Some Properties of Fe-0～50%Ni-0～15%Mn-C Alloy Simulated Cast Iron Weld Metal Composition †

– Studies on Welding Rod for Nodular Graphite Cast Iron (Report 2) –

Shosuke ITOMURA*, Wataru OSHIKAWA** and Fukuhisa MATSUDA***

Abstract

This report is continued from the previous work to obtain the optimum welding electrode which has an adequate composition for cast iron welding. Fe-0-50%Ni-0-15%Mn alloys simulated to the composition of cast iron weld metal were molten and cast into four kinds of molds to examine solidification temperature, tensile strength, shrinkage length and thermal expansion coefficient, as same as previous work .

Because of the changing size of copper mold for examining tensile strength, the cooling curves of the tensile test specimens were changed as the similar curve to that of the implant test of cast iron pre-heated to 423K.

From the results obtained in the present work , it is concluded that the adequate composition range of the cast iron weld metals is Fe-29-42%Ni-4-8%Mn. As for 30% penetration rate, these figures turn out Fe-41-60%Ni-6-12%Mn electrode.

KEY WORDS: (Cast iron) (Weld metal) (Tensile strength) (Solidification temperature) (Thermal expansion coefficient) (Fe-Ni-Mn alloy)

1. Introduction

The authors have explained in their previous report[1] that it is possible to measure the strength of the simulated weld metals during the process of cooling by rapid cooling an alloy with which weld metal compositions in case of an Fe-Ni-Mn welding rod being used to the contrary to cast iron is supposed, by reproducing columnar structure peculiar to a weld metal. However the cooling curve in the copper mold dealt with in the previous report was the one close to the case of 573K preheat in the implant test of nodular graphite cast iron[2]. Complying with such an affair, this report attempts to find the composition as welding rods for cast iron proper enough to obtain weld metals with lower solidification temperature and smaller thermal expansion coefficient than the ones of commercially-available materials by conducting experiments similar to the ones in the previous report utilizing a molten alloy with which cupper mold dimensions are changed so that cooling rate is accelerated furthermore than in case of the previous report and additionally Fe-Ni-Mn system weldment metal composition with its Ni-mass % widened 50%.

2. Experimental

To allow selection of welding rods for base materials be an adequate one , it is to be hoped that the weld metals formed from the welding rods and the base metals that are molten and diluted will possess solidification temperatures and thermal expansion coefficients close enough to the ones of the base metals, hot crack will not occur, and tensile strength at a room temperature will be ample and sufficient. To examine these properties with an alloy simulated Fe-Ni-Mn-series weldment metals by means of a casting method, composition of the constituents was aligned so that their target will be attained using the raw materials shown in **Table 1**, the alloy was melted in air in high-frequency induction furnace.

Table 1 Chemical composition of raw materials used (mass%)

	C	Si	Mn	P	S	Ni
FC	3.48	1.68	0.38	0.035	0.02	—
SK3	1.03	0.38	0.95	0.020	0.016	—
FeMn	0.97	1.36	75.50	0.19	0.006	—
Ni	0.01	—	—	—	—	99.97

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* Associate Professor, University of the Ryukyus
** Research Associate, University of the Ryukyus
*** Professor

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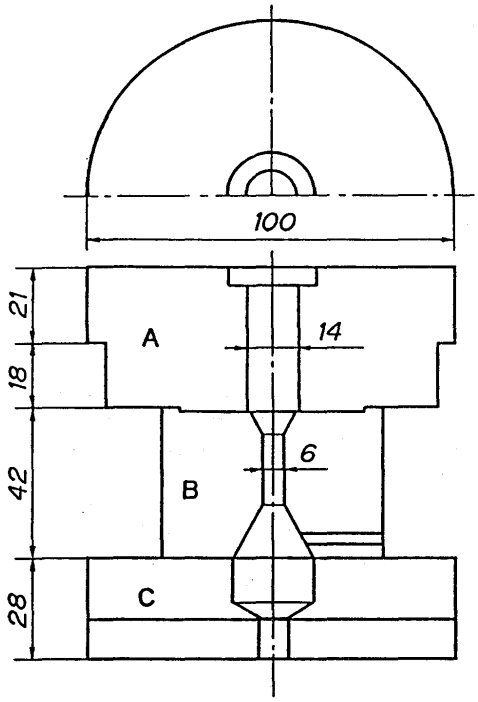

