Metallographic Analyses

8 PoDFA Samples of January 1st, 2006

For
Mr. John Smith
International Aluminum Casting
Quebec, Canada

Report Date: January 4th, 2006
Batch Reference: B20060001
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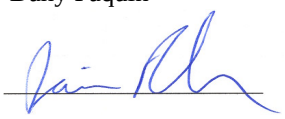
Approved by: 

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Metallographic Analysis Results

Sample Number				**#1**	**#2**	**#3**	**#4**
Location				Exit Furnace	Exit Furnace	Exit Furnace	After Degasser
Alloy				A356	A356	A356	A356
Plant				Quebec	Quebec	Quebec	Quebec
Sampling Date				1/1/2006	1/1/2006	1/1/2006	1/1/2006
Sampling Time				14:25	14:35	14:48	14:59
Cast Number							
	Inclusion	*Chemical Symbol*	*Unit*				
Oxide Films	Number	γ-Al_2O_3	[#/kg]	9	3	21	2
	Length			Short, Med, Long	Short	Short, med	Short
	Thickness			Thin	Thin, Thick	Thin, Med	Thin
Carbides	Small Carbide	Al_4C_3 < 3 µm	[mm²/kg]	0.218	0.233	0.174	0.032
			[%]	30%	39%	22%	17%
	Large Carbide	Al_4C_3 > 3 µm	[mm²/kg]	0.073	0.048	0.111	0.008
			[%]	10%	8%	14%	4%
Magnesium Oxides	Magnesium Oxide	MgO	[mm²/kg]	0.058	0.066	0.174	0.013
			[%]	8%	11%	22%	7%
	Cuboid	$MgAl_2O_4$-Cuboid	[mm²/kg]			0.016	0.002
			[%]	Trace		2%	1%
	Metallurgical Spinel	$MgAl_2O_4$-Spinel	[mm²/kg]	0.029	0.042	0.071	0.002
			[%]	4%	7%	9%	1%
Refractory Materials	Reacted Refractory	(Spinel-like)	[mm²/kg]	0.022			0.004
			[%]	3%	Trace		2%
	Unreacted Refractory	α-Al_2O_3, CaO, SiO_2, ...	[mm²/kg]			0.024	
			[%]			3%	
		C (Graphite)	[mm²/kg]	0.007		0.024	0.002
			[%]	1%		3%	1%
Metal Treatments	Potential Chloride	$MgCl_2$, NaCl, $CaCl_2$,…	[mm²/kg]	0.007	0.012		0.041
			[%]	1%	2%	Trace	22%
	Fluxing Salt [1]	Varies with flux type	[mm²/kg]				
			[%]				
Additions	Boron Treatment	(Ti, V)B_2	[mm²/kg]				
			[%]				
	Phosphorus Modifier	AlP	[mm²/kg]				
			[%]				
	Grain Refiner	TiB_2, TiC	[mm²/kg]	0.313	0.197	0.198	0.085
			[%]	43%	33%	25%	45%
Total Inclusion Content			**[mm²/kg]**	**0.727**	**0.596**	**0.790**	**0.188**
Total without Grain Refiner			**[mm²/kg]**	**0.415**	**0.400**	**0.593**	**0.103**
Comments:				Presence of $TiAl_3$ constituents at the interface.	Porous filter at the interface - Presence of shrinkage porosity.	Presence of $TiAl_3$ constituents and huge gas porosities at the interface.	

[1] Could also be Bone ash particles. Please refer to section Results Table Description at the end of the report.

Metallographic Parameters

Filtered weight	[kg]	1.32	1.5	1.05	1.5
Method		GRID	GRID	GRID	GRID
Magnification	[X]	100	100	50	100
Measured chord length	[mm]	12.5	12.6	12.4	12.6
Filter condition		GOOD	POROUS	GOOD	GOOD
Mould number		3019-1	3019-2	3020-1	3020-2

