

# COMPATIBILITY OF WELDED PROPELLANT SYSTEMS WITH NEW GREEN PROPELLANTS

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# COMPATIBILITY OF WELDED SYSTEMS WITH NEW GREEN PROPELLANTS

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- ▶ Description of Tests
- ▶ LMP-103S Results
- ▶ HTP Results
- ▶ Conclusions



European  
**Astrotech**

## DESCRIPTION OF TESTS

- ▶ Testing followed ECSS guidelines
- ▶ 10 material samples for immersion in LMP-103S
- ▶ 9 material samples for immersion in HTP
- ▶ 8 month exposure time (maximum) = 5.33 year on-orbit exposure time
- ▶ Determining degradation of welds and materials
- ▶ Determining degradation of propellants



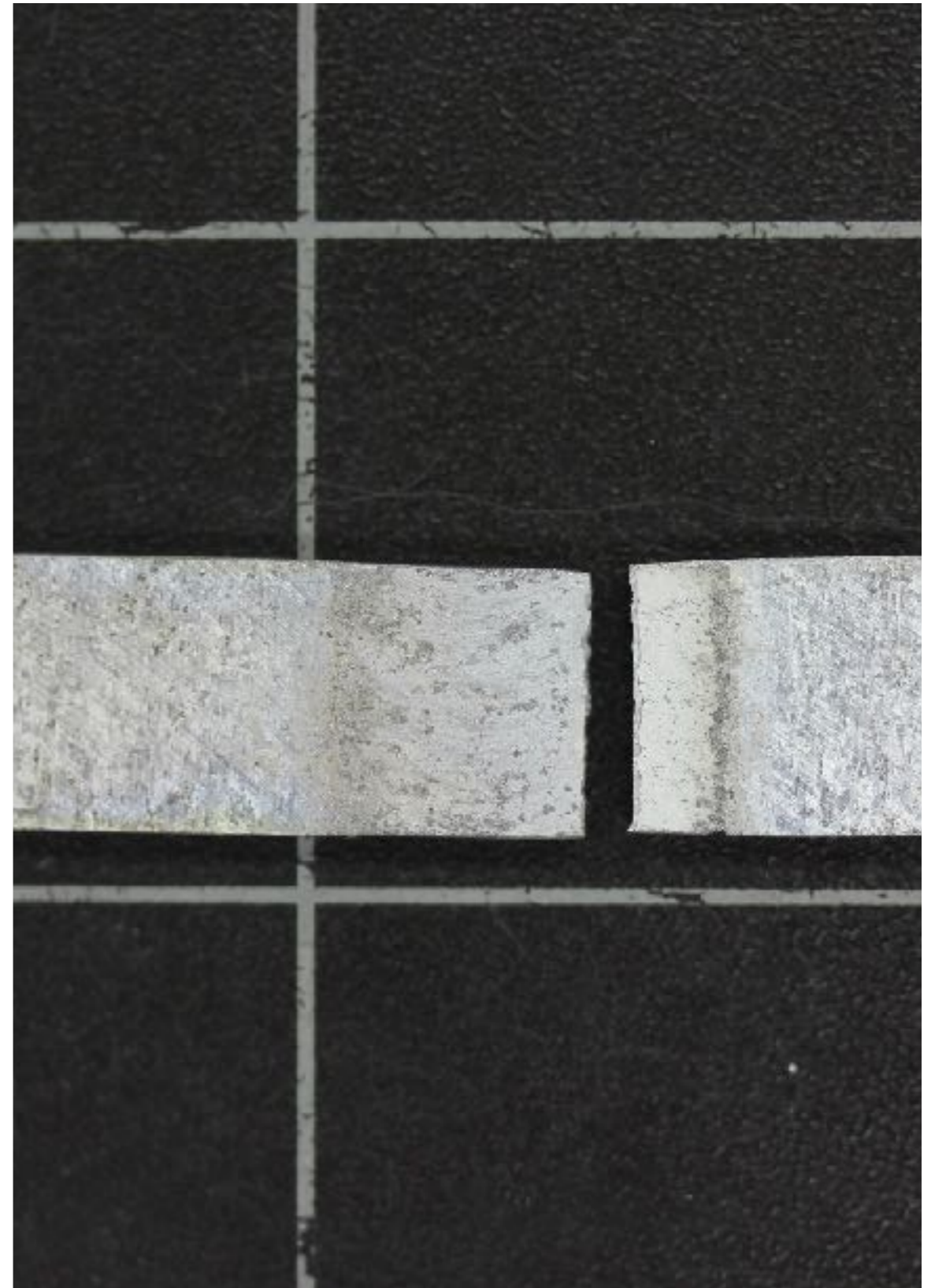
## PROPELLANT TESTING

- ▶ Propellant decomposition/  
pressure rise
- ▶ ICP analysis
- ▶ Propellant assay



## MATERIALS TESTING

- ▶ Mass Loss Tests
- ▶ Burst Tests
- ▶ Weld inspection (by sectioning, polishing, etching and examination)
- ▶ Fracture Toughness
- ▶ Hardness Tests



