FAC Assessment for SA106 Pipe with Elbows and Welds

Materials Safety Technology Development Division,
Korea Atomic Energy Research Institute (KAERI)

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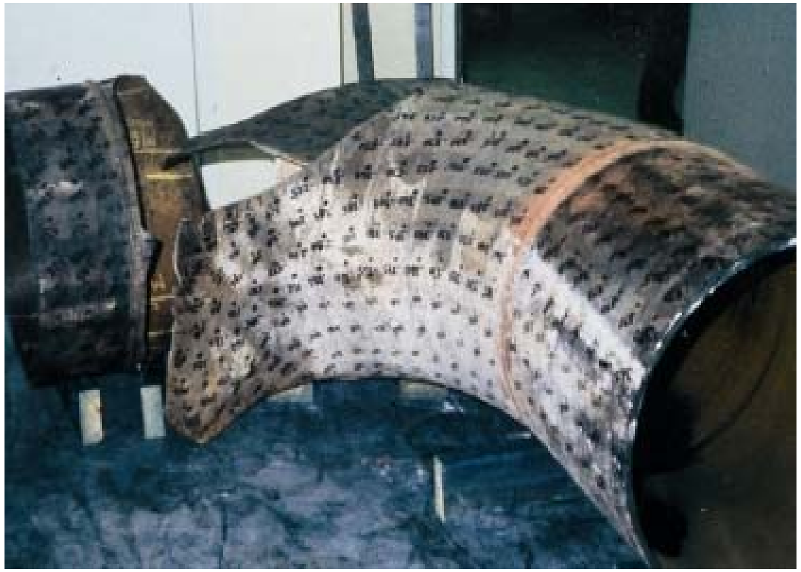
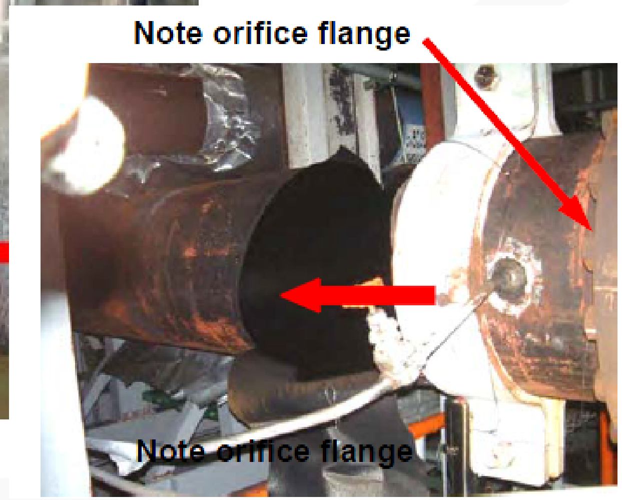
CONTENTS

01

Introduction

Introduction





➢ **Surry 2, 1986, 8 injuries**

➢ **Mihama 3, 2004, 11 injuries**

- **Flow accelerated corrosion (FAC) is one of major degradation problems including human injuries in NPP.**
- **FAC is managed using COMSY, CICERO and CHECWORKS**
- **Improvement of piping management accuracy is needed for safe long term operation. Especially effect of multi components on FAC is needed. Asymmetric FAC occurred in Mihama 3 due to complex flow.**

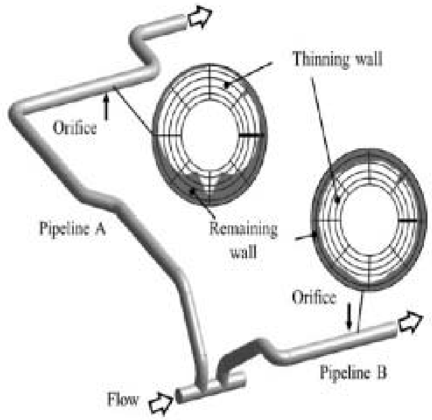


Fig. 1. Schematic layout of pipeline in Mihama nuclear power plant.

FAC test facility

Operating Specification	KAERI
Main Loop Pressure (MPa)	4.0
Main Loop Temperature (℃)	235
Main Flow Rate (L/min)	2300

- Construction of FACTS (Flow Accelerated Corrosion Testing System, Korea) was finished in 2016.
- FACTS is composed of pressurizer, 2 water tanks, chemical tank, 2 heaters, 2 heat exchangers, 2 circulation pumps, injection pump, sensors (DO, CT, pH, DH) and etc.
- Alarming and CCTV systems were equipped.

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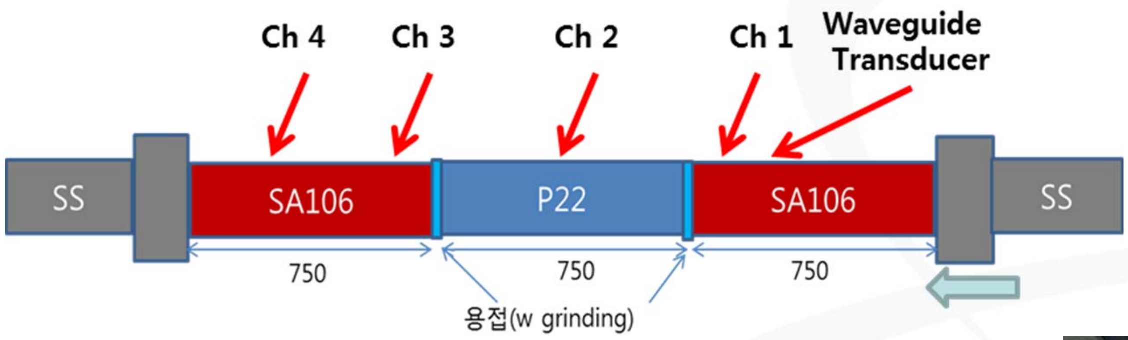
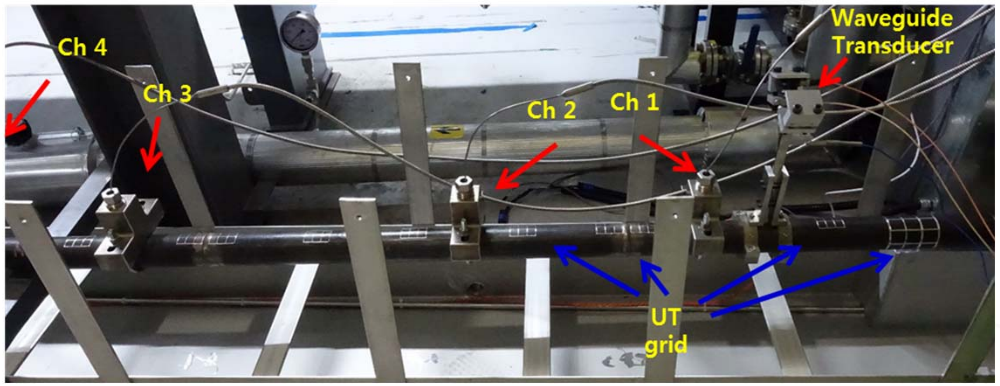
02 Experimental

