Fractographic Features and Classification of Weld Solidification Cracks†

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The authors have shown in the previous papers[1, 2] discussing the weld solidification crack of stainless steels that the fractographic feature of solidification crack induced by the Trans-Varestraint test well reflects the solidification mode. This short paper summarizes the fractographic features of solidification cracks of various stainless steels, 9%Ni steel, Incoloy and Inconel alloys. Their chemical compositions are shown in **Table 1**. In

Table 1 Chemical compositions of materials used (wt. %)

	C	Si	Mn	P	S	Cr	Ni	others	thickness (mm)
SUS310S*	0.08	0.94	1.58	0.022	0.007	24.7	20.4	(δ: 0 %)**	3
SUS316 (A)	0.078	0.53	1.29	0.032	0.013	17.04	11.03	Mo: 2.27 (δ: 0.03)	3
SUS316 (B)	0.05	0.92	1.40	0.030	0.009	17.43	12.01	Mo: 2.53 (δ: 4.6)	3
SUS304	0.072	0.52	0.91	0.030	0.005	18.12	8.74	(δ: 3.0)	3
SUS304+N	0.072	0.52	0.91	0.030	0.005	18.12	8.74	N: 0.154 (δ: 0)	3
SUS321	0.050	0.89	1.19	0.029	0.011	17.47	9.43	Ti: 0.31 (δ: 4.3)	3
SUS347	0.040	0.61	1.26	0.026	0.007	18.18	9.69	Nb: 0.62 (δ: 5.3)	3
SUS430	0.060	0.61	0.52	0.021	0.006	16.54	0.13		3
9%Ni steel	0.046	0.21	0.50	0.013	0.007	–	9.28		13
Incoloy 800	0.08	0.34	1.04	0.010	0.017	20.21	31.68	Cu: 0.48, Al: 0.35, Ti: 0.43	3
Inconel 600	0.06	0.31	0.26	0.008	0.002	15.45	75.15	Fe: 8.27, Al: 0.22, Ti: 0.19, Mg: 0.010	3
Inconel 713C	0.13	0.14	tr.	–	<0.005	13.38	bal.	Fe: 0.38, Al: 6.25, Ti: 0.73, Nb+Ta: 2.11 Co: 0.30, Mo: 4.13, B: 0.011, Zr: 0.09	3

* SUS is the designation for stainless steel in Japan Industrial Standard (JIS)
** δ is content of delta-ferrite in the weld metal measured with a Ferrite Scope

Table 1 SUS304+N means a weld metal which was obtained by welding SUS304 with TIG-arc process using Ar+20%N_2 shielding gas. Moreover, Table 1 shows contents of delta-ferrite in the weld metals of austenitic stainless steels which were measured with a Ferrite Scope.

The welding conditions at the Varestraint test were welding current of 100A, arc voltage of 12 ~ 13V and welding speed of 150mm/min except for 9%Ni steel. Those for 9%Ni steel were 300A, 20V and 100mm/min. The augmented strain at the Varestraint test was 3.75% except for 9%Ni steel of 4.3%.

The cracked surface of SUS310S in **Photo. 1** and SUS430 in **Photo. 2** gives a feature composed of dendritic Type D, transient Type D-F and flat Type F. This reflects the simple solidification mode of these materials where a solid solution is formed during the solidification in spite of the difference in primary phase [1, 2]. In brief, the feature is related to the change in the distribution of residual liquids at the interdendritic region vs. temperature.

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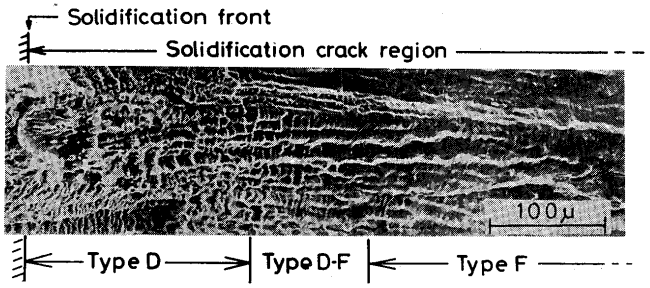