Fig.1 Copper mold configuration of the loading test

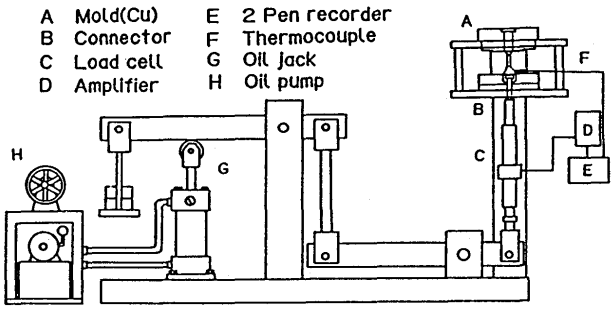

Fig.2 Schematic drawing of loading test apparatus

Figure 1 shows the copper mold for tensile tests whose mold heat content is magnified by enlarging the diameters of both cope and drag molds by 100mm and by lengthening the length by 20mm without changing the diameter 6mm of the test zone in order to quicken the cooling rate of the tensile test pieces more than the case in the previous report. At the time when the load is applied, the test piece was unified into a single piece together with the insertion of a high-tensile strength bolt 8mm in diameter into the lowest stage of the 3-stage-type mold composed of the upper, middle and bottom stages, whose individual stages are of the symmetrically-split mold type. So the load will be applied only to the test zone after the mold is released.

In **Fig. 2**, a schematic diagram of the loading test apparatus which is an improved version of the one used in the previous report.

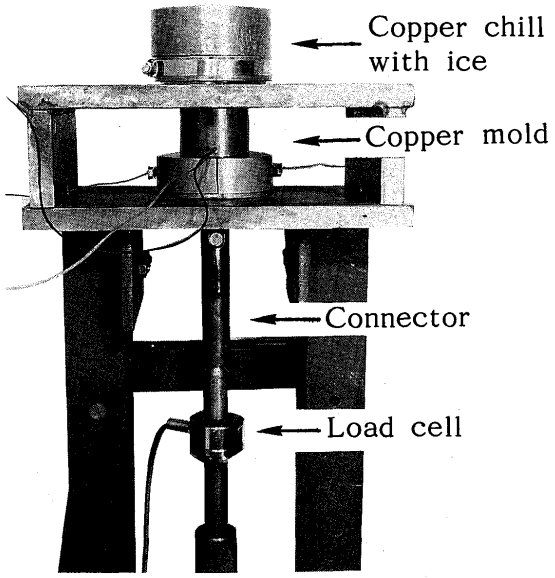

Fig.3 Loading test setup

Meanwhile in **Fig. 3**, a state of a copper mold with which setting is made is illustrated.

30 seconds after the molten metal is poured, the drag is removed and a copper chill in which 100g of ice is contained is immediately placed on the cope. Concurrently with this, the mold is cooled with a fan. At that time,the test zone temperature has been lowered to approximately 570K, and the load is gradually started to be applied with a jack. With this apparatus, the maximum load applied onto the test piece with a lever-operated test apparatus was determined as 17kN (stress of approximately 600MPa with the supposition that the testing part diameter was 6mm). The loading speed was so arranged as to be approximately 65N per second. With the lapse of time of 240-270 seconds after pouring, the load reached the maximum. With the specimens which did not rupture after lowering to a room temperature, their tensile strength was measured separately with a universal material tester. The metrological methods for solidification temperature and amount of contraction are the same as the ones given in the previous report.

3. Results and Discussion

3.1 List of experimental results

In **Table 2**, a list of experimental results is shown. The values of the nominal stress with asterisks indicate the rupture stress of the test pieces. Since graphite crucibles were used for melting of almost all the specimens, there was mixture of carbon with the molten metal to the result of exceeding the target value 1%. This tendency, which was due to the reaction between Mn and crucibles, appeared remarkably as the amount of Mn additive increased.

