ON SULFUR HOT CRACKING OF WELD METAL

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1. Introduction

It is well known that sulfur produces a filmy iron sulfide of low melting point in a steel-weld metal and causes hot cracking in it. Especially in the case of low nickel steel-weld metal containing over 2.5% of nickel, this harmful effect of sulfur is remarkable and it has been found that even a small amount of sulfur, such as 0.01%, can cause the hot cracking[1)2)].

In this report the effect of alloying elements, which can effectively change the iron sulfide into the other sulfides of higher melting point and of globular form, was studied in order to prevent such hot cracking.

The sulfide forming tendency of alloying elements in steel has been determined by the electrolytic isolation method, as follows[3)4)]:

$$Zr > Ti > Mn > Nb > V > Cr > Al > Mo > W > (Fe) > Ni > Co > Si$$

Zirconium, titanium or manganese has the larger sulfide forming tendency and forms globular sulfide.

Electrode wires containing these elements were prepared and their effects on the prevention of hot cracking were examined by a restrained test specimen with a circumferential weld metal which was deposited by automatic CO_2–O_2 arc welding.

2. Experimental Method

To evaluate the hot cracking susceptibility of weld metal, the specimen was placed on a round table rotated by a motor, and then it was restrained by four bolts. The size of the specimen was 150 mm square and 13 mm in thickness, and it had a circular groove in the center, as shown in Fig. 1. The weld metal was deposited in the groove by CO_2–O_2 arc welding process with the following welding conditions:

Welding current; 450~480 A, Arc voltage; 36 V, Welding speed; 40 cm/min, Shielding gas; CO_2 15 l/min+O_2 5 l/min.

A cracked angle was measured on each specimen as shown in Photo. 1.

As it had been experimentally confirmed that a low nickel alloyed steel was very susceptible to hot cracking by sulfur, a 3.5% nickel steel was used for base metal and 3.5% and 2.5% nickel steels for electrode wires[1)2)]. Their chemical compositions are shown in Table 1.

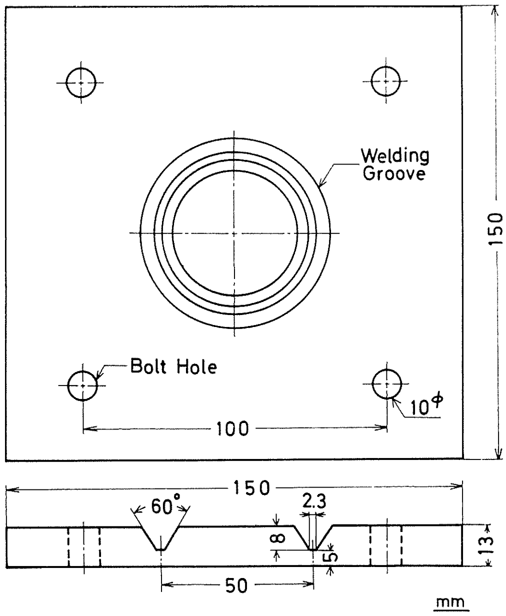
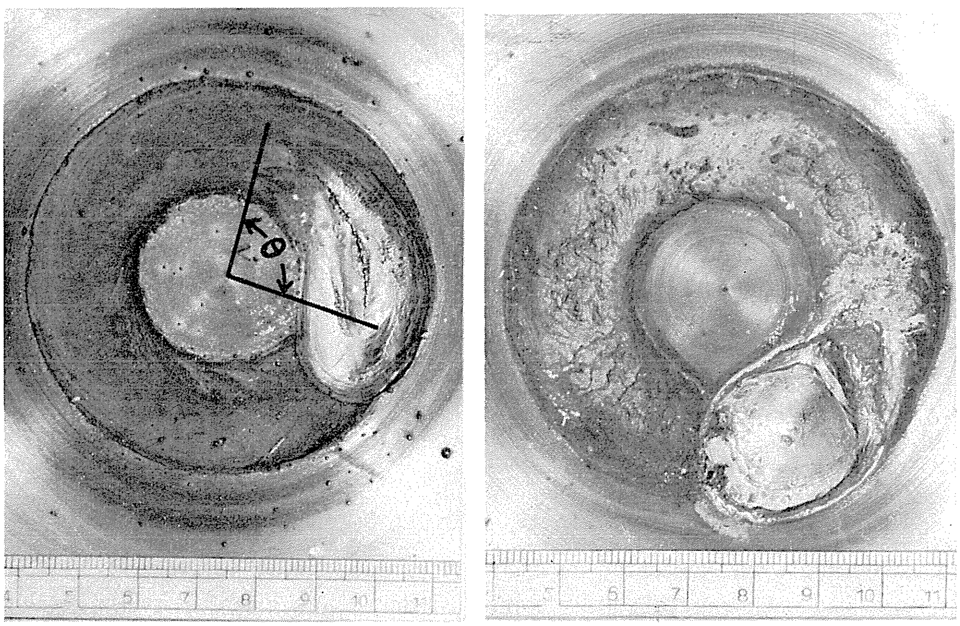


