Research on Characteristics of Filler Metal and Flux Influencing on the Toughness of a Carbon Steel Weld†

—Minor Elements and Alloying Elements Influencing on the Toughness of Weld—

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Abstract

To understand the influence of minor elements and alloying elements on the toughness of a mild steel and a 50kg/mm² class steel, low hydrogen type electrodes of basicity 4.2 was selected for fixing Fe-Ti and Fe-B in the flux respectively 0.7 and 1.5%. From this experiments A-type electrode of 1.15%Mn-0.9%Ni-Ti-B rather than B-Type electrodes 1.35%Mn-0.5%Ni-Ti-B showed superior impact characteristics below −40°C while upper shelf energy is lowered at the room temperature.

Also A-Type electrode showed lower deviation of stable impact value and smooth transition curve at various temperature.

KEY WORDS: (Filer metal) (Flux) (Charpy V-notch Toughness) (Weld) (Minor Elements) (Alloying Elements) (Low hydrogen type electrodes)

1. Introduction

In the study optimal contents of Ti and B is fixed through lots of experiments while contents of Mn and Ni are varied to survey the toughness characteristics for the prevention from the abrupt change and scatterings of impact value at the low temperature.

From experiments two types of electrode-one is 1.15%Mn-0.9%Ni-Ti-B and the other is 1.35%Mn-0.5%Ni-Ti-B are considered to yield superior results.

2. Experiments

2.1 Type of tests

Flux composition: Specimens of all weld metal were prepared according to JIS Z 3212 of which electrodes were made to vary alloying elements of Ni and Mn in the low hydrogen electrode of basicity 4.2.
The charpy V-notch test and the tensile test were done. The metal structure and the fracture surface were also examined.

2.2 Base Metal and Core Rod

Base metal for experiments is a general purpose steel plate for a welded structure designated by JIS SM41 of the thickness of 19mm.
Three layers of butterings were made for all weld metal testing in accordance with JIS standards.
The core rod is the wire for a covered welding electrode designated by JIS SWRY 11.

2.3 Flux Compositions

Through preparatory testings, contents of Ti and B in the flux of the covered electrode of basicity 4.2 were determined. Refering to Abson and Pargeter's study Mn contents in the weld metal were fixed 1.15% and 1.35% while varying contents of Ni.
Contents of Ni were also fixed 0.5% and 0.9% respectively while varying contents of Mn.
Chemical compositions of fluxes in this experiments is shown in the **Table 1**.

Table 1 Chemical Analysis of Coating Flux

Spec. & Grade	Thick. (mm)	Chemical Composition (wt%)					Ceq.
		C	Si	Mn	P	S	
SM41	19	0.16	0.28	8.87	8.820	8.815	0.225

* Ceq. = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15

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Table 2 Summary of Composition Change Range Group (I ~ VI)

Contents / Group	Dosing Ratio (wt%) Fe-Si	Fe-Mn	Metal Ni	Fe-Ti	Fe-B	Variable	Test No. θ1	θ2	θ3	θ4	θ5	θ6	θ7	θ8	θ9	Remarks
I	10	2.5–6.5	1.3	0.7	1.5	Fe-Mn	2.5	3	3.5	4	4.5	5	5.5	6	6.5	Change Fe-Mn (2.5–6.5%) at Metal Ni 1.3%
II	10	2–6	2.5	0.7	1.5	Fe-Mn	2	2.5	3	3.5	4	4.5	5	5.5	6	Change Fe-Mn (2–6%) at Metal-Ni 2.5%
III	10	4	1–5	0.7	1.5	Ni	1	1.5	2	2.5	3	3.5	4	4.5	5	Change Metal Ni (1–5%) at Fe-Mn 4%
IV	10	5.5	0.5–3	0.7	1.5	Ni	0.5	1	1.5	2	2.5	3	–	–	–	Change Metal Ni (0.5%–3%) at Fe-Mn 5.5%
V	10	4	2.5	–	–	–	–	–	–	–	–	–	–	–	–	Omitted-Ti, B from best formula (II-5)
VI	10	4	–	0.7	1.5	–	–	–	–	–	–	–	–	–	–	Omitted Ni from best formula (II-5)

