

Microfouling on austenitic stainless steel weldments immersed in Bombay harbour waters

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Received 21 April 1997, revised 22 December 1997

The test coupons of austenitic stainless steel (SS 304, SS 304 L, SS 316, SS 316 L) weldments were exposed in the harbour waters of Bombay over a period of 20 days and the composition of microfouling film was studied. During the exposure period, diatom and bacterial settlement including sulphate reducing bacteria (SRB) was relatively high on the weld zones. Not all the diatom species encountered in the surface waters of Bombay harbour have shown their preference in forming the biofilms. *Amphora coffaeiformis*, *Cyclotella meneghiana*, *Nitzschia panduriformis*, *Cymbella turgida*, and *Pinnularia fasciata* were observed as dominating diatom species in the biofilms formed on weldments.

Austenitic stainless steels of 300 series are commonly employed in various marine based industries and nuclear power plants¹. A weld zone in steels becomes a very important and critical area for microbially influenced corrosion. The information on the effect of biofilms on corrosion is lacking in respect of weldments. Further, amongst the resident microorganisms of biofilms, diatoms which constitute the greatest percentage and settle in large numbers within a few days of immersion, have received little attention than their bacterial counterpart. The present work therefore, reports the colonisation of austenitic stainless steel weldments, by both bacterial and diatom population, when immersed in Bombay harbour waters (lat. 18° 55' N, long. 72° 50' E)

Welded coupons (100 × 50 × 10 mm) of 300 series austenitic stainless steel (SS) alloys viz. SS 304, SS 304 L, SS 316, SS 316 L (Table 1) were prepared by grounding a single V- edge and welding via the Tungston Inert Gas (TIG) welding process. The coupons had three distinct zones, the base metal of respective alloys, the weld zone and the heat affected zone. Test welded coupons were fixed at 1 m below the lowest low tide mark over a period of 20 days. The coupons after withdrawal were rinsed with sterile seawater to remove loosely adherent materials from the surface. The biofilm was removed with the help of a sterile teflon scraper and by using sterile seawater which was adjusted to 50 ml. Aliquots were employed for the estimation of aerobic bacteria², anaerobic sulphate

Table 1—Elemental composition of austenitic steels employed in the study

Austenitic type	Composition in %							
	C	Mn	Si	Cr	Ni	P	S	Mo
304	0.039	1.71	0.40	18.7	8.28	0.020	0.013	-
304L	0.040	1.38	0.32	18.0	8.64	0.013	0.017	-
316	0.041	1.59	0.50	17.3	14.11	0.010	0.011	2.243
316L	0.040	1.35	0.31	18.2	9.5	0.013	0.013	2.200

reducing bacteria³ and diatoms⁴. The diatoms were identified to the species level wherever possible with the help of available literature^{5,6}.

The present study reveals that whereas SS 304 and SS 304 L preferred greater types (12 to 16) of diatom species settling mainly on base metal and welded zones, total number of diatoms per sq. cm

was recorded more on SS 316 and SS 316 L weldments (Table 2). Edyvean & Moss⁷ recorded 19 taxa with 6 groups dominating the population on cathodically protected steels. The higher number of bacteria encountered on the weld zone indicates that the area is conducive for settlement and growth of bacteria. The aerobic bacteria was highest on the weld zone followed by heat affected zone and base metal of 304, 304 L and 316 stainless steel. Conversely, SS 316 L did not show much difference in the bacterial abundance at the weld zone. Population of SRB was highest on the weld zone of SS 304 followed by weld zones of SS 304 L, SS 316 and SS 316 L (Table 2). Enos & Taylor⁸ examined 32 stainless steels and weld metal combinations and reported that each of the test metal was coated with a biofilm of SRB in varying thickness and that most of the samples showed a distinct corrosion along the fusion line on the weld zone. Licina¹ observed that MIC of stainless steel is characterised by pitting most commonly at the weldment.

