

# **HASTELLOY<sup>®</sup> HYBRID-BC1<sup>®</sup> ALLOY**

## **Preliminary Data**

**Haynes International, Inc.  
1020 West Park Avenue  
Kokomo, IN 46904-9013, USA**

**<http://www.haynesintl.com>**

**HAYNES**  
**International**

# Preliminary Results/ Outline

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- Comparative corrosion data in the presence of Fe<sup>3+</sup> and Cu<sup>2+</sup> ions, in boiling H<sub>2</sub>SO<sub>4</sub>
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  - 30% and 70% sulfuric acid, at 93°C

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- 1, 3 and 10 hours/800°, 1000°, 1200°, 1400°, 1600°, and 1800°F/AC
- 6, 15 and 30 min/1000°, 1200°, 1400°, 1600°, 1800°, and 2000°F/AC

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- 0.2%offset yield strength
- Ultimate tensile strength
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- Fabrication
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- References

# Principal Features of the HYBRID-BC1<sup>®</sup> Alloy

The HYBRID-BC1<sup>®</sup> alloy is a nickel-based alloy containing 22% molybdenum and 15% chromium. This alloy was designed to bridge the gap between the B family (NiMo) of alloys and the C family (Ni-Cr-Mo) of alloys. Principle uses include high temperature organic acid processes, refining industry applications and a wide variety of chemical applications involving hydrochloric and sulfuric acid with various oxidizing impurities that neither the B or C-family of alloys can handle.

The importance of hydrochloric and sulfuric acids to the chemical process industries cannot be overstated. There has always been a desire for materials with improved resistance to these two acids, without the drawbacks associated with the nickel-molybdenum alloys. The HYBRID-BC1 alloy is significantly more resistant to HCl and H<sub>2</sub>SO<sub>4</sub> than the Ni-Cr-Mo alloys and additionally, is resistant to oxidizing chemicals in the acid that are very detrimental to B-Family alloys. The alloy also possesses exceptional resistance to pitting, crevice attack and stress corrosion cracking, in the presence of hot chloride salt solutions. The chromium addition allows the alloy to display passive behavior in most environments like a C-family alloy.

HYBRID-BC1 alloy can be formed, welded and machined in a similar manner to the C-family of alloys. Major uses include vessels, heat exchangers (plate or tubular), valves and piping for the chemical industry. The alloy is available in most common product forms including plate, sheet and strip, billet, bar wire, pipe and tubing.

Wrought forms of this alloy are furnished in the solution heat treated condition unless otherwise specified. Work is underway to attain a UNS number (in 2009), ASTM specifications (in 2009) and an ASME Boiler Code Case (in 2010).

## Field Test Program

Welded samples of the HYBRID-BC1 alloy are readily available at no charge for laboratory or in plant corrosion testing. Limited materials are available at no charge for small component trials. Analysis of the corrosion resistance of tested materials can also be performed and the results provided to the customer as a free technical service. By testing the HYBRID-BC1 alloy against C-2000<sup>®</sup> alloy and B-3<sup>®</sup> alloy the best of the high nickel alloys can be selected for your service.

# Nominal Chemical Composition of the HYBRID-BC1 Alloy

## Chemical Composition (weight %)

Metal #	Ni	Co	Fe	Cr	Mo	W	Mn	Si	Cb	V	Al	Ti	C
2360	62 <sup>a</sup>	-	2*	15	22	-	0.25	0.08*	-	-	0.5*	-	0.01*

<sup>a</sup>Balance

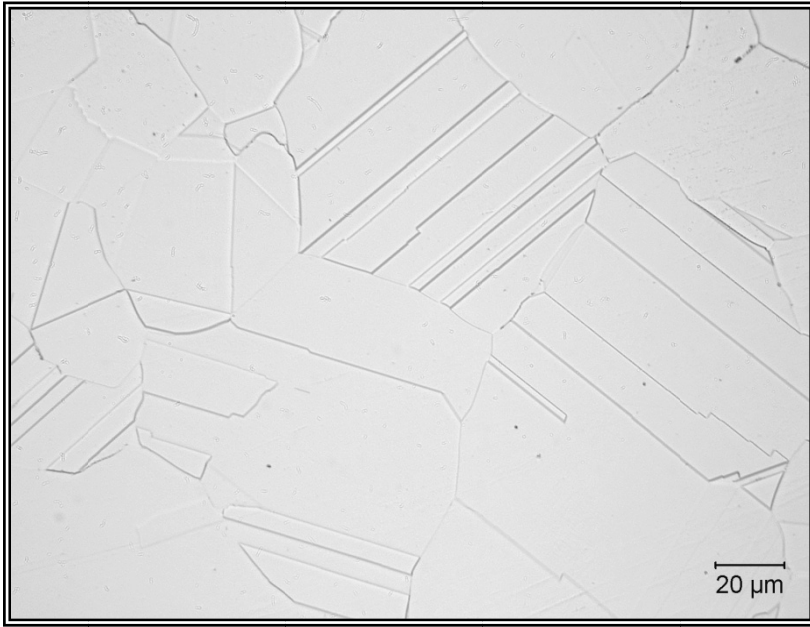
\*Maximum

## Material Safety Data Sheet

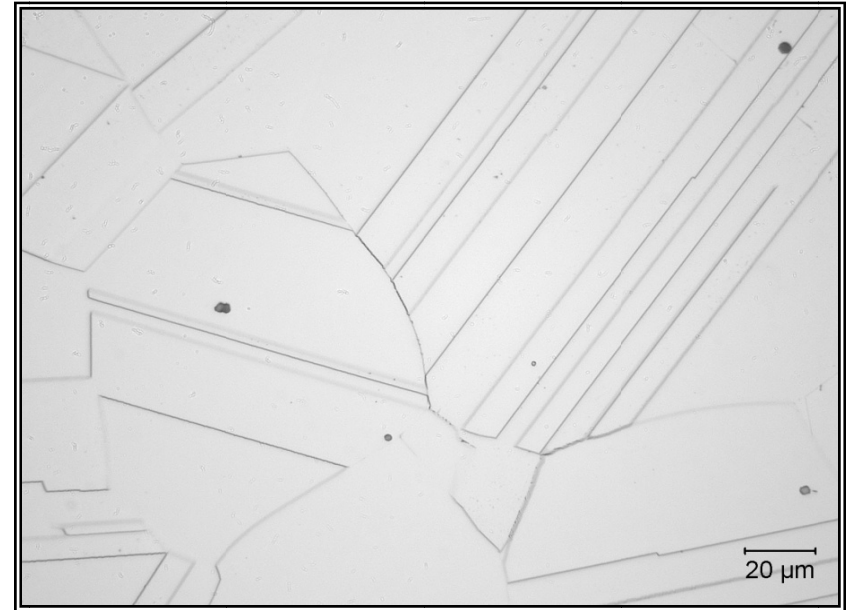
For information concerning material safety data, ask for or download the Material Safety Data Sheets H2071 and H-2072.

**HASTELLOY<sup>®</sup>, HYBRID-BC1<sup>®</sup>, C-2000<sup>®</sup> and B3<sup>®</sup> are a registered trademarks of Haynes International, Inc.**

# Microstructures of the HYBRID-BC1<sup>®</sup> Alloy



- 3.2 mm (0.125") **sheet** thickness
- Bright Annealed at 1162°C (2125°F)
- ASTM Average Grain Size 3½ - 4



- 6.35 mm (0.250") **plate** thickness
- Black annealed at 1149°C (2100°F)
- ASTM average grain size 3½

# Physical Properties of the HYBRID-BC1 Alloy: British Units

Temp. (°F)	Specific Heat (btu/lb.°F)	Thermal Conductivity (btu.in/ft <sup>2</sup> .h.°F)	Thermal Diffusivity (ft <sup>2</sup> /h)	Electrical Resistivity (μΩ.in)	Mean Coefficient of Thermal Expansion (μin/in.°F)
RT	0.096	64	0.10	49.9	-
212	0.099	73	0.11	50	6.4
392	0.102	83	0.12	50.3	6.6
572	0.1048	94	0.14	50.5	6.8
752	0.1072	104	0.15	50.7	6.9
932	0.110	114	0.16	51.1	7.1
1132	0.109	122	0.17	51.8	7.1
1292	0.145	139	0.19	50.2	7.1
1472	0.142	146	0.20	50	7.7
1652	0.146	135	0.18	49.3	8.0
1832	-	142	0.19	48.9	8.3

**Density: 0.319 lb/in<sup>3</sup>**

# Physical Properties of the HYBRID-BC1 Alloy: British Units

Temp. (°F)	Dynamic Modulus of Elasticity (Young's Modulus) (psi)
72	$31.54 \times 10^{-6}$
100	$30.78 \times 10^{-6}$
200	$30.65 \times 10^{-6}$
300	$30.43 \times 10^{-6}$
400	$29.79 \times 10^{-6}$
500	$29.48 \times 10^{-6}$
600	$28.90 \times 10^{-6}$
700	$28.86 \times 10^{-6}$
800	$28.29 \times 10^{-6}$
900	$27.86 \times 10^{-6}$
1000	$27.47 \times 10^{-6}$
1100	$27.32 \times 10^{-6}$
1200	$27.00 \times 10^{-6}$

# Physical Properties of the HYBRID-BC1 Alloy: Metric Units

Temp. (°C)	Specific Heat (J/Kg.°C)	Thermal Conductivity (W/m.°C)	Thermal Diffusivity (cm <sup>2</sup> /s)	Electrical Resistivity (μΩ.m)	Mean Coefficient of Thermal Expansion (μm/m. °C)
RT	402	9.3	0.026	1.26	-
100	416	10.5	0.029	1.27	11.5
200	429	11.9	0.031	1.27	11.9
300	439	13.5	0.035	1.28	12.2
400	449	14.9	0.038	1.28	12.5
500	461	16.4	0.041	1.29	12.7
600	457	17.5	0.043	1.31	12.7
700	609	20	0.049	1.27	12.8
800	597	21.1	0.051	1.27	13.9
900	613	19.5	0.047	1.25	14.4
1000	-	20.4	0.049	1.24	14.9

Density: 8.83 g/cm<sup>3</sup>

# Physical Properties of the HYBRID-BC1 Alloy: Metric Units

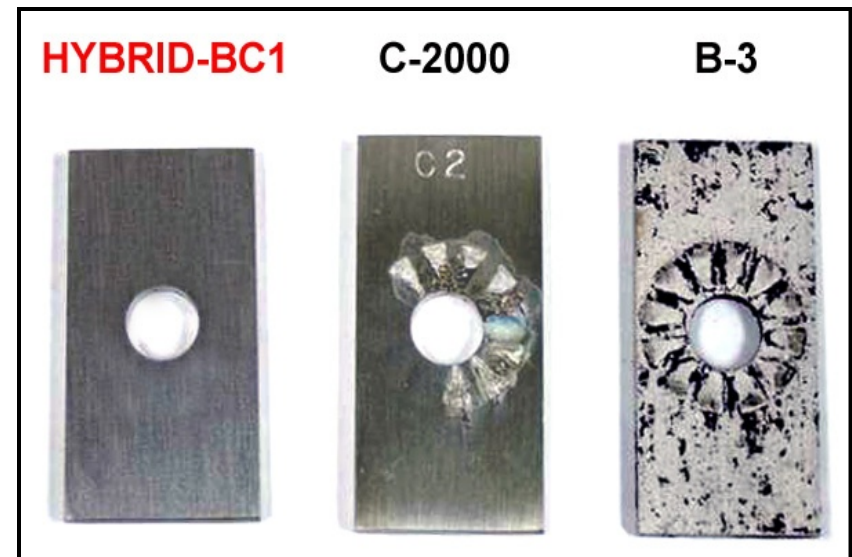
<b>Temp., °C</b>	<b>Dynamic Modulus of Elasticity (Young's Modulus), GPa</b>
22	217
38	212
93	211
149	210
204	205
260	203
316	199
371	199
427	195
482	192
538	184
593	188
649	186

# Localized Corrosion Data of the HYBRID-BC1 Alloy As Base Metal

## Comparative Critical Pitting Temperature (CPT) & Critical Crevice Temperature (CCT)

Alloy	CPT, °C	CCT, °C
HYBRID-BC1	>85°	>85°
C-4	>85°	50°
C-276	>85°	55°
C-22	>85°	80°
C-2000	>85°	80°
C-22HS (MA)	>85°	>85°
C-22HS (MA + HT)	>85°	75°
59	>85°	>85°
686	>85°	>85°
MAT-21	>85°	>85°

Acidified 6% FeCl<sub>3</sub>: ASTM G 48C and G 48D



Macrographs in acidified 6% FeCl<sub>3</sub>, at 125°C

# Stress Corrosion Cracking Data of the HYBRID-BC1 Alloy

Times Required to Induce Stress-Corrosion Cracking in U-Bend Sample of Nickel Alloys in Boiling 45% MgCl<sub>2</sub> (ASTM G 30 & G 36)

Alloy	Time in Cracking Hours
<b>HYBRID-BC1</b>	<b>No cracking in 1008</b>
<b>C-4</b>	<b>No cracking in 1008</b>
<b>C-276</b>	<b>No cracking in 1008</b>
<b>C-22</b>	<b>No cracking in 1008</b>
<b>C-2000</b>	<b>No cracking in 1008</b>
<b>C-22HS (MA)</b>	<b>No cracking in 1008</b>
<b>C-22HS (MA + HT)</b>	<b>No cracking in 1008</b>
<b>59</b>	<b>No cracking in 1008</b>
<b>686</b>	<b>No cracking in 1008</b>



**HYBRID-BC1 Alloy**  
(No cracking after 1008 h)

# **HYBRID-BC1 Alloy Uniform Corrosion Data and Iso-Corrosion Diagrams in Different Mineral Acids**

Several iso-corrosion diagrams are presented in this package. These diagrams were constructed from numerous data points, and each one defines, for a given alloy and solution, the “**very safe**”, “**moderately safe**” and “**unsafe**” concentration/temperature regime. These correspond to the corrosion rate ranges 0-0.1 mm/y (0-4 mpy), 0.1-0.5 mm/y (4 -20mpy) and > 0.5mm/y (20mpy).

Each of these iso-corrosion diagrams was constructed using numerous corrosion rate values, generated at different acid concentrations and temperatures. The green line represents those combinations of the acid concentration and temperature at which a corrosion rate of 0.1 mm/y (4 mils per year) is expected, based on laboratory tests. Below the line, rates under 0.1 mm/y are expected! Similarly, the red line indicates the combinations of acid concentration and temperature at which a corrosion rate of 0.5 mm/y (20 mils per year) is expected. Above the red line, rates of over 0.5 mm/y are expected. Between the green and red lines, corrosion rates are expected to fall between 0.1 and 0.5 mm/y.

These results were obtained from laboratory tests and have to be used only as a general guide line to differentiate the corrosion performance of the new alloy in the several chemical products versus the other comparative materials.

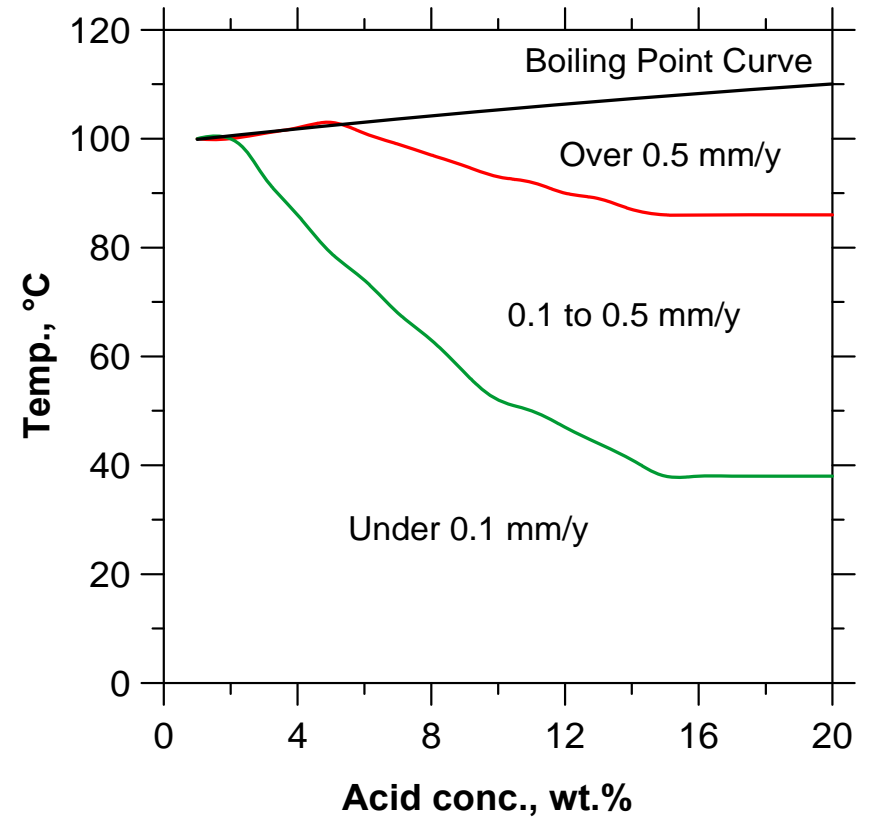
# Iso-corrosion diagram for HYBRID-BC1 Alloy in Hydrochloric Acid

Corrosion rates (mpy) in Reagent Grade Hydrochloric Acid

Acid Conc. wt. %	100°F	125°F	150°F	175°F	200°F	Blg
	38°C	52°C	66°C	79°C	93°C	
1%					0.3 <sup>2</sup>	0.4 <sup>2</sup>
1.5%					0.5 <sup>2</sup>	2.3 <sup>2</sup>
2%					0.8 <sup>2</sup>	4 <sup>2</sup>
2.5%					1.4 <sup>2</sup>	5.9 <sup>2</sup>
3%					3 <sup>2</sup>	8.4 <sup>2</sup>
5%		0.1 <sup>1</sup>	0.6 <sup>1</sup>	3.2 <sup>1</sup>	12.3 <sup>1</sup>	17.9 <sup>2</sup>
10%	0.6 <sup>2</sup>	5 <sup>1</sup>	10.5 <sup>1</sup>	15.1 <sup>1</sup>	20.9 <sup>1</sup>	
15%	4.8 <sup>2</sup>	8.2 <sup>1</sup>	11 <sup>1</sup>	17.4 <sup>1</sup>	22.6 <sup>1</sup>	
20%	4.6 <sup>2</sup>	7.1 <sup>1</sup>	11.4 <sup>1</sup>	17.9 <sup>1</sup>	26.6 <sup>1</sup>	74.8 <sup>1</sup>
25%	4.1 <sup>2</sup>	6.6 <sup>2</sup>	10.8 <sup>2</sup>			66.9 <sup>2</sup>
30%	3.2 <sup>2</sup>	5.5 <sup>2</sup>	9.6 <sup>2</sup>			71.1 <sup>2</sup>
37%	1.6 <sup>2</sup>	3.5 <sup>2</sup>	7.2 <sup>2</sup>			72.6 <sup>2</sup>

<sup>1</sup> Job 23-07 (4-24)

<sup>2</sup> Job 3-08 (4-24)