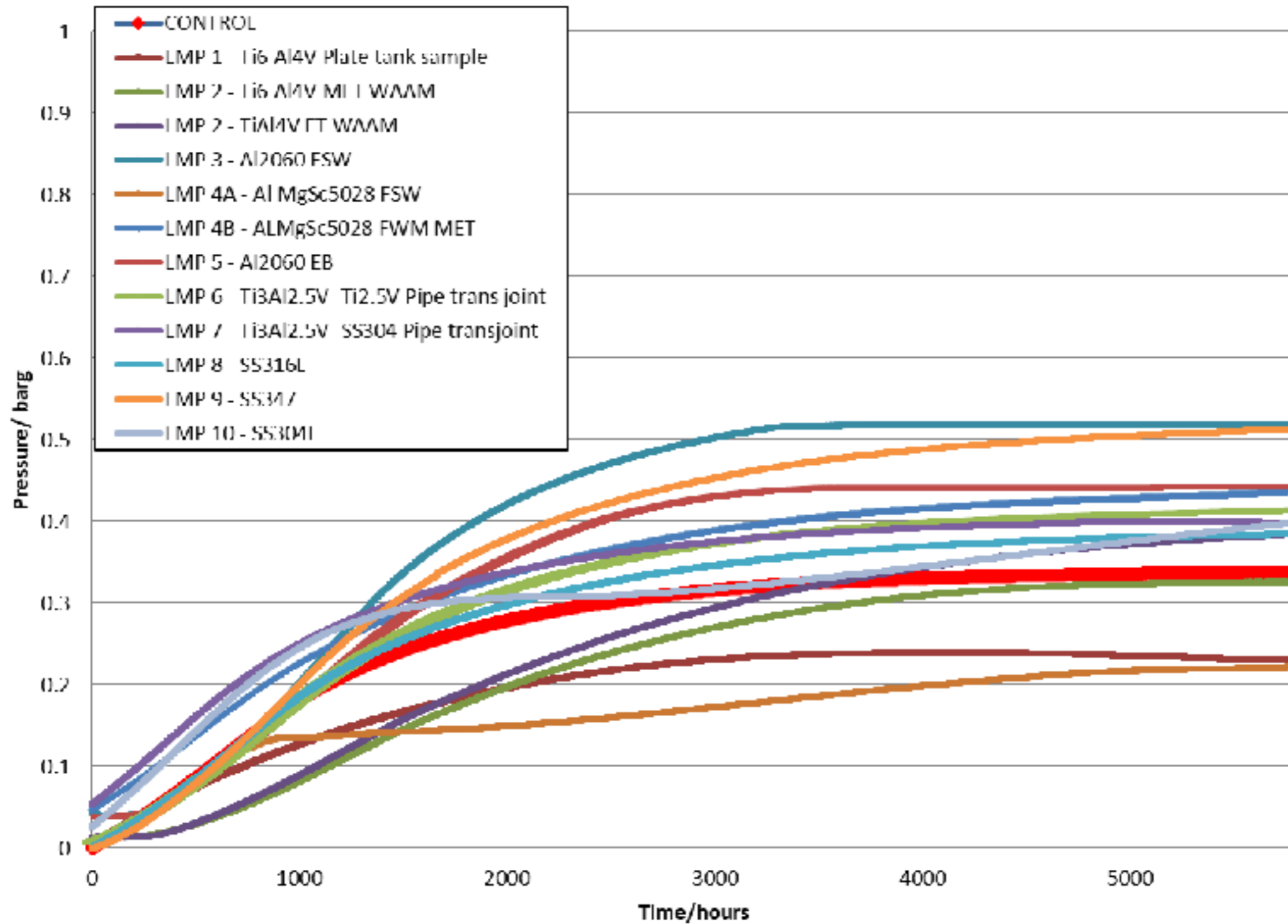
# LMP-103S RESULTS

Material sample	Type	Welding Technique
LMP 1- Ti6Al4V	Plate Tank sample	EB
LMP 2 - Ti6Al4V	Tank sample	WAAM
LMP 3 - Al2060	Tank sample	FSW
LMP 4 - AlMgSc 5028	Tank sample	FSW
LMP 5 - Al2060	Tank sample	EB
LMP 6 - Ti3Al2.5V- Ti2.5V	Pipe Transition Joint	OTIG
LMP 7 - Ti3Al2.5V- SS304	Pipe Transition Joint	RFW
LMP 8 - SS316L	Pipework	TIG
LMP 9 - SS347	Pipework	TIG
LMP 10 - SS304L	Pipework	TIG



# LMP-103S DECOMPOSITION

## LMP 103S Pressure vs Time Graph



# ICP TESTS

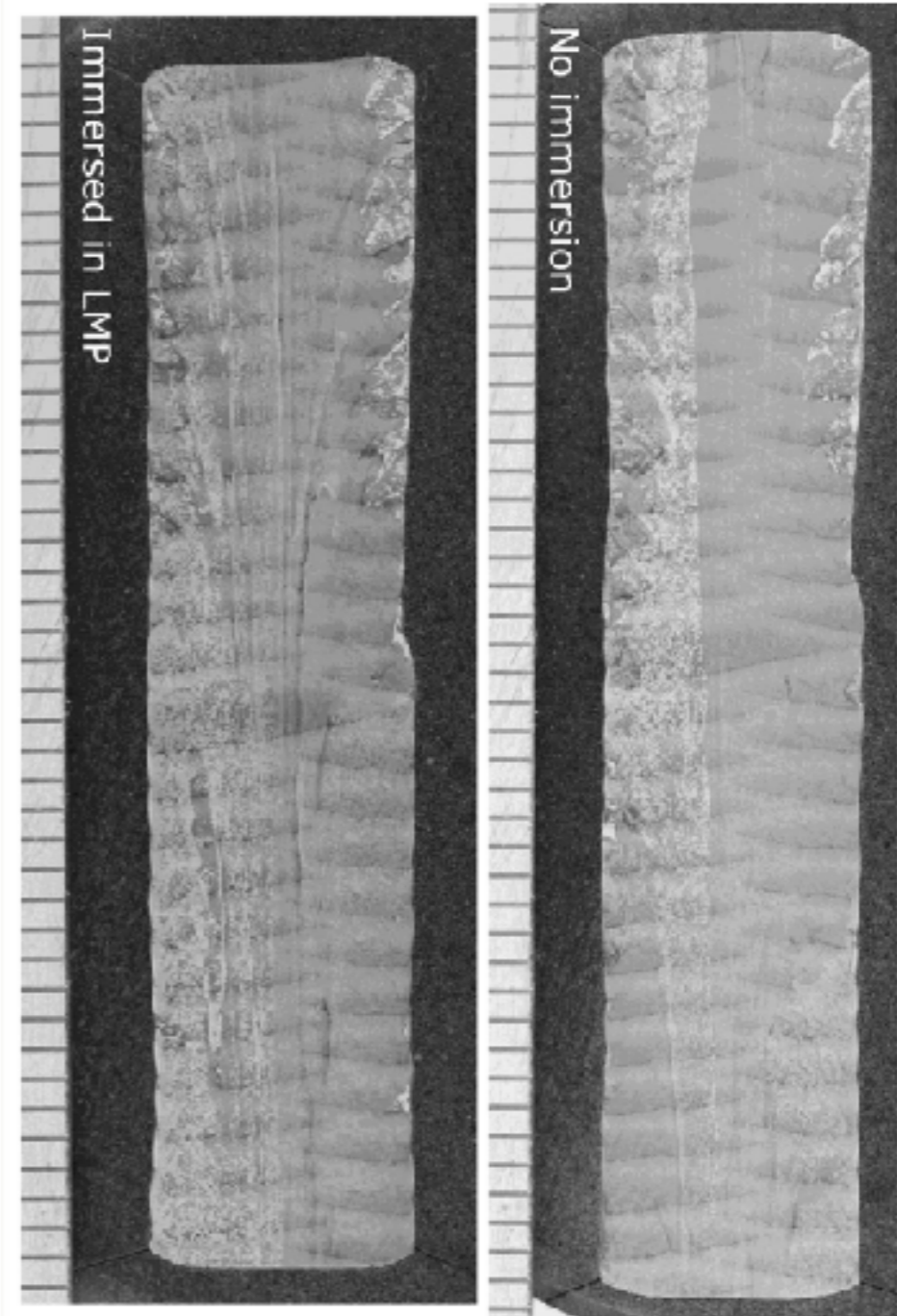
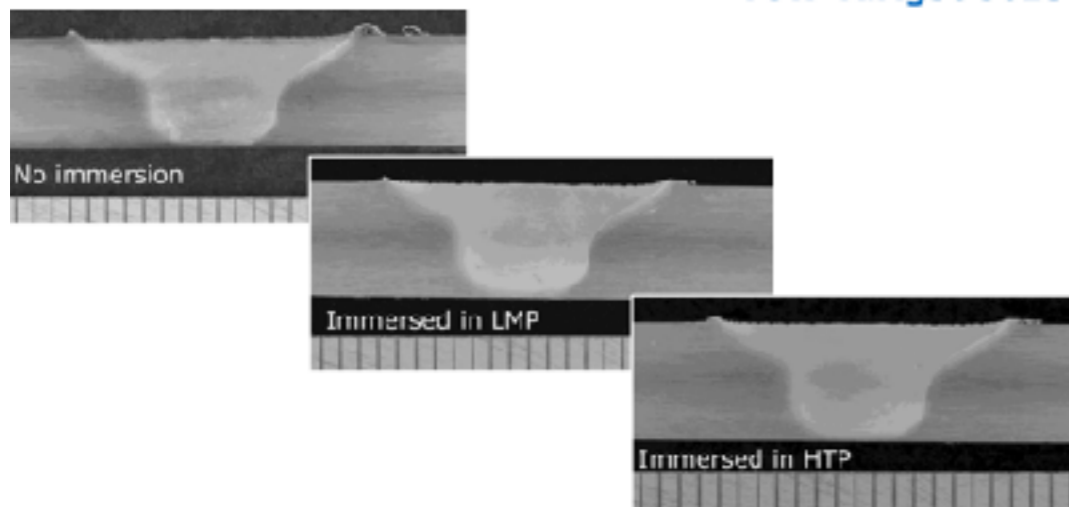
Material sample	Type	Welding Technique	Element, ppm											
			Al	Mg	Sc	Fe	Cu	Ti	V	Ni	Cr	Mn	Mo	Si
Ti6Al4V	Plate Tank sample	EB	<0.08	-	-	0.07	-	<0.009	<0.03	-	-	-	-	-
Ti6Al4V	Tank sample	WAAM	<0.08	-	-	0.04	-	<0.009	<0.03	-	-	-	-	-
Al2060	Tank sample	FSW	<0.08	-	-	<0.03	0.30	-	-	-	-	-	-	-
AlMgSc 5028	Tank sample	FSW	<0.08	0.1	<0.0002	<0.03	-	-	-	-	-	-	-	-
Al2060	Tank sample	EB	<0.08	-	-	<0.03	0.30	-	-	-	-	-	-	-
Ti3Al2.5V - Ti2.5V	Pipe Transition Joint	OTIG	<0.08	-	-	<0.03	-	<0.009	<0.03	-	-	-	-	-
Ti3Al2.5V - SS304	Pipe Transition Joint	RFW	<0.08	-	-	<0.03	-	<0.009	<0.03	<0.2	<0.03	<0.01	-	0.2
SS316L	Pipework	TIG	-	-	-	<0.03	-	-	-	<0.2	<0.03	<0.01	<0.4	0.1
SS347	Pipework	TIG	-	-	-	0.03	-	-	-	<0.2	<0.03	<0.01	-	0.2
SS304L	Pipework	TIG	-	-	-	<0.03	-	-	-	<0.2	<0.03	<0.01	-	0.2
Blank Sample (Control)			<0.08	0.05	0.0003	<0.03	<0.03	<0.009	<0.03	<0.2	<0.03	<0.01	<0.4	5.8