Table 2 Summary of experimental results

Test No.	Set %		Chemical composition (mass %)				Tensile strength	Thermal expansion coeff.	Solid. Temp	Shrinkage rate	Hardness
	Ni	Mn	Ni	Mn	C	Si	(MPa)	$\times 10^{-6}$/K	(K)	(%)	(Hv)
1	0	0	0.10	0.92	0.96	0.48	*313	7.2	1685	2.44	564
2	0	5	0.08	5.37	1.83	0.79	*162	22.0	1583	3.20	448
3	0	10	0.10	9.63	2.04	1.04	*145	20.9	1551	3.00	484
4	0	15	0.09	13.75	2.52	0.99	*77	16.5	1465	3.04	547
5	5	0	3.79	0.92	0.89	0.47	*304	16.8	1683	2.92	316
6	5	5	4.29	5.15	1.52	0.62	630	27.2	1618	2.88	310
7	5	10	4.44	9.44	1.85	0.92	*571	22.8	1529	3.20	357
8	5	15	4.66	13.50	2.60	1.09	*36	19.8	1455	3.20	529
9	10	0	10.07	0.87	0.95	0.49	*489	25.7	1676	2.96	297
10	10	5	9.59	5.15	1.43	0.71	716	25.0	1618	2.94	304
11	10	10	9.88	9.37	2.21	0.82	*481	26.5	1529	3.12	364
12	10	15	10.17	13.26	2.41	1.08	*388	23.5	1484	3.18	465
13	15	0	14.90	0.83	1.01	0.53	*531	25.0	1668	2.96	256
14	15	5	13.93	5.04	1.52	1.04	646	27.2	1602	2.82	301
15	15	10	14.33	8.70	2.23	0.80	784	19.4	1524	3.09	349
16	15	15	15.17	13.53	2.04	1.20	668	27.9	1410	3.28	365
17	20	0	19.05	0.78	0.94	0.50	657	25.7	1670	2.78	245
18	20	5	18.56	4.91	1.66	0.63	778	23.1	1594	2.31	298
19	20	10	17.91	8.91	2.05	1.02	*466	22.8	1537	3.12	366
20	20	15	18.67	12.80	2.22	1.25	*588	22.6	1501	3.20	424
21	25	0	23.07	0.72	0.99	0.55	761	22.0	1662	2.70	266
22	25	5	19.88	4.79	1.78	0.83	820	27.9	1572	3.00	310
23	25	10	21.74	8.75	2.23	1.13	821	22.8	1506	2.95	396
24	25	15	21.37	12.57	2.81	1.18	*488	23.5	1431	3.04	464
25	30	0	26.45	0.68	0.98	0.53	732	20.5	1658	2.68	329
26	30	5	23.82	4.69	1.83	0.95	806	19.1	1565	2.76	338
27	30	10	23.89	8.58	2.15	1.16	*561	19.8	1520	2.90	461
28	30	15	26.15	12.36	2.66	1.27	*467	22.0	1435	2.96	419
29	35	0	29.93	0.64	1.02	0.57	713	11.6	1651	2.26	266
30	35	5	26.88	4.59	1.60	0.88	746	18.3	1587	2.32	333
31	35	10	28.16	8.45	2.56	1.40	*510	19.4	1466	2.74	395
32	35	15	29.80	12.16	2.60	1.21	*560	15.0	1454	2.72	383
33	40	0	34.48	0.60	1.18	0.60	606	6.5	1644	2.08	243
34	40	4	34.69	4.41	1.42	0.87	721	16.4	1605	2.03	255
35	40	8	41.31	7.95	2.14	1.05	783	17.5	1542	2.14	331
36	40	12	43.84	12.77	2.10	1.11	714	17.8	1526	1.88	278
37	45	0	37.20	0.56	1.08	0.63	664	7.6	1638	2.04	253
38	45	4	40.77	4.44	1.48	0.87	757	19.0	1605	2.00	277
39	45	8	41.00	8.38	1.94	1.03	673	15.3	1556	1.75	299
40	45	12	43.15	12.23	2.11	1.12	783	19.1	1525	1.90	315
41	50	0	41.77	0.52	1.03	0.60	1048	11.6	1643	2.10	248
42	50	4	43.34	4.43	1.66	0.94	661	20.5	1592	1.71	292
43	50	8	48.13	8.17	2.08	1.10	626	16.0	1543	1.52	276
44	50	12	51.47	12.22	2.61	1.26	805	19.7	1492	1.70	333
45	55	0	44.06	0.48	1.05	0.62	*631	10.5	1641	2.06	245
46	60	0	48.30	0.45	1.06	0.60	*721	16.1	1638	2.20	226

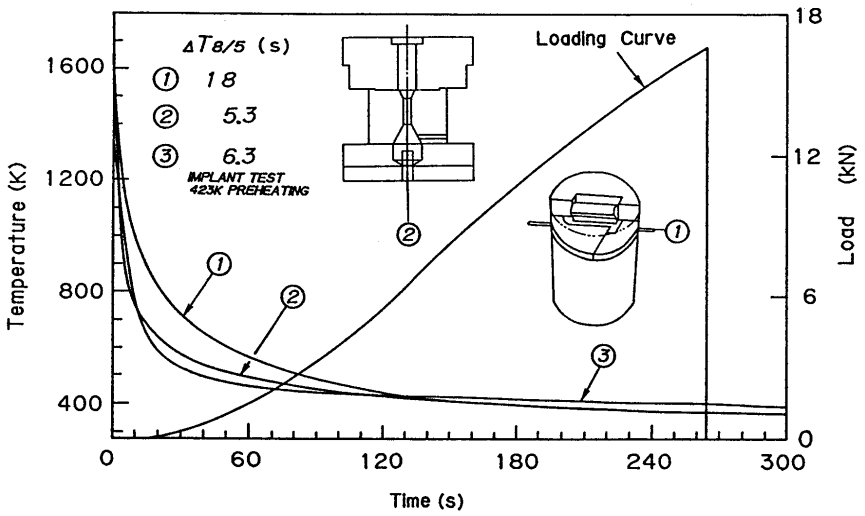

Fig.4 Examples of cooling curves and loading curve

The thermal expansion coefficient is given as a mean value between 303 and 573K. The thermal expansion coefficient in a temperature range referred to above was obtained, based upon author's report[3] in purport: while change of the contraction of the weld joint in the cooling process caused lowering of temperature ranging from a high temperature to approximately 570K, the contraction was gradually made with some intervals of stagnation, after that, rapid contraction was resumed at around 370K.