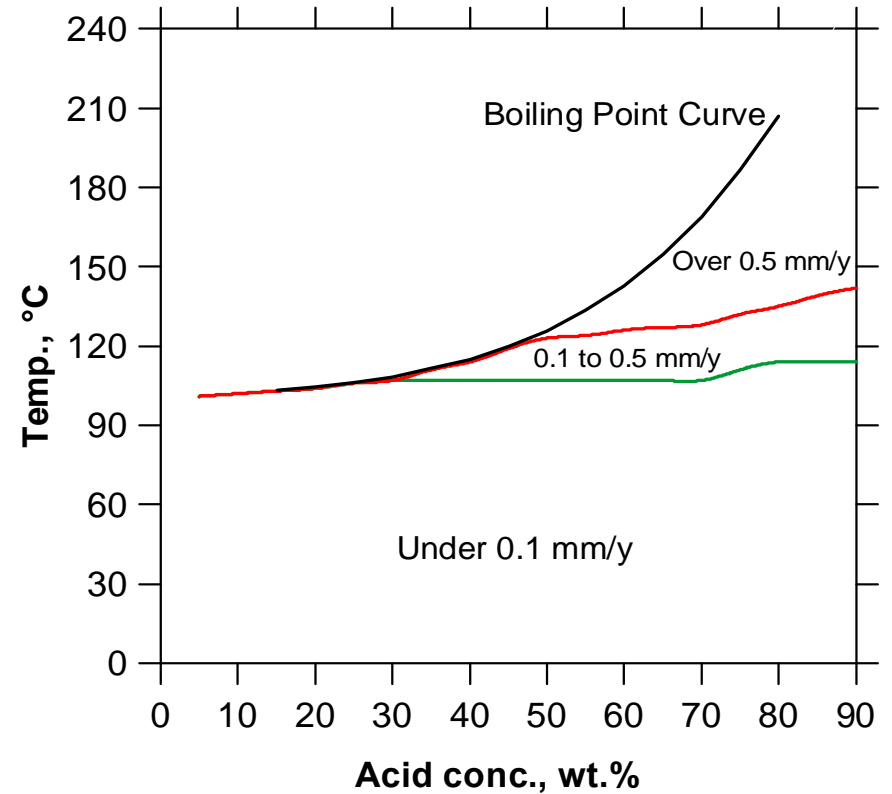
# Iso-Corrosion Diagram for HYBRID-BC1 Alloy in Sulfuric Acid

**Corrosion rates (mpy) in Reagent Grade Sulfuric Acid**

Acid Conc. wt. %	200°F	225°F	250°F	275°F	300°F	Blg
	93°C	107°C	121°C	135°C	149°C	
10%	2.6 <sup>1</sup>					1.3 <sup>2</sup>
20%						2.4 <sup>2</sup>
30%	3.2 <sup>1</sup>					3.6 <sup>2</sup>
50%	2.3 <sup>1</sup>	4.5 <sup>2</sup>				9.4 <sup>2</sup>
70%	1.2 <sup>1</sup>	4.3 <sup>2</sup>	8.5 <sup>2</sup>	67.4 <sup>2</sup>		
80%		1.9 <sup>2</sup>	9.4 <sup>2</sup>	20.5 <sup>2</sup>		
90%	1.2 <sup>1</sup>	2.5 <sup>2</sup>	5.5 <sup>2</sup>	14.8 <sup>2</sup>	34.9 <sup>2</sup>	
96%		4.3 <sup>2</sup>	8.2 <sup>2</sup>	17.9 <sup>2</sup>	43.6 <sup>2</sup>	

<sup>1</sup> Job 24-07 (4-24)

<sup>2</sup> Job 4-08 (4-24)



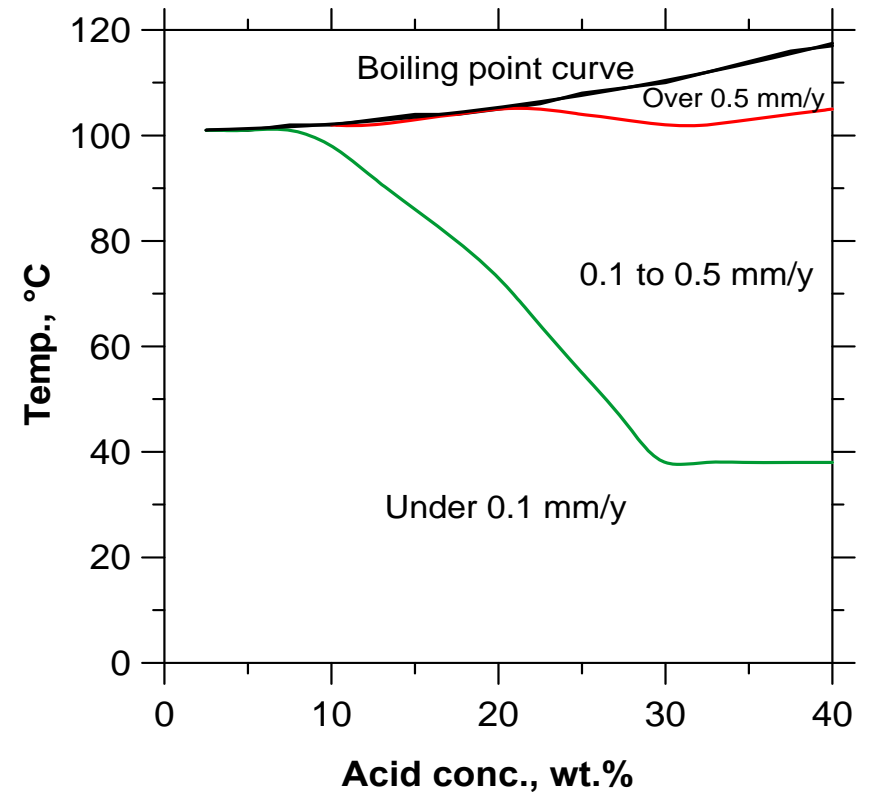
# Iso-Corrosion Diagram for HYBRID-BC1 Alloy in Hydrobromic Acid

**Corrosion rates (mpy) in Reagent Grade Hydrobromic Acid**

Acid Conc. wt. %	100°F	125°F	150°F	175°F	200°F	BOILING
	38°C	52°C	66°C	79°C	93°C	
5%						3.1 <sup>2</sup>
10%				0.4 <sup>2</sup>	2 <sup>1</sup>	8.4 <sup>2</sup>
20%			1.4 <sup>2</sup>	12.4 <sup>2</sup>	14.7 <sup>1</sup>	18.5 <sup>2</sup>
30%	4.3 <sup>2</sup>	6.7 <sup>2</sup>	9.5 <sup>2</sup>	12.1 <sup>2</sup>	14.7 <sup>1</sup>	26.9 <sup>2</sup>
40%	3.7 <sup>2</sup>	5.7 <sup>2</sup>	8 <sup>2</sup>	10.9 <sup>2</sup>	13.4 <sup>1</sup>	33.3 <sup>2</sup>

<sup>1</sup> Job 23-07 (4-24)

<sup>2</sup> Job 5-08 (4-24)



# Iso-Corrosion Diagram for HYBRID-BC1 Alloy in Hydrofluoric Acid

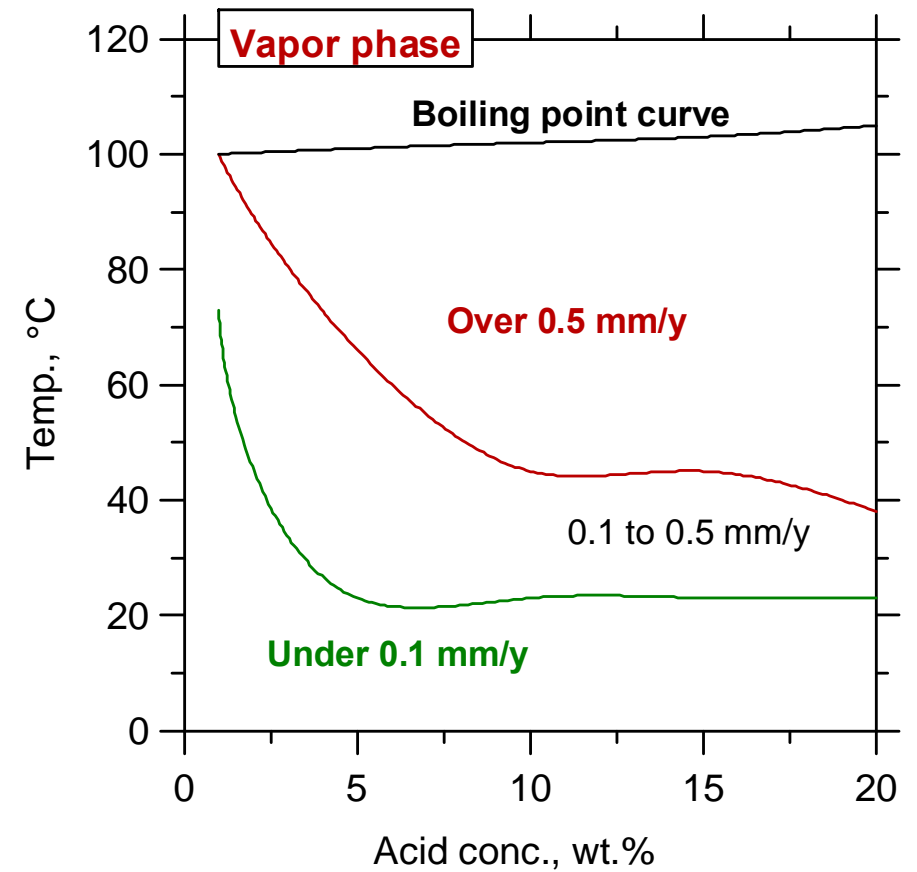
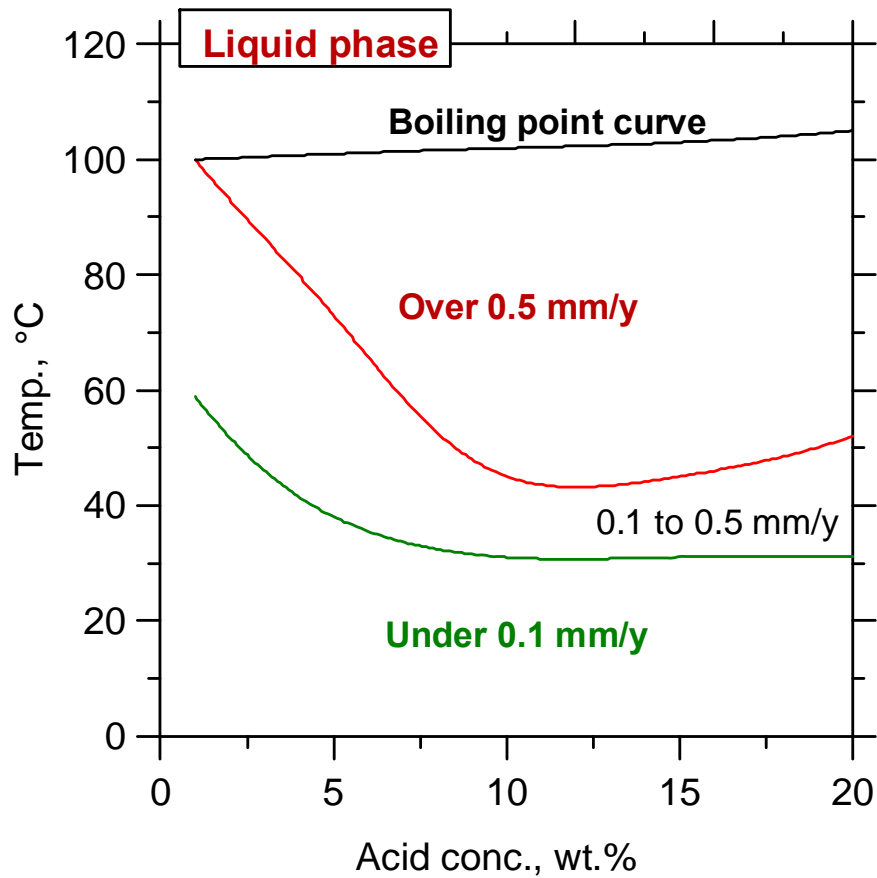
Corrosion rates (mpy) in Reagent Grade Hydrofluoric Acid

Acid Conc. wt.%	75°F	100°F	125°F	150°F	175°F	200°F
	23°C	38°C	52°C	66°C	79°C	93°C
1% (liquid)		1.3 <sup>1</sup>	2.6 <sup>1</sup>	7.0 <sup>1</sup>	9.4 <sup>1</sup>	16.3 <sup>2</sup>
1% (vapor)		1.2 <sup>1</sup>	2.5 <sup>1</sup>	2.7 <sup>1</sup>	6.5 <sup>1</sup>	11.2 <sup>2</sup>
5% (liquid)	0.7 <sup>1</sup>	3.8 <sup>1</sup>	10.7 <sup>1</sup>	15.5 <sup>1</sup>	42.6 <sup>1</sup>	
5% (vapor)	4.6	6.6 <sup>1</sup>	13.2 <sup>1</sup>	20.4 <sup>1</sup>	48 <sup>1</sup>	
10% (liquid)	0.9 <sup>1</sup>	6.7 <sup>1</sup>	25.5 <sup>1</sup>	26 <sup>1</sup>	38.5 <sup>1</sup>	
10% (vapor)	7.2 <sup>1</sup>	9.8 <sup>1</sup>	46.8 <sup>1</sup>	34.7 <sup>1</sup>	39.2 <sup>1</sup>	
15% (liquid)	1.0 <sup>2</sup>	10.7 <sup>2</sup>	40.8 <sup>2</sup>			
15% (vapor)	10.1 <sup>2</sup>	13.7 <sup>2</sup>	36.7 <sup>2</sup>			
20% (liquid)	1.2 <sup>1</sup>	9.2 <sup>1</sup>	19.6 <sup>1</sup>	44.9 <sup>1</sup>	88.1 <sup>1</sup>	
20% (vapor)	12.3 <sup>1</sup>	20.9 <sup>1</sup>	18.8 <sup>1</sup>	64 <sup>1</sup>	69.5 <sup>1</sup>	

<sup>1</sup>Job 6-08 (1-240)

<sup>2</sup>Job 14-10 (1-240)

# Iso-Corrosion Diagram for HYBRID-BC1 Alloy in Hydrofluoric Acid



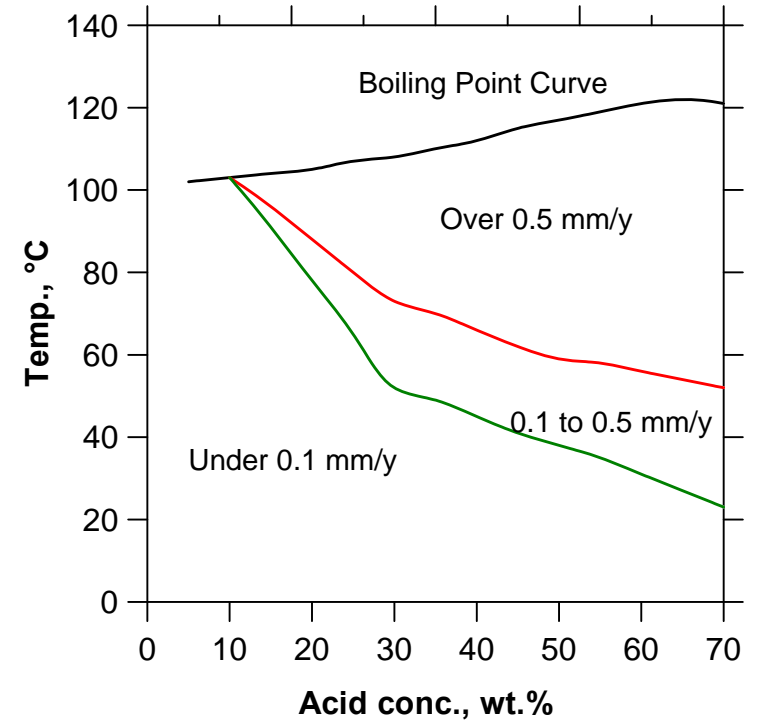
# Iso-Corrosion Diagram for HYBRID-BC1 Alloy in Nitric Acid

**Corrosion rates (mpy) in Reagent Grade Nitric Acid**

Acid Conc., wt. %	75°F	100°F	125°F	150°F	175°F	200°F	Blg
	23°C	38°C	52°C	66°C	79°C	93°C	
10%					1.5 <sup>2</sup>	2.7 <sup>1</sup>	5.2 <sup>1</sup>
30%		2.6 <sup>2</sup>	5.2 <sup>2</sup>	11 <sup>2</sup>	29.3 <sup>2</sup>	186 <sup>1</sup>	
50%		4.2 <sup>2</sup>	11.5 <sup>2</sup>	38.7 <sup>2</sup>	175 <sup>2</sup>	685 <sup>1</sup>	
70%	3.2 <sup>2</sup>	7.4 <sup>2</sup>	21.1 <sup>2</sup>	103 <sup>2</sup>	375.5 <sup>2</sup>	808 <sup>1</sup>	

<sup>1</sup> Job 24-07 (4-24)

<sup>2</sup> Job 7-08 (4-24)

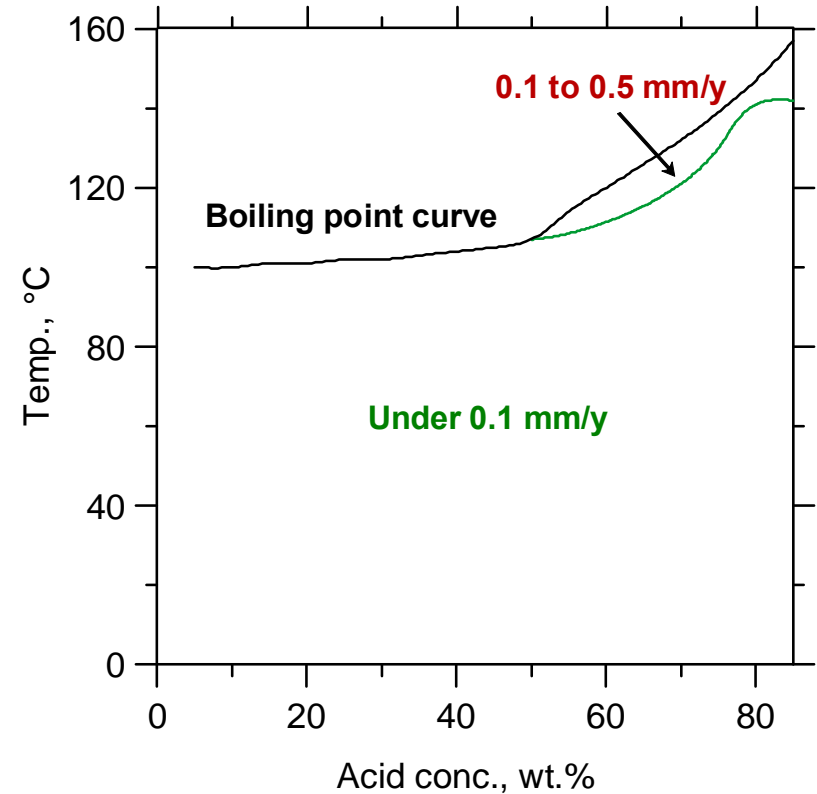


# Iso-Corrosion Diagram for HYBRID-BC1 Alloy in Phosphoric Acid

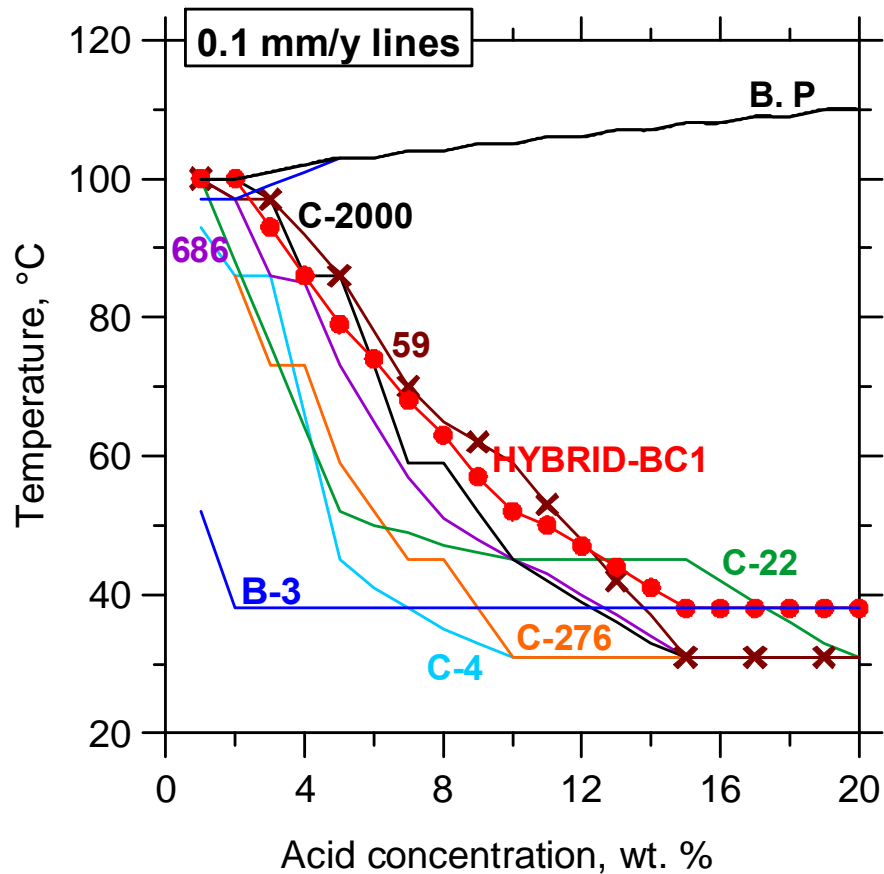
Corrosion rates (mpy) in Reagent Grade Phosphoric Acid

