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Synopsis :

New covered electrodes KS-1000 suited to repair welding of such structures as bridges and highways etc. under pulsating stress (varying stress) in service conditions have been developed by examing the effect of chemical compositions on hot crack sensitivity of the metal welded under pulsating stress. KS-1000 electrodes have excellent anti-cracking characteristics, and the critical root gap opening displacement range for cracking of the newly-developed electrodes under pulsating stress is much larger than that of conventional electrodes. Though KS-1000 has only a strength level of 490 MPa, it is possible to apply it to 590-MPa class high tensile strength steel by using it for the root pass, where hot cracks in weld metal were mainly observed, and to apply conventional electrodes to the remaining passes. KS-1000 electrodes are suited not only to repair welding of the structure under pulsating stress but also to tack welding and restraint welding for jigs.

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Newly Developed Electrode KS-1000 for Repair Welding under Varying Stress*


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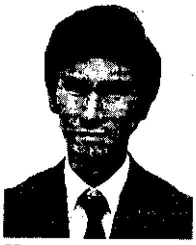
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Synopsis:

*New covered electrodes **KS-1000** suited to repair welding of such structures as bridges and highways etc. under pulsating stress (varying stress) in service conditions have been developed by examining the effect of chemical compositions on hot crack sensitivity of the metal welded under pulsating stress.*

KS-1000 electrodes have excellent anti-cracking characteristics, and the critical root gap opening displacement range for cracking of the newly-developed electrodes under pulsating stress is much larger than that of conventional electrodes.

Though KS-1000 has only a strength level of 490 MPa, it is possible to apply it to 590-MPa class high tensile strength steel by using it for the root pass, where hot cracks in weld metal were mainly observed, and to apply conventional electrodes to the remaining passes.

KS-1000 electrodes are suited not only to repair welding of the structure under pulsating stress but also to tack welding and restraint welding for jigs.

1 Introduction

When repairing, reinforcing, or rebuilding of existing structures such as bridges, while such structures are kept in service; i.e., with no limitation placed on the traffic of vehicles, etc. in consideration of community conveniences, it is sometimes necessary to conduct welding under vibrational stress and varying stress in addition to under the static stress due to dead load. In particular, for a welded joint which undergoes relative displacement of the groove face due to varying stresses (welding under varying stresses), hot cracking often occurs with any electrodes currently in the market. This presents considerable difficulty in welding performances, which influences on the life of the structures.

The authors investigated the effect of the chemical composition of weld metal on the formation of weld cracks under varying stresses. As a result, they have succeeded in developing a new covered electrode **KS-1000** with excellent anti-hot crack properties by fully taking into consideration the chemical composition of weld metal.

It was confirmed that the anti-hot crack properties of the weld metal made with this electrode is about three times that of conventional electrodes and that this crack-resisting property is also sufficient for root-gap opening displacements measured in actual bridges.

2 Development of KS-1000

It has been established[1,2] that cracks generated under varying stresses are what is called hot cracks including both solidification cracks and cracks caused by the ductility deterioration at high temperatures. In this coated

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electrode KS-1000 developed specially for repair welding, therefore, C, Si, P and S contents are reduced and the Mn/S ratio is increased, thereby taking thorough measures to prevent solidification cracks and to improve ductility at high temperatures.

3 Welding Crack Sensitivity of Electrode KS-1000

3.1 Trans-Varestraint Test

The evaluation of hot crack sensitivity of this new electrode was made using the Trans-Varestraint test (TIG remelt method: 180 A, 14 V, 7 cm/min).

Chemical compositions of all-deposited weld metals obtained using various electrodes are shown in **Table 1.** Results of the test are shown in **Table 2.** As is apparent from these results, no cracks are formed in the least with KS-1000 even if a 9% bending strain is applied. Thus, the crack-resisting property of the electrode is excellent.

Table 1 Chemical compositions of all-deposited weld metals made with electrodes KS-1000 and conventional electrodes D 4316 and D 5816 (wt. %)

Electrode	C	Si	Mn	P	S	Ni	Mo
KS-1000	0.03	0.22	1.44	0.008	0.001	—	—
D 4316	0.04	0.43	0.06	0.008	0.005	—	—
D 5816	0.06	0.52	1.10	0.014	0.007	0.62	0.23

Table 2 Results of Trans-Varestraint tests

Electrode	Bending strain			
	2%	4%	6%	9%
KS-1000	○ (0)	○ (0)	○ (0)	○ (0)
D 4316	● (1.5)	● (2.7)	● (4.8)	—
D 5816	● (1.9)	● (3.5)	● (5.9)	—

○: No cracked ●: Cracked ( ): Total crack length (mm)

3.2 Welding Crack Sensitivity Test under Varying Stress

3.2.1 Welding crack test method

To evaluate the weld crack sensitivity under varying stress based on the assumption of an actual repairing, reinforcing, or remodeling of bridges, the welding crack test method under varying stress was adopted by conducting a test welding in which varying stresses were applied with the aid of a 1500 kN electro-hydraulic servo-type fatigue test machine. The shapes of test specimens are shown in **Fig. 1**. The displacement cycles employed are shown in **Fig. 2**. The chemical compositions and mechanical properties of the test steel plate (JIS G 3106 SM58) are given in **Table 3**.