Table 3 Typical Chemical Compositions of Raw-Material Flux Used

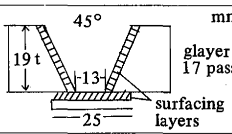
Element / Raw Material	Chemical Compositions (wt%) o	Si	Mn	P	S	Fe	Ni	Al	Ti	B
Fe-Mangan	1.3	1.0	78.8	0.12	0.012	Rem	–	–	–	–
Fe-Silicon	0.12	42.7	–	0.02	0.013	Rem	–	–	–	–
Metal-Nikel	0.012	0.02	–	0.003	0.002	–	99.3	–	–	–
Fe-Titanium	0.045	0.10	–	0.013	0.011	Rem	–	–	42.8	–
Fe-Boron	0.25	1.22	–	–	–	Rem	–	0.5	–	18.14

For convenience, flux compositions for the experiments were shown in **Table 2.**
Table 2 shows the basic formula of Group I to Group VI. **Table 3** shows alloying elements intentionally added to the basic formula of fluxes.

2.4 Test Procedures

Test specimens and welding conditions are shown in the **Table 4.**
Location of specimen extraction was center along the weld line and the middle to the thickness.

Table 4 Edge Preparation and Welding Conditions

Division	Groove Design	Electrode Dia (mm)	Welding Position	Amp	Volt	Speed (cm/min)	Interpass Temp. (°C)
Plate for Composition Change		4.0ϕ	Flat	AC 160–180	24–26	27–28	93–107
Division	Groove Design	Electrode Dia (mm)	Welding Position	Heat Input			Interpass Temp. (°C)

Five specimens for charpy V-notch impact testing were extrated from each weld.
Chemical analysis of C, Si, Mn, P and S was done by the wet method in accordance with JIS Z 1252.
And other elements was analyzed by a inductivity copuled plasma spectrometer. Mechanical testing was done in accordance with JIS Z 3111. Fractography of test specimens surfaces was observed by SEM.
Shapes and distributions of inclusions and metal were analyzed by the SEM. A qualitative analysis was carried out with EDS.

3. Results

3.1 Tests of Flux Composition

3.1.1 Chemical composition in weld metal

Chemical compositions in the weld metal differs among flux groups as shown in the **Table 5.**
Contents of Ni and Mn in the weld metal differs owing to amounts of metal transfer from the metal Ni and Fe-Mn in the flux into the weld metal. The correlation between Ni and Mn contents in the weld metal and those the flux can be secured by the least square method.
Equations of the correlations are

$$X = 0.35X' + 0.02$$
$$Y = 0.15Y' + 0.55$$

Where
X = Ni contents in the weld metal
X' = Ni contents in the flux
Y = Mn contents in the weld metal
Y' = Fe-Mn contents in the flux

The metal transfer rate of Ni is 2.3 times than that of Mn.

3.1.2 Mechanical Properties and Toughness Variations

Mechanical properties and charpy V-notch impact values are shown in **Table 6.**
The extreme maximum and minimum are excluded for the calculation of the average value.