FIG. 1. Test specimen.



(a) 0% Ti $\theta=88°$ (b) 1.9% Ti $\theta=0°$

PHOTO. 1. Measured angle of hot cracking of 3.5% Ni steel-weld metal and effect of titanium addition on it.

TABLE 1. Chemical Compositions of the Materials Used

Materials			C	Si	Mn	P	S	Ni	Ti	Zr	Mn/S	Ti/S
Base Metal	3.5 Ni Steel		0.13	0.26	0.52	0.011	0.008	3.41	—	—	65	0
Electrode Wires	2.5 Ni Steel	A	0.06	0.78	1.46	0.011	0.025	2.63	0.32	—	58	13
		B	0.06	0.77	1.31	0.005	0.017	2.63	0.12	—	77	7
		C	0.06	0.67	1.78	0.008	0.014	2.62	—	—	127	0
	3.5 Ni Steel		0.07	0.76	1.42	0.012	0.025	3.63	0.31	—	57	12
Ferro-Alloys	Fe-S		0.02	0.06	0.16	0.006	1.4	—	—	—		
	Fe-Ti		0.064	0.10	0.12	0.007	0.008	—	70.4	—		
	Fe-Zr		0.48	38.5	—	—	—	—	—	42.5		
Metallic Mn			—	—	99.9	—	—	—	—	—		

3. Experimental Results

At first the influence of sulfur content of three electrode wires, A, B and C in the Table 1, was checked up on the hot cracking susceptibility. The cracked angle θ was plotted against the sulfur contents and the Mn/S ratios of electrode wires and of weld metals, as shown in Fig. 2. The cracked angle increases with the increase of sulfur content, and with the decrease of Mn/S ratio. In spite of the stronger sulfide forming tendency of titanium than that of manganese, no effect of titanium content of electrodes A and B was recognized in this experiment. This might come from the fact that the Ti/S ratios of electrode wires A and B are much lower than the Mn/S ratios of these electrode wires, as shown in Table 1.

Then the effects of the stronger sulfide forming elements, titanium and zirconium, were preliminarily examined by the following method. Small particles (8~14 mesh) of ferro-titanium, ferro-zirconium or metallic manganese were put in the groove of the test specimen, which was deposited by 3.5 Ni Steel electrode wire.

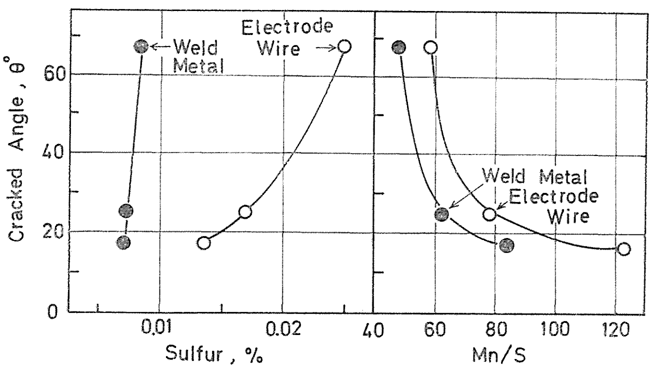


FIG. 2. Effects of sulfur content and Mn/S ratio of electrode wires and of weld metals on hot cracking of 3.5% Ni steel-weld metals.