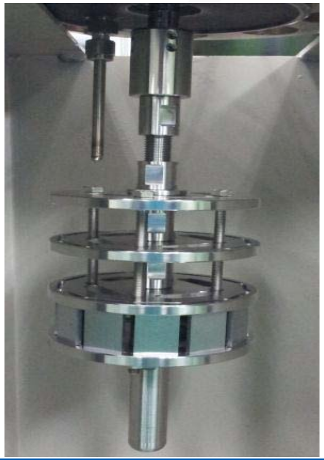
Test section 1 (straight pipe with dissimilar weld)

Alloy	C	Si	Mn	Cu	Cr	Ni	Mo
SA106 Gr.B	0.19	0.24	0.98	0.02	0.04	0.02	0.01
SA335 P22	0.1	0.22	0.42		2.08		0.94



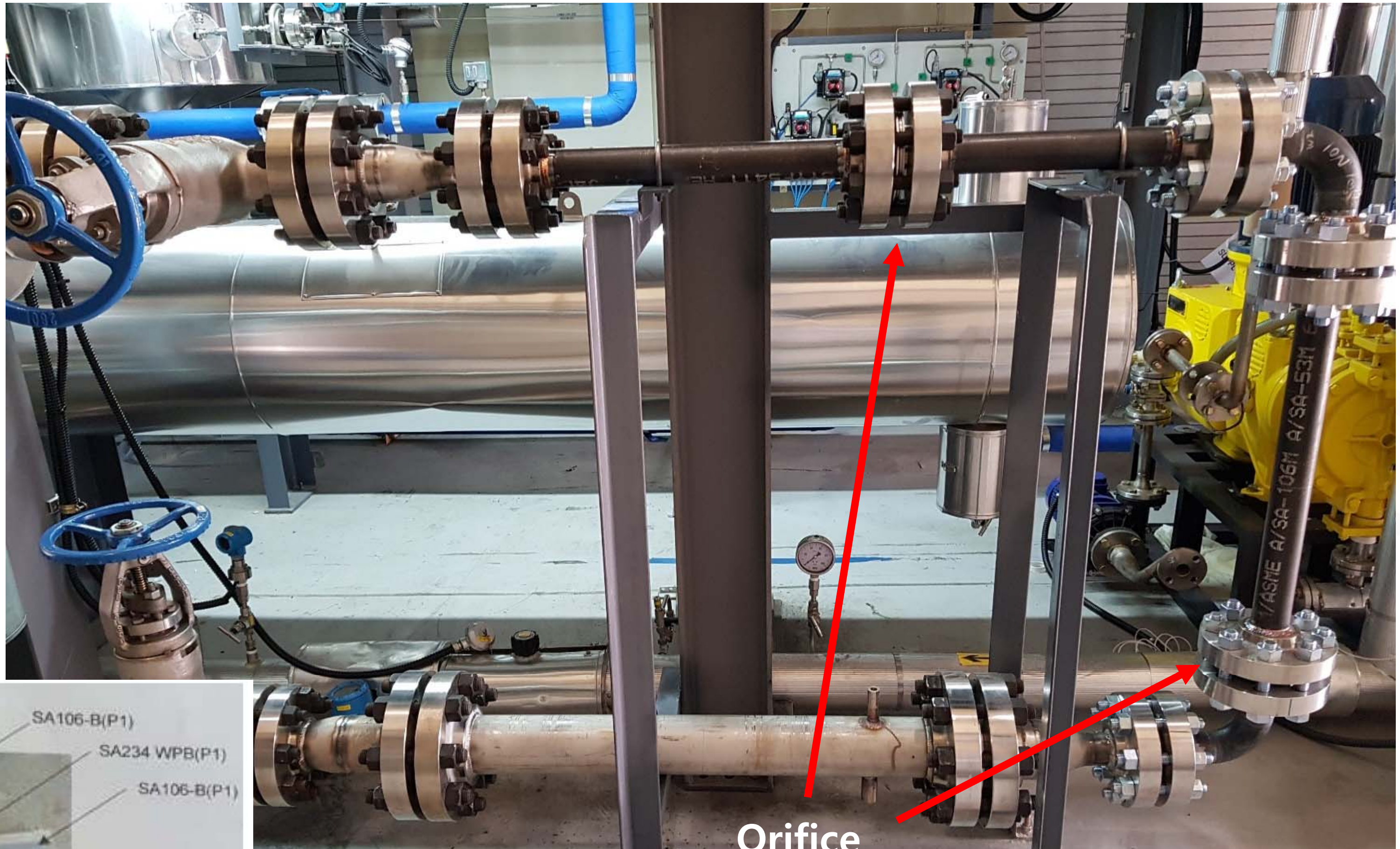
- Pressure: 1.0 MPa
- Temperature: 150℃
- Test section pipe dia. : 2 inch
- Flow velocity : 7~12 m/s
- DO < 5 ppb, pH ~ 7
- Test time : 50 days(1,200 hrs)





- Rotating electrode

Test section 2 (pipe with elbow and orifice)



	T (°C)	Flow rate (m/s)
RUN2	150	3
RUN3	130	3

R/d = 1.52
R = radius of elbow (76mm)
d = pipe diameter (50mm)
ß = do(orifice ID)/d(pipe diameter) = 0.8

