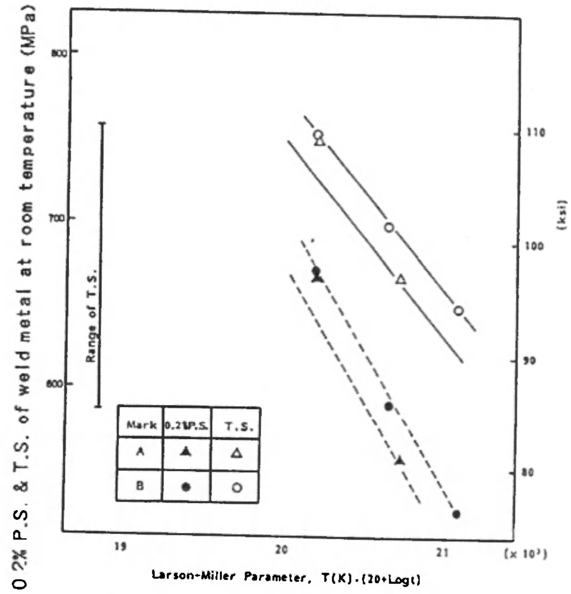


Fig. 9. *Tensile properties of SMAW weld metal vs. LMP on PWHT*

Table 6. Chemical composition of weld metals

Mark	C	Si	Mn	P	S	Ni	Cr	Mo	V	Nb
SAW A	0.10	0.15	0.63	0.007	0.005	0.05	2.35	0.99	0.25	0.012
SAW B	0.10	0.14	0.67	0.006	0.004	0.05	2.35	0.97	0.27	0.011
SAW C	0.11	0.17	0.67	0.009	0.005	0.02	2.30	1.01	0.26	0.016
SMAW A	0.08	0.33	0.51	0.005	0.005	0.05	2.38	1.01	0.30	0.019
SMAW B	0.08	0.38	0.53	0.005	0.005	0.05	2.40	1.01	0.32	0.020