Acid Conc., wt. %	250°F	275°F	300°F	Blg
	121°C	135°C	149°C	
50				4.9
70	4.2 <sup>1</sup>			7.4 <sup>1</sup>
75	0.9			7.8 <sup>1</sup>
80	0.7 <sup>1</sup>	0.7 <sup>1</sup>		12.9 <sup>1</sup>
85	0.5 <sup>1</sup>	0.8 <sup>1</sup>	18.2 <sup>1</sup>	26.2 <sup>1</sup>

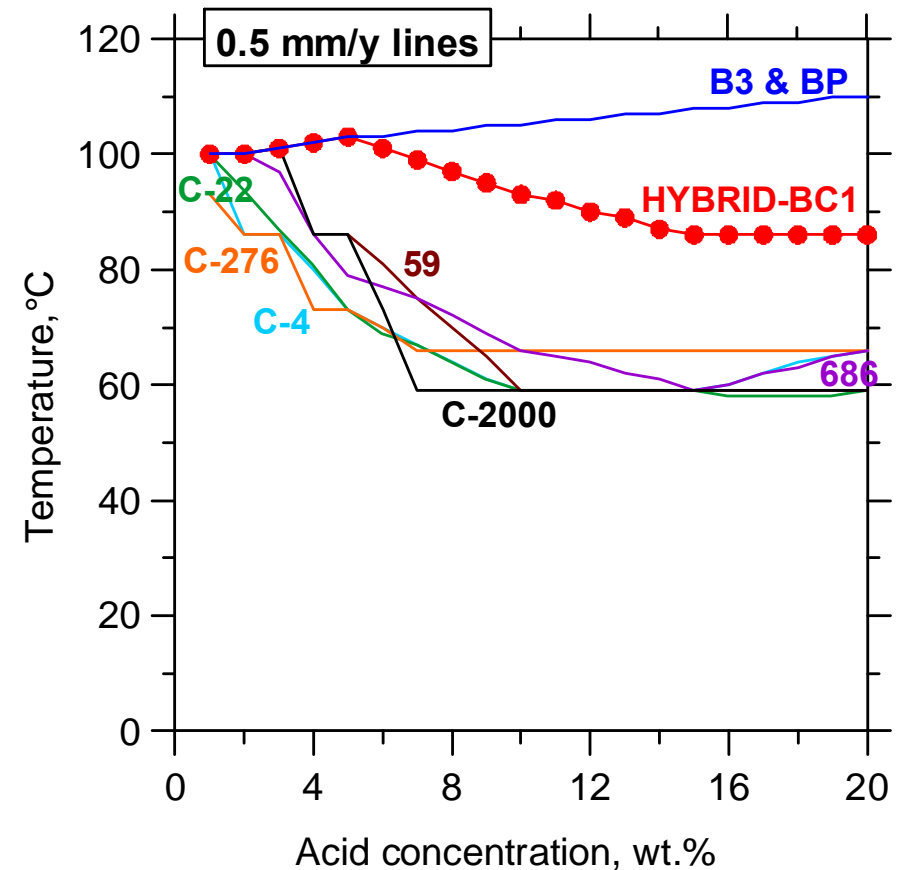
<sup>1</sup>Job 8-08 (4-24)



# Comparison of the 0.1 & 0.5 mm/y Lines for HYBRID-BC1 Alloy versus the other Ni-Base Alloys, in Hydrochloric Acid

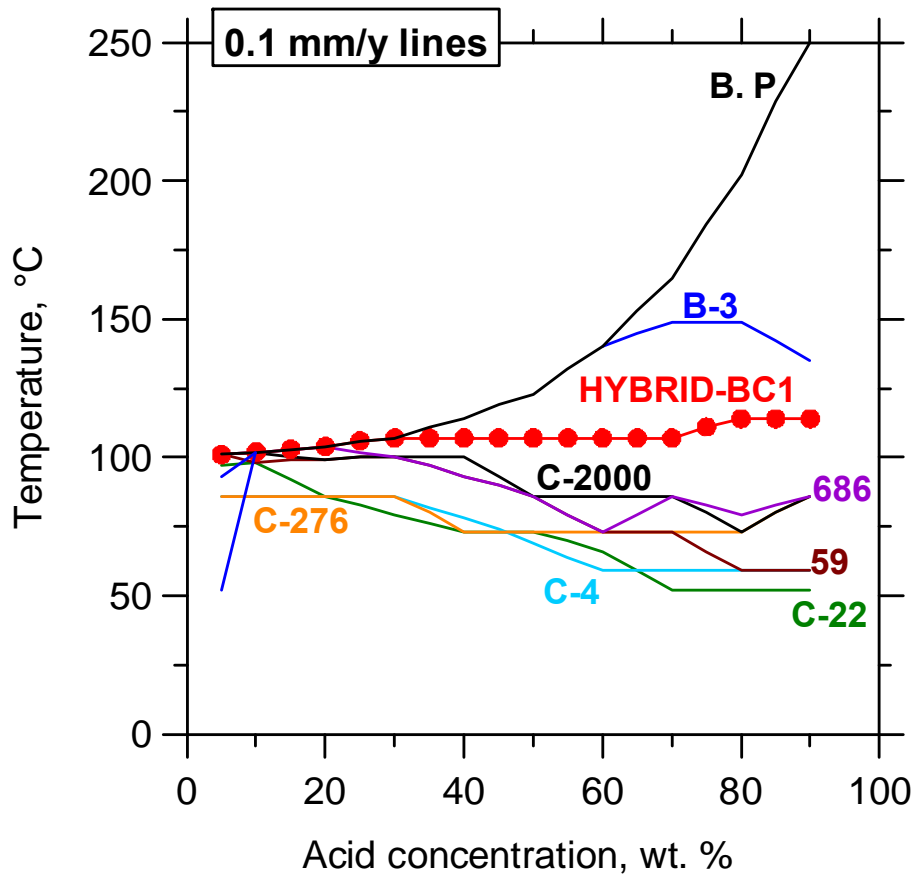


Comparison of 0.1 mm/y lines for HYBRID-BC1, C-22, C-276, C-2000, 59, 686, and B-3 alloys in hydrochloric acid.

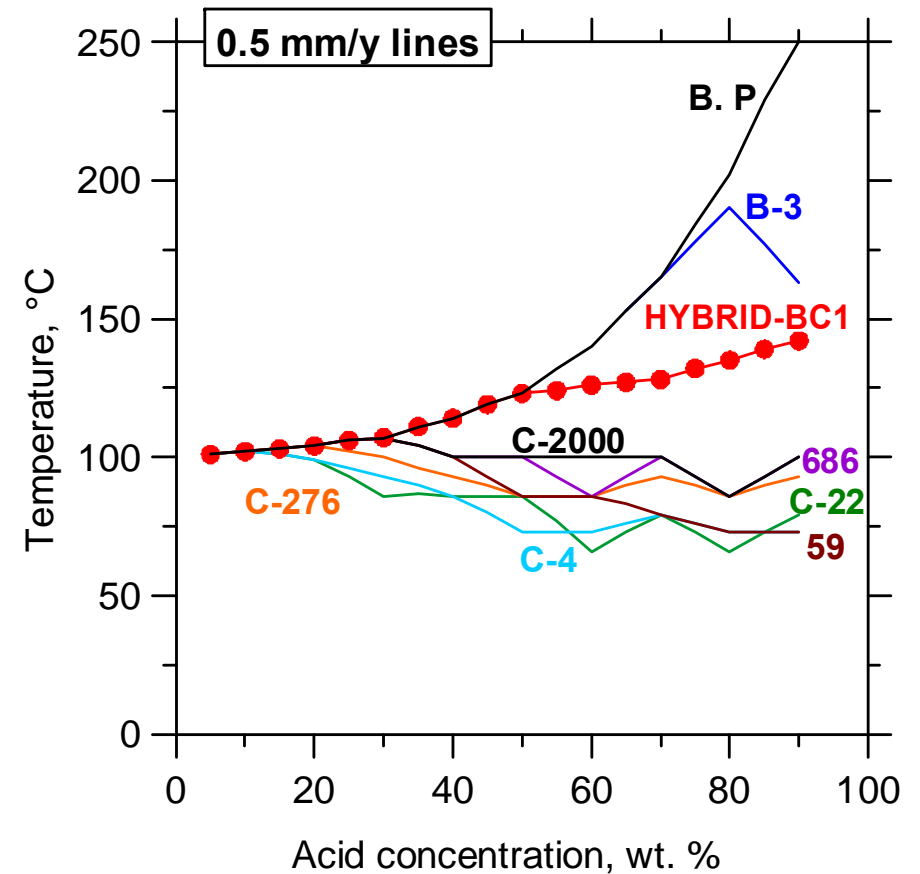


Comparison of 0.5 mm/y lines for HYBRID-BC1, C-22, C-276, C-2000, 59, 686 and B-3 alloys in hydrochloric acid.

# Comparison of the 0.1 and 0.5 mm/y Lines for the HYBRID-BC1 Alloy versus the other Nickel-Base Alloys, in Sulfuric Acid

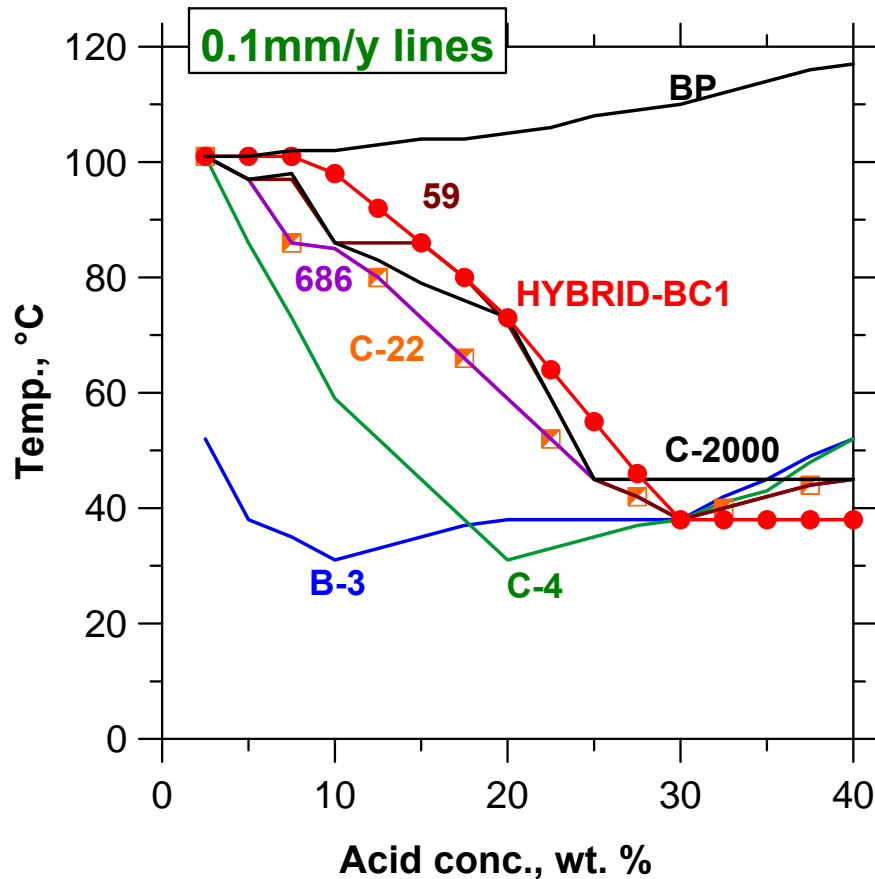


Comparison of 0.1 mm/y lines for HYBRID-BC1, C-4, C-22, C-276, C-2000, 59, 686, and B-3 alloys in sulfuric acid.

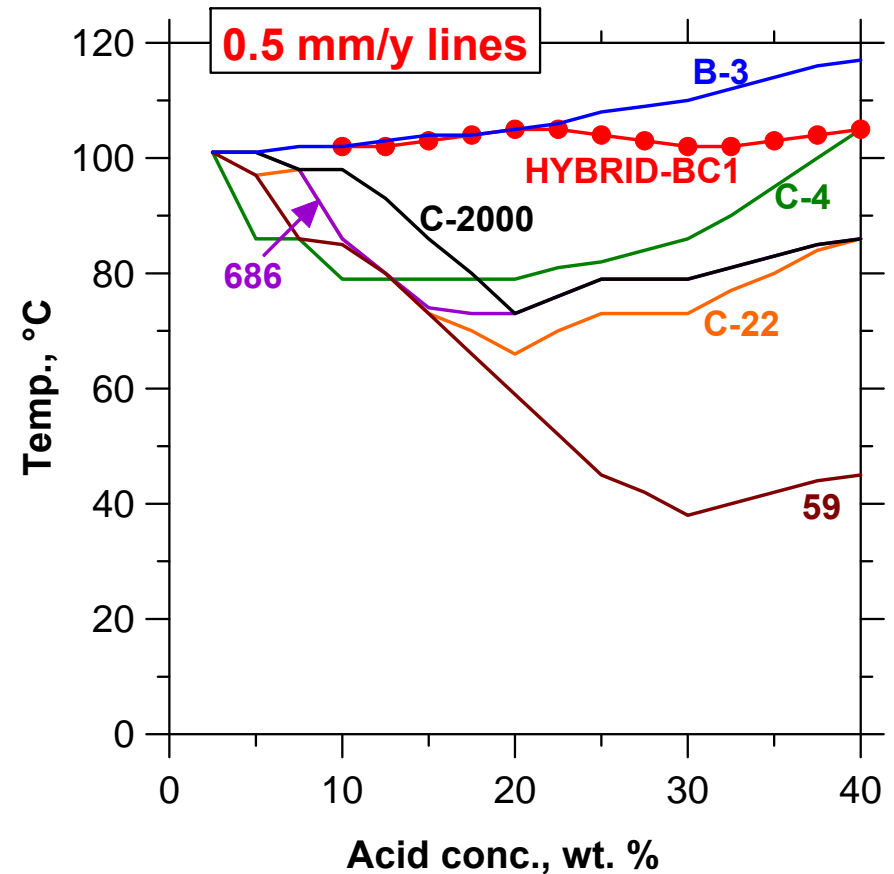


Comparison of 0.5 mm/y lines for HYBRID-BC1, C-4, C-276, C-22, C-2000, 59, 686, and B-3 alloys in sulfuric acid.

# Comparison of the 0.1 and 0.5 mm/y Lines for the HYBRID-BC1 alloy versus the other Ni-Base Alloys, in Hydrobromic Acid

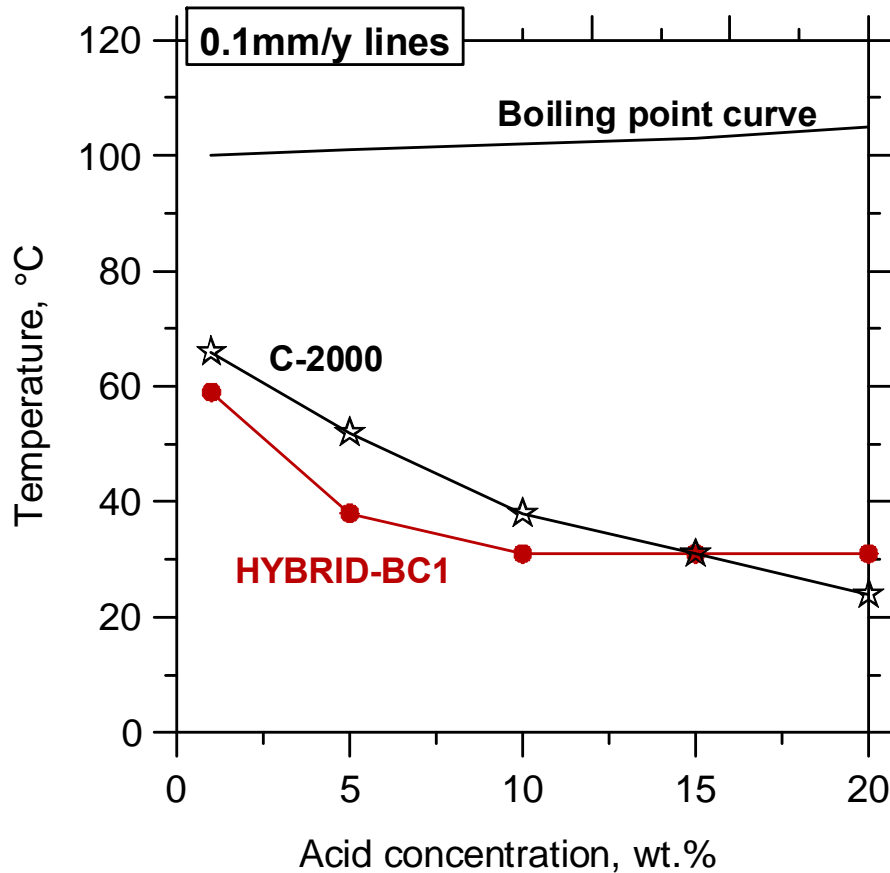


Comparison of 0.1 mm/y lines for HYBRID-BC1, C-2000, 59, 686, C-4, C-22, and B-3 alloys in HBr.

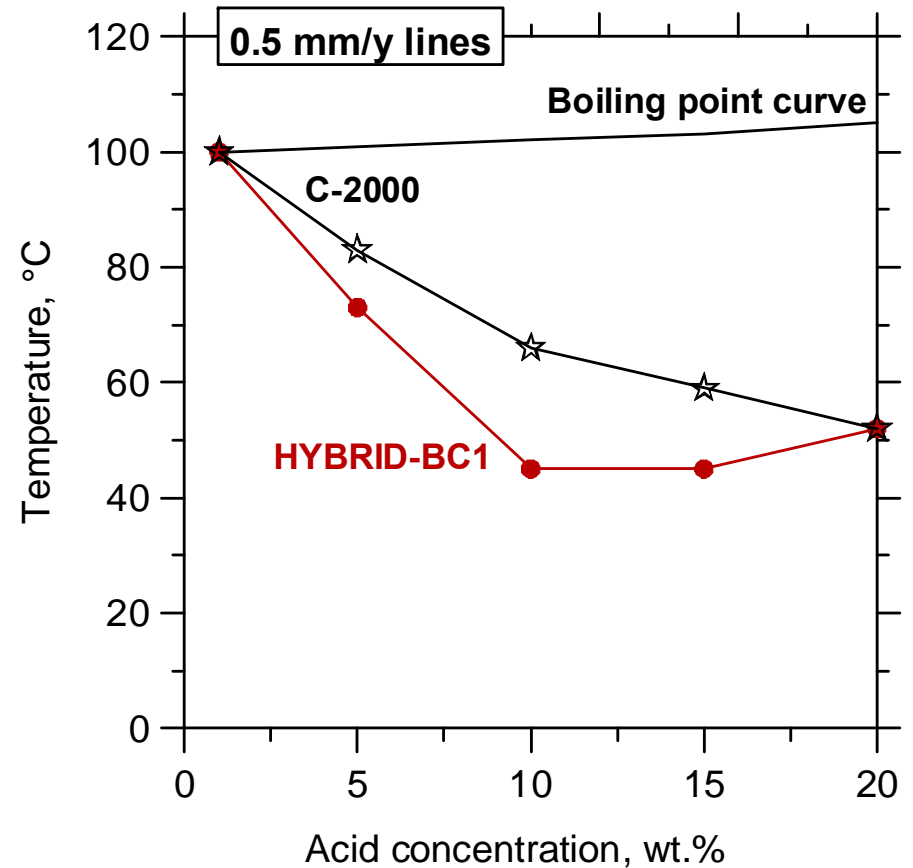


Comparison of 0.5 mm/y lines for HYBRID-BC1, C-2000, 59, 686, C-4, C-22, and B-3 alloys in HBr.