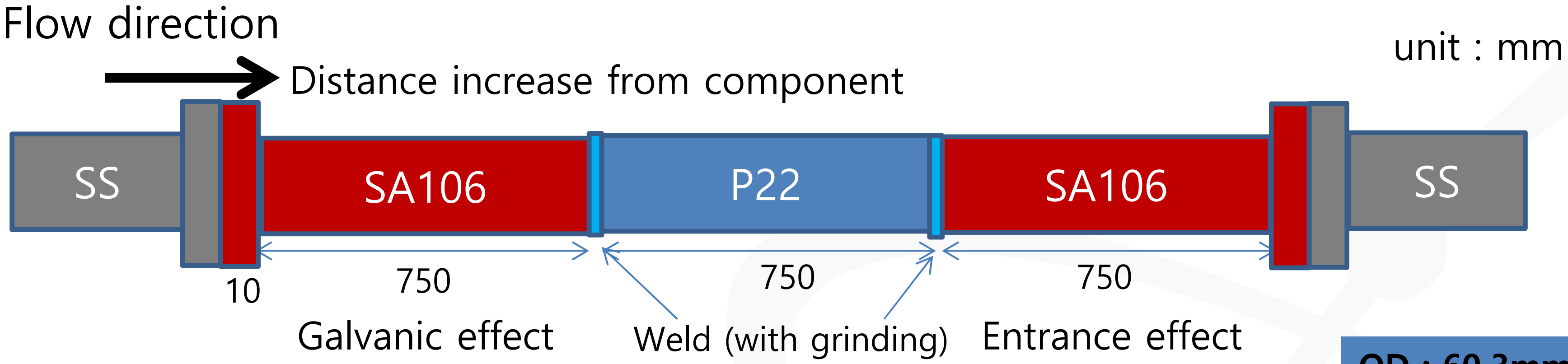
03

Results and discussion

Test section 1

- SA106/P22/SA106 straight pipe with dissimilar weld

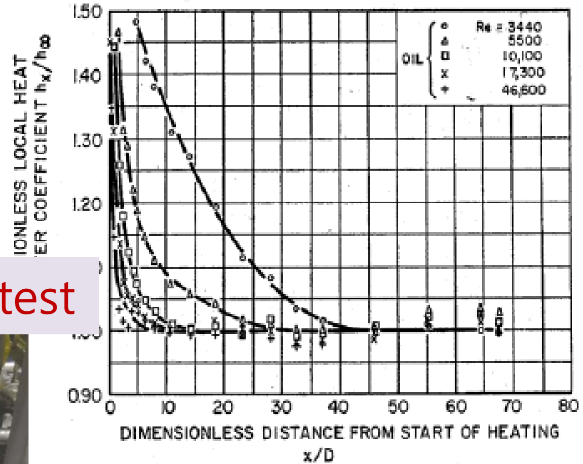
Test section 1



OD : 60.3mm
ID : 49.22mm

- **Flow rate, pH effect**
- **Cr effect (entrance and galvanic effect)**
- **Distance effect from component**

1. **10m/s, pH 7 (1200hr)**
2. **12m/s, pH 7 (1200hr)**
3. **7m/s, pH 7 (1200hr)**
4. **10m/s, pH 7 (915hr)**
5. **10m/s, pH 9 (1200hr)**
6. **12m/s, pH 9 (312hr)**
7. **10m/s, pH 9 (1200hr)**



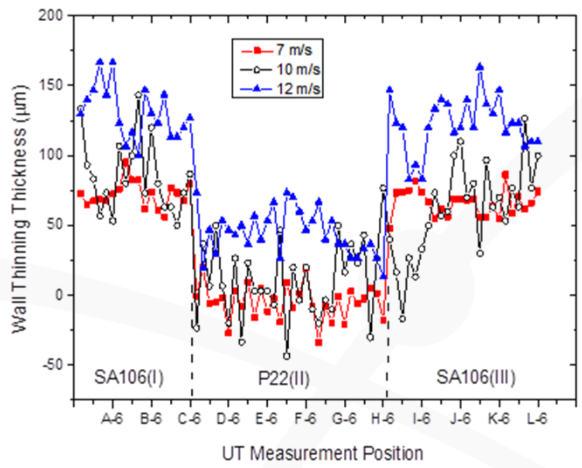
Total 7227hrs test

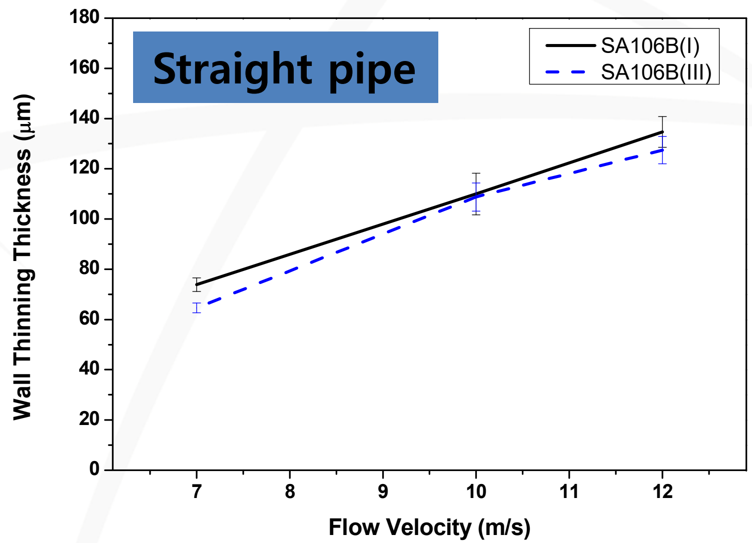
$Re = \rho \cdot V \cdot L / \mu$
$h_D = w/A/(C_o - C_\infty)$
w : mass flow rate

Comparison between pipe and rotating electrode (RE)

Flow direction

Flow rate (m/s)	2	4	7	10	12
FAC rate (mm/yr) for cylindrical specimen	0.83	1.38		9.1	
Reynolds number (xE6) for cylindrical specimen	1.1	2.2		5.5	
FAC rate (mm/yr) for pipe specimen			0.54	0.8	0.99
Reynolds number (xE6) for pipe specimen			1.6	2.3	2.7