The shrinkage rate is the value obtained by dividing the amount of the contraction ranging from immediately after pouring to 303K with the 50mm test length .

3.2 Cooling curves

In **Fig.4**, three kinds of cooling curves are shown. (a) A cooling curve of the test piece to measure the amount of contraction (the curve (1)). (b) The cooling curve of the tensile test piece (the curve (2)). (c) The cooling curve in case of the 423K preheat in the implant test of nodular graphite cast iron (the curve (3)) [2]. Although the cooling time between 1073 and 773K($\Delta T_{8/5}$) is given as 5.3 sec and 6.3 sec respectively with the curves (2) and (3), it can be said as a whole that both the curves exhibit almost the same cooling state. Accordingly it is concluded that the cooling state on the tensile test piece is rapider than the one in the previous report and is closer to the case of 423K preheat. According to the implant test results [2] the authors have reported, it is revealed that none of significant difference is noticed with the state of no preheat and the 423K preheat although the preheat effect appears distinctly at 573K.

3.3 Tensile strength of tested alloy

The tensile strength is shown in **Fig.5**. The maximum value of the tensile strength was obtained as

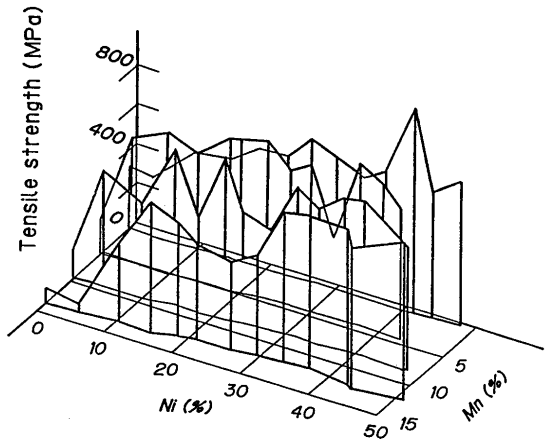

Fig.5 Tensile strength for various Ni and Mn contents

1048 MPa with the specimen of No. 41 (41.77% Ni, 0.52% Mn), whereas the minimum value was gained as 36.3MPa with the specimen of No. 8 (4.66% Ni, 13.50% Mn). As a whole, the strength is lowered as the amount of the Mn additive increase. On the contrary, the strength is raised as the amount of Ni additive increase. With respect to the tensile strength, it is judged that the value of more than 500MPa will be sufficient because the strength of the weldment of a commercially-available welding rod 95% Ni is 480MPa and the value is maintained as approximately 520MPa with Fe-55% Ni[4]. In this experiment, the tensile strength is 500MPa in ranges of more than 10% Ni , and below 10% Mn .

3.4 Solidification temperature of tested alloy

Figure 6 shows solidification temperatures of the specimens obtained by applying the molten metal into a cartridge made by a shell mold for solidification temperature measurement as is the same as that in the previous report. As one of the advantageous points of the nickel containing welding electrode used as ones for cast

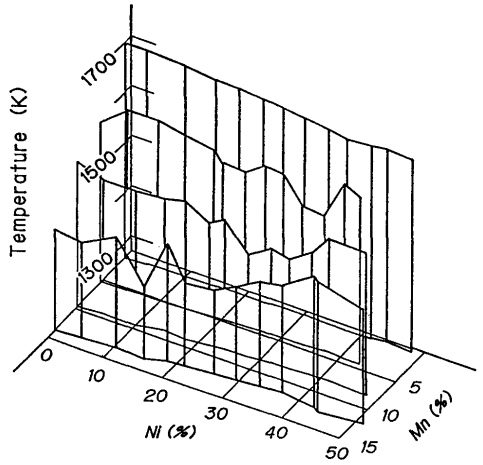

Fig.6 Solidification temperature

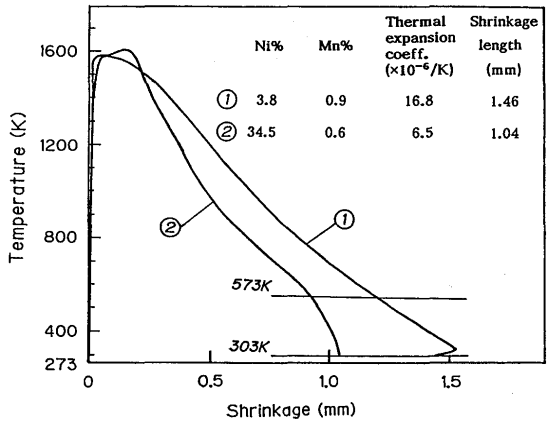

Fig.7 Examples of shrinkage curve . Ni 3.8% specimen shows martensite transformation expansion below 333K