Table 5 Chemical Compositions of Weld Metal

Group	No.	Chemical Composition (wt%)							
		C	Si	Mn	P	S	Ni	Ti	B
I	1	0.068	0.48	0.92	0.014	0.006	0.50	0.022	0.0020
	2	0.070	0.48	1.02	0.013	0.010	0.48	0.024	0.0020
	3	0.075	0.50	1.06	0.014	0.009	0.48	0.026	0.0024
	4	0.074	0.50	1.12	0.015	0.008	0.50	0.023	0.0030
	5	0.072	0.49	1.25	0.014	0.007	0.49	0.023	0.0023
	6	0.074	0.51	1.31	0.013	0.006	0.48	0.024	0.0024
	7	0.078	0.52	1.37	0.013	0.006	0.50	0.027	0.0023
	8	0.080	0.50	1.47	0.013	0.010	0.51	0.023	0.0022
	9	0.082	0.54	1.50	0.015	0.009	0.49	0.022	0.0021
II	1	0.067	0.44	0.81	0.014	0.006	0.92	0.026	0.0023
	2	0.070	0.46	0.86	0.014	0.009	0.90	0.024	0.0025
	3	0.071	0.46	0.96	0.015	0.009	0.92	0.024	0.0021
	4	0.075	0.49	1.00	0.013	0.008	0.91	0.024	0.0022
	5	0.075	0.51	1.15	0.013	0.006	0.93	0.025	0.0023
	6	0.076	0.51	1.20	0.015	0.008	0.89	0.026	0.0023
	7	0.077	0.51	1.28	0.015	0.010	0.90	0.025	0.0024
	8	0.080	0.53	1.34	0.015	0.012	0.91	0.025	0.0023
	9	0.081	0.53	1.39	0.014	0.006	0.92	0.026	0.0021
III	1	0.075	0.45	1.15	0.013	0.006	0.30	0.026	0.0023
	2	0.072	0.45	1.14	0.014	0.009	0.60	0.025	0.0024
	3	0.076	0.47	1.18	0.013	0.008	0.71	0.024	0.0022
	4	0.073	0.50	1.16	0.013	0.010	0.91	0.021	0.0023
	5	0.071	0.53	1.75	0.014	0.009	1.11	0.024	0.0024
	6	0.070	0.49	1.15	0.014	0.009	1.19	0.025	0.0026
	7	0.074	0.50	1.17	0.013	0.006	1.38	0.027	0.0024
	8	0.072	0.48	1.14	0.013	0.008	1.60	0.026	0.0023
	9	0.070	0.47	1.15	0.014	0.008	1.76	0.026	0.0024
IV	1	0.070	0.45	1.37	0.014	0.003	0.20	0.027	0.0024
	2	0.074	0.48	1.35	0.015	0.008	0.35	0.022	0.0023
	3	0.069	0.48	1.37	0.015	0.006	0.50	0.023	0.0024
	4	0.072	0.50	1.36	0.014	0.010	0.75	0.026	0.0021
	5	0.074	0.52	1.37	0.013	0.009	0.84	0.023	0.0027
	6	0.075	0.52	1.37	0.013	0.006	1.06	0.022	0.0021
V		0.076	0.48	1.17	0.013	0.009	0.92	Tr	–
VI		0.076	0.50	1.16	0.014	0.010	0.02	0.025	0.0022

The optimal formula of flux composition for each Group are regarded as follows,

I-7	(1.35%Mn – 0.5%Ni – TiB)	vE-60	10.2 kg-m
II-5	(1.15%Mn – 0.9%Ni – Ti-B)	vE-60	11.2 kg-m
III-4	(same as II-5)	vE-60	10.8 kg-m
IV-3	(same as I-7)	vE-60	10.0 kg-m
V	(1.15%Mn – 0.9%Ni)	vE-60	2.2 kg-m
VI	(1.15%Mn – Ti-B)	vE-60	4.8 kg-m

3.1.3 Microstructure

The impact value of the charpy V-notch specimens of Group II-5, I-7, VI and V are respectively 11.2, 10.2, 4.8, 2.2 kg-m at –60°C.

Optical micrographs of those are seen in the **Fig. 1-1** through **1-4**. Fine accicular ferrites distributes inside the grains of Group II and I-7.

It is also observed that the proeutectoid ferrite on the grain boundary is suppressed.

The grain boundary ferrite and ferrite side plate are observed the micrographs of Group VI and V.

The charpy V-noch toughness improves as accicular ferrite increases.