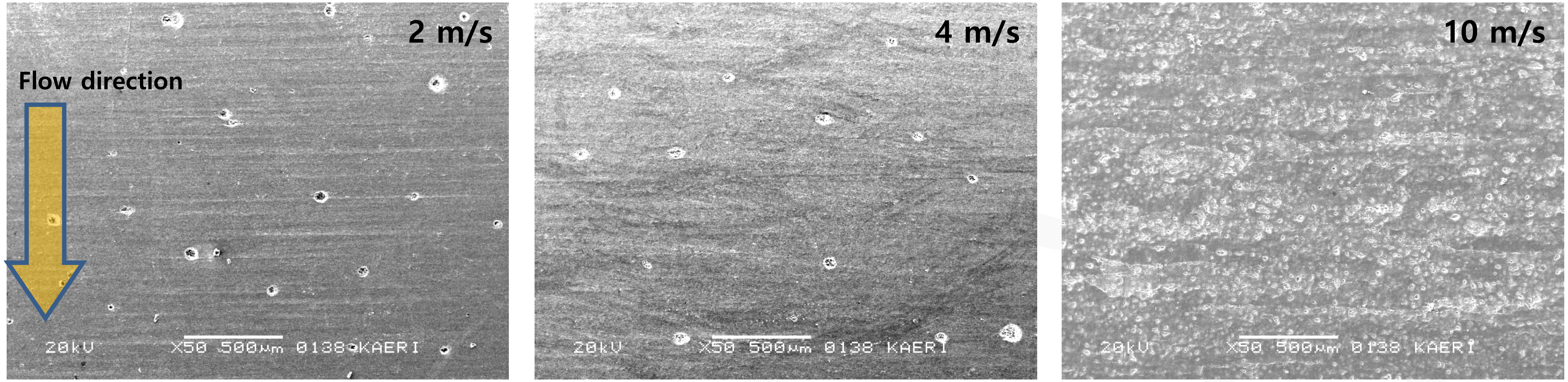
Surface appearance for test section 1

flow →

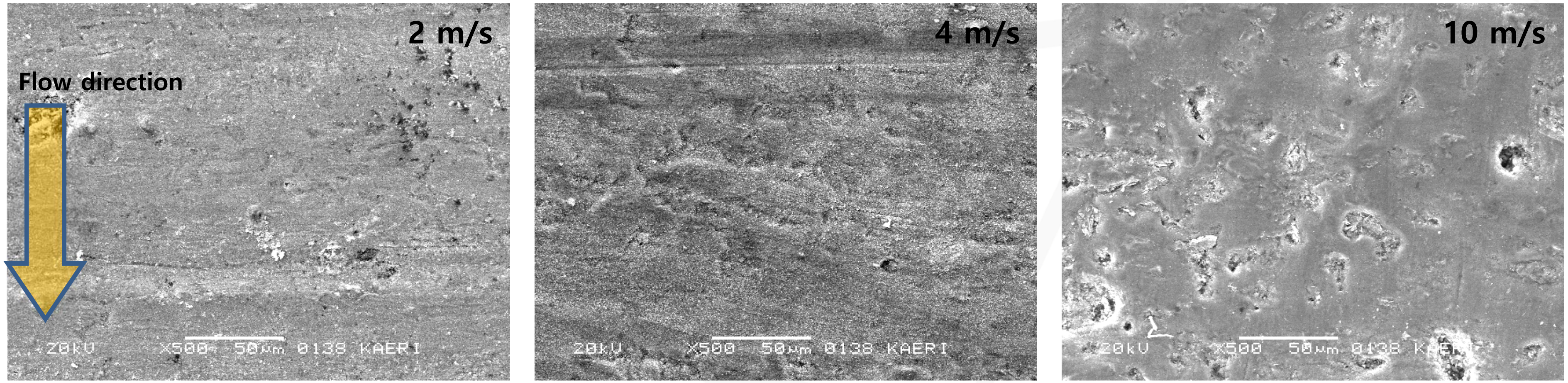
Magnification	SA 106	P 22
50		
200		

- There is an orange peel pattern for SA106.

Surface appearance after 1670hrs exposure using rotating electrode



x50, low magnification

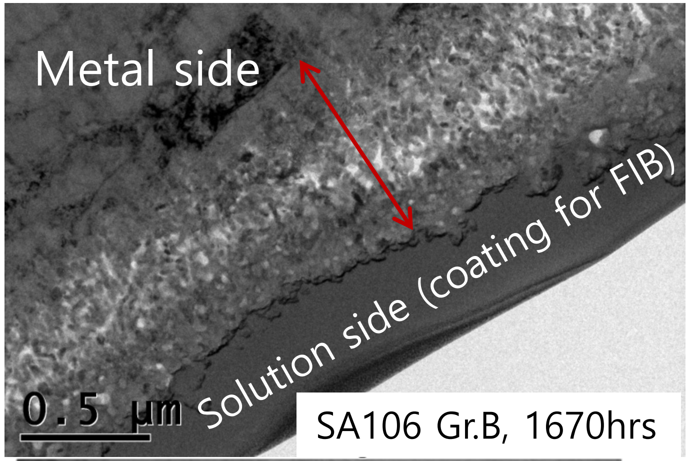


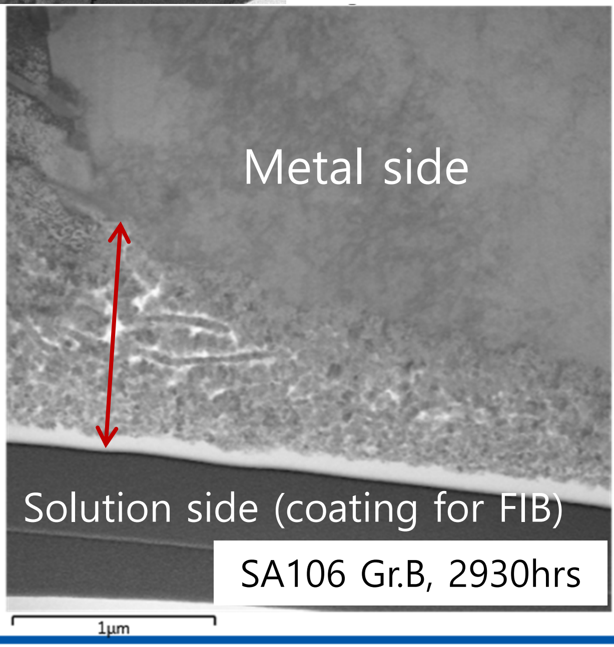
x500, high magnification

- There is no orange peel pattern.
- Pit size and density with the flow rate

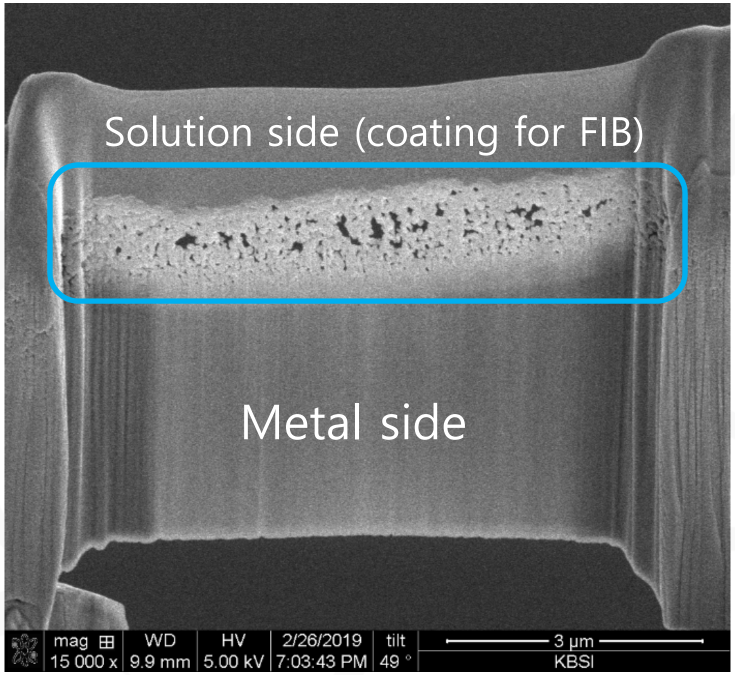
Oxide analysis (TEM)