Photo. 1 Cracked surface of SUS310S

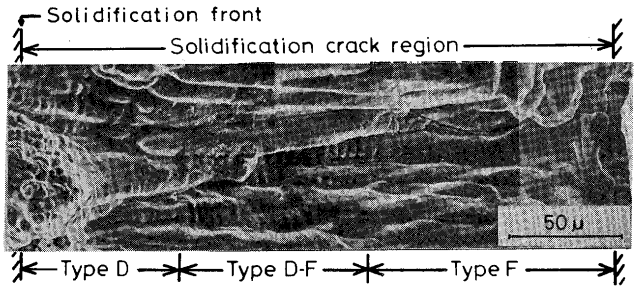

Photo. 2 Cracked surface of SUS430

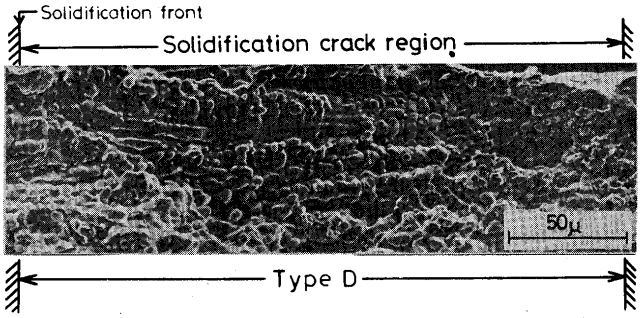

Photo. 3 Cracked surface of SUS304

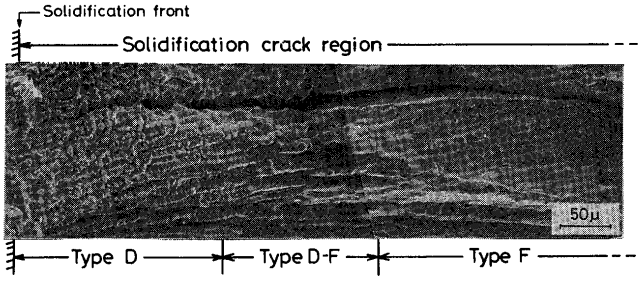

Photo. 4 Cracked surface of SUS304+N where delta-ferrite is 0%.

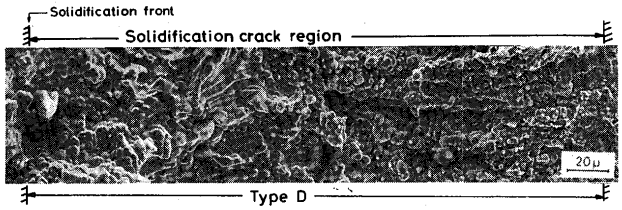

Photo. 5 Cracked surface of SUS321

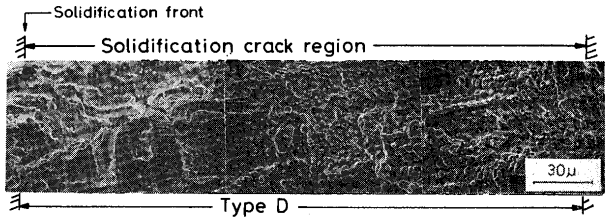

Photo. 6 Cracked surface of SUS347

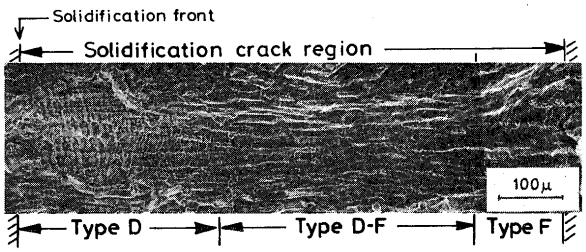

Photo. 7 Cracked surface of SUS316 (A) where delta-ferrite is 0.03%.

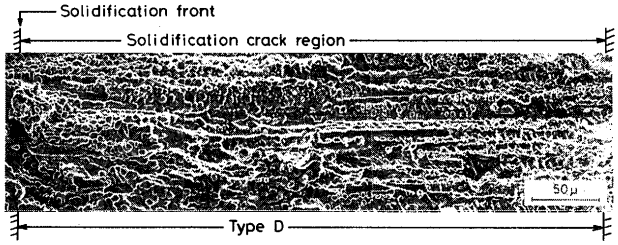

Photo. 8 Cracked surface of SUS316 (B) where delta-ferrite is 4.6%.