# Comparison of the 0.1 and 0.5 mm/y Lines for the HYBRID-BC1 alloy versus C-2000 Alloy, in Hydrofluoric Acid (liquid phase)

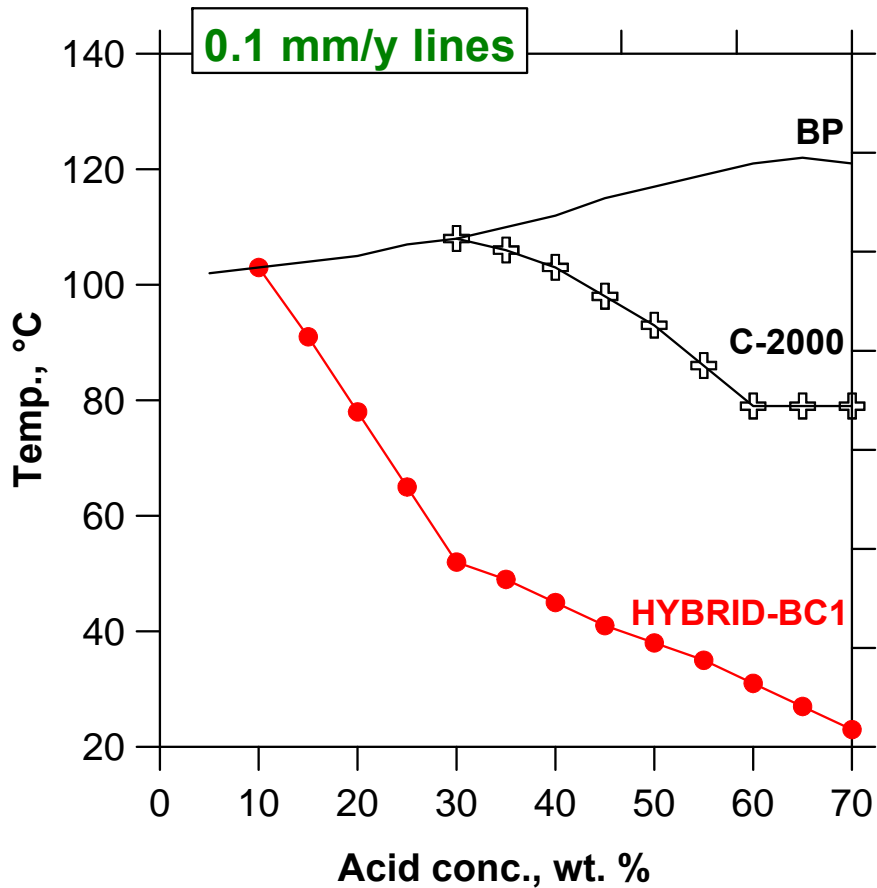


Comparison of 0.1 mm/y lines for HYBRID-BC1 and C-2000 alloys in hydrofluoric acid (liquid phase).

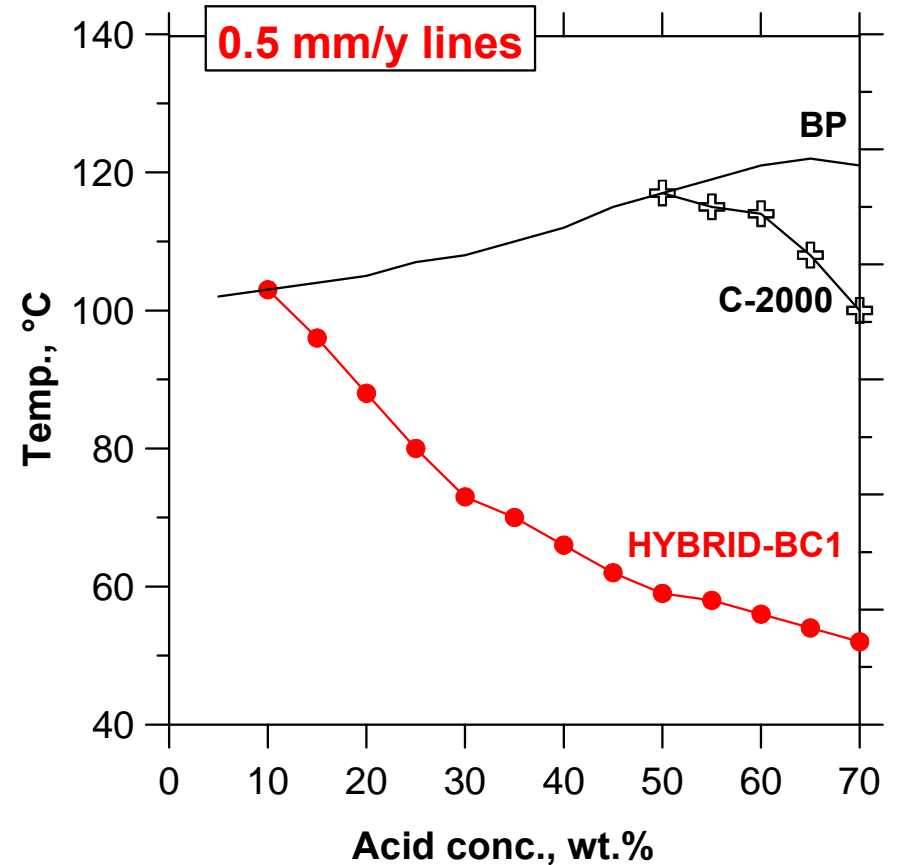


Comparison of 0.5 mm/y lines for HYBRID-BC1 and C-2000 alloys in hydrofluoric acid (liquid phase).

# Comparison of the 0.1 and 0.5 mm/y Lines for the HYBRID-BC1 alloy versus C-2000 Alloy, in Nitric Acid

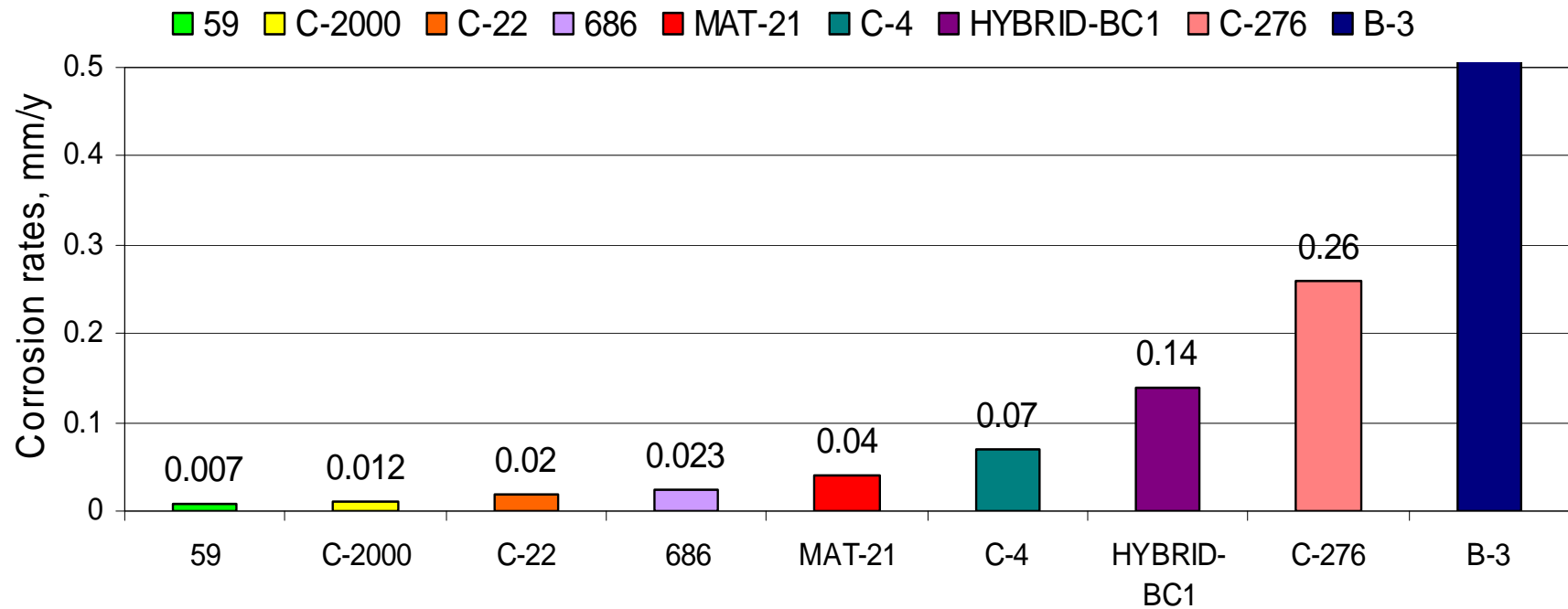


Comparison of 0.1 mm/y lines for HYBRID-BC1 and C-2000 alloys in HNO<sub>3</sub>



Comparison of 0.5 mm/y lines for HYBRID-BC1 and C-2000 alloys in HNO<sub>3</sub>

# Comparative Behavior in 10% HNO<sub>3</sub>, boiling



# Comparative Corrosion Data in Dilute 1 and 2.5% HCl Purged with O<sub>2</sub> and N<sub>2</sub>

Corrosion Rates for HYBRID-BC1, B-3 and C-2000 Alloys in 1% and 2.5% in Hydrochloric Acid  
Purged with O<sub>2</sub> and N<sub>2</sub> during 96 hours, at Different Temperatures

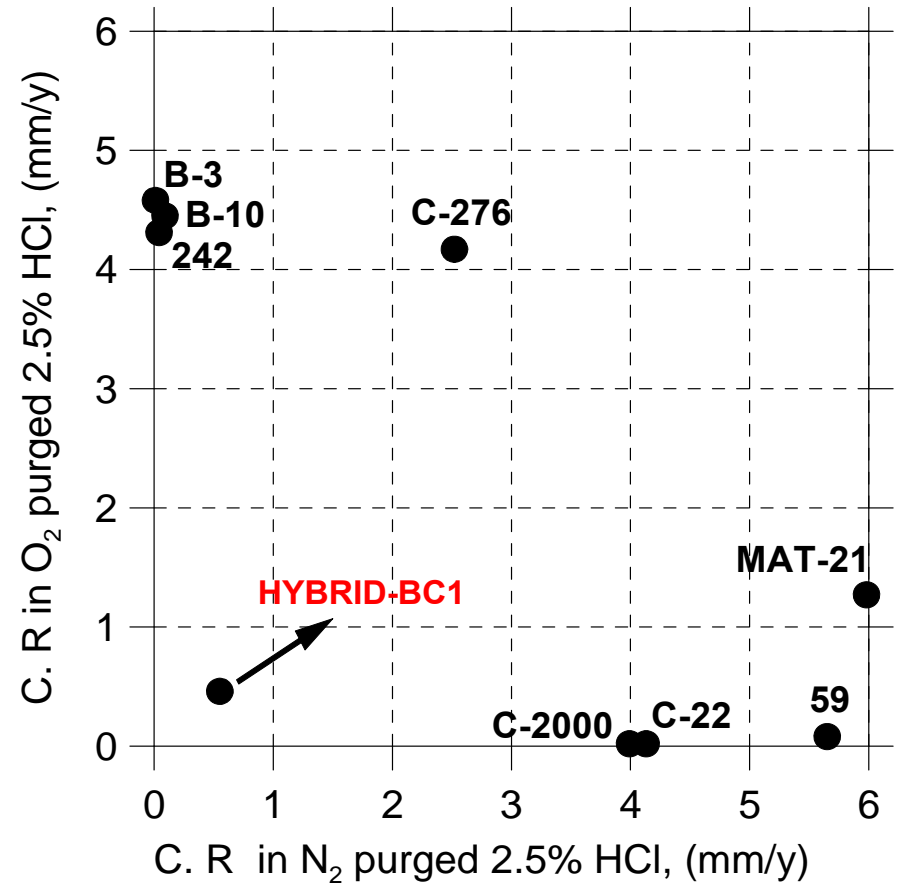
Media	Temp. °C	Corrosion Rates					
		HYBRID-BC1		C-2000		B-3	
		mpy	mm/y	mpy	mm/y	mpy	mm/y
1% HCl + O <sub>2</sub>	135	10.4	0.26	0.30	0.01	N/T*	N/T
1% HCl + N <sub>2</sub>		2.70	0.07	81.20	2.06	2.30	0.07
1% HCl + O <sub>2</sub>	149	25.50	0.65	1.50	0.04	N/T	N/T
1% HCl + N <sub>2</sub>		3.80	0.10	76.10	1.93	3.40	0.09
2.5% HCl + O <sub>2</sub>	107	9.40	0.24	0.30	0.01	196	4.98
2.5% HCl + N <sub>2</sub>		10.30	0.26	94.30	2.40	1.50	0.02
2.5% HCl + O <sub>2</sub>	121	18.20	0.46	0.70	0.02	180.5	4.58
2.5% HCl + N <sub>2</sub>		21.80	0.55	157	3.99	0.10	0.01
2.5% HCl + O <sub>2</sub>	135	40.20	1.02	2.80	0.07	N/T	N/T
2.5% HCl + N <sub>2</sub>		20.40	0.52	405.5	10.30	0.90	0.02

\*N/T = Not Tested

# Comparative Corrosion Performance of the studied Alloys in Dilute 2.5% HCl Purged with O<sub>2</sub> and N<sub>2</sub>

Autoclaves tests in 2.5% HCl purged with O<sub>2</sub> and N<sub>2</sub> during 96 hours, at 121°C

ALLOY	Corrosion Rates (mm/y)	
	Oxygenated 2.5% HCl	Nitrogenated 2.5% HCl
HYBRID-BC1	0.46	0.55
B-3	4.58	0.01
B-10	4.45	0.09
242	4.30	0.04
C-276	4.17	2.52
C-22	0.02	4.13
C-2000	0.02	3.99
VDM-59	0.08	5.65
MAT-21	1.27	5.98
C-4*	16.52	8.75
INCONEL 686*	8.93	8.23



Corrosion rates in nitrogen and oxygen purged at 2.5% HCl of the studied alloys, at 121°C.

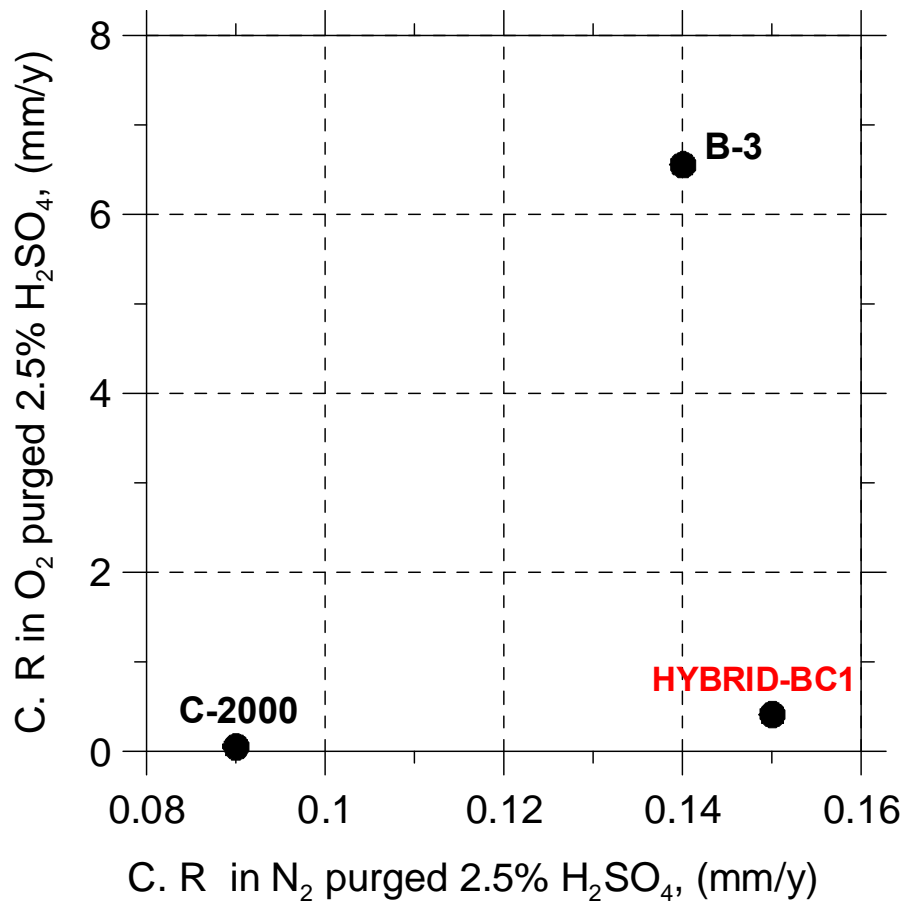
\*C-4 and INCONEL 686 alloys are not shown in the graph because of their very high corrosion rates

# Comparative Corrosion Data in Dilute 2.5% and 5% H<sub>2</sub>SO<sub>4</sub> Purged with O<sub>2</sub> and N<sub>2</sub> purged

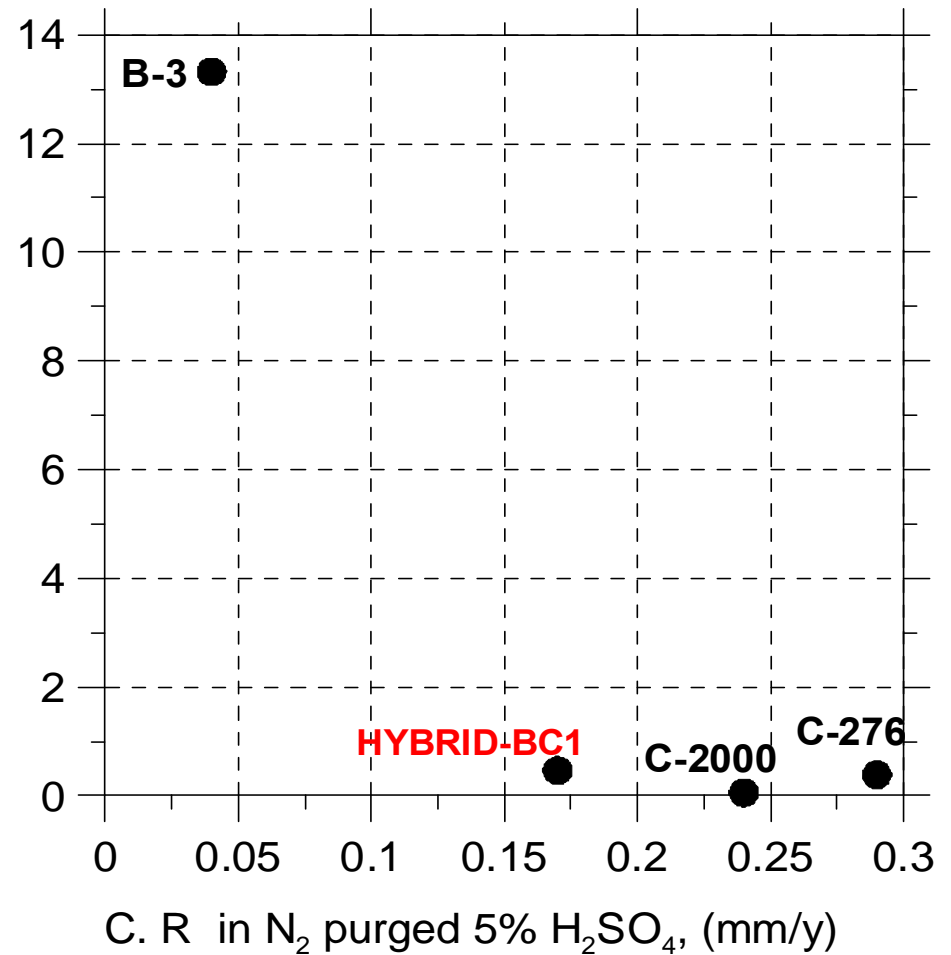
Corrosion Rates for HYBRID-BC1, B-3 and C-2000 Alloys in 2.5% and 5% in Sulfuric Acid  
Purged with O<sub>2</sub> and N<sub>2</sub> during 96 hours, at Different Temperatures