Rotating electrode





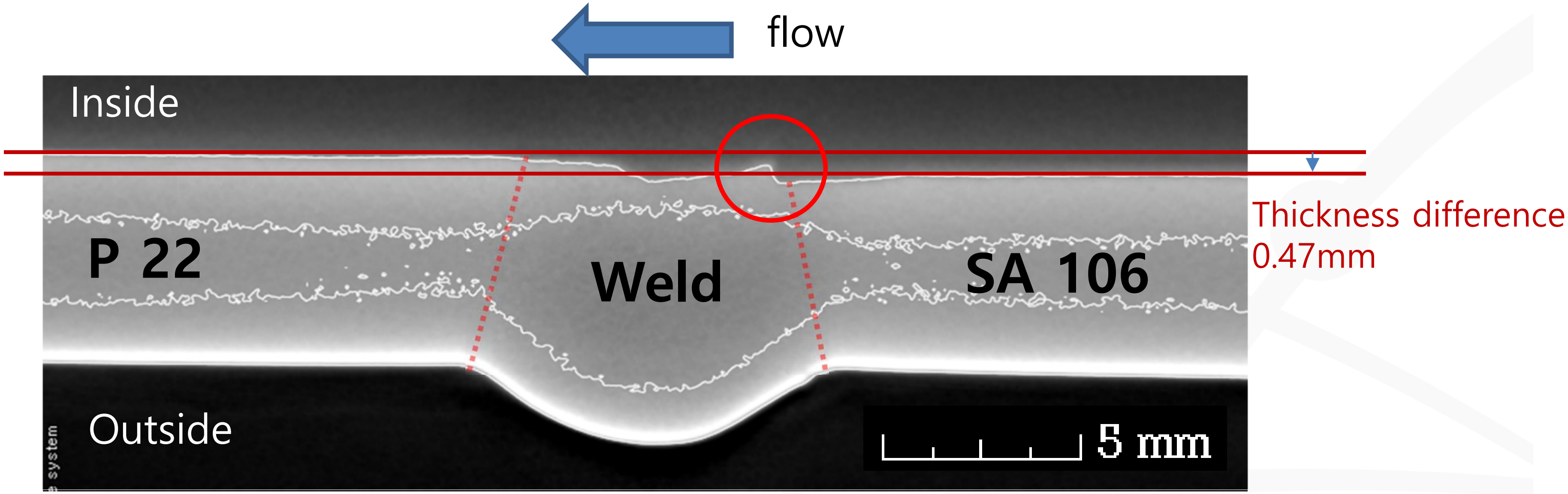
Straight pipe



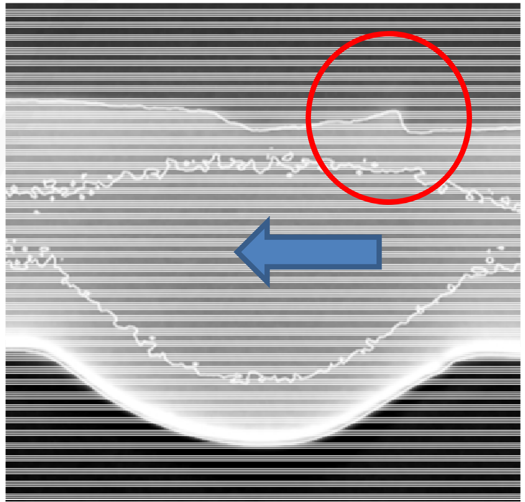
Oxide thickness 1.3μm

- Unlike the difference in surface shape of the two kinds of specimens (i.e. straight pipe and rotating coupon), the oxide morphology shows patterns in thickness and porosity similar for both SA106 specimens.

CT image for SA106-SA335 pipe section from low Cr to high Cr



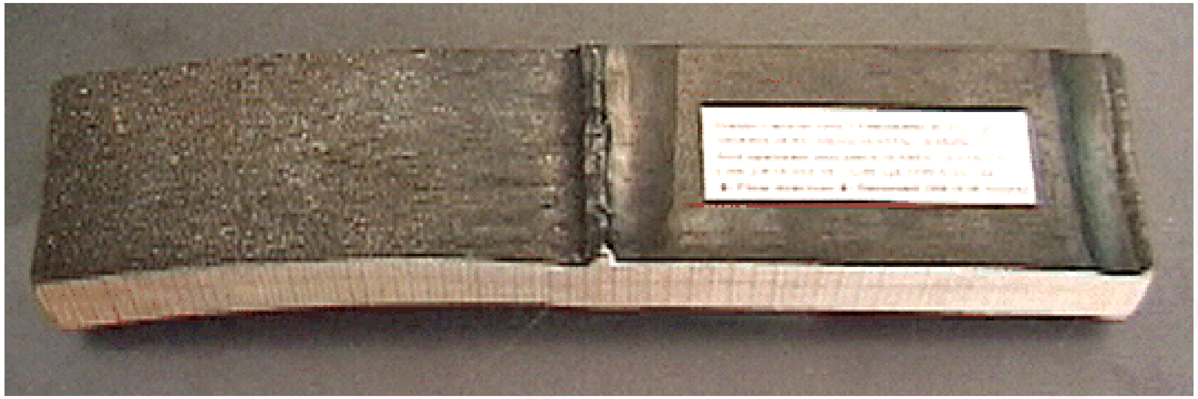
- FAC rate difference between SA106 and SA335
- There is a steel vertical wall at the boundary due to FAC rate difference between SA106 and weld metal (Cr 0.15wt%) and then turbulence produced by barrier layer. This may be potential problem in view of long term maintenance.

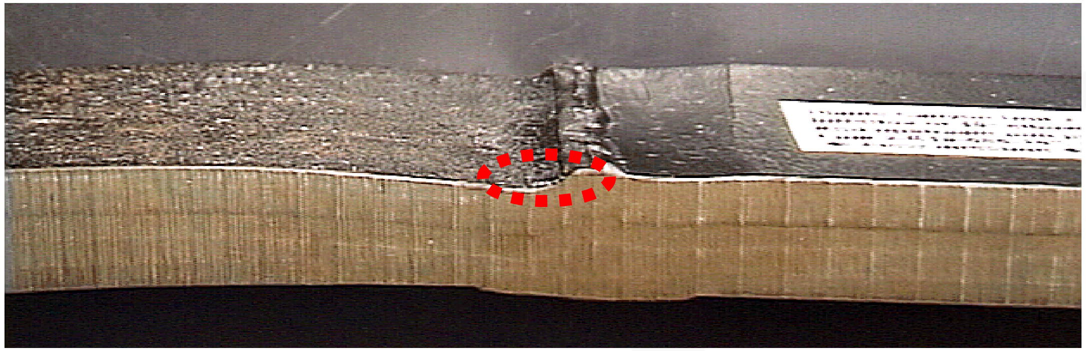


How about opposite flow direction (from high Cr to low Cr)? (Entrance effect)