# WELD INSPECTION

- ▶ Metallography showed no noticeable effects to microstructure
- ▶ Some discolouration of stainless steel in Ti-SS pipe transition joint

FSW AlMgSc 5028

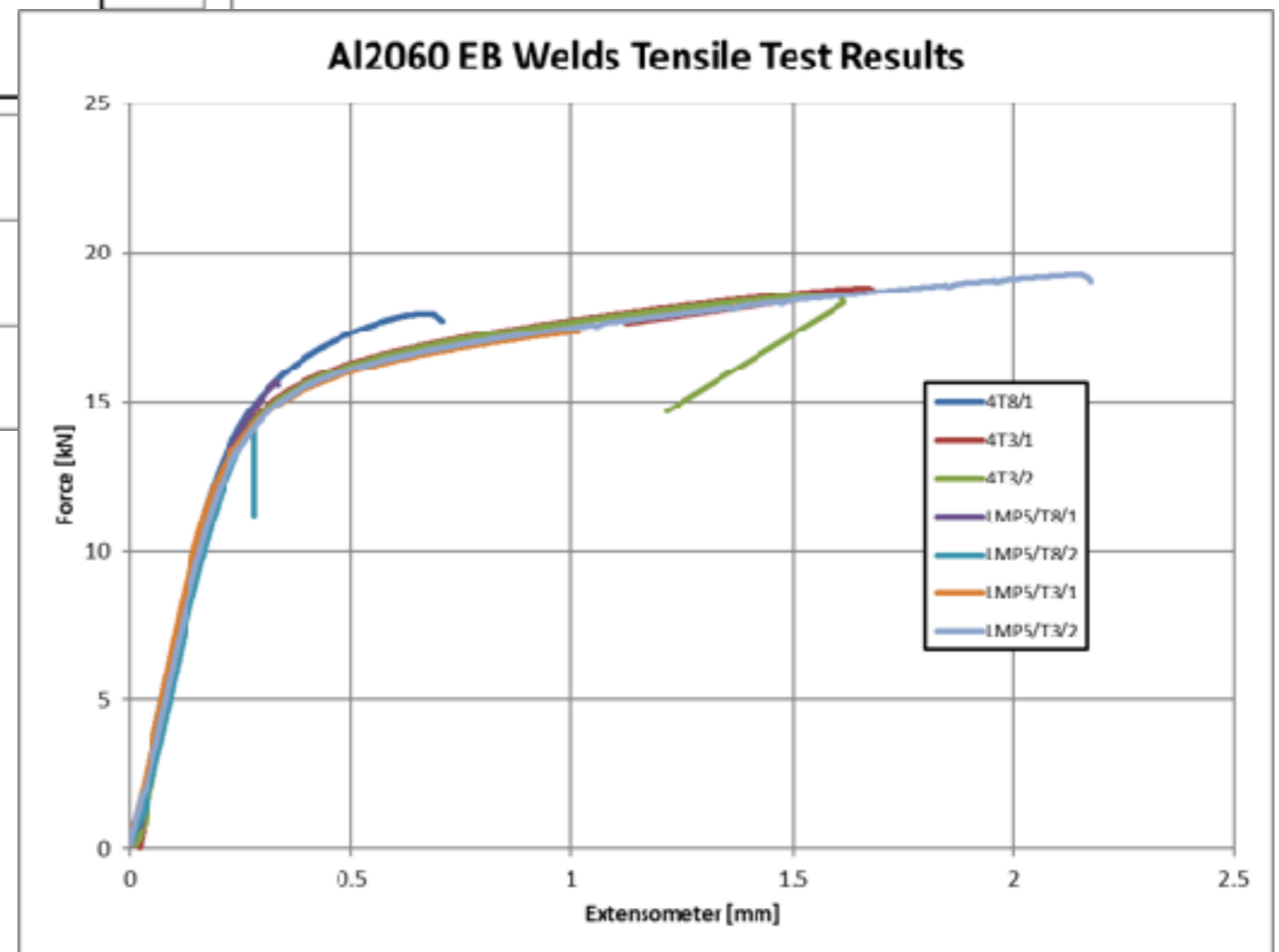
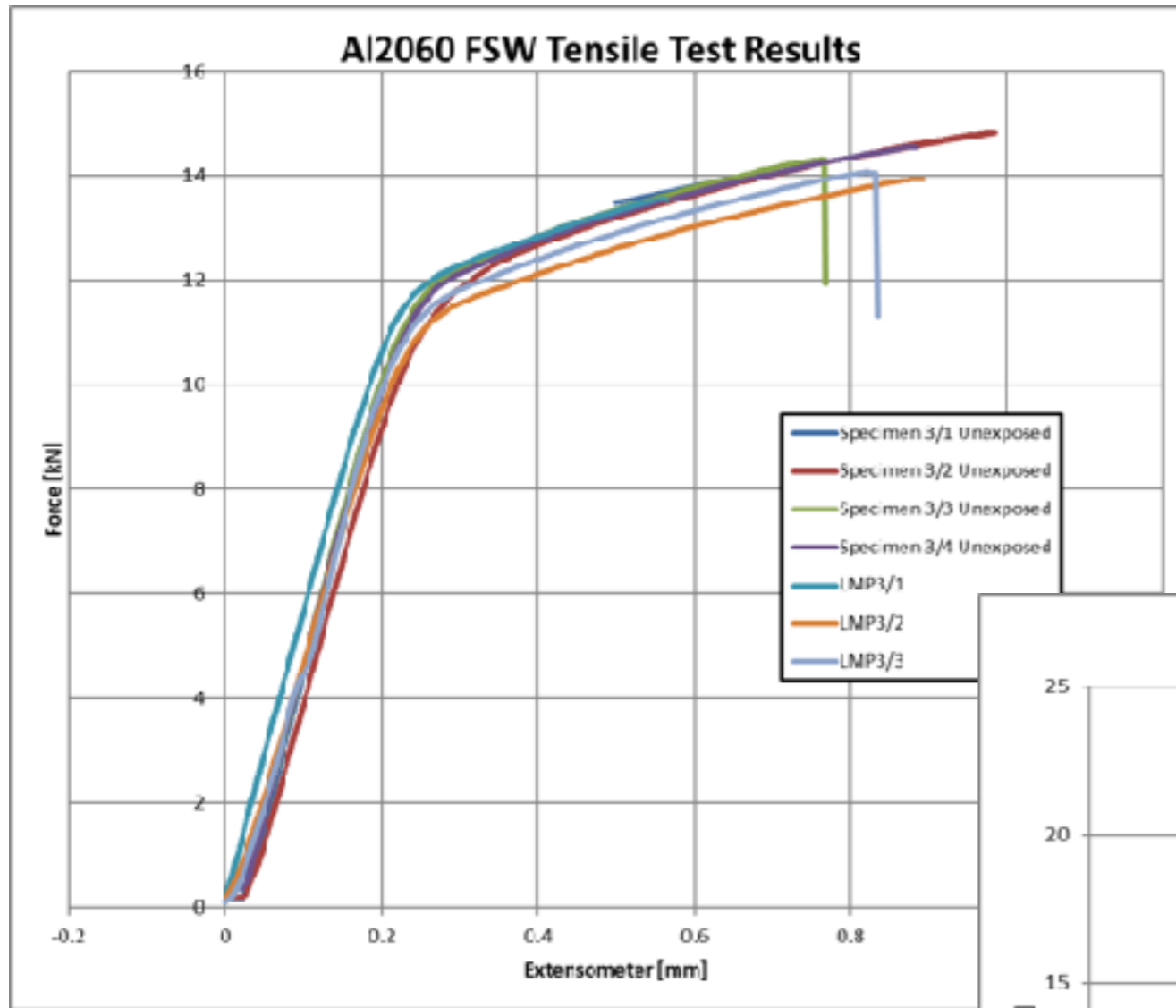