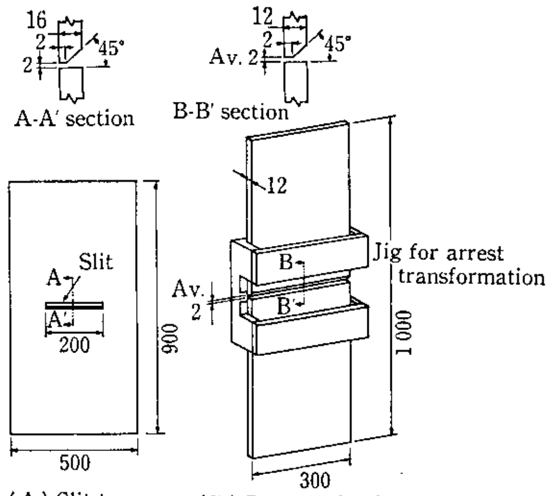


Fig. 1 Shape and dimension for weld cracking tests under pulsating stress (unit: mm)

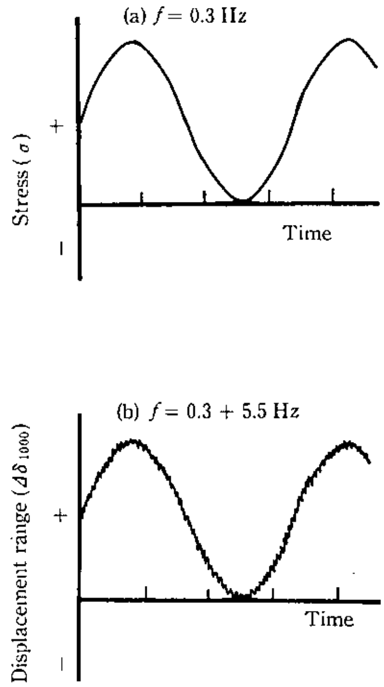


Fig. 2 Displacement of specimens during weld cracking tests under pulsating stress

The slit type test specimen in (A) in Fig. 1 was prepared with a local repair welding work assumed. For this test, a varying load was assumed to be the one of the complete pulsating stress as shown in Fig. 2(a). Before welding, a clip gauge was installed at the middle of the slit and the root-gap opening displacement range ($\Delta\delta$) was measured during welding.

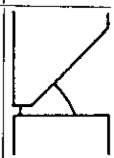
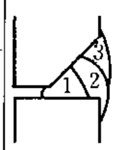
The specimen illustrated in Fig. 1(B) is of a pre-

Table 3 Chemical compositions and mechanical properties of steels used for weld cracking tests under pulsating stress

Type of specimen	Spec. JIS G 3106	Thickness (mm)	Chemical composition (wt. %)					Tensile property		
			C	Si	Mn	P	S	YP (MPa)	TS (MPa)	El. (%)
Slit	SM58	16	0.12	0.25	1.69	0.018	0.003	637	686	34
Prerestraint free	SM58	12	0.15	0.38	1.39	0.019	0.006	500	617	35

straint-free type and is supposed for a case where the length of a welded portion is relatively large as with reinforcing and rebuilding of bridges. Loads resulting from varying stresses are assumed to be controlled within the displacement range ($\Delta\delta_{1000}$) between the chucks of 1000 mm, with completely pulsating stresses as shown in Fig. 2(b) applied. In this case, the load was increased in such a manner that it overcame the self-restraint as the welding of the specimen proceeded and thus $\Delta\delta_{1000}$ will be kept at a specified level. In this case, overlapping waves composed of two kinds of sine waves of 0.3 and 5.5 Hz with different amplitudes were used as the displacement cycles as shown in Fig. 2(b) and the displacement range of the higher cycles (5.5 Hz) was so set as to account for 10% of $\Delta\delta_{1000}$.[3] The welding conditions employed on this occasion are given in **Table 4**.

Table 4 Welding conditions of weld cracking tests under pulsating stress

Type of specimen	Welding position	Pass	Current (A)	Voltage (V)	Speed (cm/min)	Pass sequence
Slit	Flat	1	160	24	10	
Pre-restraint free	Hori-zontal	1	150	24	10	
		2			7~12	
		3				

3.2.2 Change in displacement in welding

The tendency of the root-gap opening displacement range $\Delta\delta$ in the case of the welding of the slit type specimen under controlled load is shown in **Fig. 3**. $\Delta\delta$ at a point C is equivalent to about 60% of the initial value ($\Delta\delta = 0.15$ mm) when the welding of half the full slit length is completed, and that at a point E when the welding is completed accounts for about 20%.