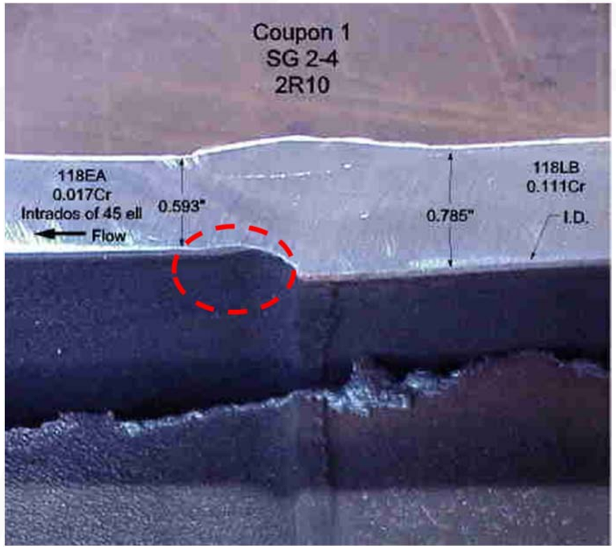
Low Chrome Carbon Steel

High Chrome Carbon Steel





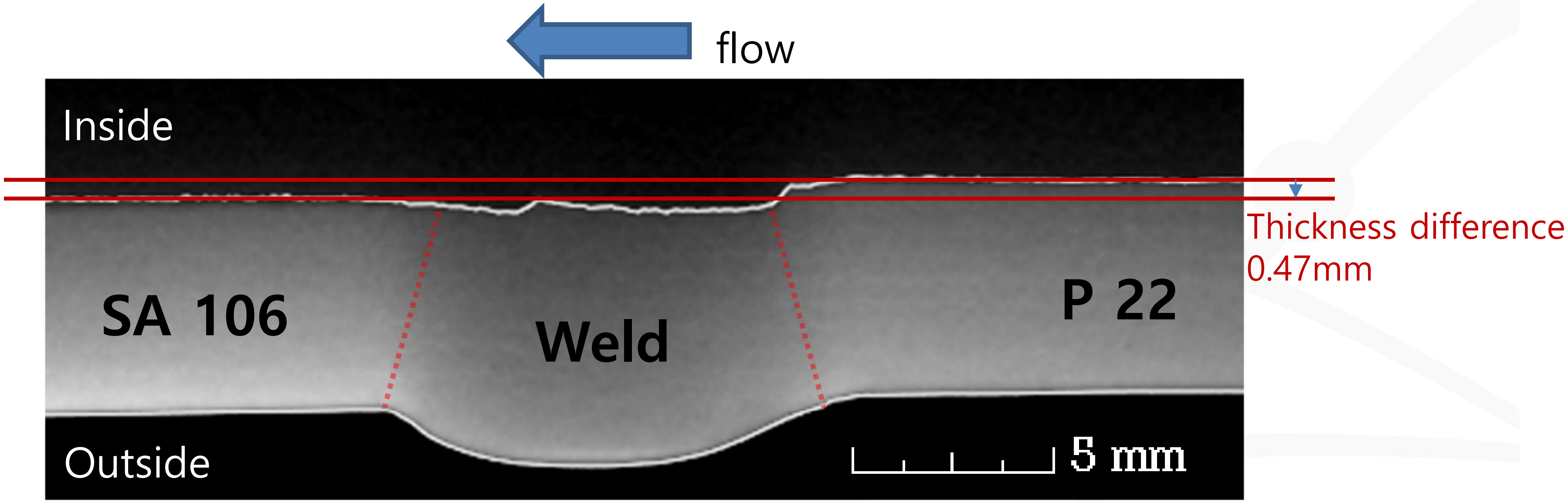
Flow direction



Diablo Canyon - Feedwater

H. Crockett and J. Horowitz, "Entrance effect", presented at FAC 2008, March 18-20, 2008, Lyon, France.

CT image for SA106-SA335 pipe section from high Cr to low Cr

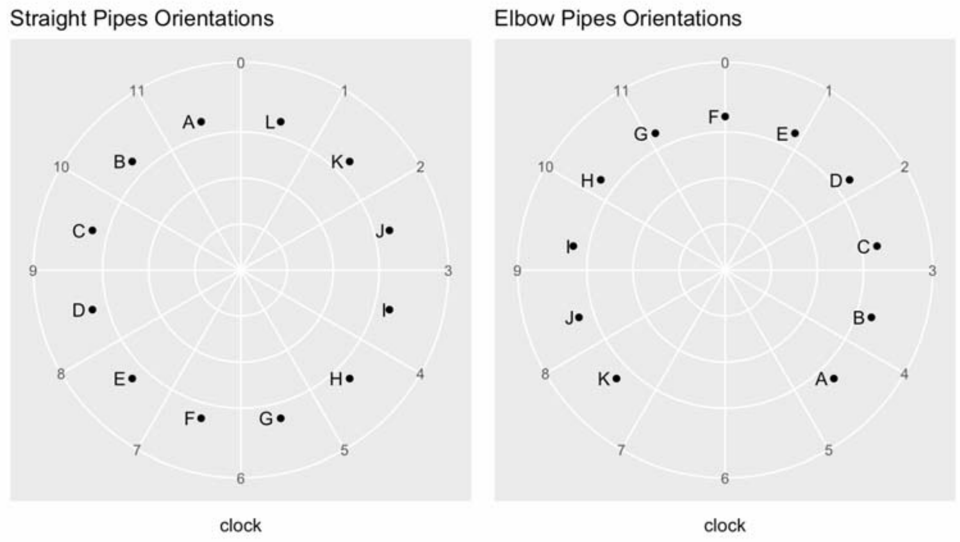


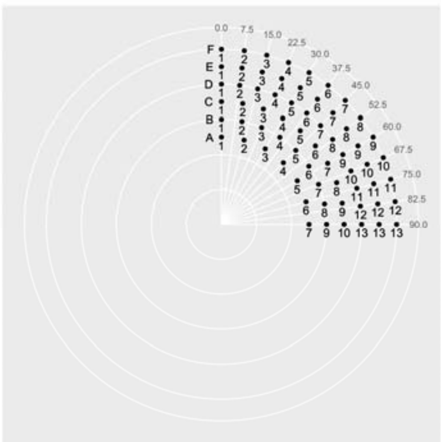
- The susceptible material at the boundary between resistant material and susceptible material is thinned faster due to the concentration gradient of Fe ions in the boundary region.
- Weld metal more susceptible than P22 (SA335), and SA106 more susceptible than weld metal, were thinned more at the boundary.
- However, there was no steep vertical wall that should be considered for FAC management.