iron in so many of opportunities, closeness of the solidification temperature to the one of cast iron is pointed out. When the weld metal is higher in solidification temperature than the base metal on the weldment part, the unmixed zone located between the weld metal and the base material is to be finally solidified. In this occasion, tensile stress is to be applied both from the weld metal and the base metal in a stage where the unmixed zone is solidified. This should be said quite an unfavorable matter. From this, it is desirous for the solidification temperature of the weld metal to be equivalent to the one of the base metal. As can be seen in Fig. 6, 1685K is maintained with an Fe-1%Mn-1%C alloy to which no Ni is added. Furthermore with 48.3% Ni additive (No. 46) as well, the value of 1638K is believed to be still very high in comparison with the solidification temperature of the cast iron;approximately 1425K. As is seen above, the Ni-additive does not almost contribute the lowering of the solidification temperature. On the contrary, it is comprehended that the solidification temperature was remarkably lowered when the additive of Mn increased. It is noticed that the temperature is lowered to 1583K with No.2 (0.08%Ni, 5.37%Mn). Likewise it is noticed that lowering is caused to the extent of 1465K. Accordingly it can be said that Mn-additive is an effective element to lower the solidification temperature of the weld metals.

3.5 Amount of contraction, thermal expansion coefficient and shrinkage rate

Examples of the contraction curves are shown in **Fig.7**. The methods to measure the contraction with the shift of the stainless bolt in the copper mold are quite the same as the ones in the previous report. Since the expansion and contraction of the copper mold and stainless bolts are included in the measured amount of the contraction of the test piece, the result which is rectified by previously measuring their expansion and contraction respectively is illustrated in the figure. The amount of contraction of the curve (1) (No.5) exhibits the maximum value 1.54mm at 333K. After that, expansion of 0.08mm can be seen caused by martensite transformation. Furthermore at 303K at the time of completion of the experiment, 1.46mm was exhibited. With respect to a method to prevent welding crack by decreasing the restraint stress making use of the expansion at the time of martensite transformation, a report has already been released by Tamura et al.[5]. With the curve (2) (No. 33), the amount of the contraction at 303K exhibited 1.04 mm providing the mean value in the experimental specimens.

The shrinkage rate which means amount of the contraction of the whole of the specimens from immediately after the pouring to room temperature divided by 50 mm of test length is shown in **Fig.8** , whereas a mean thermal expansion coefficient between 303K and 573K is shown in **Fig.9**. Illustrated in **Fig.10** is an average shrinkage rate from solidification temperature. The amount of the contraction is in a range from 1.08mm to 1.70mm, whereas the thermal expansion coefficient is in a range of 6.5 ~ 27.9$\times 10^{-6}$/K. The thermal expansion coefficient of usual gray cast iron, high or low-carbon cast iron, or meehanite cast iron at the temperature to the extent of 283-573K is 10.5 ~ 14$\times 10^{-6}$/K[6]. The one at the temperature of 303-573K of the curve (1) shown in Fig. 7 takes contrary to the above the value rather larger than the one given in the literature. However since phase transformation expansion is caused, the value is regarded as a smaller value viewed in consideration of the thermal expansion coefficient of the whole of the specimen with which the experiment was conducted. Despite that, the amount of the contraction 1.46mm is regarded as a larger one in all the specimens and the specimen in question is hard to be said