# FRACTURE TOUGHNESS

Specimen ID	Material	Weld	Environmental Condition	Fracture Toughness J (kJ/m <sup>2</sup> )
FW-F1	AlMgSc5028	Friction Stir	Unexposed	267.3
FW-F2				276.1
FW-F3				283.6
FW-F4			LMP4	293.5
FW-F5				321.0
FW-F6				273.6
FW-F7			HTP3	247.8
FW-F8				244.1
FW-F9				314.9
EB-F1 (4A)	Ti6Al4V	Electron Beam	Unexposed	48.7
EB-F2 (4B)				45.8
EB-F3 (4C)				58.3
EB-F4 (1A)			LMP1	55.3
EB-F5 (1B)				49.9
EB-F6 (1C)				68.3
EB-F7 (2A)			HTP1	52.8
EB-F8 (2B)				68.1
EB-F9 (2C)				53.2
WA-F1	WAAM Ti6Al4V	N/A	Unexposed	197.4
WA-F2				239.2
WA-F3				236.0
WA-F4			LMP	269.8
WA-F5				230.0
WA-F6				244.9



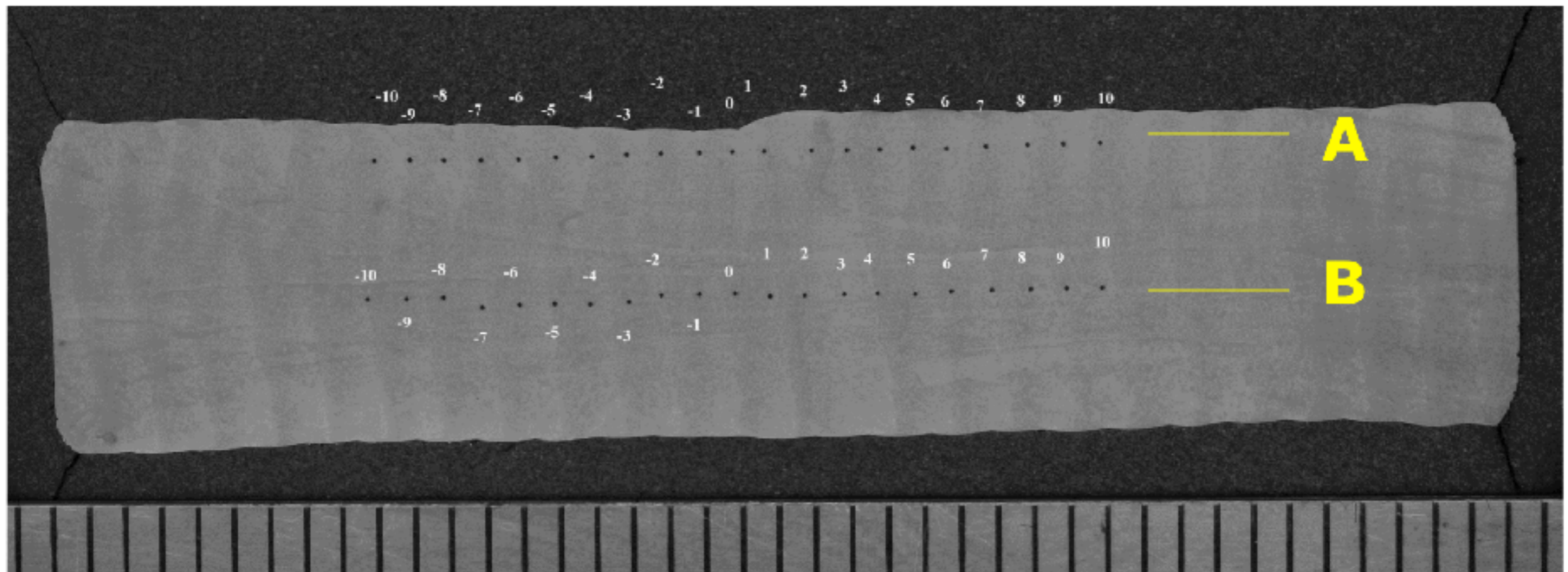
# FRACTURE TOUGHNESS



# HARDNESS TESTING

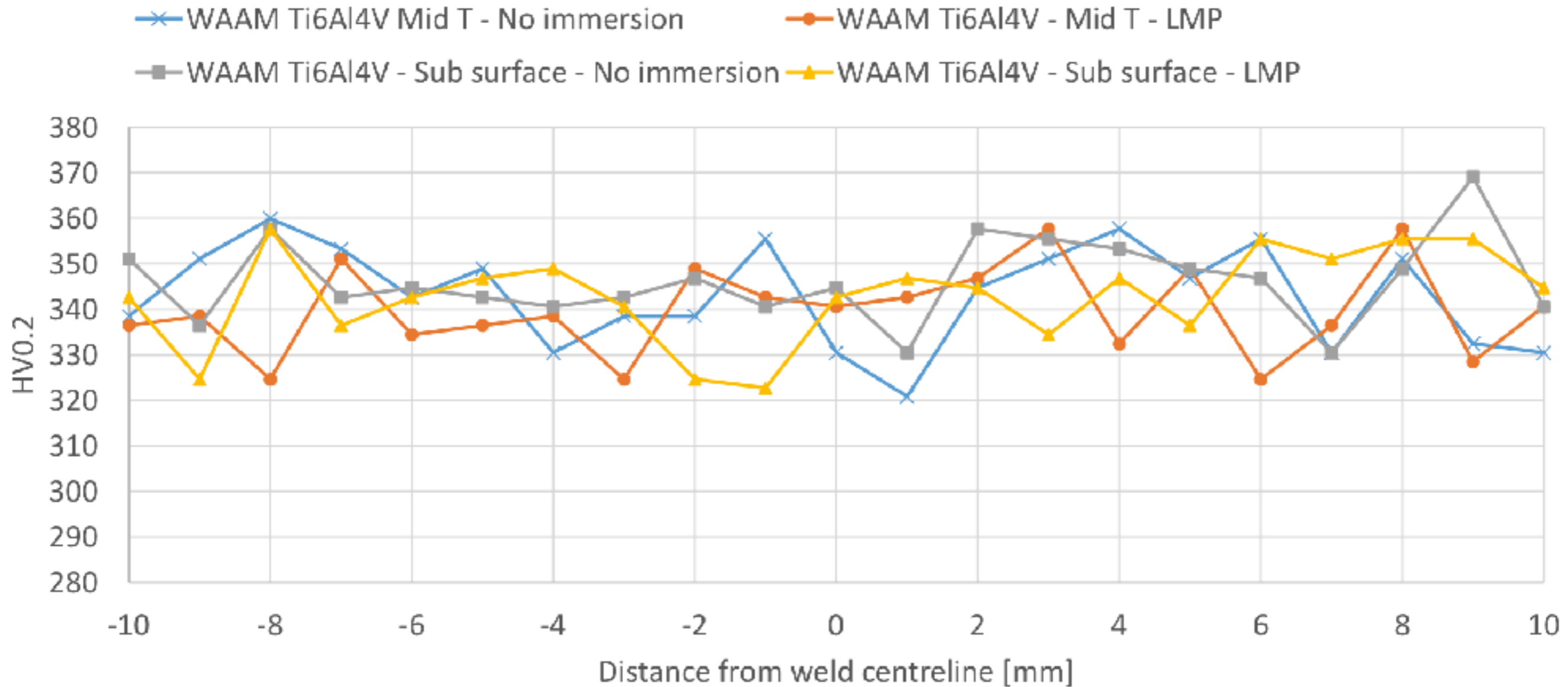
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- Two profiles (see below):
  - A. Sub surface
  - B. Along mid-thickness
- Suggested space between indentations 1mm
- Suggested indentation load 5 Kg