3.1.4 Observation of Fractographs

Figure 2-1 through **2-4** shows the SEM fractographs of

Table 6 Mechanical Properties of Weld Metal

Group	No.	Mechanical Properties				Impact Value (kgf · m at –60°C)					
		TS (kg/mm²)	YP (kg/mm²)	EL (%)	RA (%)	1	2	3	4	5	$\bar{X}$
I	1	56.2	50.2	28.4	67.5	6.9	5.1	*7.1	6.6	*4.9	6.2
	2	57.0	50.4	28.0	68.0	5.7	7.5	6.0	*9.4	*5.6	6.4
	3	57.8	51.2	29.0	68.2	7.5	*7.0	7.9	7.1	*8.3	7.5
	4	58.3	51.6	29.4	69.3	*9.9	8.7	9.6	7.6	*7.5	8.7
	5	59.0	51.6	29.5	70.0	*10.2	*8.2	9.1	9.9	8.9	9.3
	6	60.1	51.8	30.4	69.7	9.8	*10.1	*8.4	9.7	9.0	9.5
	7	60.8	52.0	31.2	70.8	*11.7	9.3	10.4	10.9	*9.1	10.2
	8	62.1	53.8	28.4	68.2	5.7	7.1	*10.0	6.1	9.3	7.5
	9	63.4	55.2	26.8	65.0	*4.7	5.9	6.7	7.8	*8.3	6.8
II	1	56.8	50.3	27.7	66.1	6.9	*8.1	7.1	*2.3	5.5	6.5
	2	57.3	50.2	30.8	66.7	9.3	*9.4	6.2	5.5	*5.2	7.0
	3	57.8	51.6	30.2	68.3	8.3	7.2	7.9	*8.9	*6.1	7.8
	4	58.2	51.4	30.8	70.2	8.1	*10.3	9.4	8.0	*7.6	8.5
	5	58.8	51.8	31.8	72.0	11.3	10.6	11.7	*13.2	*10.1	11.2
	6	60.3	52.0	30.0	68.4	*9.5	8.2	*8.1	8.7	7.7	8.2
	7	61.5	52.4	27.5	68.0	*5.4	6.5	8.1	*9.3	7.9	7.5
	8	63.4	55.8	26.8	66.0	5.9	*7.3	*5.2	6.1	6.6	6.2
	9	64.5	56.2	25.8	65.2	*7.9	7.2	5.9	4.3	*3.1	5.8
III	1	55.5	48.8	28.2	70.2	5.2	5.2	5.2	*5.0	*6.4	5.2
	2	56.3	30.4	29.3	70.6	*9.0	5.4	5.9	*5.1	8.5	6.6
	3	57.6	51.2	30.5	70.3	*9.5	*7.9	8.1	9.3	9.0	8.8
	4	58.0	51.2	31.9	73.2	*11.3	10.9	*9.8	10.6	11.1	10.8
	5	59.9	51.7	31.0	72.4	9.3	*9.9	8.9	8.8	*8.7	9.0
	6	60.5	52.0	29.6	70.0	*9.3	7.5	7.8	7.2	*7.1	7.5
	7	61.4	53.2	28.2	69.8	6.7	5.2	8.3	*8.4	*4.3	6.8
	8	62.5	54.0	27.0	69.0	*7.5	6.7	7.2	5.3	*5.0	6.4
	9	63.8	35.4	26.3	66.2	*5.0	*5.7	5.6	5.1	5.2	5.3
IV	1	57.2	50.5	28.2	70.6	*5.9	7.1	6.9	7.6	*8.1	7.2
	2	58.0	51.0	28.4	70.0	8.7	*11.0	6.9	*6.8	10.8	8.8
	3	58.8	52.0	30.3	68.8	10.0	10.4	*11.1	9.6	*9.5	10.0
	4	60.5	52.2	29.8	67.4	7.7	9.0	*10.0	7.9	*7.6	8.2
	5	61.4	52.8	29.0	65.9	*6.9	7.3	7.7	6.9	*7.5	7.3
	6	62.8	53.8	28.3	65.2	5.7	*5.1	6.3	6.0	*6.4	6.0
V		59.2	50.3	28.4	71.3	1.7	1.7	3.2	*1.4	*3.7	2.2
VI		56.6	50.1	29.6	67.0	*7.5	4.5	*4.3	6.4	3.5	4.8