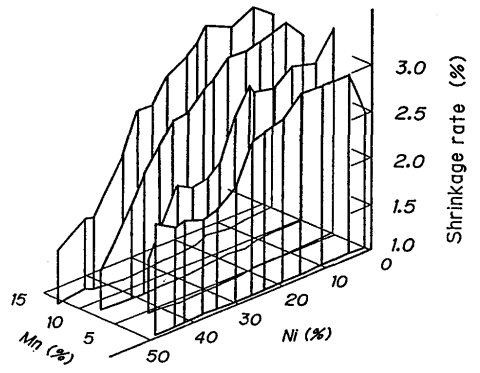

Fig.8 Shrinkage rate various Ni and Mn contents

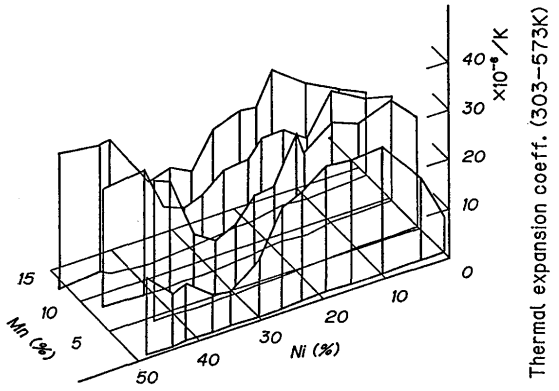

Fig.9 Thermal expansion coefficient from 303 to 573K

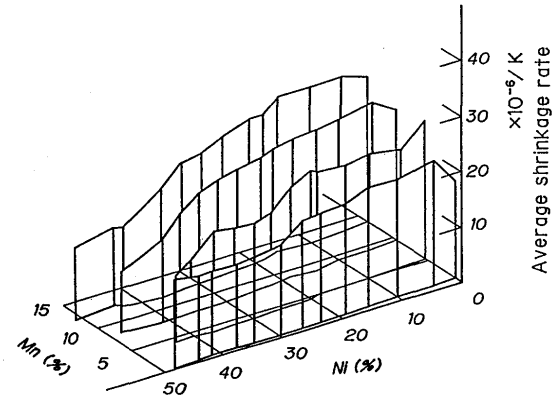

Fig.10 Average shrinkage rate from solidification temperature

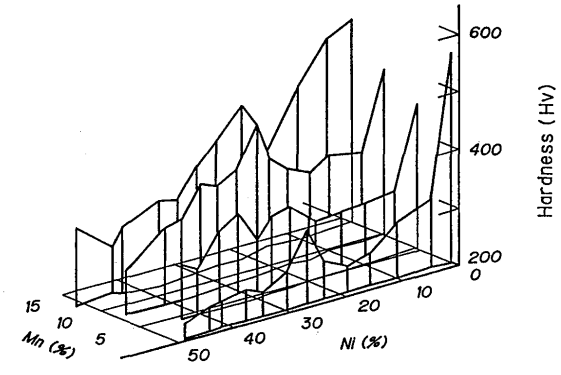

Fig.11 Vickers hardness for various Ni and Mn contents

effective enough for the sake of prevention of welding crack. The thermal expansion coefficient of the curve (2) has become smaller than the value of the curve (1), and furthermore the amount of the contraction is also small. Thus it can be said that the specimen is quite an effective one for the purpose of welding crack prevention.

Figures 8 and 10 exhibit almost the same tendencies. Since the phase transformation expansion is caused as described in the above on a point where Ni additive is small, rather smaller values are exhibited with the amount of the contraction and thermal expansion coefficient. As the Ni amount is increased, the values are drastically raised and are later decreased. After the Ni amount exhibited the minimum value at around 35%, the values are again increased. The Mn-additive is in an increasing tendency of these properties as its amount is increased, and has an effect to lower solidification temperature as previously stated. However increasing the amount recklessly does not necessarily mean obtaining good weld metals. The same thing can be said with the hardness to be referred to in the next chapter.

3.6 Vickers hardness

In **Fig.11** , micro Vickers hardness with the individual specimens is shown.The hardness is obtained in accordance with the following procedure. (1) Measurement is made 5 times. (2) Excluding the maximum and minimum of the values obtained in the measurement, a mean value in a style deriving from the remaining 3 measured values was gained. Complying with the fact that No. 1 (0.10%Ni, 0.92%Mn) takes Hv 564 (load 2.94N; the same so forth), the specimen containing approximately 0.10% of Ni and possessing a large amount of martensite and the specimen containing Mn as much as 5.37-13.7% exhibit high values of Hv 448-547. Although a slight amount of martensite was noticed with 3.8%Ni additive specimen as well, the hardness is lowered to the extent of Hv 316 because of the fact that there is a little more amount of austenite. The specimen containing more than 10% of Ni without adding Mn becomes to be of the microstructure of exclusively austenite and is soft enough. With the specimens with 19.1%Ni and 34.5%Ni, Hv 245 and Hv 243 are obtained. Furthermore with the specimen with 48.3%Ni (No. 46), a value of Hv 226 was exhibited. Since double carbide appears when Mn is added, hardness is intensified and there is especially a large amount of carbide. Therefore with the specimen of No.8 (4.66%Ni, 13.50%Mn) almost close to eutectic structure, Hv 529 is obtained.

3.7 Microstructure and SEM photographs

In **Fig.12**, typical 3 examples of the Microstructure of the tensile strength test piece and scanning-type