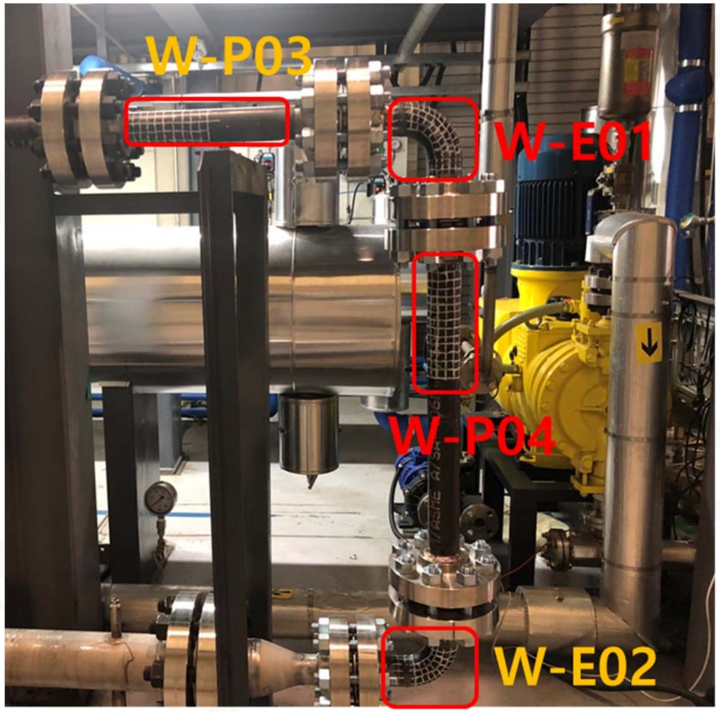
Test section 2

- Pipe with elbow and orifice

UT data notation

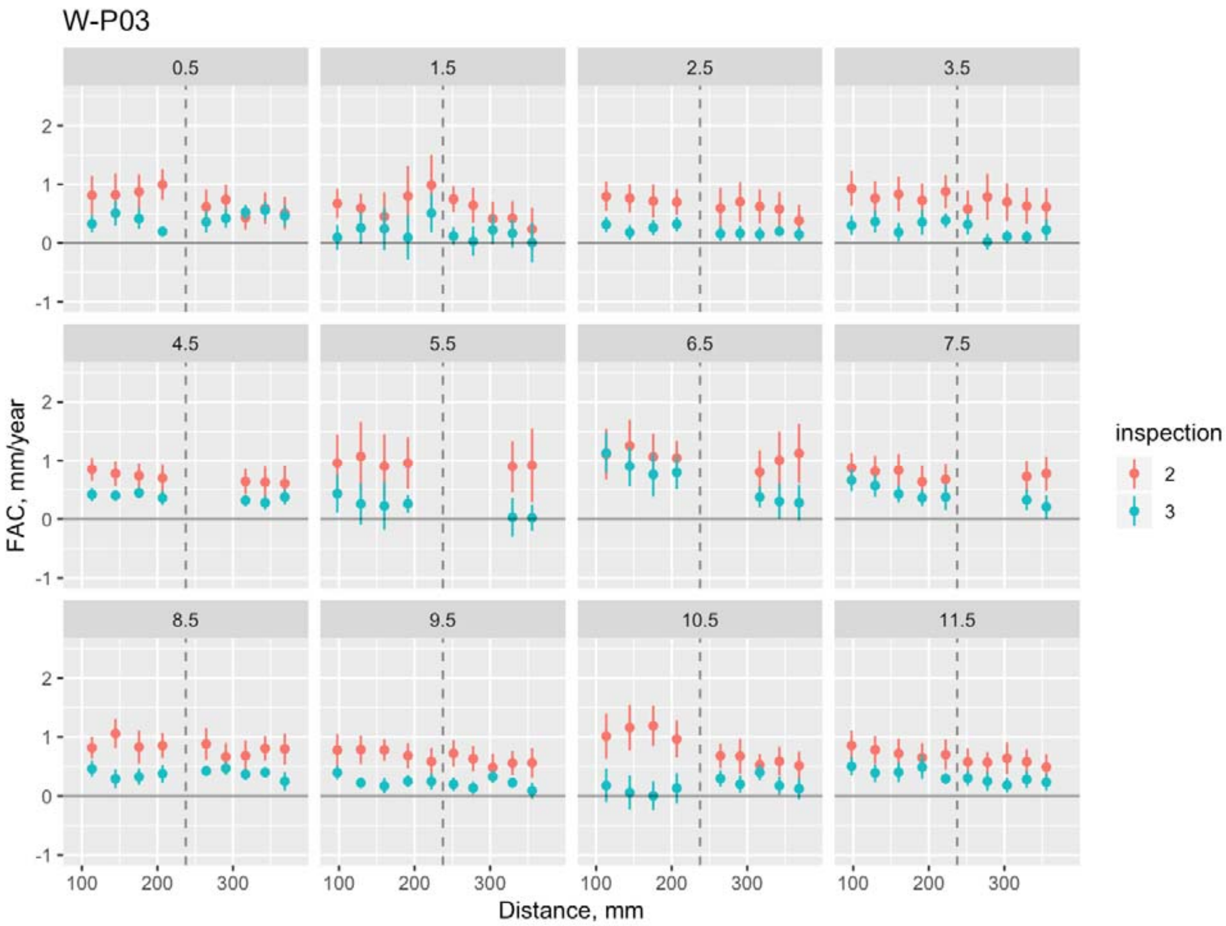






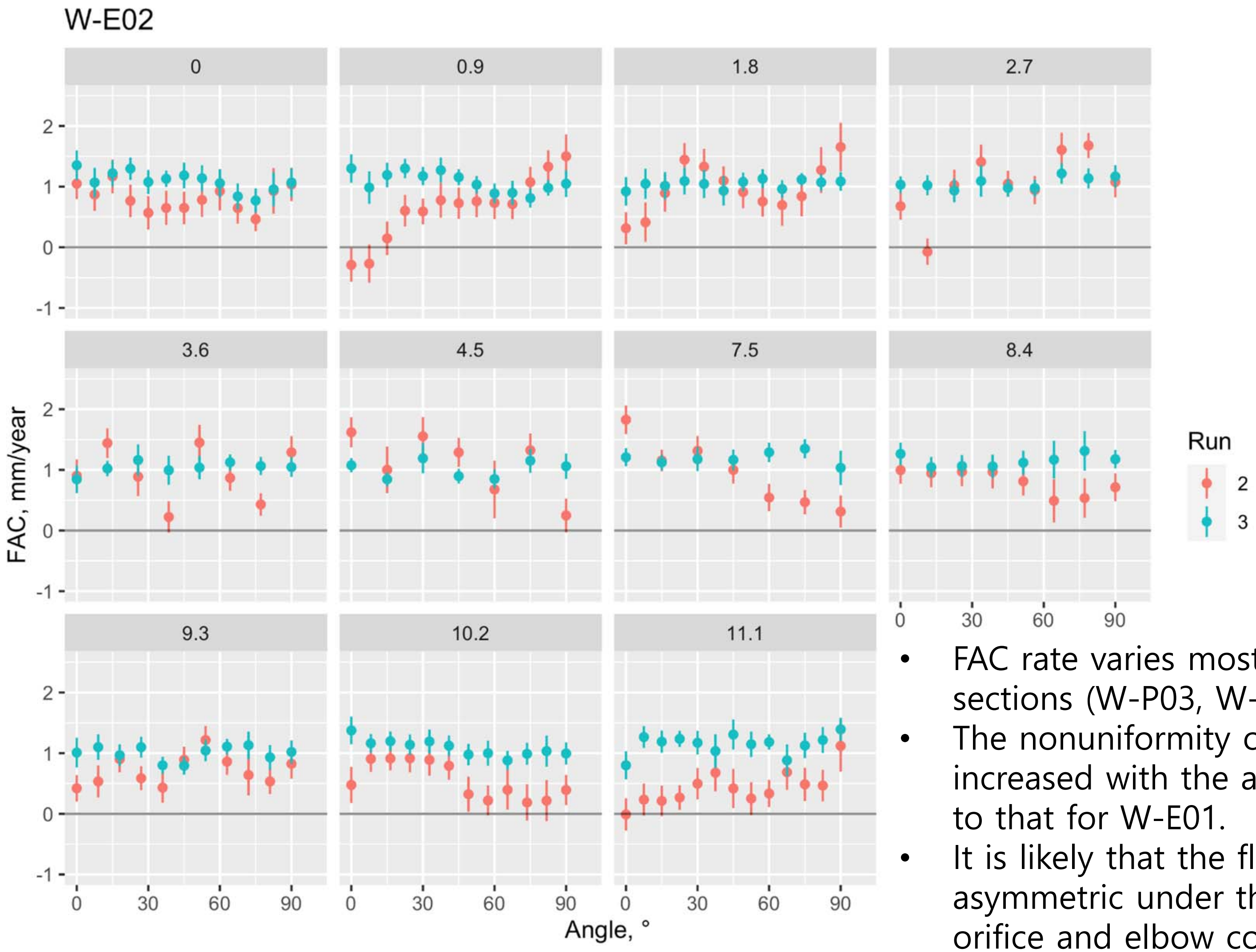
-10 times measurement
-STD : 0.02 mm

FAC rate (W-P03)



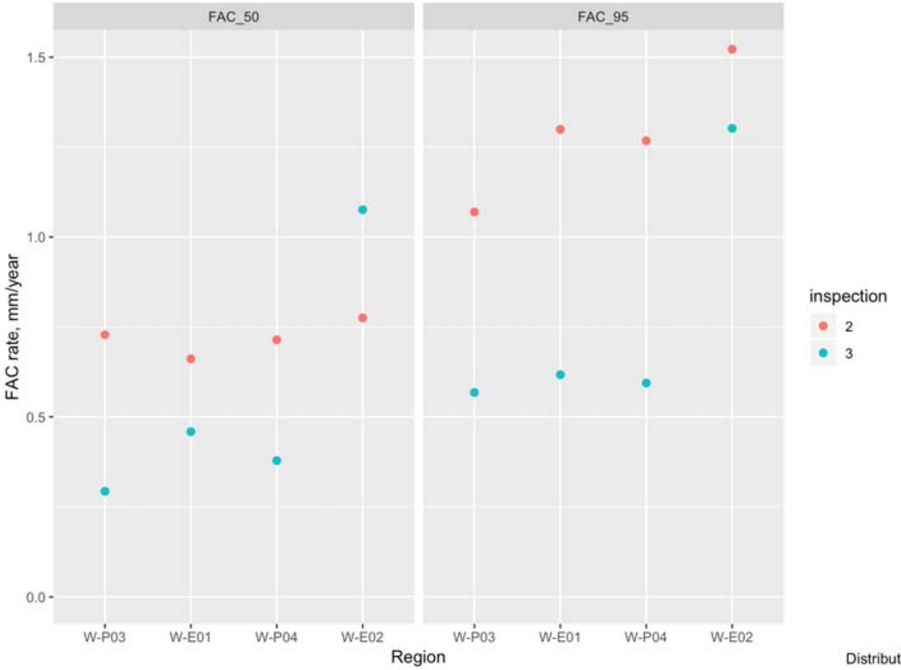
- The FAC rate of Run 2(150^{o}C) is higher than that of Run 3 (130^{o}C). FAC dependency on the temperature is determined by balancing the reaction rate related Fe ion solubility and the mass transfer related to the diffusion of ionic species.
- The FAC rate decreased slightly with the distance and then remained constant after 300 mm (around 6D, where D is the inner diameter of the pipe).
- There appears to be a higher FAC rate at 1.5, 5.5 and 10.5 at the angular positions in the radial direction, indicating that positions near the top and bottom are readily thinned compared to other circumferential positions after the first orifice.

FAC rate (W-E02)

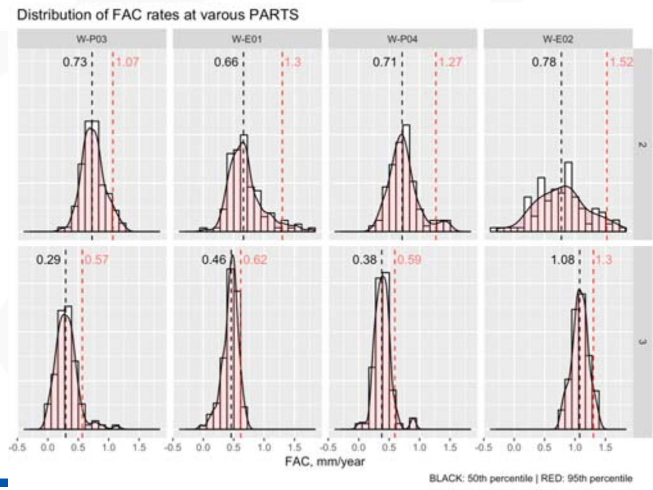


- FAC rate varies most widely among the four sections (W-P03, W-P04, W-E01 and W-E02).
- The nonuniformity of FAC rate for W-E02 increased with the angle (distance) compared to that for W-E01.
- It is likely that the flow became more asymmetric under the combined effect of the orifice and elbow compared to the effect of a single elbow.

FAC rate variation



- It was found that Run 2 at 150° C and 3 m/s resulted in a wider data band than did Run 3 at 130 ° C and 3 m/s, from comparison of 50th and 95th data percentiles. Higher rate leads wider data band.