# HARDNESS TESTING

- No obvious effect of environmental condition on sample hardness



# OTHER MATERIALS TESTING

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- ▶ No **mass** change indicates no observable corrosion
- ▶ No problems during **burst tests** @ 4 x MEOP

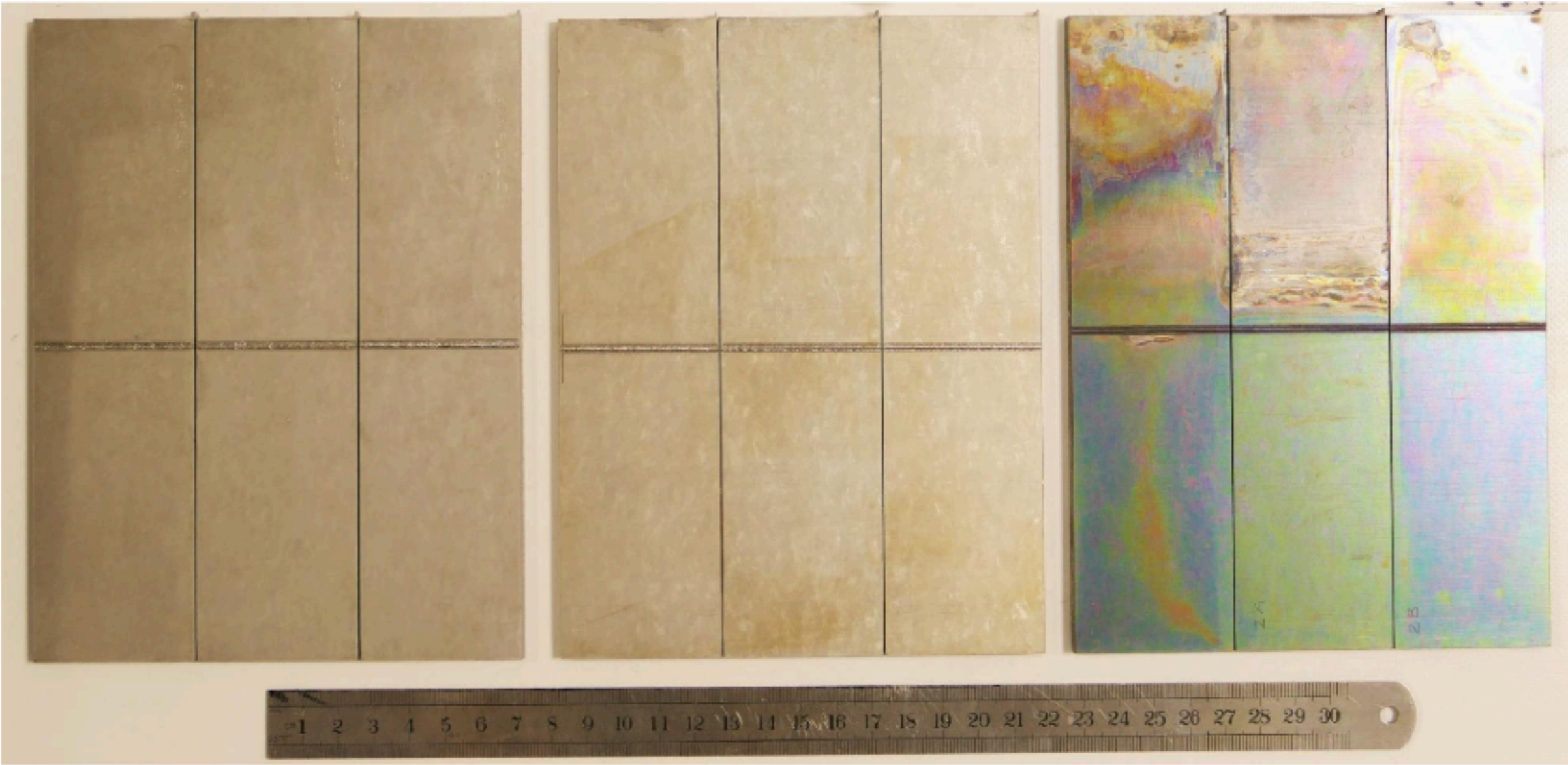
Immersed  
in HTP

Immersed  
in LMP



# OTHER MATERIALS TESTING

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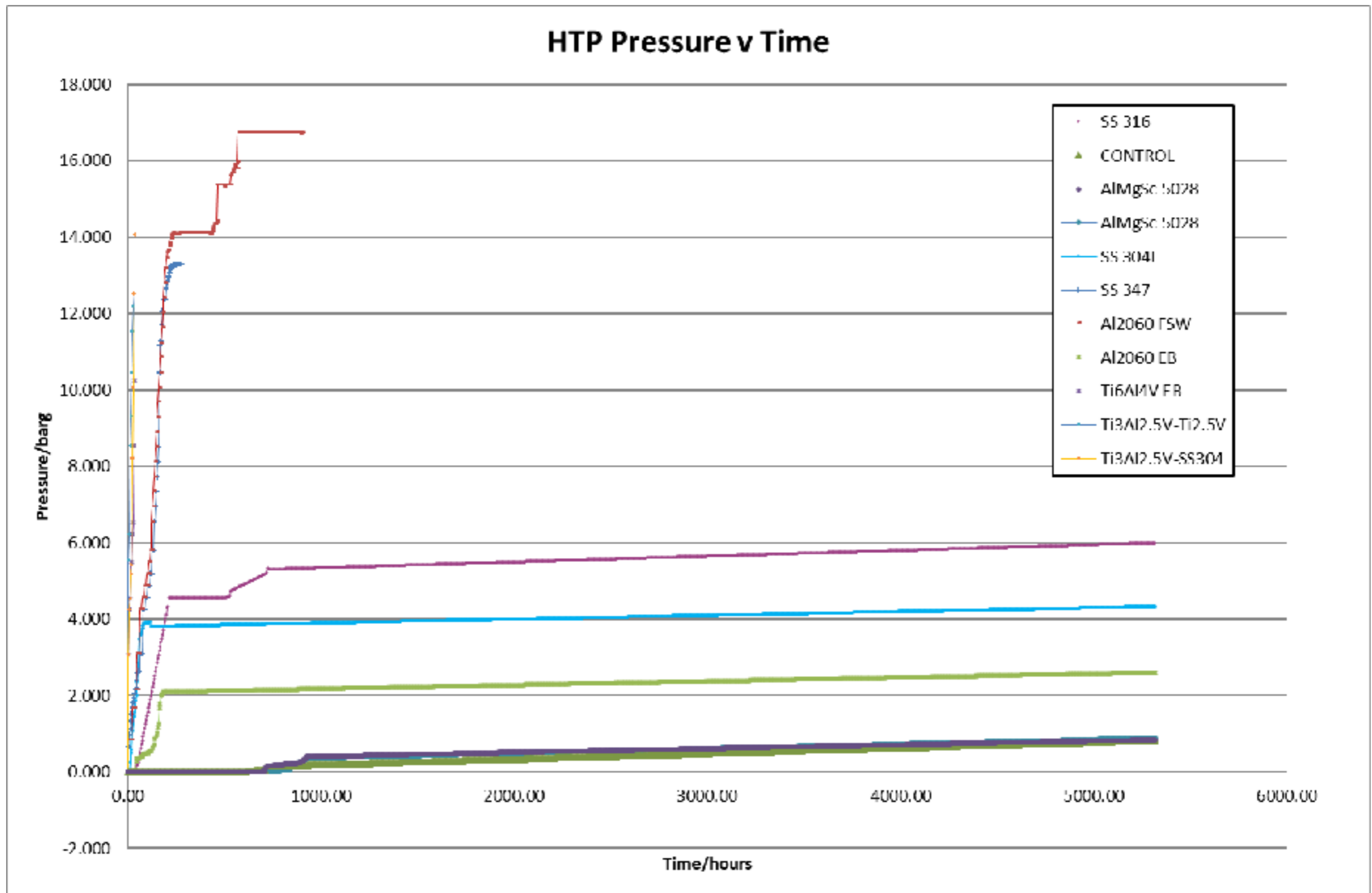
# HTP RESULTS