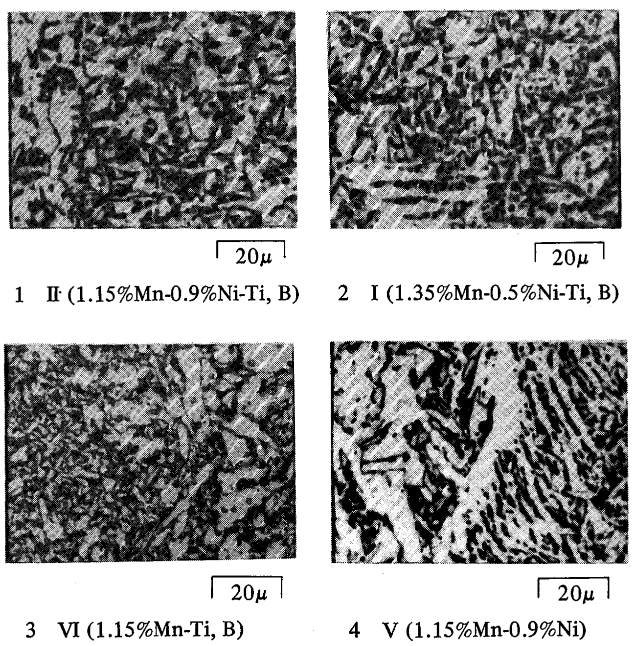
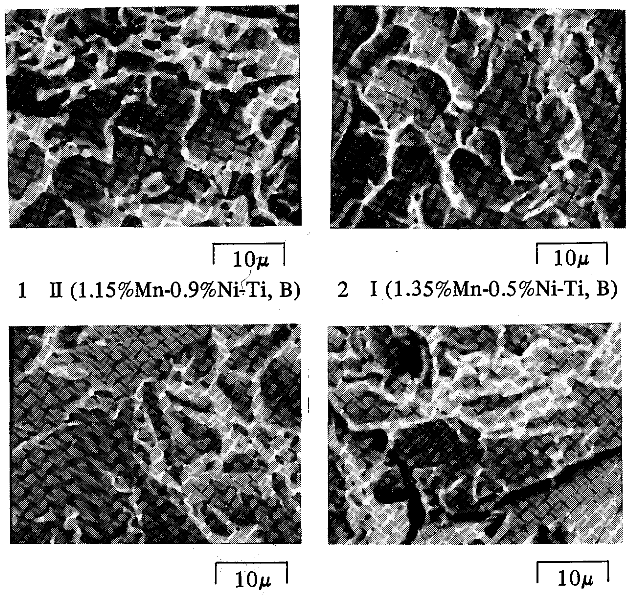


Fig. 1 Optical microstructure of columnar weld metal

charpy V-notch specimens tested at –60°C.

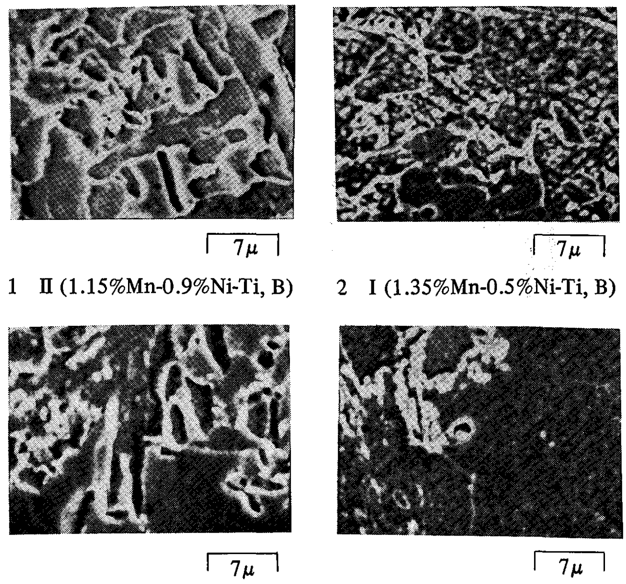
The refined facets in sequence of Group II-5, I-7, VI and V are observed while the respresentative cleavage fracture is



1 II (1.15%Mn-0.9%Ni-Ti, B) 2 I (1.35%Mn-0.5%Ni-Ti, B)

3 VI (1.15%Mn-Ti, B) 4 V (1.15%Mn-0.9%Ni)

Fig. 2 SEM fractographs of charpy V-notch specimens test at −60°C



1 II (1.15%Mn-0.9%Ni-Ti, B) 2 I (1.35%Mn-0.5%Ni-Ti, B)

3 VI (1.15%Mn-Ti, B) 4 V (1.15%Mn-0.9%Ni)

Fig. 3 SEM-Microstructure and inclusion shape

observed in Group VI and V.