- The FAC rate increased in the order W-P03 < W-P04 < W-E01 < W-E02 from the 95th percentile data.
- It is noteworthy that the highest FAC rate was obtained at the elbow following the orifice, indicating that the most complicated flow developed from the combination of conditions at orifice and elbow, compared to those at a single elbow or single orifice.



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04

Summary

Summary

- A typical orange-peel surface texture was observed for a straight pipe SA106 specimen, whereas the orange peel texture was not found for the rotating cylindrical electrode in earlier work. Unlike the difference in the surface appearance, an oxide morphology showed similar patterns in terms of the thickness and porosity irrespective of the experimental method used with the pipe specimen and rotating electrode.

- Higher FAC rate in a low Cr steel at the weld bead area was found, compared with a low Cr steel far from the weld bead, irrespective of flow direction (from high to low Cr alloy (entrance effect) and from low to high Cr alloy (opposite effect)) for a straight pipe test section.

- The FAC rate increased in the order of 'straight pipe following a single orifice', 'straight pipe following a single elbow', 'single elbow' and 'elbow following the orifice' (W-P03 < W-P04 < W-E01 < W-E02) from the 95th percentile data, indicating a synergistic effect on the FAC of the flow caused by the combined conditions of the orifice and elbow, as opposed to a single elbow or a single orifice.

THANK YOU