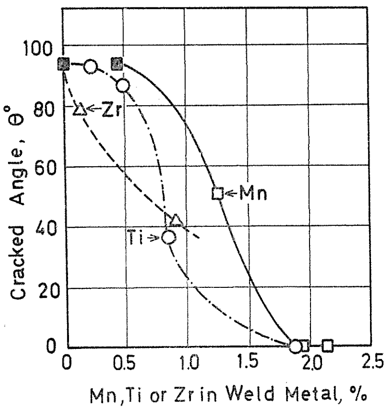


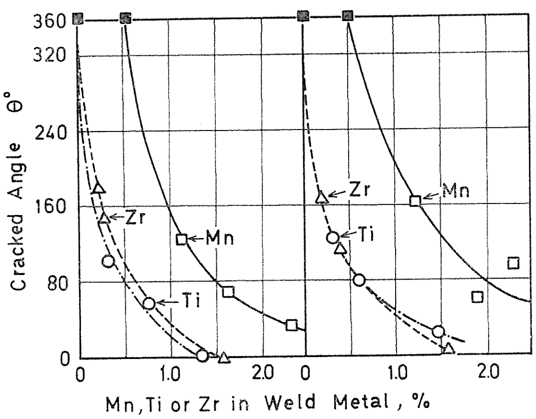
FIG. 3. Effects of alloying elements on hot cracking of weld metals containing about 0.01% sulfur.

Remarks: Alloying elements were added in groove as particles of metallic manganese, Fe-Ti or Fe-Zr alloy. Weld metal without additive particles in groove is shown by ■, which contains 0.46% manganese.

The results are shown in Fig. 3. This figure shows the effects of titanium and zirconium contents of weld metals, which contain about 0.5% manganese and 0.01% sulfur, comparing with the effect of manganese on the prevention of hot cracking.

The effects of these elements in the weld metals of higher sulfur content are also shown in Fig. 4. In this experiment a high sulfur alloyed steel (1.4% S), which was prepared by melting electrolytic iron and iron sulfide, was put in the groove together with ferro-alloys. Fig. 4 shows that the hot cracking of weld metal with such higher sulfur content (0.1～0.2%) can be more effectively prevented by titanium or zirconium than by manganese.

As the weld metal in this experiment contains not only titanium or zirconium but also manganese of about 0.5%, the experimental results in Figs. 3 and 4 do not



(a) 0.1% Sulfur (b) 0.2% Sulfur

FIG. 4. Effects of alloying elements on hot cracking of weld metals containing 0.1～0.2% sulfur.

Remarks: Alloying elements were added in groove as particles of metallic manganese, Fe-Ti or Fe-Zr alloy. Weld metal without additive particles in groove is shown by ■, which contains 0.52% manganese.

show the single effect of each alloying element. Then the manganese equivalent for the prevention of hot cracking was experimentally determined as shown in Fig. 5. In this figure the manganese equivalent is given from the following equation, which was obtained by the curve fitting calculation;

$$\theta = 360 - 264 \log\{6.45\,([Mn]+1.54\,[Ti]+1.24\,[Zr])+2.91\},$$

where θ is cracked angle; [Mn], [Ti] and [Zr] are manganese, titanium and zirconium contents in weld metal. It is deduced from this equation that titanium and zirconium are 1.54 and 1.24 times as effective as manganese for the prevention of hot cracking.

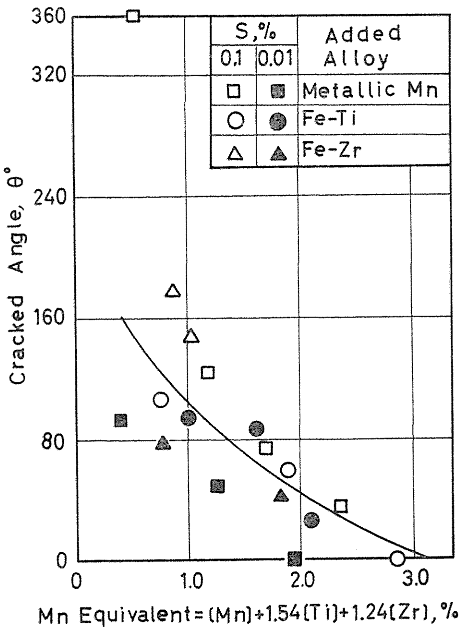


FIG. 5. Relation between cracked angle and manganese equivalent of weld metal containing 0.01～0.1% sulfur.