Material sample	Type	Welding Technique
HTP 1 - Ti6Al4V	Plate Tank sample	EB
HTP 2 - Al2060	Tank sample	FSW
HTP 3 - AlMgSc 5028	Tank sample	FSW
HTP 4- Al2060	Tank sample	EB
HTP 5 - Ti3Al2.5V- Ti2.5V	Pipe Transition Joint	OTIG
HTP 6 - Ti3Al2.5V- SS304	Pipe Transition Joint	RFW
HTP 7- SS316L	Pipework	TIG
HTP 8 - SS347	Pipework	TIG
HTP 9 - SS304L	Pipework	TIG





# HTP DECOMPOSITION

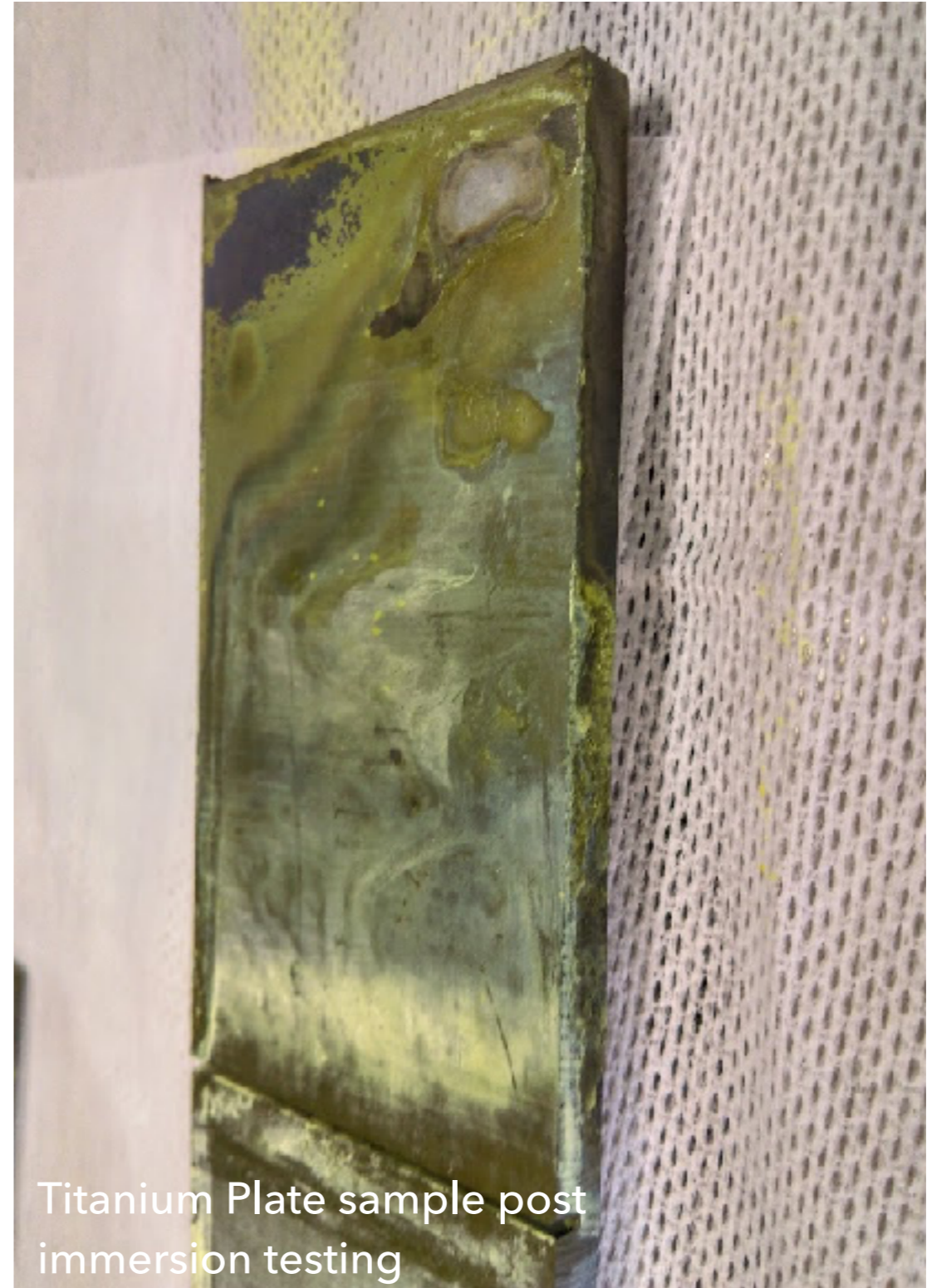


# HTP DECOMPOSITION

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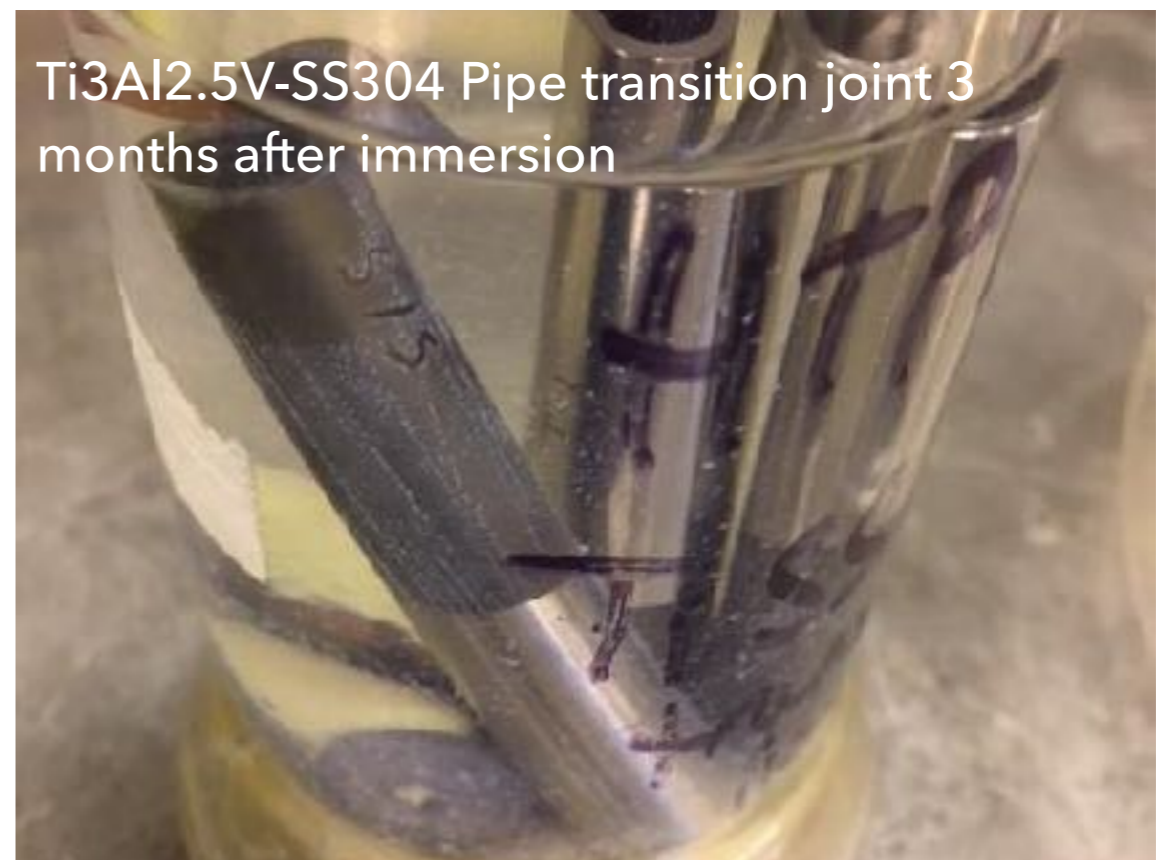
Titanium plate 3 months after immersion