Media	Temp. °C	Corrosion Rates					
		HYBRID-BC1		C-2000		B-3	
		mpy	mm/y	mpy	mm/y	mpy	mm/y
2.5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	107	7.10	0.18	0.70	0.02	N/T	N/T
2.5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		4.30	0.11	0.80	0.02	6.10	0.15
2.5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	121	16.20	0.41	2.00	0.05	258	6.55
2.5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		5.80	0.15	3.60	0.09	5.50	0.14
2.5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	135	38.5	0.98	4.50	0.11	N/T	N/T
2.5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		6.70	0.17	14.70	0.37	6.90	0.18
2.5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	149	86.50	2.20	8.10	0.21	N/T	N/T
2.5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		14.50	0.37	22.10	0.56	4.20	0.11
5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	121	18	0.46	1.90	0.05	525	13.32
5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		6.60	0.17	9.60	0.24	1.50	0.04
5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	135	46.60	1.18	7.90	0.20	N/T	N/T
5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		9.40	0.24	17.30	0.44	4.20	0.09
5% H <sub>2</sub> SO <sub>4</sub> + O <sub>2</sub>	149	N/T*	N/T	16.30	0.41	523	13.28
5% H <sub>2</sub> SO <sub>4</sub> + N <sub>2</sub>		25.2	0.64	34.30	0.87	6.80	0.17

## Comparative Corrosion Performance of the studied Alloys in Dilute 2.5% and 5% H<sub>2</sub>SO<sub>4</sub> Purged with O<sub>2</sub> and N<sub>2</sub>



Corrosion Rates in Nitrogen and Oxygen purged at 2.5% H<sub>2</sub>SO<sub>4</sub>, of the Studied Alloys, at 121°C



Corrosion Rates in Nitrogen and Oxygen purged at 5% H<sub>2</sub>SO<sub>4</sub>, of the Studied Alloys, at 121°C

# Comparative Corrosion Data in the Presence of Ferric and Cupric ions in Boiling Hydrochloric Acid

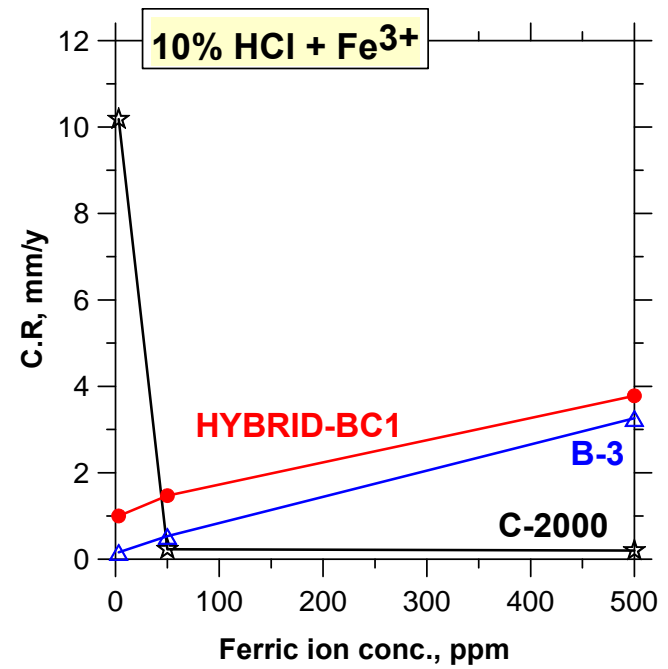
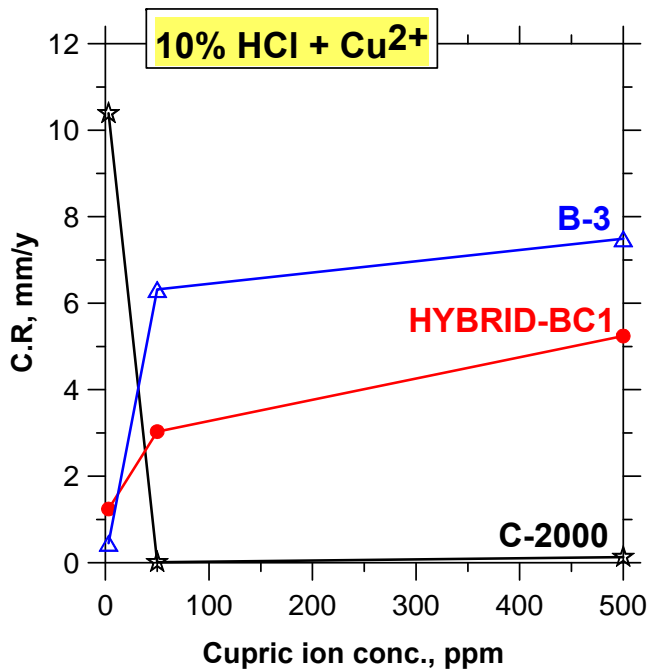
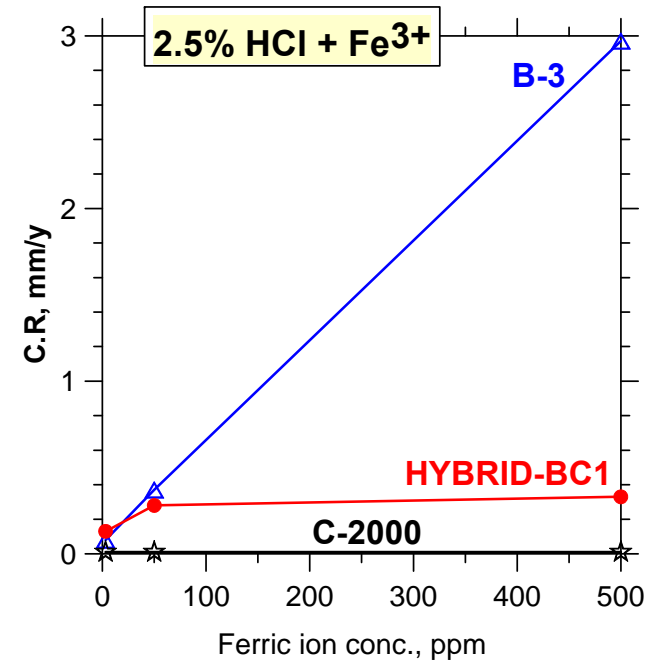
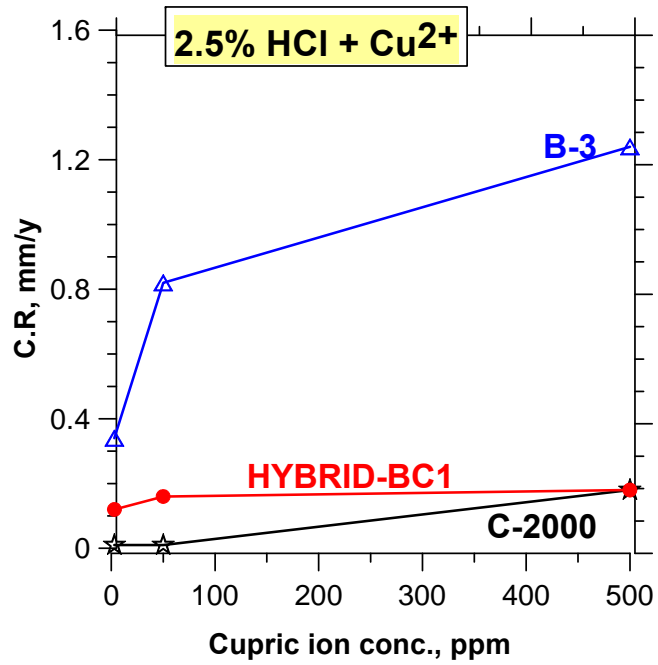
Acid, wt. %	Metallic ions Content*	Corrosion rate (mpy)					
		B-3	C-2000	HYBRID-BC1	C-4	C-276	242
Boiling 2.5% HCl	3 ppm Cu <sup>2+</sup>	13.1 <sup>1</sup>	0.4 <sup>1</sup>	4.7 <sup>5</sup>	96.8 <sup>1</sup>	64.1 <sup>6</sup>	16.9 <sup>1</sup>
	50 ppm Cu <sup>2+</sup>	32.1 <sup>1</sup>	0.4 <sup>1</sup>	6.2 <sup>5</sup>	3.6 <sup>1</sup>	2.7 <sup>6</sup>	99.5 <sup>1</sup>
	500 ppm Cu <sup>2+</sup>	49.0 <sup>1</sup>	6.9 <sup>1</sup>	7.1 <sup>5</sup>	238.0 <sup>1</sup>	2.7 <sup>6</sup>	41.5 <sup>1</sup>
	3 ppm Fe <sup>3+</sup>	3.1 <sup>4</sup>	0.3 <sup>4</sup>	5.0 <sup>5</sup>	85.6 <sup>1</sup>	70.1 <sup>6</sup>	6.6 <sup>4</sup>
	50 ppm Fe <sup>3+</sup>	14.4 <sup>2</sup>	0.4 <sup>2</sup>	11.2 <sup>5</sup>	1.2 <sup>1</sup>	2.7 <sup>6</sup>	
	500 ppm Fe <sup>3+</sup>	117.0 <sup>3</sup>	0.4 <sup>3</sup>	13.0 <sup>5</sup>	1.0 <sup>1</sup>	2.8 <sup>6</sup>	130.0 <sup>3</sup>
Boiling 10% HCl	3 ppm Cu <sup>2+</sup>	17.7 <sup>1</sup>	409.3 <sup>1</sup>	48.7 <sup>5</sup>	232.0 <sup>1</sup>	278.0 <sup>6</sup>	22.6 <sup>1</sup>
	50 ppm Cu <sup>2+</sup>	249.0 <sup>1</sup>	0.2 <sup>1</sup>	119.5 <sup>5</sup>	3.1 <sup>1</sup>	245.0 <sup>6</sup>	282.0 <sup>1</sup>
	500 ppm Cu <sup>2+</sup>	207.5 <sup>1</sup>	5.3 <sup>1</sup>	206.5 <sup>5</sup>	176.5 <sup>1</sup>	212.0 <sup>6</sup>	186.5 <sup>1</sup>
	3 ppm Fe <sup>3+</sup>	6.4 <sup>4</sup>	401.0 <sup>4</sup>	39.4 <sup>5</sup>	114.0 <sup>1</sup>	9.7 <sup>6</sup>	21.2 <sup>4</sup>
	50 ppm Fe <sup>3+</sup>	20.9 <sup>2</sup>	8.9 <sup>2</sup>	57.7 <sup>5</sup>	255.0 <sup>1</sup>	8.4 <sup>6</sup>	
	500 ppm Fe <sup>3+</sup>	128.5 <sup>3</sup>	7.8 <sup>3</sup>	149.0 <sup>5</sup>	226.0 <sup>1</sup>	9.6 <sup>6</sup>	157.5 <sup>3</sup>

\*Added as Chlorides

<sup>1</sup> Job 31-98 (4-24)    <sup>2</sup> Job 6-98 (1-24)

<sup>3</sup> Job 9-98 (1-24)    <sup>4</sup> Job 25-98 (4-24)

<sup>5</sup> Job 10-08 (4-24)    <sup>6</sup> Job 37-99 (4-24)



# Comparative Corrosion Data in the Presence of Ferric and Cupric ions in Boiling Sulfuric Acid

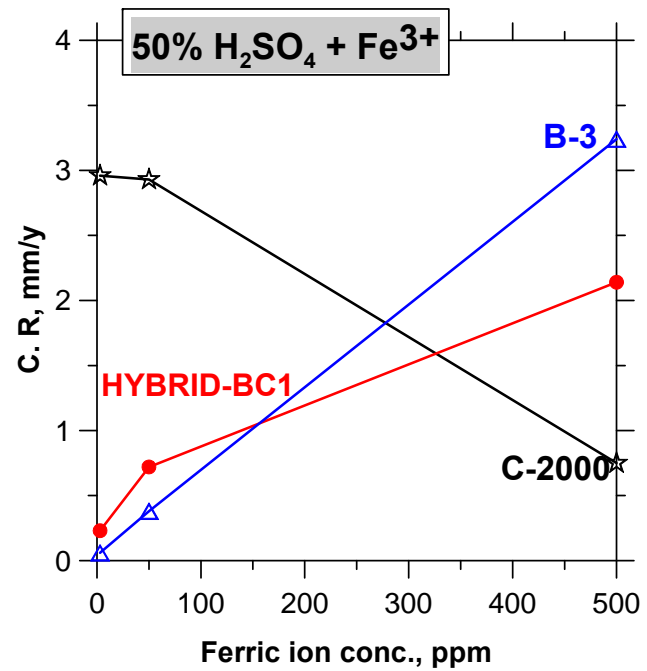
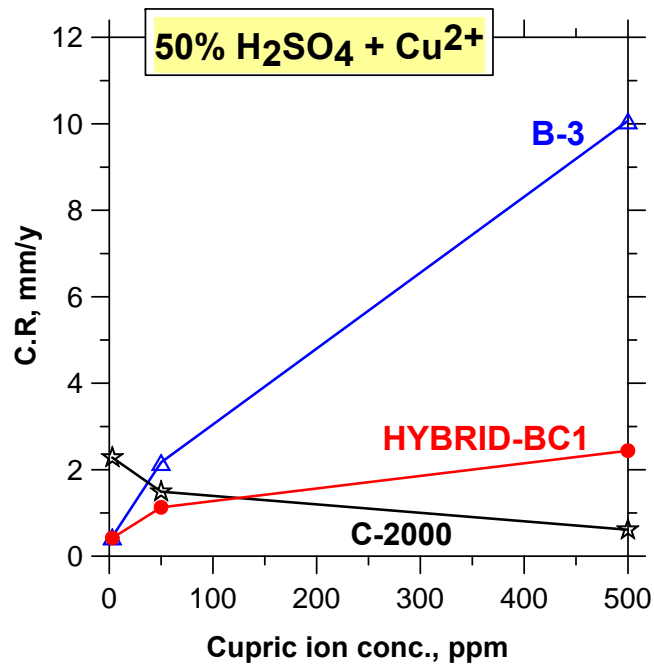
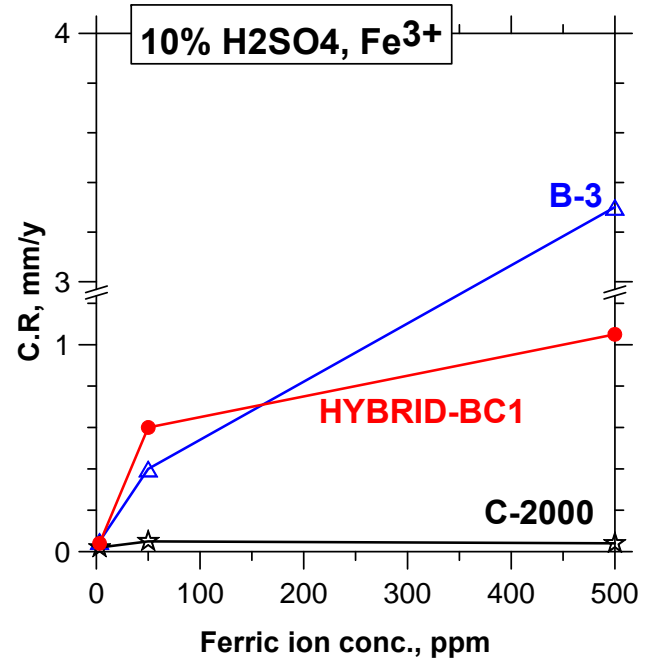
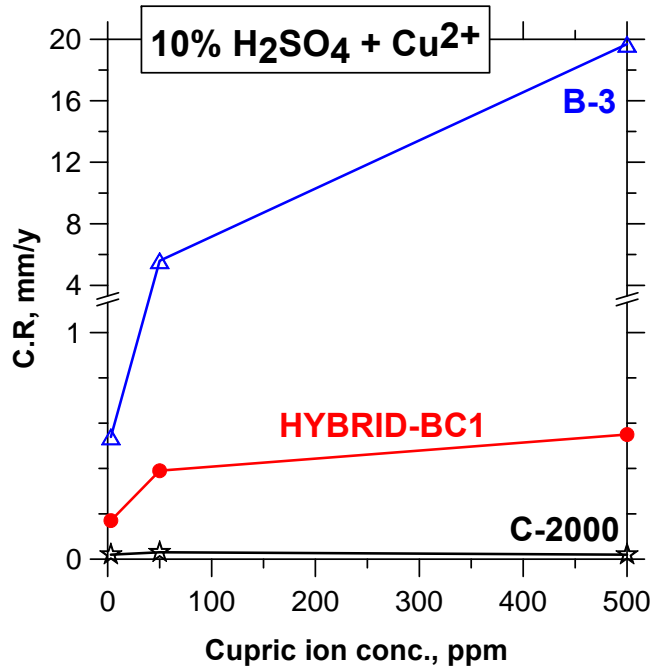
Acid	Metallic ion contents*	Corrosion rate (mpy)					
		B-3	C-2000	HYBRID-BC1	C-4	C-276	242
BOILING 10% H <sub>2</sub> SO <sub>4</sub>	3 ppm Cu <sup>2+</sup>	21.2 <sup>1</sup>	0.8 <sup>1</sup>	6.5 <sup>5</sup>	11.8 <sup>1</sup>	8.8 <sup>6</sup>	19.5 <sup>1</sup>
	50 ppm Cu <sup>2+</sup>	220.5 <sup>1</sup>	1.0 <sup>1</sup>	15.3 <sup>5</sup>	8.4 <sup>1</sup>	8.6 <sup>6</sup>	184.0 <sup>1</sup>
	500 ppm Cu <sup>2+</sup>	775.0 <sup>1</sup>	0.9 <sup>1</sup>	21.7 <sup>5</sup>	6.9 <sup>1</sup>	8.5 <sup>6</sup>	495.5 <sup>1</sup>
	3 ppm Fe <sup>3+</sup>	1.9 <sup>4</sup>	0.9 <sup>4</sup>	1.6 <sup>5</sup>	16.0 <sup>1</sup>	281.0 <sup>6</sup>	3.9 <sup>4</sup>
	50 ppm Fe <sup>3+</sup>	15.8 <sup>2</sup>	1.8 <sup>2</sup>	23.6 <sup>5</sup>	6.2 <sup>1</sup>	299.0 <sup>6</sup>	
	500 ppm Fe <sup>3+</sup>	130.0 <sup>3</sup>	1.5 <sup>3</sup>	41.2 <sup>5</sup>	5.6 <sup>1</sup>	220.0 <sup>6</sup>	131.0 <sup>3</sup>
BOILING 50% H <sub>2</sub> SO <sub>4</sub>	3 ppm Cu <sup>2+</sup>	17.8 <sup>1</sup>	89.6 <sup>1</sup>	16.4 <sup>5</sup>	90.8 <sup>1</sup>	105.0 <sup>6</sup>	22.1 <sup>1</sup>
	50 ppm Cu <sup>2+</sup>	85.6 <sup>1</sup>	58.5 <sup>1</sup>	44.7 <sup>5</sup>	88.2 <sup>1</sup>	115.0 <sup>6</sup>	85.9 <sup>1</sup>
	500 ppm Cu <sup>2+</sup>	396.5 <sup>1</sup>	24.2 <sup>1</sup>	96.2 <sup>5</sup>	157.0 <sup>1</sup>	112.0 <sup>6</sup>	275.5 <sup>1</sup>
	3 ppm Fe <sup>3+</sup>	2.5 <sup>4</sup>	116.5 <sup>4</sup>	8.9 <sup>5</sup>	311.0 <sup>1</sup>	184.0 <sup>6</sup>	7.9 <sup>4</sup>
	50 ppm Fe <sup>3+</sup>	15.1 <sup>2</sup>	115.5 <sup>2</sup>	28.2 <sup>5</sup>	323.0 <sup>1</sup>	195.0 <sup>6</sup>	
	500 ppm Fe <sup>3+</sup>	127.5 <sup>3</sup>	29.7 <sup>3</sup>	84.1 <sup>5</sup>	156.0 <sup>1</sup>	255.0 <sup>6</sup>	142.0 <sup>3</sup>