In the present study, the diatom population encountered in surface waters of Bombay harbour were mainly *Achnanthes coarctata*, *Amphora coffaeformis*, *Cyclotella striata*, *C. meneghiana*, *Navicula* sp., *Nitzschia papea*, *N. panduriformis*, *Pinnularia fasciata*, *Synedra ulna* and others. Not all the above species have shown their preference in forming the biofilm. *Amphora coffaeformis*,

Table 2—Total population of aerobic bacteria, sulfate reducing bacteria and diatoms on the four weldments immersed in Bombay harbour waters

Weldments	Aerobic bacteria (no.×10 ³ /cm ²)	SRB (no.×10 ³ /cm ²)	Diatoms population	
			Total no. of species	Total (no.×10 ³ /cm ²)
SS 304				
BM	0.33	1.17	15	6117
WZ	1.76	8.36	16	2216
HAZ	1.13	1.15	09	1761
SS 304L				
BM	0.51	6.82	12	3003
WZ	2.08	6.57	10	2566
HAZ	0.45	1.58	08	5746
SS 316				
BM	0.98	1.22	08	43525
WZ	1.89	0.33	08	23918
HAZ	1.22	1.75	08	69669
SS 316L				
BM	1.09	1.46	07	16028
WZ	2.56	0.70	09	22212
HAZ	1.45	3.19	08	30426

BM=Base metal ; WZ=Welded zone ; HAZ=Heat affected zone; SRB=Sulfate reducing bacteria

Table 3—Population density (%) of 5 dominating diatom species settled on stainless steel weldments immersed in Bombay harbour waters for 20 days

Weldments	<i>Amphora coffaeformis</i>	<i>Cyclotella meneghiana</i>	<i>Cymbella turgida</i>	<i>Nitzschia panduriformis</i>	<i>Pinnularia fasciata</i>
SS 304					
BM	40.28	25.68	8.25	9.92	6.85
WZ	15.44	69.45	4.48	5.28	2.83
HAZ	24.14	58.30	2.30	8.61	4.64
SS 304L					
BM	43.10	20.75	20.75	12.29	0.00
WZ	7.20	64.65	6.62	8.53	5.88
HAZ	5.74	78.38	8.04	4.14	1.60
SS 316					
BM	44.66	3.26	17.69	17.69	14.05
WZ	25.99	4.00	18.18	29.30	15.09
HAZ	29.54	3.84	12.40	42.29	5.58
SS 316L					
BM	48.40	2.62	7.52	13.13	17.55
WZ	45.25	8.78	6.88	17.21	14.28
HAZ	49.47	0.00	10.31	16.23	14.69

BM=Base Metal ; WZ=Welded Zone ; HAZ=Heat affected zone ; SRB=Sulfate reducing bacteria

C. meneghiana, *N. panduriformis*, *Cymbella turgida* and *Pinnularia fasciata* dominated in the biofilm formed on all the four weldments. *Cyclotella meneghiana* appeared to be more dominant on the weld zone and heat affected zones of SS 304 and SS 304 L whereas *A. coffaeiformis* was found consistently predominant on all the four weldments. However, the latter preferred base metal zone (> 40 %) except in SS 316 L where it predominated in all the three i.e. base metal, weld zone and heat affected zones. *Cymbella turgida* preferred settlement on SS 316 and to some extent on base metal of SS 304 L, whereas both *Nitzschia panduriformis* and *Pinnularia fasciata* dominated in the biofilms formed on SS 316 and SS 316 L weldments (Table 3). *Amphora coffaeiformis* which has been recorded consistently predominating in all the zones of weldments has earlier been reported as a very tolerant species to wide varieties of pollutants and toxicants^{9,10}.

The authors thank Mr. G J Kulkarni of the Metallurgy Division of NMRL, for providing

different types of weldments employed in the study and also for the chemical analysis of the alloys. Thanks are also due to Dr. P C Deb, Director NMRL, and Prof. G. N. Mathur Director DMSRDE, Kanpur for their constant encouragement in pursuing this study.

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