3.1.5 Observation of Inclusions

To analyze shapes and composition of inclusions SEM photomicrographs of the plane etched specimens were examined as shown in **Fig. 3-1** through **3-4**.

It was observed that inclusions concentrated on the ferrite grain boundaries.

Observing **Fig. 4-1** through **4-4**, inclusions of Mn-Al-Si type and TiO type are favorable rather than those of MnS type.

These facts is in a good agreement with Grong's investigation.

4. Discussion

When Ni is applied on the base metal, the impact value is usually improved in proportion to contents, while on the weld metal, at the point of 0.9 percentage of deposited metal, impact value, elongation, reduction of area are decreased as shown in table 5, 6 but tensile strength has been increased by 6.2 ± 0.3 kg/mm^2/% Ni at weld metal.

It is recognized that Ni content of deposited weld metal in the range of less than 0.9% has grain refinement effect, while in the range of more than 0.9% impact value is decreased, because Ni, one of Austenite enlargement element becomes valuable to hydrogen attack.

Moreover, Ni expedites precipitation of carbides, so tensile strength is continuously increased, but EL, RA is decreased straightly.

In addition, as shown in the test IV Fig. 1-4 which is deleted Ni contents from optimum formula II-5. It is clearly find out the coarsed structure as they are mainly combined with grainboundary ferrite and ferrite side plate.

The optimum condition of Mn was most excellent with the result of 11.2kg-m at vE −60°C when the Mn contents is 1.15% among deposited metal with the fixed 0.9% of Ni.

Especially, the tensile strength has been increased by 12.8 ± 0.4 kg/mm^2/% Mn at weld metal, thus it is assumed that such facts as mentioned above is due to solid solution strengthening as described in Grong's study.

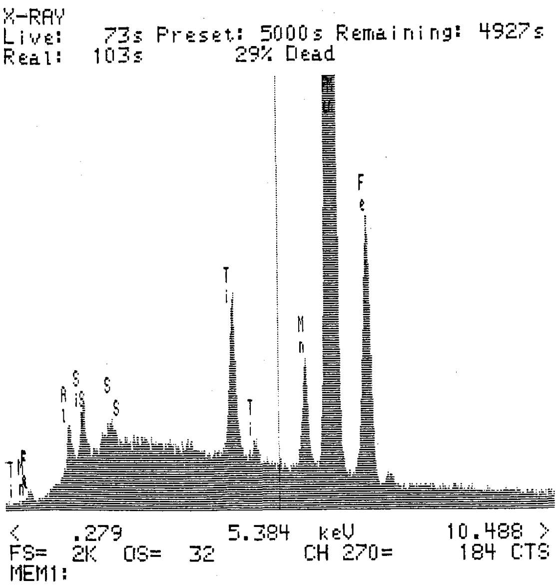
In the range of less than 1.15% of Mn, Mn improves hardenabity which leads to structure refinement, and scattering of precipitate.

Accordingly, TS, EL, RA, impact value are increased. However, in the range of more than 1.15% of Mn, the above − mentioned impact value RA, EL are assumed to be decreased as much of elongated MnS inclusion is precipitated.