On the basis of the preliminary examination, some heats containing various amounts of titanium, zirconium or manganese were melted in the laboratory and electrode wires in 2 mm diameter were prepared from them. Their chemical compositions are shown in Table 2.

The same hot cracking tests above mentioned were carried out by these electrode wires. Fig. 6 shows the results. Zirconium or titanium addition into electrode wire together with manganese of 1.0～1.3% is more effective than the single manganese addition. Only small amount of zirconium or titanium remains in the weld metal as shown in Fig. 7 (a). Fig. 7 (b) shows the relation between the manganese equivalent of weld metal and the cracked angle.

Photo. 1 (a) shows the appearance of the crack, the crack starts from the crater and runs in the center of weld metal. It propagates along the grain boundaries of the columnar structure of weld metal. No crack in weld metal,

TABLE 2. Chemical Compositions of the Experimental Electrode Wires

Electrode Wires	Elements (%)								Ti/S	Zr/S
	C	Si	Mn	P	S	Ni	Ti	Zr		
M 1	0.03	0.60	1.82	0.007	0.026	3.22	—	—	—	—
M 2	0.03	0.60	2.18	0.007	0.035	3.42	—	—	—	—
M 3	0.04	0.61	2.20	0.016	0.032	3.51	—	—	—	—
T 1	0.02	0.64	1.10	0.004	0.030	3.51	0.60	—	20	—
T 2	0.03	0.60	1.01	0.004	0.036	3.51	0.90	—	25	—
T 3	0.02	0.77	1.27	0.004	0.033	3.51	1.12	—	34	—
Z 1	0.01	0.36	0.97	0.004	0.032	3.60	—	0.15	—	5
Z 2	0.05	0.64	1.26	0.019	0.029	3.56	—	0.35	—	12

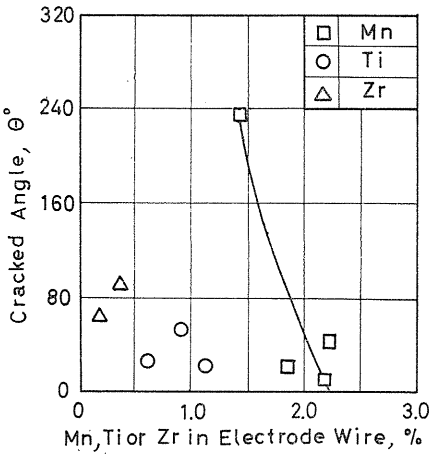


FIG. 6. Effects of alloying elements in electrode wires on hot cracking of weld metal.
Remark: Electrode wires alloyed by titanium or zirconium contain also 1.0~1.3% manganese.

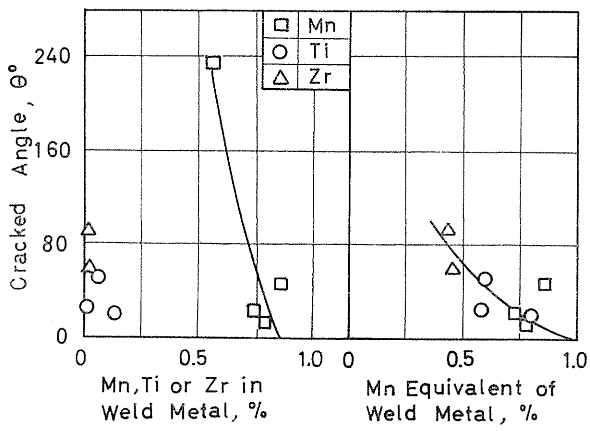


FIG. 7. Effects of alloying elements and manganese equivalent in weld metals on hot cracking.
Remarks: 1. Weld metals alloyed by titanium or zirconium contain also 0.4~0.6% manganese
2. Mn Equivalent=[Mn]+1.54[Ti]+1.24[Zr].

which contains titanium of 1.9%, is shown in Photo. 1 (b).