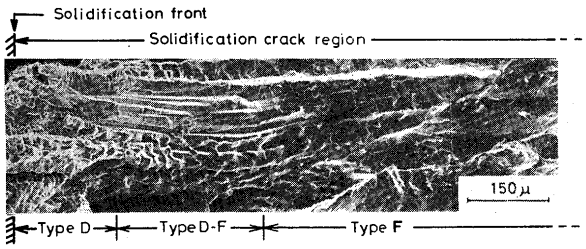

Photo. 9 Cracked surface of 9%Ni steel

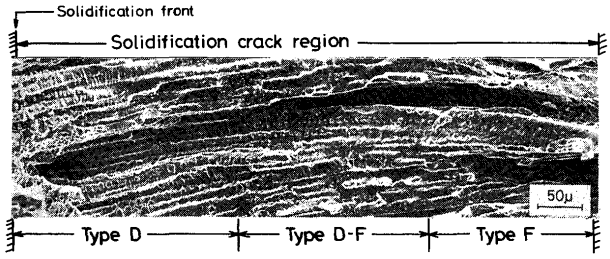

Photo. 10 Cracked surface of Incoloy 800

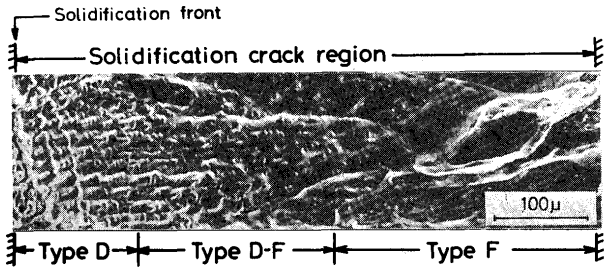

Photo. 11 Cracked surface of Inconel 600

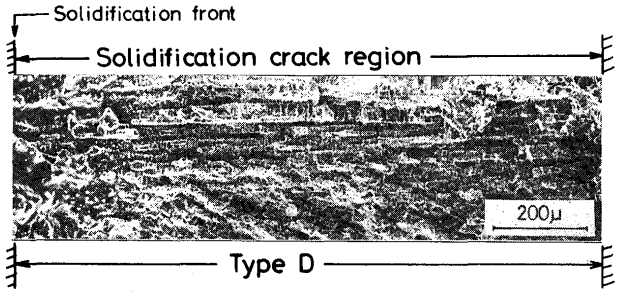

Photo. 12 Cracked surface of Inconel 713C

The cracked surface of SUS304 in **Photo. 3** gives a feature composed only of Type D. A detailed study[2] has revealed that this feature is related partly to the morphology of cellular dendrites and partly to the peritectic/eutectic reaction during the solidification. The cracked surface of SUS304+N, which contains a large amount of nitrogen known to be an austenite-stabilizer, gives a feature composed of Types D, D-F and F as shown in **Photo. 4**. The microstructure of this weld metal did not contain any delta-ferrite. Thus, this also confirms that the feature of cracked surface well reflects the solidification mode. The crack length of SUS304+N is far larger than that of SUS304 and comparable to that of SUS310S.

The cracked surfaces of SUS321 in **Photo. 5** and SUS347 in **Photo. 6** give a feature similar to SUS304, although their crack lengths are about 1.5 times as larger as that of SUS304.

The cracked surface of SUS316 (A) whose content of delta-ferrite is 0.03% gives a feature shown in **Photo. 7**, which is similar to SUS310S. On the other hand, the cracked surface of SUS316 (B) whose content of delta-ferrite is 4.6% gives a feature shown in **Photo. 8**, which is similar to SUS304. The crack length of SUS316 (A) is nearly comparable to SUS310S, and that of SUS316 (B) is almost equal to SUS304.

In 9%Ni steel, only austenite solidifies without peritectic reaction. The cracked surface in **Photo. 9** gives a feature similar to SUS310S.

The cracked surfaces of Incoloy 800 in **Photo. 10** and Inconel 600 in **Photo. 11** give a feature similar to SUS310S. On the other hand, the cracked surface of Inconel 713C in **Photo. 12** gives a feature similar to SUS304. Perhaps this is caused by the formation of a lot of eutectic constituents at the last stage of solidification of Inconel 713C.

As a whole, the cracked surfaces above mentioned are classified into two groups, namely, Group I making the feature of Types D, D-F and F, and Group II making the feature of only Type D. The classifications are as follows:

Group I -- SUS310S, SUS304+N, SUS316 (A) (with very little delta-ferrite as 0.03%), SUS430, 9%Ni steel, Incoloy 800 and Inconel 600.

Group II -- SUS304, SUS321, SUS347, SUS316 (B) (with much delta-ferrite as 4.6%) and Inconel 713C.

By the way, it is noteworthy[3] that the solidification cracked surfaces of commercially pure aluminum 1070 and aluminum alloys 5052 and 5083 are classified into Group I and that the cracked surface of aluminum alloy 2017 forming distinct eutectic constituents is nearly classified into Group II.

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References

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