Furthermore, the required load (ΔP) for keeping $\Delta\delta_{1000}$ at 0.5 mm for the prerestraint-free specimen is shown in **Fig. 4**. The required load increases gradually as welding proceeds and reaches about 80 kN when the first pass is completed and about 120 kN when the second pass is completed. This figure also includes the displacement range ($\Delta\delta_{300}$) for a gauge length of

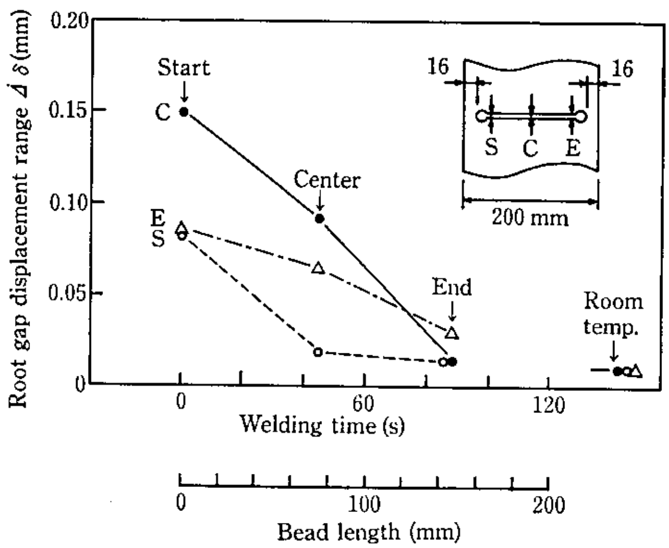


Fig. 3 Variation of root gap displacement during weld cracking tests under pulsating stress (Slit type specimen)

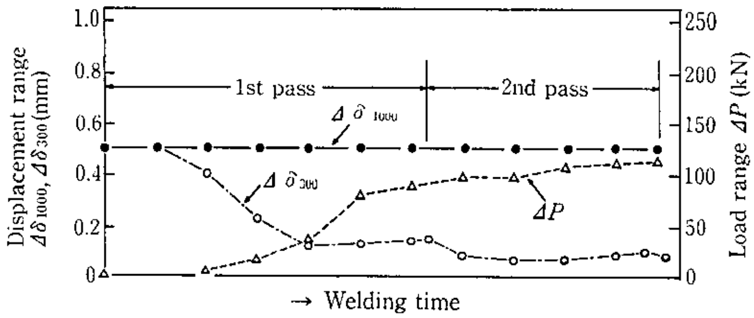


Fig. 4 Variation of displacement and load during weld cracking tests under pulsating stress (Prerestraint free type specimen)

300 mm with weld lines interposed. After the completion of the welding of the first pass, this $\Delta\delta_{300}$ is about 0.1 mm, which is about 1/5 of the initial value of 0.5 mm. This $\Delta\delta_{300}$ decreases further when the welding of the second pass is performed.

These decreases in $\Delta\delta$ and $\Delta\delta_{300}$ result in a increase in self-restraint with the progress of welding and show that displacements (strains) are distributed all over in the length direction of the specimen between the chucks of the fatigue test machine.

These phenomena suggest that weld cracks under varying stresses tend to be initiated at the welding start point. In addition, they suggest that if the welding of the first pass is completed, the displacement range is reduced to such a level that weld cracks scarcely occur under varying stresses in the second and the following welding.

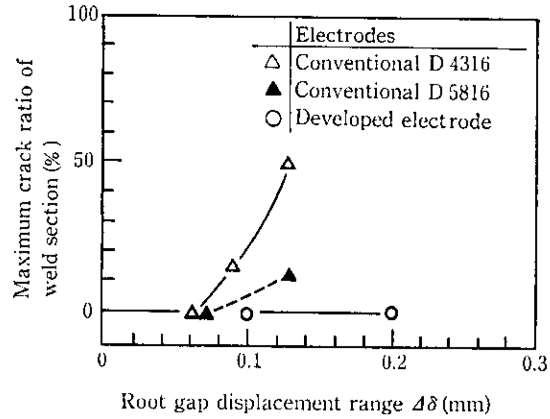


Fig. 5 Results of weld cracking tests under pulsating stress (Slit type specimen)

3.2.2 Results of weld cracking test

The relationship between the initial $\Delta\delta$ setting and the crack ratio of weld section is shown in **Fig. 5** for the slit type specimen. Cracks are formed even at $\Delta\delta$ of 0.1 mm or less in both the commercial electrodes D 4316 and D 5816, whereas no cracks are formed in the least with KS-1000 even when $\Delta\delta$ is 0.2 mm.