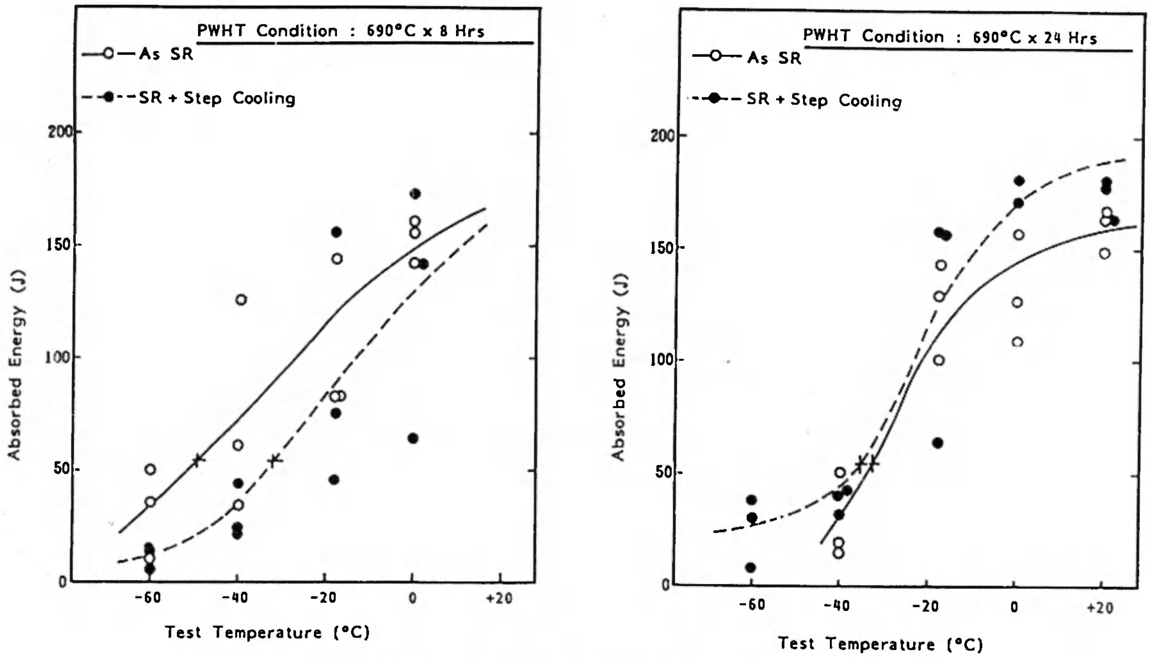


Fig. 10. *Impact properties of SAW weld metal*

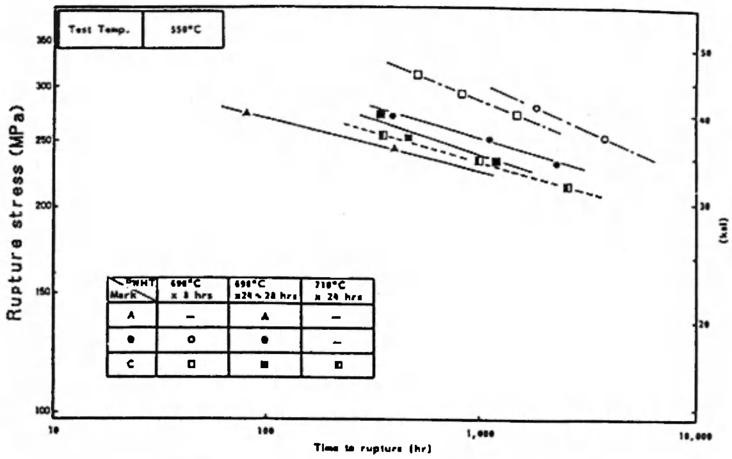


Fig. 11. *Creep rupture curve of SAW weld metals*

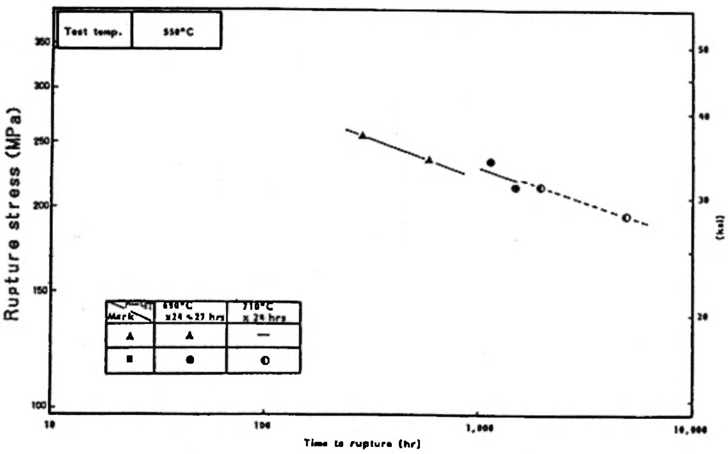


Fig. 12. *Creep rupture curve of SMAW weld metals*

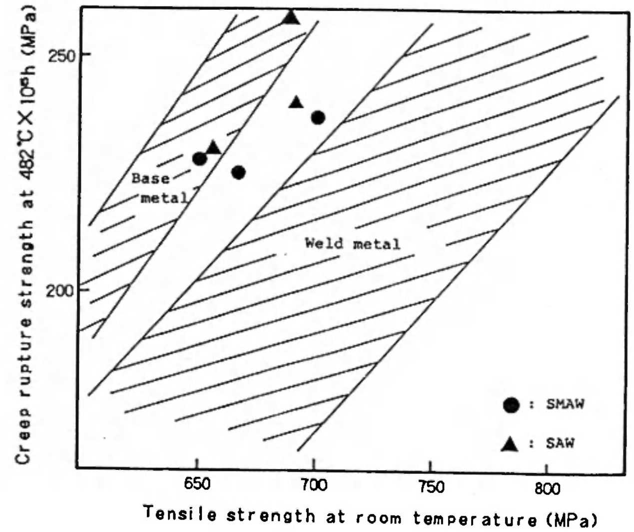


Fig. 13. *Tensile strength at room temperature vs. creep rupture strength of newly developed weld metals*