\*Added as Chlorides

<sup>1</sup> Job 31-98 (4-24)    <sup>2</sup> Job 6-98 (1-24)

<sup>3</sup> Job 9-98 (1-24)    <sup>4</sup> Job 25-98 (4-24)

<sup>5</sup> Job 11-08 (4-24)    <sup>6</sup> Job 37-99 (4-24)



# Corrosion Data in 50%, 60%, 70%, 80%, and 90% Sulfuric Acid Containing 0 to 1,000 ppm Ferric and Cupric Ions, at 107°C

## Data in the presence of ferric ions, at 107°C

Conc. Fe <sup>3+</sup> ppm	Corrosion rates, mm/y			
	50% H <sub>2</sub> SO <sub>4</sub>	70% H <sub>2</sub> SO <sub>4</sub>	80% H <sub>2</sub> SO <sub>4</sub>	90% H <sub>2</sub> SO <sub>4</sub>
0	0.13	0.07	0.06	0.07
10	0.11	0.09	0.07	0.08
25	0.14	0.10	0.09	0.09
50	0.17	0.13	0.11	0.12
100	0.28	0.19	0.17	0.16
250	0.58	0.52	0.28	0.27
500	1.17	0.67	0.53	0.43
1000	2.34	1.27	0.84	0.52

Job 1-09 (4-24)

## Data in the presence of cupric ions, at 107°C

Conc. Cu <sup>2+</sup> ppm	Corrosion rates, mm/y			
	50% H <sub>2</sub> SO <sub>4</sub>	70% H <sub>2</sub> SO <sub>4</sub>	80% H <sub>2</sub> SO <sub>4</sub>	90% H <sub>2</sub> SO <sub>4</sub>
0	0.13	0.07	0.06	0.07
10	0.20	0.13	0.12	0.14
25	0.24	0.16	0.14	0.17
50	0.28	0.18	0.14	0.22
100	0.28	0.19	0.20	0.31
250	0.38	0.25	0.24	0.57
500	0.45	0.28	0.33	0.63
1000	0.56	0.33	0.77	0.47

Job 1-09 (4-24)

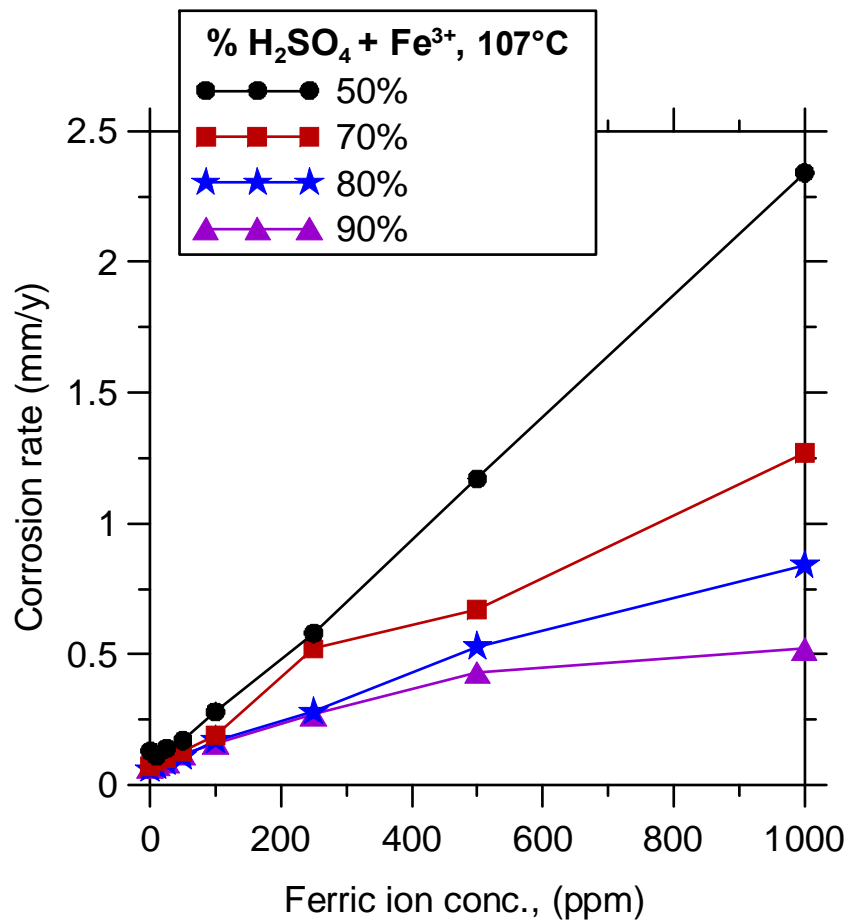


FIGURE 1. Effect of ferric ions on the corrosion rates of the HYBRID-BC1 alloy in different concentrations H<sub>2</sub>SO<sub>4</sub>, at 107°C.

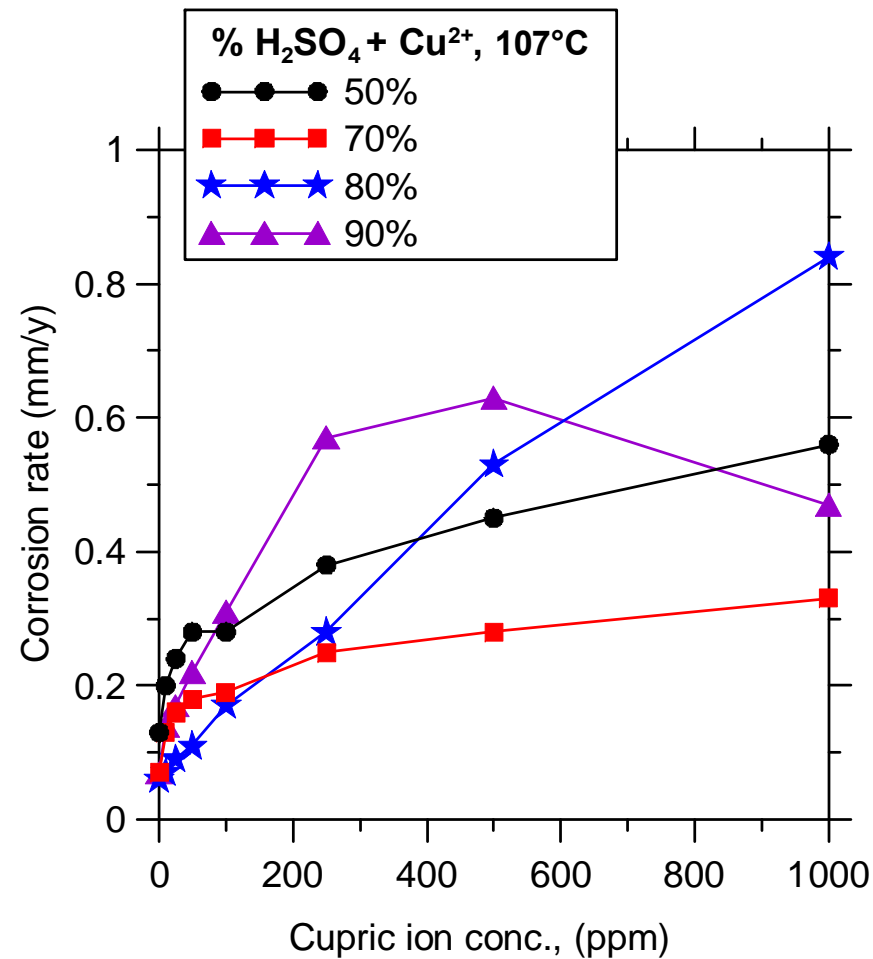


FIGURE 2. Effect of cupric ions on the corrosion rates of the HYBRID-BC1 alloy in different concentrations H<sub>2</sub>SO<sub>4</sub>, at 107°C.

## Corrosion Data in 50, 60, 70, 80, and 90 Sulfuric Acid Containing 0 to 1,000 ppm Ferric and Cupric Ions, at 121°C

### Data in the presence of ferric ions, at 121°C

Conc. Fe <sup>3+</sup> ppm	Corrosion Rates, mm/y			
	50% H <sub>2</sub> SO <sub>4</sub>	70% H <sub>2</sub> SO <sub>4</sub>	80% H <sub>2</sub> SO <sub>4</sub>	90% H <sub>2</sub> SO <sub>4</sub>
0	0.15	0.28	0.15	0.14
10	0.19	0.34	0.18	0.17
25	0.22	0.35	0.15	0.17
50	0.27	0.40	0.18	0.19
100	0.40	0.60	0.19	0.23
250	0.96	0.42	0.37	0.27
500	1.50	0.87	0.59	0.40
1000	2.88	1.67	1.05	0.44

Job 1-09 (4-24)

### Data in the presence of cupric ions, at 121°C

Conc. Cu <sup>2+</sup> ppm	Corrosion Rates, mm/y			
	50% H <sub>2</sub> SO <sub>4</sub>	70% H <sub>2</sub> SO <sub>4</sub>	80% H <sub>2</sub> SO <sub>4</sub>	90% H <sub>2</sub> SO <sub>4</sub>
0	0.15	0.28	0.15	0.14
10	0.33	0.34	0.23	0.32
25	0.46	0.43	0.48	0.54
50	0.71	0.48	0.27	0.57
100	0.63	0.98	0.52	0.56
250	0.97	0.39	0.316	0.53
500	1.28	0.53	0.44	0.70
1000	1.22	0.85	0.67	0.70

Job 1-09 (4-24)

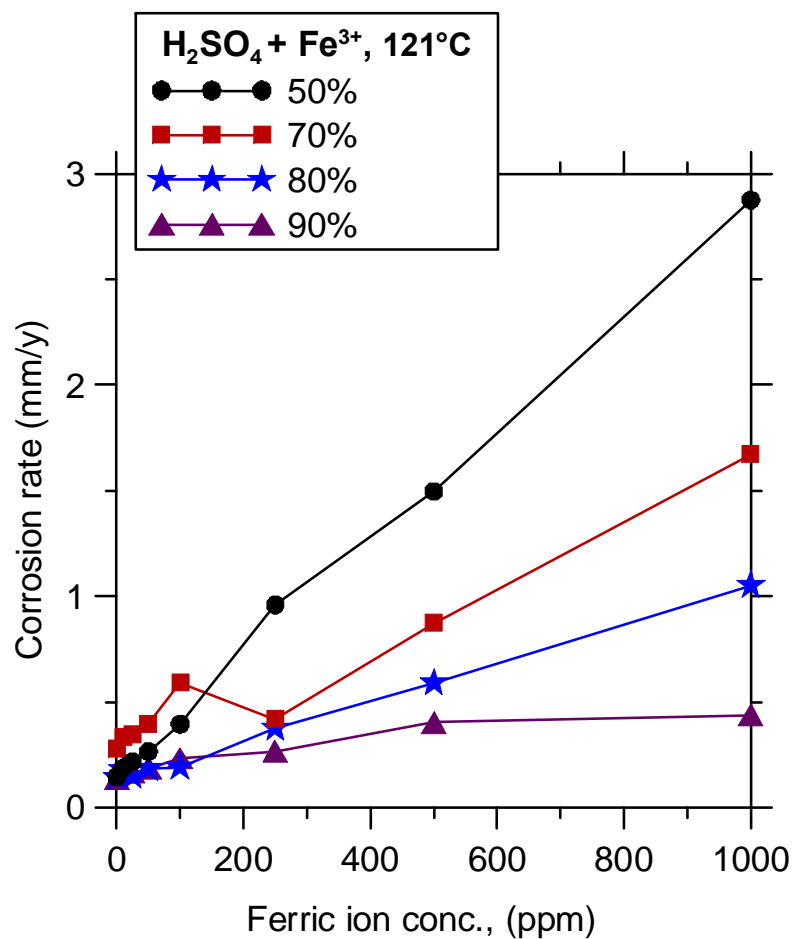


FIGURE 1. Effect of ferric ions on the corrosion rates of the HYBRID-BC1 alloy in different concentrations H<sub>2</sub>SO<sub>4</sub>, at 121°C.

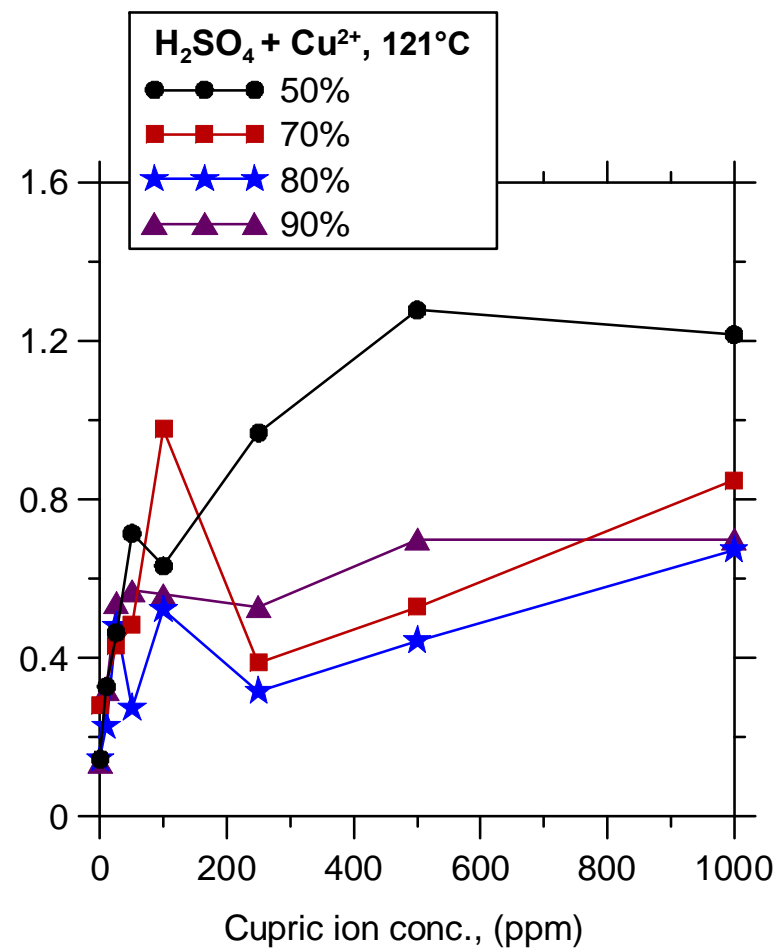
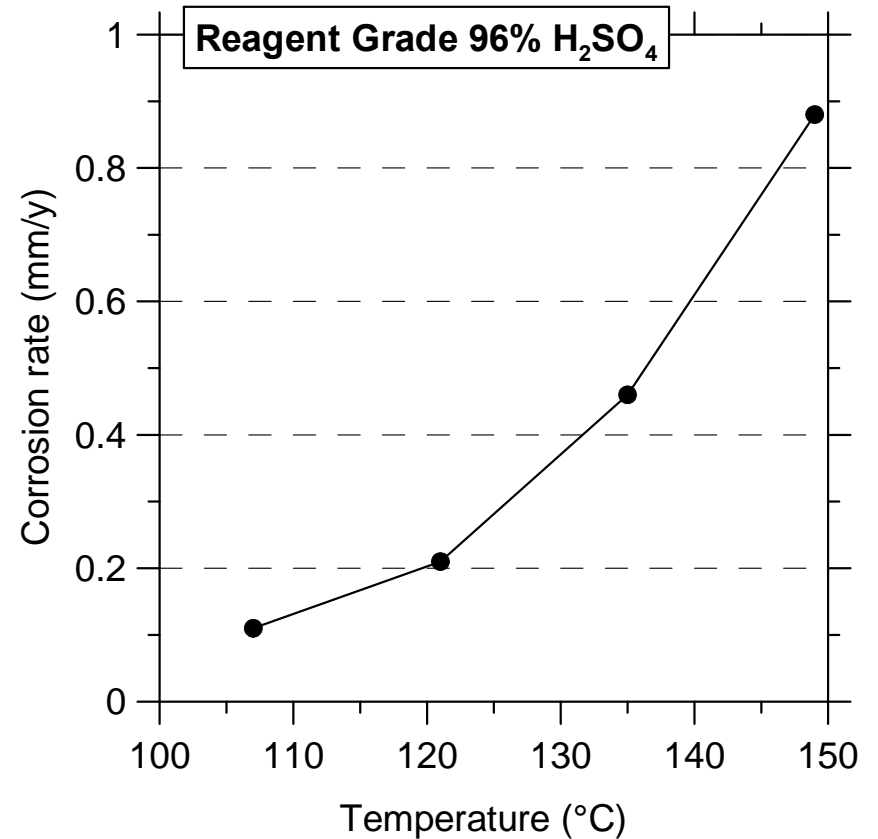


FIGURE 5. Effect of cupric ions on the corrosion rates of the HYBRID-BC1 alloy in different concentrations of H<sub>2</sub>SO<sub>4</sub> at 121°C.

# Corrosion Data in Concentrated 96% Sulfuric Acid

Temp. °C	Periods	Corrosion Rates	
		mpy	mm/y
107	4-24	4.2	0.10
121	4-24	8.1	0.21
135	4-24	16.4	0.42
149	4-24	32.6	0.83

Job 11-08 (4-24)



Corrosion performance of the HYBRID-BC1 alloy in concentrated 96 % H<sub>2</sub>SO<sub>4</sub>, at different temperatures.