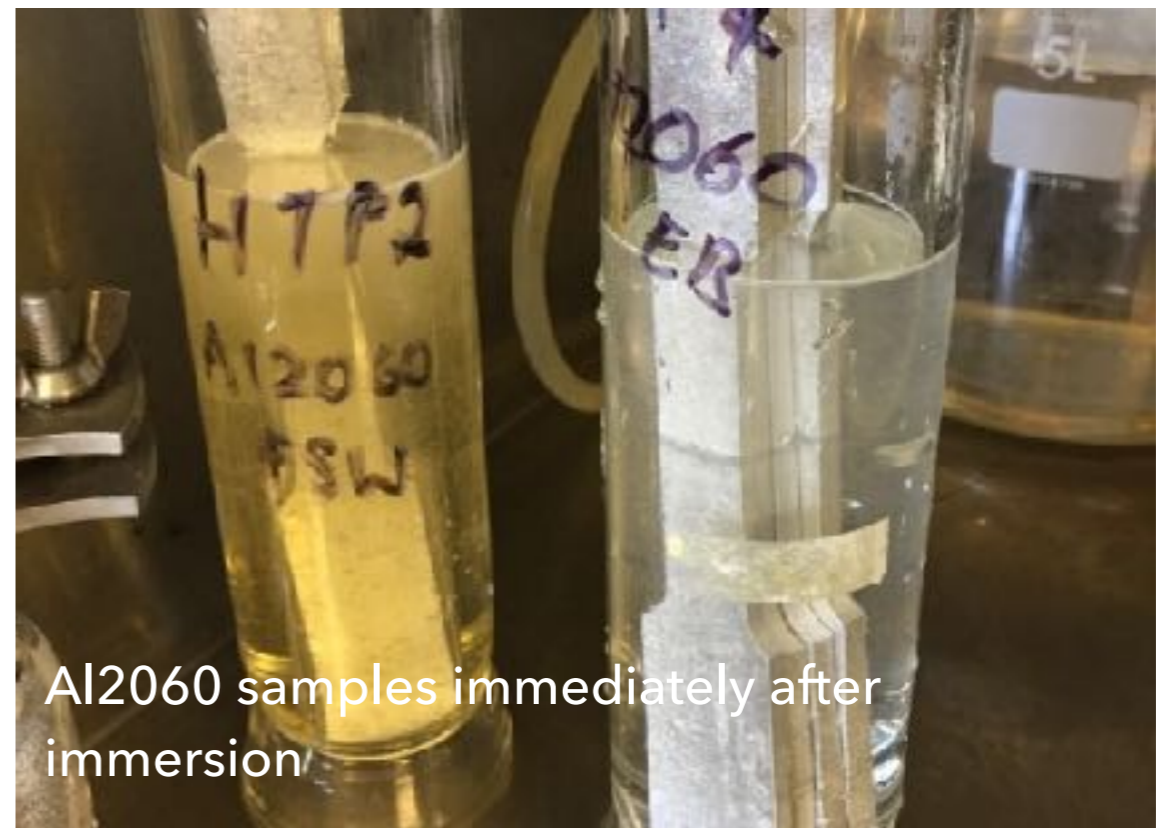
Titanium Plate sample post immersion testing



Ti3Al2.5V-Ti2.5V Pipe Transition joint after 1 week



Ti3Al2.5V-SS304 Pipe transition joint 3 months after immersion



Al2060 samples immediately after immersion

# HTP DECOMPOSITION

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Material sample	Type	Welding Technique
HTP 1 - Ti6Al4V	Plate Tank sample	EB
HTP 2 - Al2060	Tank sample	FSW
HTP 3 - AlMgSc 5028	Tank sample	FSW
HTP 4- Al2060	Tank sample	EB
HTP 5 - Ti3Al2.5V- Ti2.5V	Pipe Transition Joint	OTIG
HTP 6 - Ti3Al2.5V- SS304	Pipe Transition Joint	RFW
HTP 7- SS316L	Pipework	TIG
HTP 8 - SS347	Pipework	TIG
HTP 9 - SS304L	Pipework	TIG

# ICP ANALYSIS

Material sample	Type	Welding Technique	Element, ppm											
			Al	Mg	Sc	Fe	Cu	Ti	V	Ni	Cr	Mn	Mo	Si
Ti6Al4V	Plate Tank sample	EB	11	-	-	-	-	240	1.7	-	-	-	-	-
Al2060	Tank sample	FSW	10	-	-	1.5	0.04	-	-	-	-	-	-	-
AlMgSc 5028	Tank sample	FSW	9.0	1.4	0.002	0.2	-	-	-	-	-	-	-	-
Al2060	Tank sample	EB	19	-	-	1.2	0.04	-	-	-	-	-	-	-
Ti3Al2.5V-Ti2.5V	Pipe Transition Joint	OTIG	1.4	-	-	0.3	-	0.009	<0.03	-	-	-	-	-
Ti3Al2.5V-SS304	Pipe Transition Joint	RFW	2.5	-	-	0.4	-	81	1.8	0.1	0.1	-	-	-
SS316L	Pipework	TIG	-	-	-	1.0	-	-	-	<0.2	6.1	0.03	0.8	0.78
SS347	Pipework	TIG	-	-	-	1.1	-	-	-	0.2	7.0	0.07	-	-
SS304L	Pipework	TIG	-	-	-	0.55	-	-	-	0.3	2.1	0.11	-	0.5
Blank Sample (Control)			1.1	0.36	<0.0002	0.68	<0.03	0.1	<0.03	<0.2	0.1	0.07	<0.4	0.61

# MATERIALS TESTING

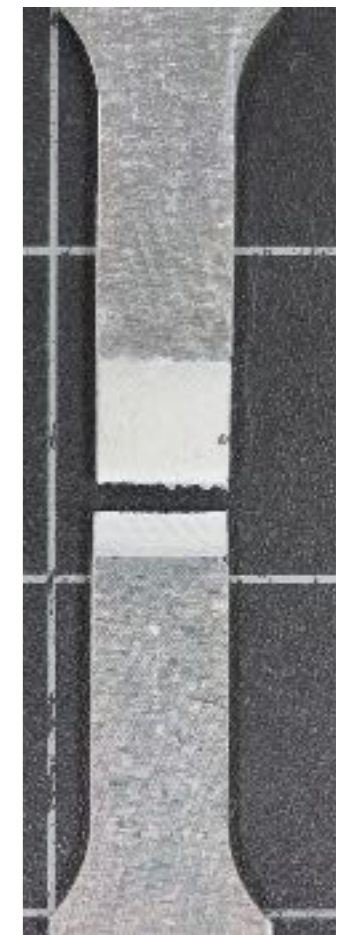
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- ▶ **Mass** changes consistent with ICP analysis
- ▶ No problems during **burst tests** @ 4 x MEOP
- ▶ Weld inspection showed discolouration but no structural defects in the weld joint or parent material