Photo. 2 shows the titanium and zirconium sulfide inclusions in weld metal of higher sulfur content. With the additions of manganese, titanium and zirconium to a certain extent, globular formed and finely dispersed sulfides appear in grain boundaries instead of filmy iron sulfide.

A further examination was qualitatively made on the sulfide inclusions by the electron probe microanalysis. The results of analysis by area scanning of iron rich and manganese rich sulfide inclusions are shown in Photos. 3 and 4, respectively. TiS and ZrS were too fine to be analyzed by the same method as FeS and MnS. Then they were analyzed by line traversing. Figs. 8 and 9 show

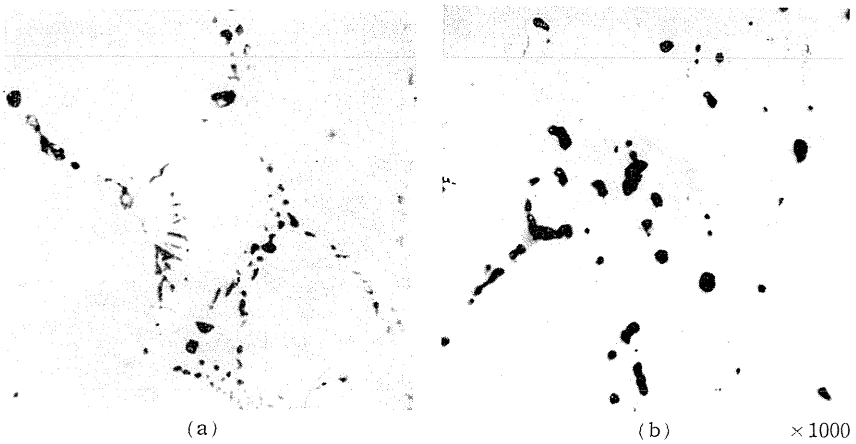


PHOTO. 2. TiS and ZrS inclusions in weld metals of 0.16% S, 0.61% Ti (a) and 0.18% S, 0.40% Zr (b).