## Corrosion Data in Concentrated 96% Sulfuric Acid in the Presence of Ferric Ions

Media	Temp. °C	Periods	Corrosion Rates	
			mpy	mm/y
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Fe	107	4-24	4.2	0.100
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Fe	121	4-24	8.1	0.206
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Fe	135	4-24	16.4	0.416
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Fe	149	4-24	32.6	0.827
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Fe	107	4-24	5.5	0.140
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Fe	121	4-24	8.9	0.226
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Fe	135	4-24	16.5	0.419
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Fe	149	4-24	36.7	0.932
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Fe	107	4-24	5.95	0.150
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Fe	121	4-24	10.2	0.259
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Fe	135	4-24	18.2	0.462
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Fe	149	4-24	36.1	0.917
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Fe	107	4-24	6.4	0.160
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Fe	121	4-24	11	0.279
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Fe	135	4-24	19.6	0.498
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Fe	149	4-24	34.4	0.873
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Fe	107	4-24	6.6	0.170
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Fe	121	4-24	15.8	0.401
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Fe	135	4-24	24.8	0.630
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Fe	149	4-24	32.5	0.825
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Fe	107	4-24	7.6	0.190
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Fe	121	4-24	13.8	0.350
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Fe	135	4-24	25.6	0.650
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Fe	149	4-24	40.4	1.026

Job 11-08 (4-24)

## Corrosion Data in Concentrated 96% Sulfuric Acid in the Presence of Cupric Ions

Media	Temp., °C	Periods	Corrosion Rates	
			mpy	mm/y
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Cu	107	4-24	5.4	0.14
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Cu	121	4-24	9.2	0.234
96% H <sub>2</sub> SO <sub>4</sub> + 3 ppm Cu	135	4-24	17	0.432
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Cu	107	4-24	14	0.360
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Cu	121	4-24	39.4	1.000
96% H <sub>2</sub> SO <sub>4</sub> + 50 ppm Cu	135	4-24	106	2.691
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Cu	107	4-24	13.4	0.340
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Cu	121	4-24	44	1.117
96% H <sub>2</sub> SO <sub>4</sub> + 100 ppm Cu	135	4-24	139	3.529
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Cu	107	4-24	10.9	0.277
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Cu	121	4-24	47.8	1.214
96% H <sub>2</sub> SO <sub>4</sub> + 250 ppm Cu	135	4-24	166	4.215
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Cu	107	4-24	11.9	0.302
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Cu	121	4-24	62.1	1.577
96% H <sub>2</sub> SO <sub>4</sub> + 500 ppm Cu	135	4-24	163.5	4.151
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Cu	107	4-24	13.2	0.335
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Cu	121	4-24	44.8	1.137
96% H <sub>2</sub> SO <sub>4</sub> + 1000 ppm Cu	135	4-24	149.5	3.796

Job 11-08 (4-24)

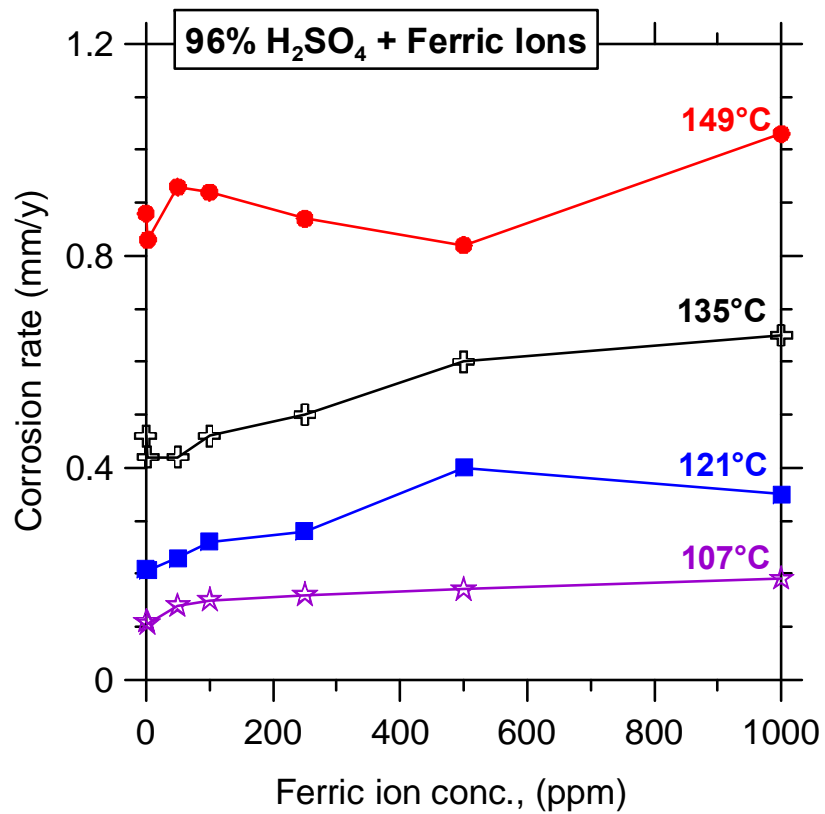


FIGURE 1. Effect of ferric ions on the corrosion rates of the HYBRID-BC1 alloy in 96% H<sub>2</sub>SO<sub>4</sub> at different temperatures.

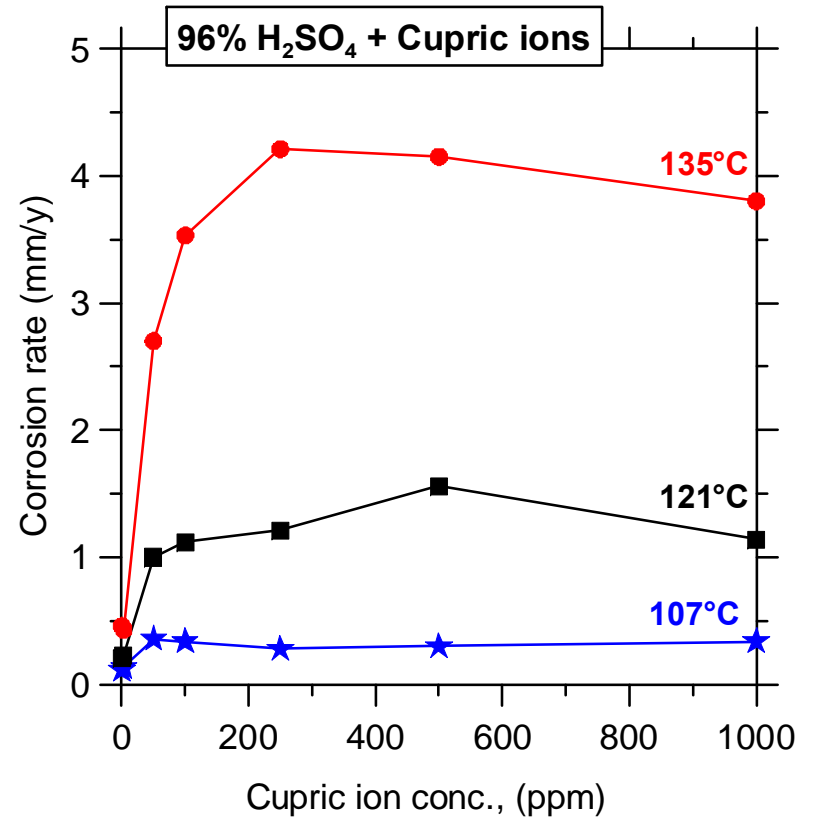


FIGURE 2. Effect of cupric ions on the corrosion rates of the HYBRID-BC1 alloy in 96% H<sub>2</sub>SO<sub>4</sub> at different temperatures.

# 10 and 20% Hydrochloric Acid Containing 1 to 1,000 ppm of Ferric Ions, at 25°, 66° and 93°C

10% HCl + Fe <sup>3+</sup> ppm	Corrosion Rates, mm/y		
	25°C	66°C	93°C
0	0.07	0.29	0.60
10	0.007	0.28	0.63
25	0.01	0.34	0.71
50	0.01	0.44	0.85
100	0.01	0.25	1.13
250	0.01	0.30	1.94
500	0.01	0.35	2.56
1000	0.02	0.38	3.45

Job 29-08 (4-24)

20% HCl + Fe <sup>3+</sup> ppm	Corrosion Rates, mm/y	
	25°C	66°C
0	0.04	0.23
10	0.04	0.25
25	0.06	0.30
50	0.08	0.38
100	0.11	0.50
250	0.14	0.97
500	0.14	1.54
1000	0.15	2.70

Job 30-08 (4-24)

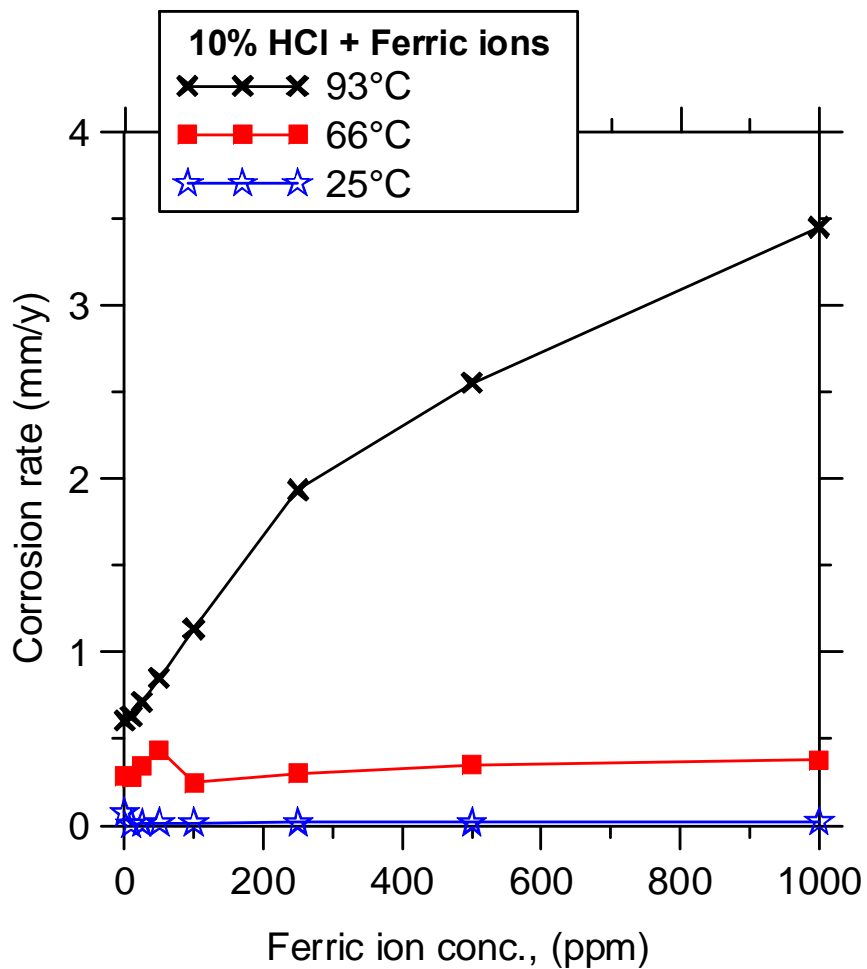


FIGURE 1. Effect of ferric ions on the corrosion rates of the HYBRID-BC1 alloy in 10% HCl at different temperatures.

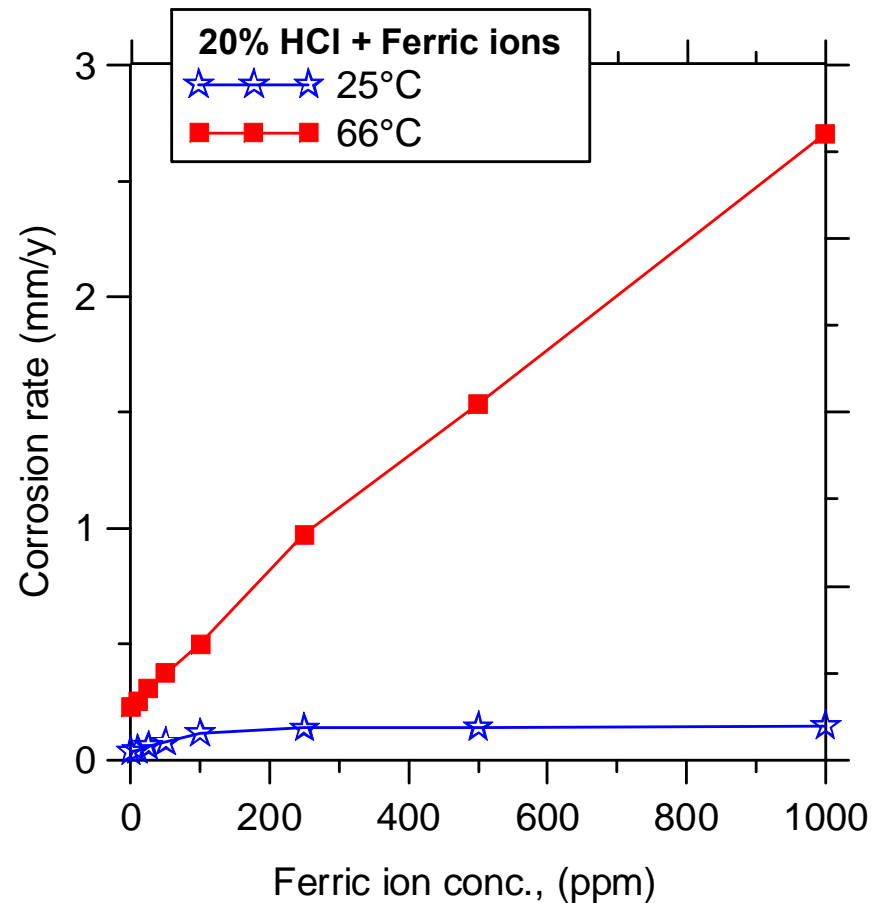
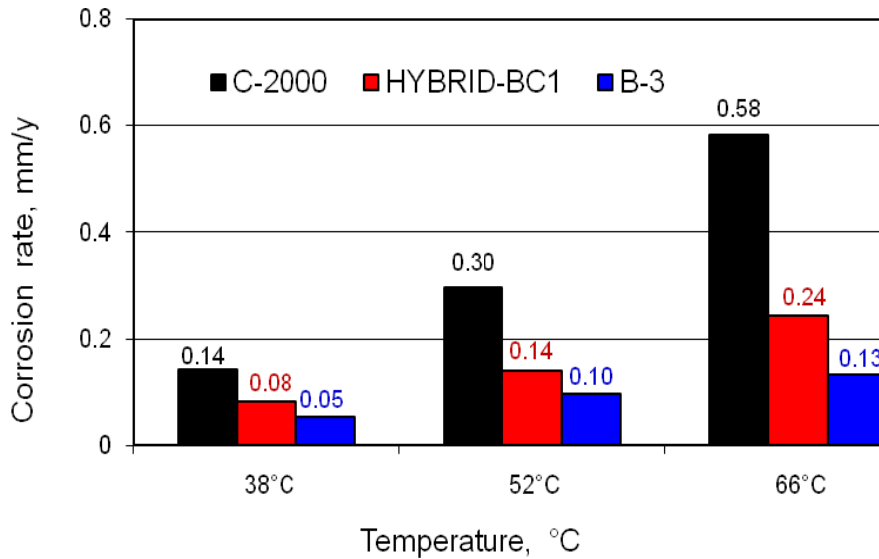
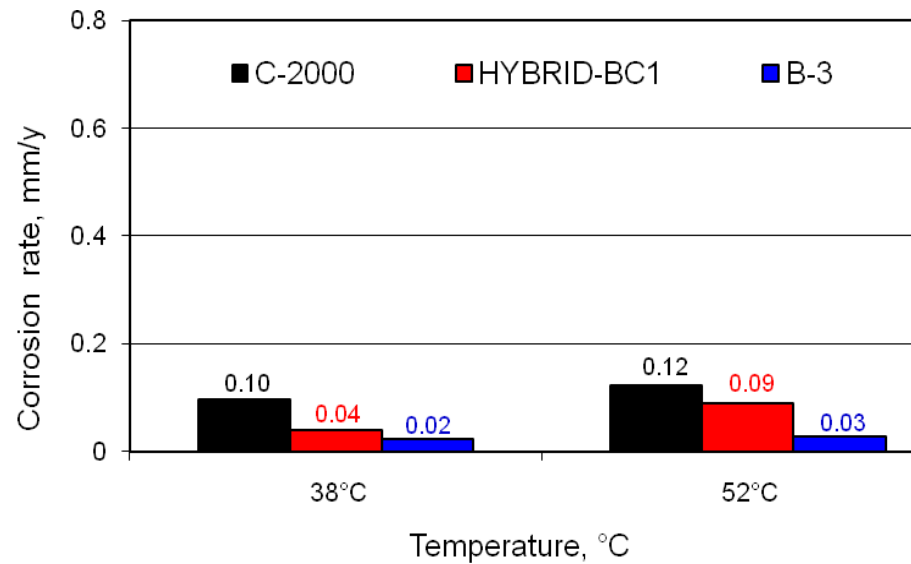


FIGURE 2. Effect of ferric ions on the corrosion rates of the HYBRID-BC1 alloy in 20% HCl at different temperatures.

# Corrosion Data in Concentrated 30 and 37% Hydrochloric Acid



**Figure 1:** Comparative corrosion rates of the HYBRID-BC1 alloy vs. C-2000 and B-3 alloys in 30% hydrochloric acid.



**Figure 2:** Comparative corrosion rates of the HYBRID-BC1 alloy vs. C-2000 and B-3 alloys in 37% hydrochloric acid.

# Corrosion Data in Chromic, Acetic and Formic Acids

Corrosion rates of the HYBRID-BC1 alloy in some other acids

Chemicals	Conc. wt. %	Temp. °C	Corrosion rates	
			mm/y	mpy
Chromic acid	5	66	0.02	0.7
		93	0.15	6.0
	10	66	0.08	3.20
		93	0.36	14.2
	20	66	0.20	8.2
		93	2.48	97.8
Acetic acid	99	Boiling	<0.01	<0.1
Formic acid	88	Boiling	0.01	0.2

Job 2-09 (4-24)

# Corrosion Data in Hydroiodic Acid

Comparative corrosion rates of the HYBRID-BC1 alloy  
Versus C-2000 and B-3 alloys in hydroiodic acid (HI)

Conc. wt. %	Temp. °C	Corrosion rate					
		HYBRID-BC1		C-2000		B-3	
		mpy	mm/y	mpy	mmy	mpy	mm/y
1	66	<0.1	<0.01	<0.1	<0.1	15.5	0.39
5	66	0.1	<0.01	<0.1	<0.01	11.9	0.30
10	66	0.1	<0.01	0.1	<0.01	14.5	0.37

Job 30-08 (4-24)

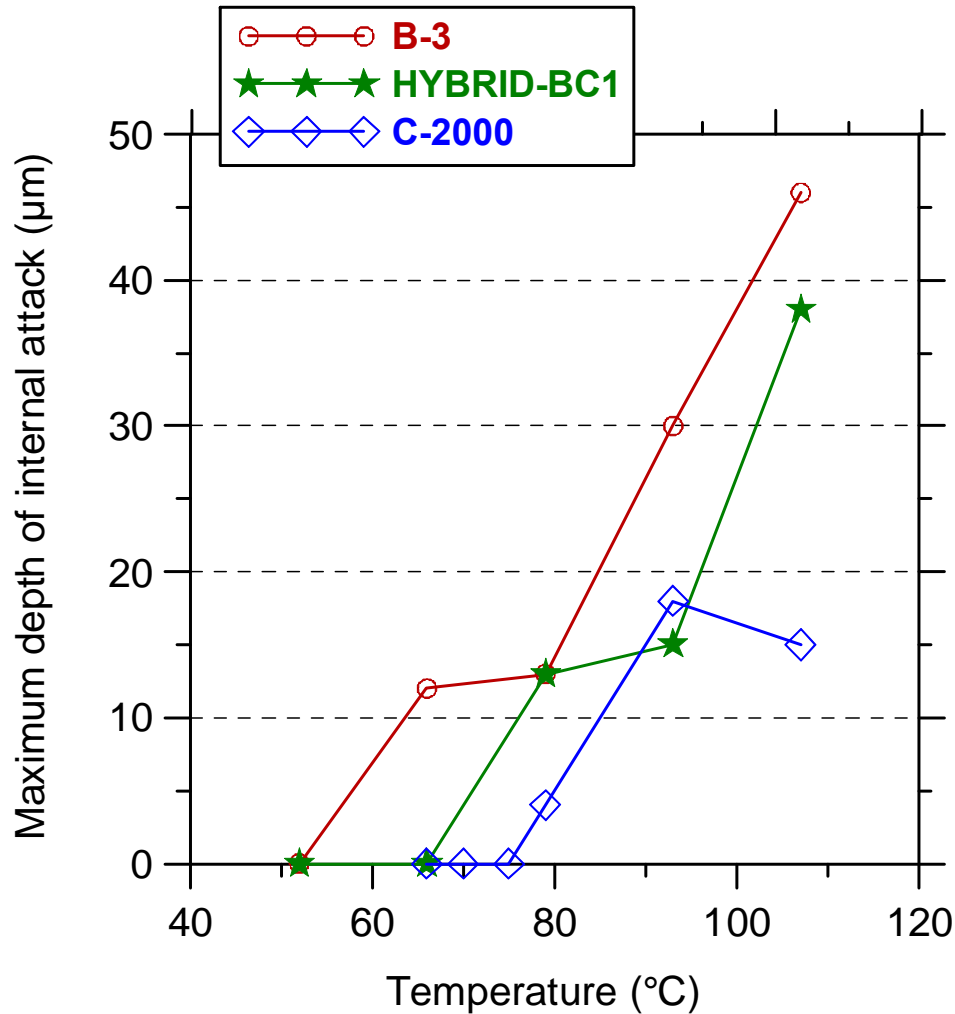
# Corrosion Data in Sodium Hydroxide

Comparative Corrosion Rates of the HYBRID-BC1 alloy  
Versus C-2000 and B-3 Alloys in 50% sodium Hydroxide (NaOH)