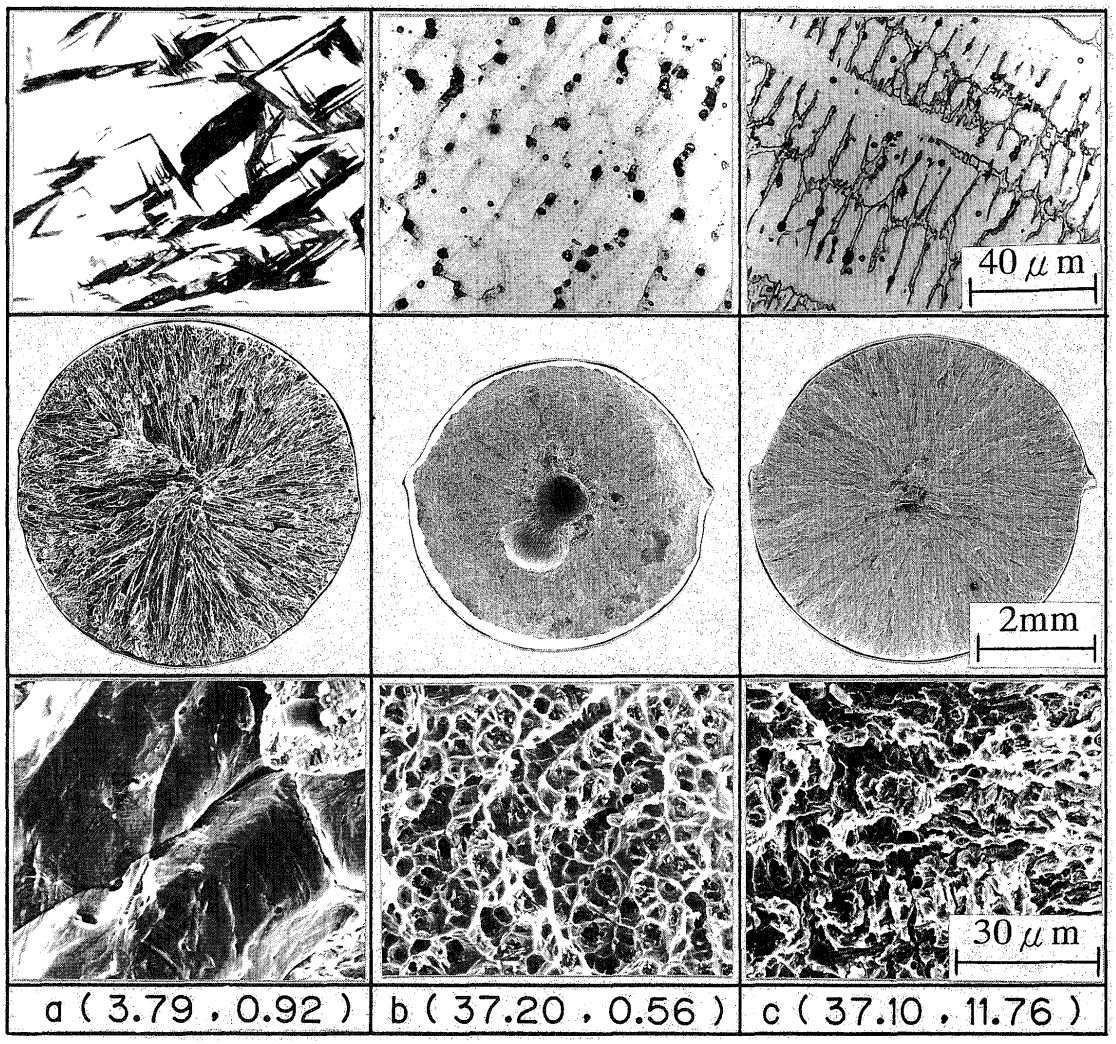

Fig.12 Examples of microstructures and SEM photographs of the specimens. Figures in the parentheses are Ni% (left) and Mn% (right), respectively.

part are shown.The upper side of the figure indicates the microstructure, whereas the middle and lower side denote the SEM photographs. (a) containing 3.79%Ni , 0.92 %Mn builds up the structure where retained austenite is mixed in the martensite structure. When Ni additive exceeds 10%, no martensite appears and the austenite structure as shown in (b) has been formed. When more than 5% of Mn is contained,microstructure where there exists carbide among the austenite dendrite has been built up as shown in (c). Also it is observed that the amount of the carbide is multiplied as the Mn additive is increased. With the SEM photographs, (a) presents a rough fracture signifying that the solidification temperature is high and fracture occurred on the interface of columnar structure, and assumes an aspect of hot cracking. When Ni is solely added to the extent of approximately 15%, a fracture as is seen in (a) has been formed. However in case of additive of more than 20%, dimple-patterned ductile fracture as is seen in (b) has been formed. When Mn is added more than 5%, a pseudo-cleavage fracture as shown in the photograph of (c) has appeared.

3.8 Adequate region in this experiment

As a result of the extensive investigation of the tensile strength, solidification temperature, thermal expansion coefficient, shrinkage rate and hardness of the alloy simulated to the weld metal, an adequate composition region shadowed in small black square mark as is seen in **Fig.13** has been obtained.The tensile strength is depicted in a one-point-chained line and a region of more than 500MPa is shown. The solidification temperature is given with the region of less than 1555K sketched in a solid line . In case of a commercially-available Fe-55%Ni welding electrode being used, the solidification temperature of the weld metal estimated from this experiment might supposedly be around 1640K. With respect to the thermal expansion coefficient, the region of less than 15 $\times 10^{-6}$ / K (303-573K) is shown in a 2-point chained line. J.A. Self et al.[7] reports that it is preferable for the mean thermal