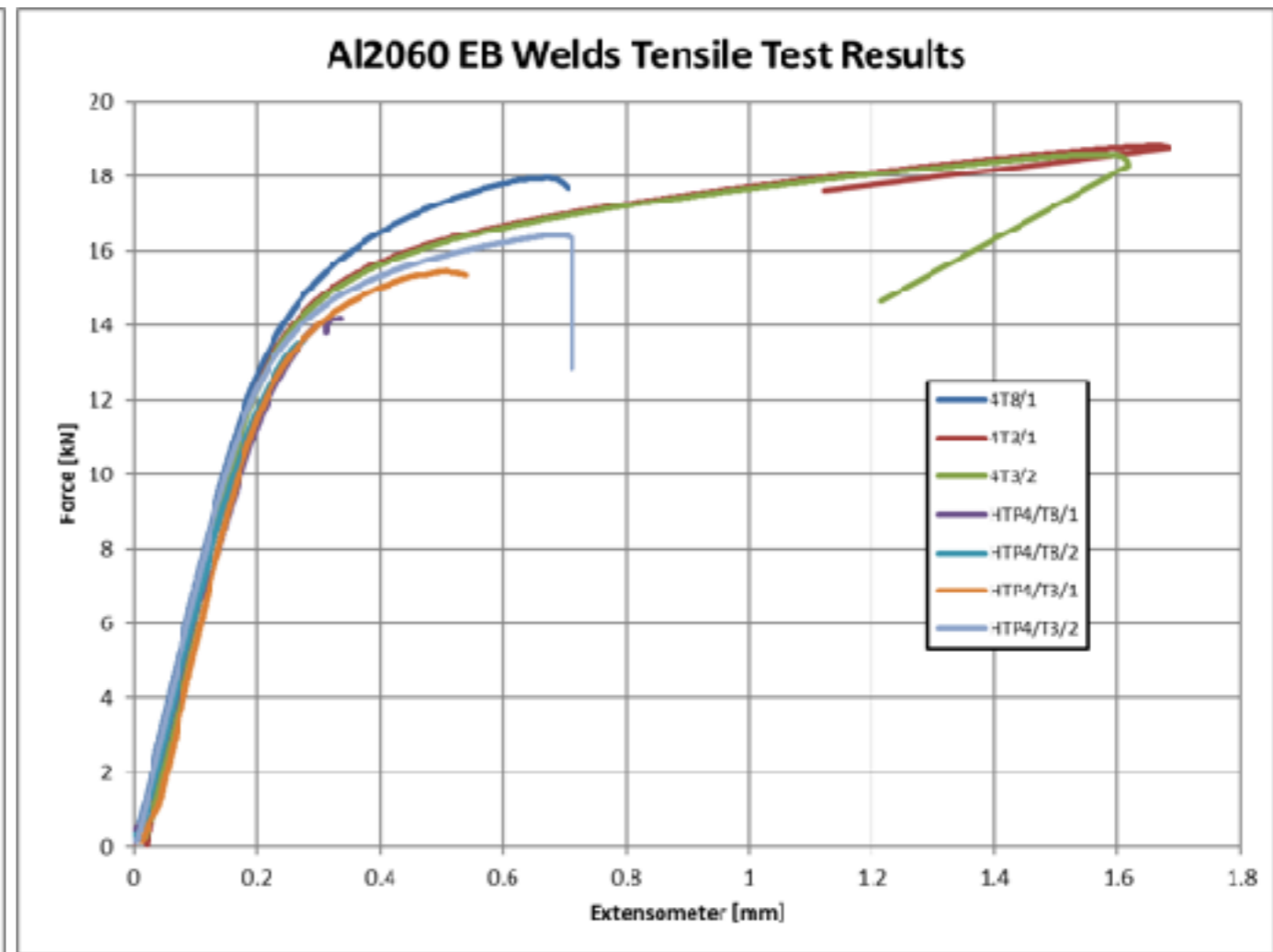
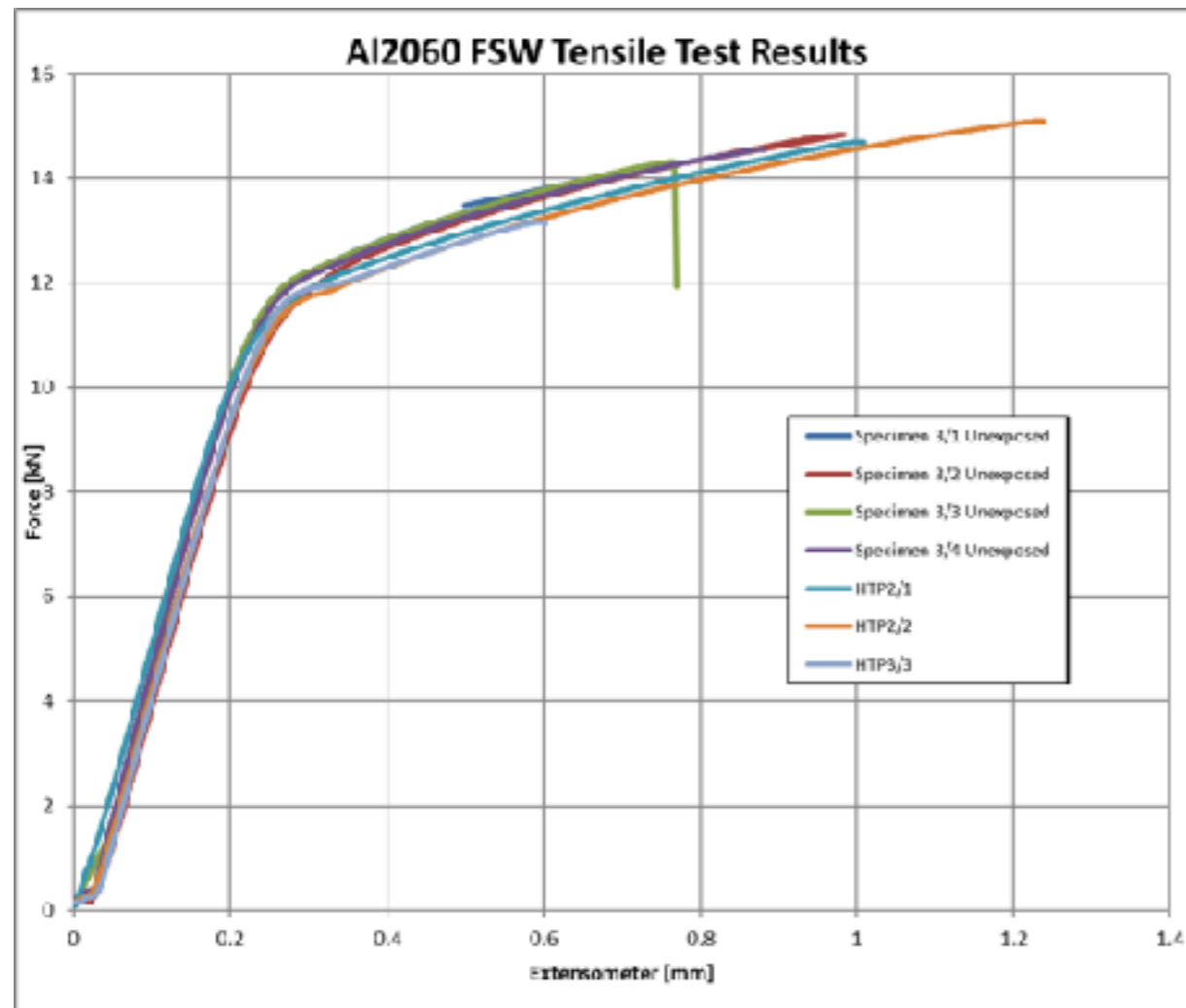
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WA-F2				239.2
WA-F3				236.0
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WA-F5				230.0
WA-F6				244.9



# TENSILE TESTING

It can be seen from the results that there is no obvious effect of environmental condition on the value of the fracture toughness for each material/ The results are consistent for each material, across all environmental conditions.





# CONCLUSIONS

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- ▶ LMP-103S - compatible with all samples tested
- ▶ HTP definitely not compatible with Titanium or SS347
- ▶ Al2060 EB, SS316 and SS304 may be compatible with HTP if given longer pre-exposure prior to loading
- ▶ Al2060 FSX not compatible with HTP - indicates FSX may be cause of rapid propellant decomposition