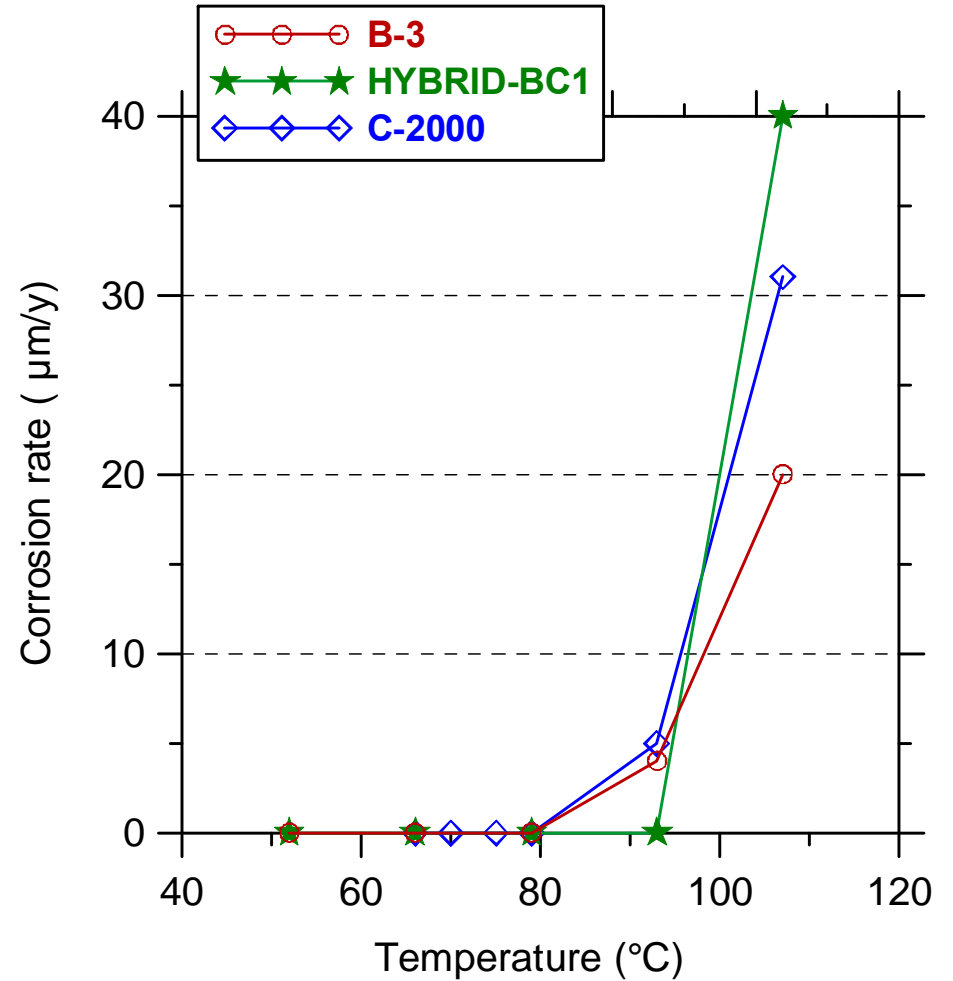
Alloy	Temp. (°C)	Corrosion Rate (mm/y)	Maximum Depth of Internal Attack (µm)
B-3	38°	<0.003	<3
	52°	<0.003	<3
	66°	<0.003	12
	79°	<0.003	13
	93°	0.004	30
	107°	0.02	46
C-2000	66°	<0.003	<3
	79°	<0.003	4
	93°	0.005	18
	107°	0.031	15
HYBRID-BC1	38°	<0.003	<3
	52°	<0.003	<3
	66°	<0.003	<3
	79°	<0.003	13
	93°	<0.003	15
	107°	0.040	38

\*Jobs 9-08 and 7-11 (4-24hrs)

# Corrosion Data in Sodium Hydroxide

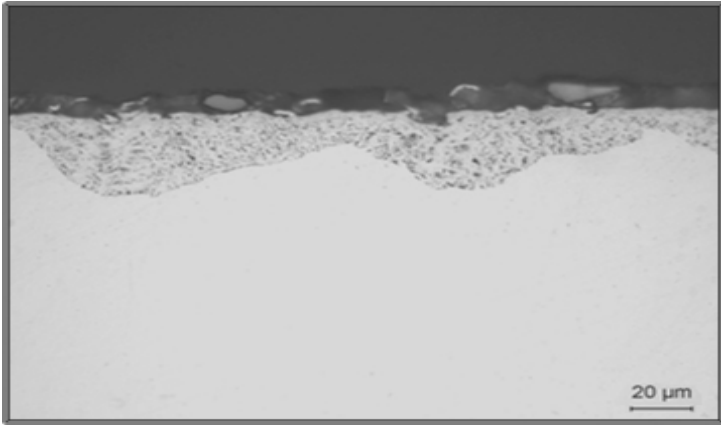


**Figure 1.** Maximum depth of internal attack of B-3, HYBRID-BC1 and C-2000 alloys in 50% NaOH for 760 hours exposure time.

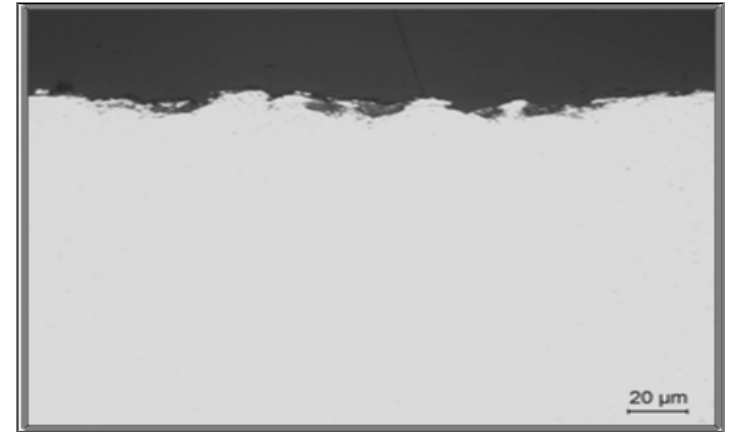


**Figure 2.** Corrosion rates of B-3, HYBRID-BC1 and C-2000 alloys in 50% sodium hydroxide for 760 hours exposure time.

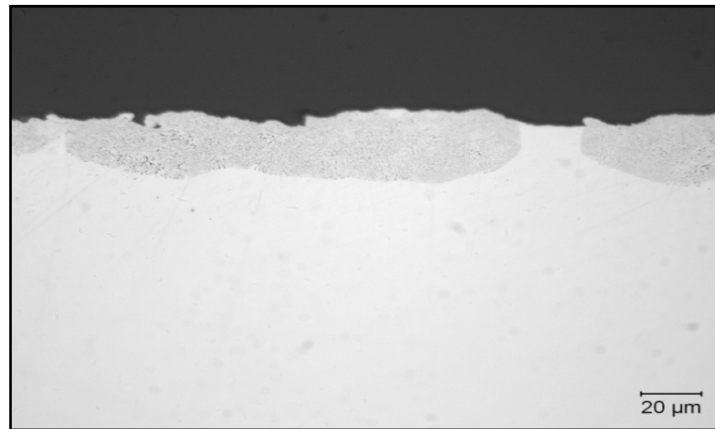
## Corrosion Data in Sodium Hydroxide



B-3<sup>®</sup> alloy: dealloying from 66°C



C-2000<sup>®</sup> alloy: dealloying from 79°C



HYBRID-BC1<sup>®</sup> alloy: dealloying from 79°C

**Figure 3.** Optical micrographs showing surface appearance of B-3<sup>®</sup>, C-2000<sup>®</sup> and HYBRID-BC1<sup>®</sup> alloys after exposure in 50% NaOH for 720 hrs at 107°C

# Comparative Welded Corrosion Data

Data in Acidified 6 wt. % FeCl<sub>3</sub> (ASTM G 48, C & D)

ALLOY	CPT, °C Base Metal	CPT, °C Weld	CCT, °C Base Metal	CCT, °C Weld
HYBRID-BC1	>85°	>85°	>85°	85°
C-4	>85°	80°	50°	40°
C-276	>85°	>85°	55°	55°
C-22	>85°	>85°	80°	80°
C-2000	>85°	>85°	80°	80°
59	>85°	>85°	>85°	>85°
686	>85°	>85°	>85°	>85°
MAT-21	>85°	-	>85°	-

Job 27-08 and Job 23-09 (72 hrs)

## Additional Welded Corrosion Data

Corrosion Performance of the HYBRID-BC1 Alloy in the "As Welded Conditions"  
Tested in the Most Relevant Chemicals vs. the Other C-type Alloys- Exposure time 4-24 h

Media	Temp. °C	Corrosion Rates (mm/y)					
		HYBRID-BC1	C-276	C-22	C-2000	59	686
2.5% HCl	Boil	0.19	1.85	3.83	0.34	10.99	0.42
10% HCl	Boil	1.08	7.20	11.02	11.20	7.10	6.42
10% HNO <sub>3</sub>	Boil	0.24	0.06	0.025	0.025	0.025	0.025
30% H <sub>2</sub> SO <sub>4</sub>	93°	0.08	0.42	0.680	0.01	0.05	0.06
70 % H <sub>2</sub> SO <sub>4</sub>	93°	0.05	0.50	0.94	0.42	5.92	0.40

Job 3-09 (4-24)

# Thermal Stability Data

Tests are underway for the following heat treatments:

- 1, 3 and 10 h/800°, 1000°, 1200°, 1400°, 1600°, and 1800°F/AC
- 6, 15 and 30 min/**1000°**, 1200°, 1400°, 1600°, 1800°, and 2000°F/AC

# Mechanical Properties of the HYBRID-BC1 Alloy

## Average Tensile Properties for 0.5" Thick Plate Material at High Temperatures

Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	RA
°F	°C	ksi	MPa	%	MPa	%	%
<b>RT</b>	<b>RT</b>	54.5	376	123.5	851	79	65
<b>200</b>	<b>93</b>	48.5	334	115.5	796	78	71
<b>300</b>	<b>149</b>	44.5	307	111.0	765	76	70
<b>400</b>	<b>204</b>	40.9	282	108.0	745	73	69
<b>500</b>	<b>260</b>	38.1	263	105.0	724	75	69
<b>600</b>	<b>316</b>	36.5	252	104.5	720	74	65
<b>700</b>	<b>371</b>	34.5	238	103.0	710	74	66
<b>800</b>	<b>427</b>	33.0	228	102.5	707	77	66
<b>900</b>	<b>482</b>	32.0	221	101.0	696	76	61
<b>1000</b>	<b>538</b>	33.0	228	102.5	707	78	61
<b>1100</b>	<b>538</b>	33.0	228	109.0	751	(a)	57
<b>1200</b>	<b>649</b>	41.3	285	111.5	769	(a)	37

(a): Specimen failed outside gage mark; value based on overall length measurement

Data generated from only one plate at 0.5" thick: transversal samples of (MO 78-072550-21)

# Welding and Fabrication of the HYBRID-BC1 Alloy

The weldability of this alloy is similar to that of C-276 alloy. To weld the C-type alloys, three processes are commonly used. For sheet welds and plate root passes, gas tungsten arc (GTAW) welding is favored. For plate welds, the gas metal arc (GMAW) process is preferred and the shielded metal arc process can be used. Submerged arc welding is not recommended as the process, for this alloy has not been developed at this time. The choice of flux, the heat input and slow cooling are issues with this process on any alloy. To minimize the precipitation of second phases in regions affected by the heat of welding, a maximum inter-pass temperature of 93°C (200°F) is recommended for the C-type alloys. Also, welding of highly cold-worked materials such as a cold formed head is strongly discouraged. A full solution anneal followed by water quenching is recommended for cold-worked head structures prior to welding them to the cold rolled shells. No anneal is necessary for cold rolled vessel shells.

## Base Metal Preparation

The joint surface and adjacent area should be thoroughly cleaned before welding. All grease, oil, crayon marks, sulfur compounds, and other foreign matter should be removed.

## Filler Metal Selections

For gas tungsten arc and gas metal arc welding, HYBRID-BC1 alloy filler wire is suggested. For shielded metal arc welding, HYBRID-BC1 alloy covered electrodes are suggested.

## Suggested Practice

Safe working conditions should be established prior to welding. Welders should be properly protected, confined spaces should be avoided, and adequate ventilation should be provided. The recommendations of ANSI/ASC Z49.1, "Safety in Welding and Cutting", should be followed.

- Surfaces to be welded, and adjacent areas, should be cleaned and degreased thoroughly prior to welding.
- The Ni-Cr-Mo alloys exhibit low penetration characteristics, therefore adequate joint access (weld angle) and minimal land are suggested.

- The interpass temperature should be held below 93°C (200°F), and excessive heating should be avoided (especially on these parts).
- The weld metal is viscous (sluggish), and therefore some torch manipulation is usually necessary. Increasing the current (amperage) will not substantially increase the fluidity of the weld puddle.
- Oxyacetylene and submerged-arc welding are not recommended.
- Covered electrodes from a new (unopened) can require no drying; however, unused electrodes should be stored in an oven in the temperature range 121°C (250°F) to 204°C (400°F).
- A backing gas of 100% argon should be used for the root pass during gas-tungsten arc or gas-metal arc welding; for shielded-metal arc welding, grinding of the back side of the root pass is necessary.
- For gas-tungsten arc welding, a constant-current power supply, equipped with a high frequency start and downslope control, is recommended; torches with gas diffuser lenses provide the optimum gas coverage.
- Post-weld stress relieving at approximately 650°C (1202°F) range is inappropriate for the Ni-Cr-Mo alloys; normally a post-weld heat treatment is not necessary, but, if stresses must be relieved, a full solution anneal at 1149°C (2100°F) is recommended, followed by water quenching.
- If more than 1% of an oxidizing shielding gas is used during gas-metal arc welding, then grinding of the weld bead between each pass is recommended.
- Water-cooled torches are recommended for gas-metal arc spray transfer and synergic transfer (above 120A).

**Typical Flat Position Parameters (Manual)**

**Shielded-Metal Arc**

<b>Electrode Diameter mm (in)</b>	<b>Arc Voltage V</b>	<b>Welding Current A</b>
2.4 (3/32)	22-24	55-75
3.2 (1/8)	22-24	80-100
4.0 (5/32)	22-25	125-150
4.8 (3/16)	24-26	150-180

### Gas-Tungsten Arc

Joint Thickness mm (in)	Tungsten Electrode* & Filler Wire Dia. mm (in)	Welding Current A	Arc Voltage V
0.8-1.6 (1/32-1/16)	1.6 (1/16)	15- 80	9-12
1.6-3.2 (1/16-1/8)	1.6 or 2.4 (1/16 or 3/32)	50-115	9-12
3.2-6.4 (1/8-1/4)	2.4 or 3.2 (3/32 or 1/8)	75-175	10-13
>6.4 (>1/4)	2.4 or 3.2 (3/32 or 1/8)	95-225	10-13

\* 2% thoriated tungsten, 2% lanthanated or 2% ceriated; 100% argon shielding gas - flow rate 12-17 l/min (25-35 cu ft/hr)

### Gas-Metal Arc

	Wire Diameter		Shielding Gas*	Welding Current A	Arc Voltage V	Travel Speed	
	mm	(in)				mm/min	(in/min)
Short Arc	0.9	(0.035)	2-5	70-90	18-20	200-250	(8-10)
	1.1	(0.045)					
Fixed Pulse	1.1	(0.045)	2-4	120-150	18-20	250-380	(10-15)
Variable Pulse (Synergic)	0.9	(0.035)	2-4	50-125	-	250-380	(10-15)
	1.1	(0.045)					
Spray	1.1	(0.045)	1 & 3	190-250	30-32	250-380	(10-15)

\* Acceptable shielding gases (not in order of preference): 1. 100% argon, 2. 75% argon + 25% helium, 3. argon + helium + CO2 (NiCoBRITE), 4. argon + helium + CO2 (Helistar® SS), 5. helium + argon + CO2 (Helistar A-1025)  
Polarity: SMAW and GMAW-DCRP, Electrode Positive, GTAW-DCSP, Electrode Negative

### Heat Treatment

Wrought forms of HYBRID-BC1 alloy are furnished in the solution annealed condition, unless otherwise specified. The standard solution annealing treatment consists of heating to 1149°C (2100°F) followed by rapid air-cooling or water quenching. Parts which have been hot formed should be solution annealed prior to final fabrication or installation.

**Forming**

HYBRID-BC1 alloy has excellent forming characteristics, and cold forming is the preferred method of shaping. The alloy can be easily cold worked due to its good ductility. The alloy is generally stiffer than the austenitic stainless steels; therefore, more energy is required during cold forming. For further information, please consult publication H-2010.

# Machining of the HYBRID-BC1 Alloy

The following are guidelines for performing typical machining operations upon the HYBRID-BC1 alloy wrought stock. Exact details for specific machining jobs will vary with circumstances of the particular job. Other tool materials not listed here may be suitable for machining the HYBRID-BC1 alloy under various conditions. For further information, please consult Haynes publication H-2010.

## Recommended Tool Type and Machining Conditions

### Operations

Drilling

### Carbide Tools

C-2 grade not recommended, but tipped drills may be successful on rigid setup of no great depth. The web must be thinned to reduce thrust. Use 135° included angle on point, Gun drill can be used.

Speed: 50 sfm.  
Oil<sup>2</sup> or water-base<sup>3</sup> coolant.

Coolant-feed carbide tipped drills may be economical in some setups.

### High Speed Steel Tools

M-33, M-40 series<sup>1</sup> or T-15: Use short drills, heavy web, 135° crank-shaft, grind points wherever possible.

Speed: 10-15 sfm.  
Feed: 0.001 in. rev. 1/8 in. dia.  
0.002 in. rev. 1/4 in. dia.  
0.003 in. rev. 1/2 in. dia.  
0.005 in. rev. 3/4 in. dia.  
0.007 in. rev. 1 in. dia.

Oil or water-base coolant.  
Use coolant feed drills if possible.

Normal  
Roughing;  
Turning or  
Facing

C-2 or C-3 grade: Negative rake square insert, 45° SCEA<sup>4</sup>, 1/32 in. nose radius.

Tool holder: 5° neg. back rake, 5° neg. side rake.

Speed: 90 sfm depending on rigidity of set up, 0.010 in. feed, 0.150 in. depth of cut.

Dry<sup>5</sup>, oil, or water-base coolant.

Finishing;  
Turning or  
Facing

C-2 or C-3 grade: Positive rake square  
insert, if possible, 45° SCEA,  
1/32 in. nose radius.

Tool holder: 5° pos. back rake, 5° pos.  
side rake.

Speed: 95-110 sfm, 0.005-0.007 in.  
feed, 0.040 in. depth of cut.

Dry or water-base coolant.

#### NOTES:

<sup>1</sup> M-40 series High Speed Steels include M-41, M-42, M-43, M-44, M-45 and M-46 at the time of writing. Others may be added and should be equally suitable.

<sup>2</sup> Oil coolant should be a premium quality, sulfo-chlorinated oil with extreme pressure additives. A viscosity at 100°F from 50 to 125 SSU.

<sup>3</sup> Water-base coolant should be premium quality, sulfo-chlorinated water soluble oil or chemical emulsion with extreme pressure additives. Dilute with water to make 15:1 mix. Water-base coolant may cause chipping and rapid failure of carbide tools in interrupted cuts.

<sup>4</sup> SCEA - Side cutting edge angle or lead angle of the tool.

<sup>5</sup> At any point where dry cutting is recommended, an air jet directed on the tool may provide substantial tool life increase. A water-base coolant mist may also be effective.

# Specifications of the HYBRID-BC1 Alloy

UNS 10362

ASME Code Case No. 2648 (sheet, plate, strip, billet rod/bar, seamless pipe & tube; welded pipe & tube; fittings; and forgings)

ASME Code Case No. 2653 (F = 44, bare welding rod)

**WARNING:** This product and fumes generated from the normal use of this product contain Manganese. The inhalation of welding rod fumes containing Manganese has been associated with the development of serious Parkinson's Disease-like symptoms, Parkinsonism, Manganism and other central Manganism nervous system conditions. Such symptoms may include impaired speech, balance and movement. Avoid breathing fumes generated in the welding process by utilizing appropriate environmental controls, including but not limited to ventilation, exhaust and respirators.