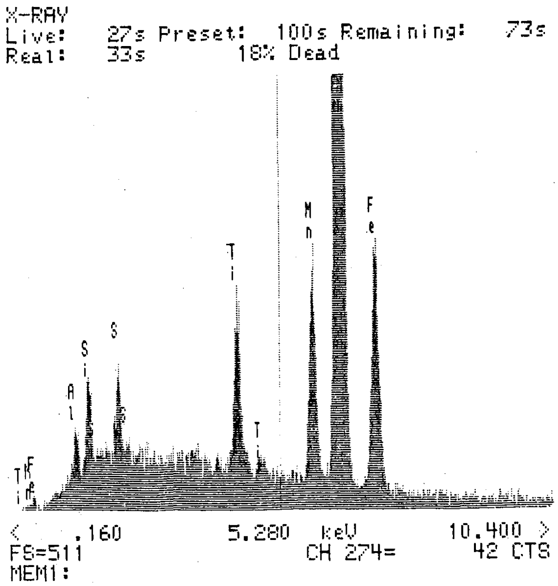
5. Conclusions

To evaluate effects of Ni adding alloying in Ti-B type of electrode, first contents of Ti and B was varied and then varying contents of Mn and Ni while keeping those of Ti and B constant charpy V-notch toughness, microstructures and inclusion were evaluate. From the above studies following conclusing were drawn;

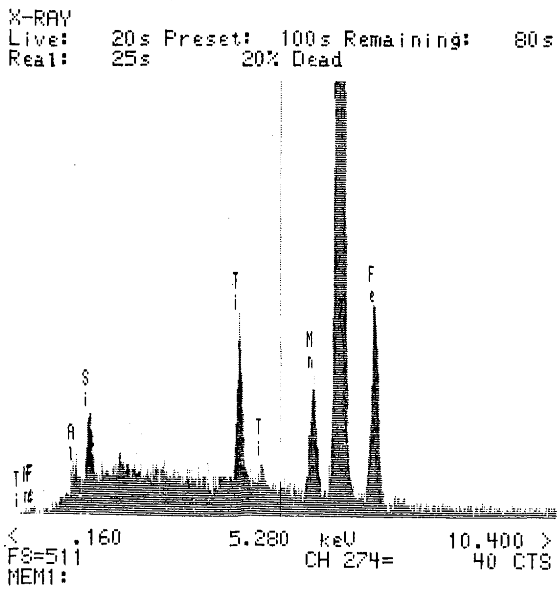
(1) On the basis of basicity 4.2 the optimal compositions of weld metal are 1.35%Mn-0.5%Ni-Ti-B. But the absorbed energy of the formula in the region of the



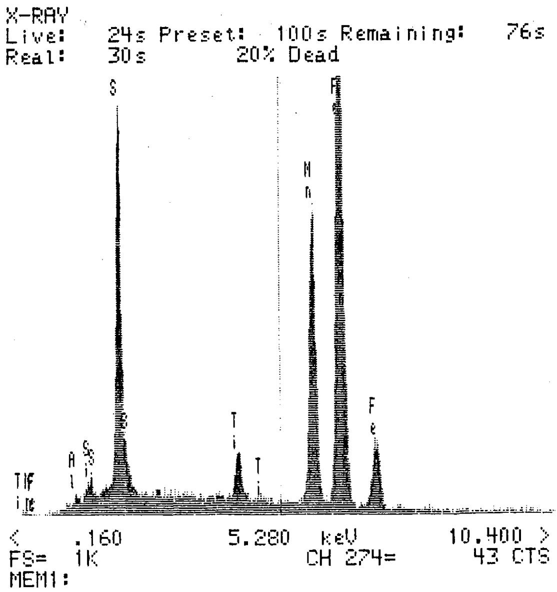
1 II-5 (1.15%Mn-0.9%Ni-Ti, B)



2 I-7 (1.35%Mn-0.5%Ni-Ti, B)



3 VI (1.15%Mn-Ti, B)



4 V (1.15%Mn-0.9%Ni)

Fig. 5 Example of Energy Dispersive X-Ray Spectrometer Analysis of Inclusion

upper shelf is high while the charpy V-notch toughness is inferior to that of the latter. These facts may be attributed to the lumpy MnS and Ni.

(2) From the observation of microstructure, charpy V-notch toughness improves as the grain boundary ferrite and ferrite side plat reduces and the accicular ferrite increases.

(3) Inclusions were mainly on the grain boundary ferrite. The lumpy inclusions consisting of mainly MnS lowers the charpy V-notch toughness.

(4) From the observation of the fractographs better toughness of the charpy V-notch is achieved as the facets and the cleavage fracture become less.

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