5.2 Tensile Properties of Weld Metals

In Fig. 8 and Fig. 9, the tensile properties of weld metals are shown. These tables and figures show that the tensile properties of weld metals satisfy the requirement of base metal, ASME code case 1960.

5.3 Impact Properties of Weld Metals

Typical impact properties of SAW weld metal are shown in Fig. 10. These properties also satisfy the requirement.

5.4 Creep Rupture Strength of Weld Metals

Creep rupture test results of weld metals are reported in Fig. 11 and Fig. 12. The relation between tensile strength and creep rupture strength is illustrated in Fig. 13. This figure reveals that weld metals made of newly developed welding consumables have almost the same creep rupture properties as V-modified 2.5 Cr-1Mo steel.

6. CONCLUSION

An increase of creep rupture strengths without increasing tensile strengths at room temperature has been achieved by decreasing the content of C, Mn and N in weld metals. Other mechanical properties of weld metals have satisfied the requirement of V-modified 2.5 Cr-Mo steel. The newly developed welding consumables are expected to provide an actual application for V-modified 2.5 Cr-1Mo steel.

REFERENCES

1. Hojo, I. et al., IIW/IIS, Doc.II-1045-85

Some Hazards of Welding Fume

Lesley Ashburner, 3M Occupational Health and Environmental Safety
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As many welders are already aware, packs of electrodes and bare wires carry a health warning against the dangers of welding fume. What are these dangers and what should welders to to ensure that they have adequate protection? There are all kinds of face masks and respirators on the market. Some are disposable, some made of rubber, others consist of a simple gauze pad, many only protect against large dust particles and provide little protection against the fine particulate of welding fume and the potential health hazards that it presents.

A common health hazard associated with welding is fume fever, often caused by exposure to zinc or galvanized metals. The effects, which include fever, chills, nausea, body and head aches, are similar to influenza symptoms and usually begin with 24 hours of overexposure to a metal fume. These are short lived and full recovery is normally made until the next overexposure.

The potential effects of overexposure to substances commonly associated with welding should be clearly understood by welders and employers alike. In fact, not all are as easy to recover from as fume fever, some are far more serious. Although many of the following substances are found in welding materials, much of the evidence as to their potential health effects has been obtained from other industries and processes.

Cadmium Oxide

Short term exposure to cadmium oxide in high concentrations of 0.5 mg/m^3 or more can cause irritation of the breathing passageways and pulmonary oedema (fluid in the lungs). At concentrations of 50 mg/m^3 the reaction is usually delayed but is sometimes fatal. Long term exposure to low concentrations can lead to emphysema, a disease which affects the ability of the lungs to transfer oxygen to the bloodstream, and also damages kidneys.

Cobalt

Cobalt fume irritates the nose and throat and some reports suggest that it causes respiratory diseases ranging from coughs and shortness of breath to permanent disability.

Copper

Often causing a metal fume fever similar to that associated with zinc and galvanised surfaces, the health effects of copper fumes include irritation of the nose and throat as well as nausea.

Fluorides

Found in many electrode fluxes and coatings, exposure to fluorides can cause eye, nose and throat irritation and skin rashes. High concentrations over long periods may result in pulmonary oedema and bone damage.

Iron Oxides

Other respiratory irritants and the major fume to which welders are exposed are iron oxides. Affecting nose, throat and lungs, long term exposure can cause siderosis (deposits of iron oxides in the lungs, visible on x-ray but believed to have no harmful consequences).

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