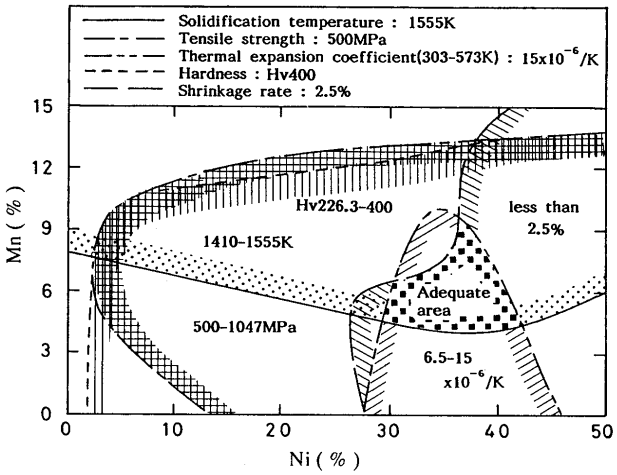

Fig.13 Adequate chemical composition area for cast iron weld metal

expansion coefficient of 293-823K not to exceed 20×10^{-6} / K. Supposing that comparison is made with the mean thermal coefficient of 303-823K in this experiment, the value of 15×10^{-6}/K (303-573K) becomes approximately 17×10^{-6}/K by taking the temperature region as 303-823K. Furthermore although there is difference of 10K in J.A. Self et al.'s temperature interval, the adequate composition region is expected to moreover be widened.

As to the shrinkage rate less than 2.5% is determined as the adequate region. This is out of the reason that the mean thermal expansion coefficient from 1555K to 300K (room temperature) supposed to be 20×10^{-6} / K would make 1.25mm shrinkage for 50mm length test piece. With respect to the hardness, less than Hv 400 was depicted in a broken line . Nodular graphite cast iron is approximately H_B 320 at the maximum in hardness in accordance with JIS G5502,or the value is approximately Hv 350 when it is converted to the Vickers hardness. On the other hand, K. Ishizaki et al.[8]report that H_{RC} 30 ~ 45 is the adequate region based upon a Rockwell C scale. Converting the value to the Vickers hardness, approximately H_V 300 ~ 450 is gained. Thus the values less than Hv 400 is determined as the adequate region.

4. Conclusions

As a result of the investigation regarding the strength of alloys simulating the Fe-Ni-Mn-C weld metals in accordance with a method in pursuant to an implant test by applying a load at about 570K during the cooling process concurrently with such procedures of casting in a split-type copper mold and the several kinds of their properties, the following results were obtained.

(1) For the purpose of making the solidification temperature of the weldment metals to be closer to that of cast iron, only Ni additive is insufficient and Mn additive is quite effective. However once thermal expansion coefficient is considered, Mn additive assumes a minus aspect. Hence an adequate amount of Mn additive is desirous.

(2) With an Fe-Ni alloy containing less than 5% of Ni, phase transformation expansion due to martensite transformation below 370K and contraction is a little decreased. Despite that, its effect cannot be expected so much because of the fact that the amount of the contraction of the whole is very large. In this occasion, the hardness is raised because martensite structure is maintained. However when Ni is contained more than 10%, the austenite becomes columnar structure. Thus the hardness is lowered.

(3) Judging from a viewpoint in the experiment of this time that the tensile strength is high, thermal expansion coefficient is small and hardness is not so high, Ni attains the optimum in the vicinity of approximately 29 ~ 42%. Furthermore it is concluded that Mn is good in a region of approximately 4 ~ 8%.

(4) By calculating the above results under the supposition that the penetration rate with the base metals is 30%, Ni 41 ~ 60%, Mn 5 ~ 12% are adequate as composi-tion of the welding rod.

References

1) S. Itomura, S. Azuma. and F.Matsuda; Loading Test of Simulated Weld Metal during Cooling, Trans.JWRI 22-1 (1993)

2) S.Itomura,K.Heshiki,F.Matsuda and Y.Kikuta;Preheating Effect on Critical Rupture Stress of Nodular Graphite Cast Iron Welds,Trans.J.W.S.,22-1(1991),66-71

3) S. Itomura, K. Heshiki, F. Matsuda and Y. kikuta ; Contraction Process and RRC Test of Nodular Graphite Cast Iron Weldments, J.of J.W.S.,9-2(1991),239-245(in Japanese)

4) Kobe Steel Corp. Kobelco Welding Materials General Catalogue (1988) 360-361 (in Japanese)

5) H.Tamura, N.Kato, S.Yokoi and Y.Ishii;Electroslag welding of cast iron, J.of J.W.S , 43-8 (1974), 794-804 (in Japanese)

6) ED Committee ; Engineering Data Book for Castings , General Foundry Center (1980), 54 (in Japanese)

7) J.A.Self, S.A.Abdulgader and D.L.Olson;Fe-Mn-Ni-Cu-C Filler Metal Ductile Cast Iron for Welding, Welding J., 64-11(1985). 322s-326s

8) K . Ishizaki, J.G.Mora, M. Salas and A. Davila ;Simulation Study on Ductile Cast Iron Welding by Austenitic Filler Metal, Trans. J.W.S.,15-2(1984), 3-8