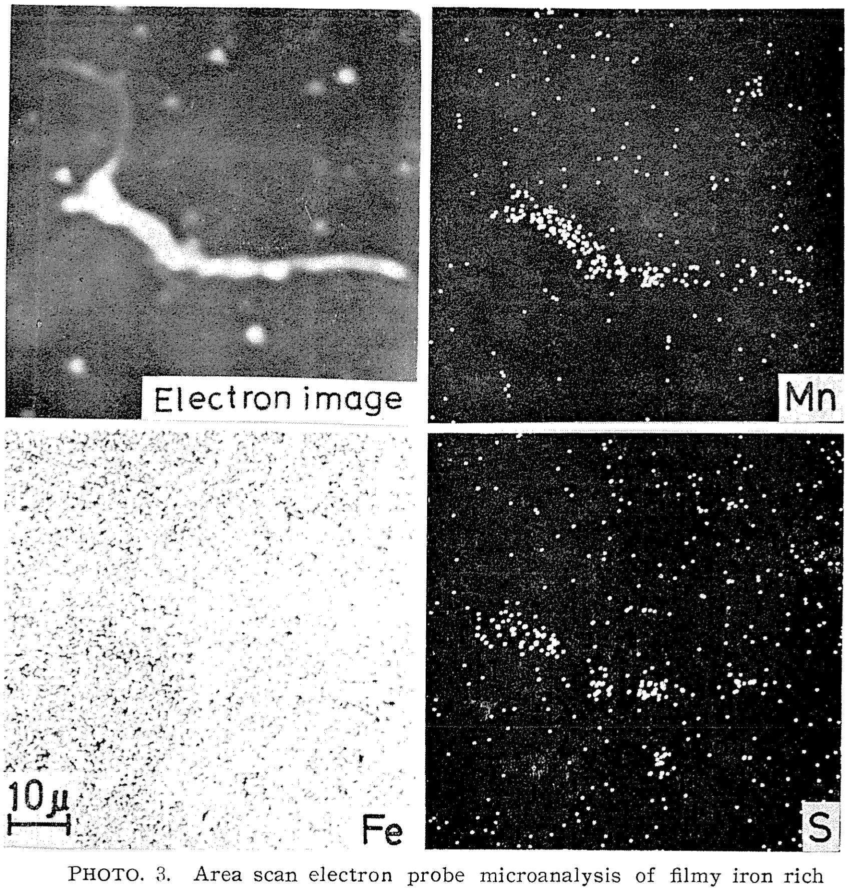


PHOTO. 3. Area scan electron probe microanalysis of filmy iron rich sulfide inclusion.

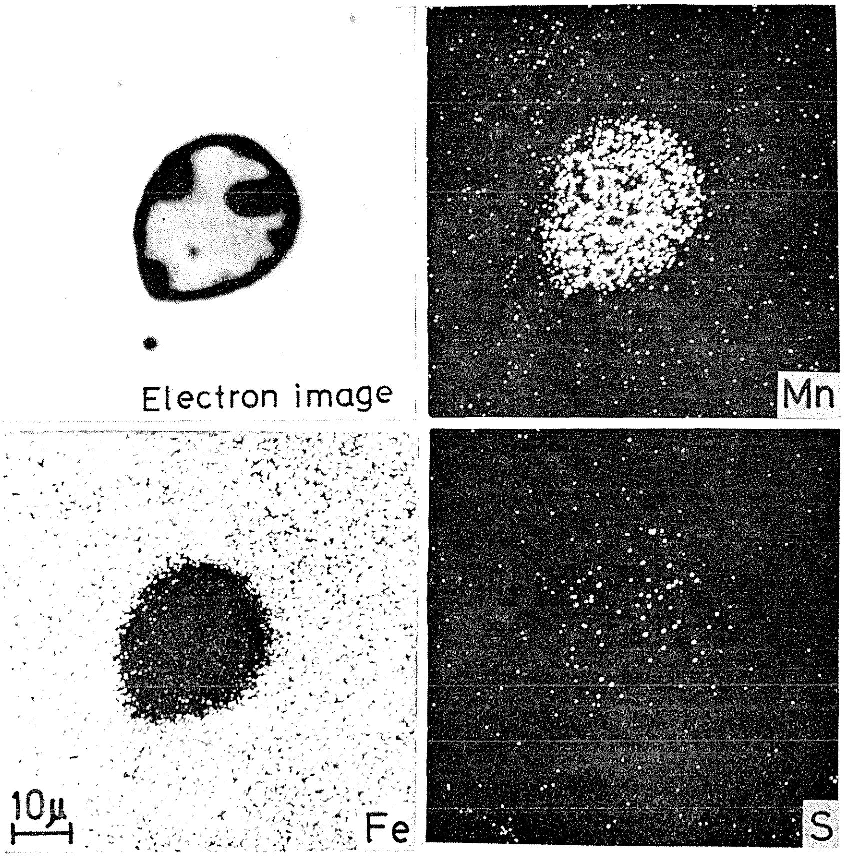


PHOTO. 4. Area scan electron probe microanalysis of MnS inclusion.

the results of analyses on the globular formed sulfides of titanium and zirconium, respectively.

It was clarified by the experiment that zironium, titanium and manganese were effective to prevent hot cracking of weld metal. But these alloying elements may decrease the notch toughness and the ductility of weld metal. Then the

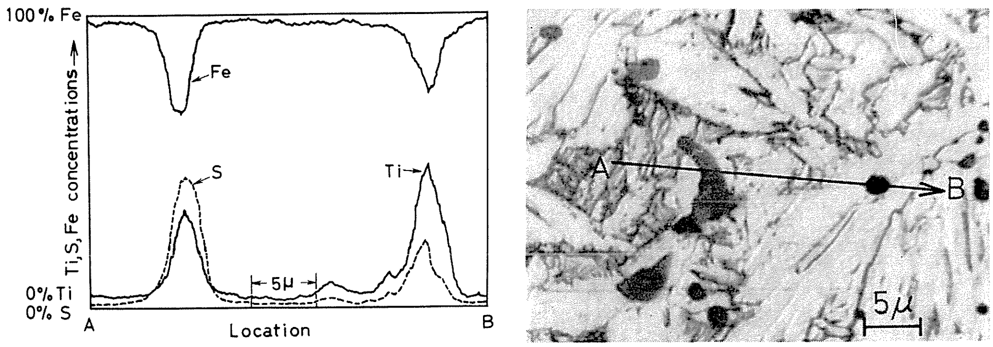


FIG. 8. Line traverse electron probe microanalysis of TiS inclusion.