The relationship between $\Delta\delta_{1000}$ and the crack size in prerestraint-free specimens is shown in **Fig. 6** for each crack initiating position in the direction of weld line. With KS-1000, the formation of cracks is not observed in the least even at $\Delta\delta_{1000}$ of 1.0 mm, whereas with commercial electrodes (D 5816) cracks are formed even at $\Delta\delta_{1000}$ of 0.3 mm and cracks occur along almost the full length of the weld line at $\Delta\delta$ of 1.0 mm.

As is apparent from the figure, cracks are formed especially on the side of welding start point. Furthermore, cracks are not formed in the second and follow-

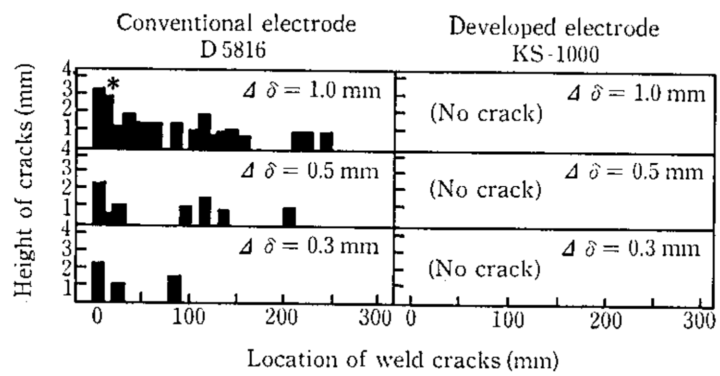


Fig. 6 Distribution of cracks in specimens tested under pulsating stress (Prerestraint free type specimen) Note: *Inclusive of 2nd pass layer

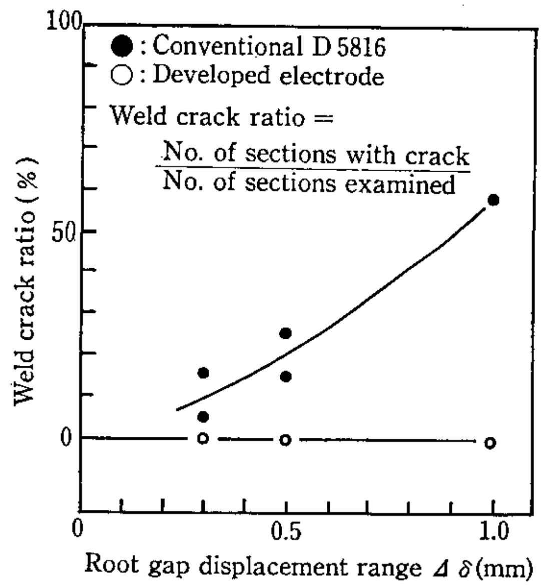


Fig. 7 Results of weld cracking tests under pulsating stress (Prerestraint free type specimen)

ing passes except when a through crack is formed in the first pass. These results are in good agreement with the tendency in the crack generation estimated from the above-mentioned decreases in $\Delta\delta_{300}$ and $\Delta\delta$ arising from the increase in the self-restraint associated with the progress of welding.

For the prerestraint-free specimen, the full length weld bead was cut at 10-mm intervals and was ground. Ground surfaces thus obtained were examined using a microscope. The relationship between $\Delta\delta_{1000}$ and the weld crack ratio (number of sections with cracks/total number of the sections examined) is shown in **Fig. 7**. As is apparent from the figure, cracks are formed at $\Delta\delta_{1000}$ of 0.3 mm with the commercial electrode D 5816 and cracks are formed in 60% of the weld line at $\Delta\delta_{1000}$ of 1.0 mm. In contrast to this, the occurrence of cracks is not observed in the least with the newly developed electrode even at $\Delta\delta_{1000}$ of 1.0 mm.

4 Conclusions

Kawasaki Steel has developed the covered electrode KS-1000 designed especially for the repair welding of bridges kept in service.

(1) The weld cracking test under varying stresses was conducted using a fatigue test machine at varying cycles $f = 0.3$ and $0.3 + 5.5$ Hz.

(2) The hot cracks under varying stresses with commercial electrodes tend to occur concentratedly on the side of welding start.

(3) In KS-1000, for which weld metal compositions with reduced C, Si, P and S contents are considered, no cracks are formed in the least at an opening displacement range ($\Delta\delta$) of 0.2 mm with the slit type specimen and at an opening displacement range ($\Delta\delta_{1000}$) of 1.0 mm with the prerestraint-free specimens.

(4) KS-1000 can withstand about three times as large as the $\Delta\delta$ of conventional electrodes and shows weld crack resistance high enough for the maximum $\Delta\delta$ measured in actual bridge.

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