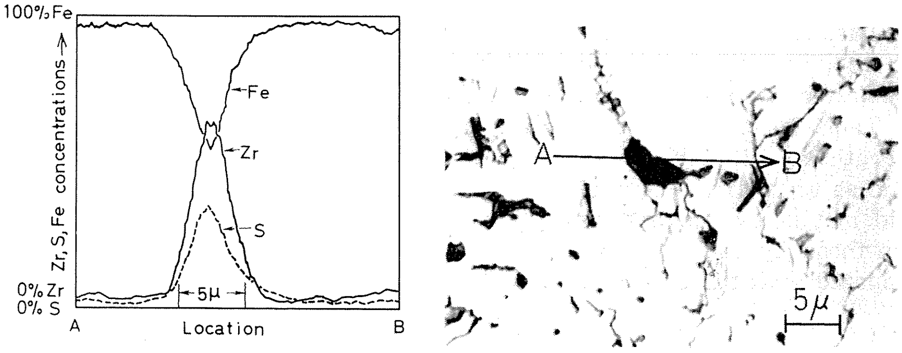


FIG. 9. Line traverse electron probe microanalysis of ZrS inclusion.

TABLE 3. Chemical Compositions and Mechanical Properties of Weld Metals Obtained by Experimental Electrode Wires

Electrode Wires Used	Elements (%)							
	C	Si	Mn	P	S	Ni	Ti	Zr
3.5 Ni	0.09	0.09	0.38	0.011	0.022	3.67	—	—
M 3	0.10	0.11	0.68	0.008	0.024	3.40	—	—
T 1	0.04	0.20	0.48	0.006	0.025	3.55	0.04	—
Z 2	0.07	0.08	0.36	0.006	0.022	3.40	—	0.01
Base Metal	0.13	0.26	0.52	0.011	0.008	3.41	—	—

Electrode Wires Used	Yild Strength (kg/mm^2)	Tensile Strength (kg/mm^2)	Elongation (%)	Charpy Impact Value (2 mmV-Notch) ($kg\text{-}m/cm^2$)	
				−40°C	0°C
3.5 Ni	40.4	58.0	16	2.8	2.9
M 3	39.9	56.2	29	6.0	8.9
T 1	42.0	58.2	38	6.7	10.6
Z 2	41.7	52.5	26	4.3	8.0
Base Metal	41.8	56.2	53	22.0	22.3

mechanical properties of the welded joint by these electrode wires were examined. Vee-butt joint of 3.5% nickel steel plate in 13 mm thickness was welded by CO_2-O_2 arc welding with the experimental electrode wires, and Charpy impact test and tension test were carried out on the welded joint.

Table 3 shows their chemical compositions and mechanical properties. Yield strength and ultimate tensile strength of these weld metals are all nearly the same as those of the base metal. Althougth elongation and impact values of the weld metals by the experimental electrode wires M 3, T 1 and Z 2 are larger than those by the usual 3.5% nickel steel electrode wire, no weld metal can be compared with the base metal in ductility and toughness.

4. Conclusion

The effects of the stronger sulfide forming elements, zirconium, titanium and manganese on the prevention of weld metal hot cracking were experimentally examined on a 3.5% nickel steel-weld metal by a restrained, circumferential deposit hot cracking test. And it was confirmed that the cracked angle decreases with the increace of these elements in the electrode wires or the weld metals. The manganese equivalent for the prevention of hot cracking was experimentally determined as $[Mn]+1.54[Ti]+1.24[Zr]$.

These elements alloyed in the electrode wires can improve also ductility and toughness of the weld metals.

References

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