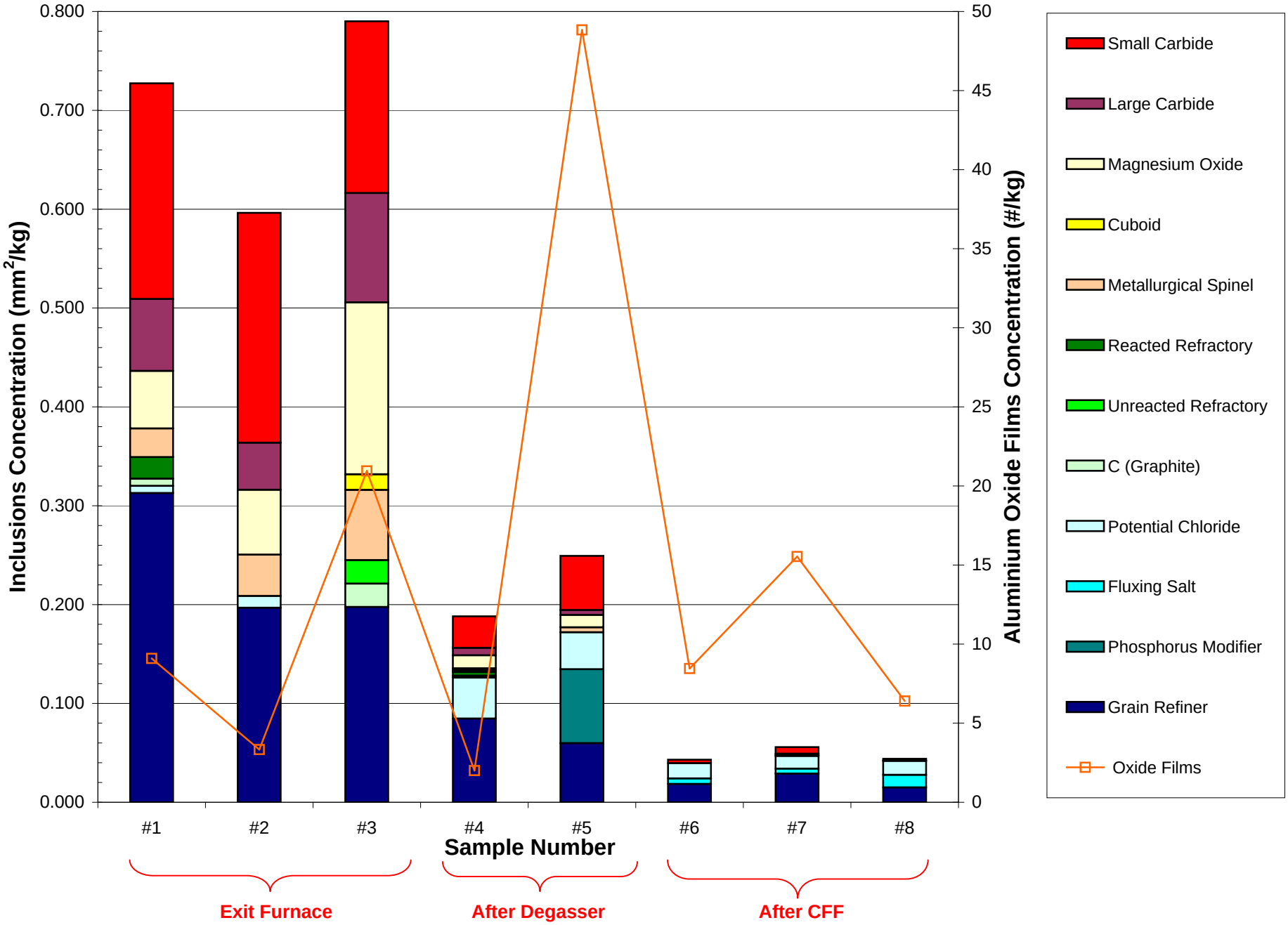
Metallographic Analysis Results

Sample Number				**#5**	**#6**	**#7**	**#8**
Location				After Degasser	After CFF	After CFF	After CFF
Alloy				A356	A356	A356	A356
Plant				Quebec	Quebec	Quebec	Quebec
Sampling Date				1/1/2006	1/1/2006	1/1/2006	1/1/2006
Sampling Time				15:32	15:47	15:58	16:12
Cast Number							
	Inclusion	*Chemical Symbol*	*Unit*				
Oxide Films	Number	γ-Al_2O_3	[#/kg]	49	8	16	6
	Length			Short	Short	Short	Short
	Thickness			Thin, Med	Thin	Thin	Thin
Carbides	Small Carbide	Al_4C_3 < 3 µm	[mm²/kg]	0.055	0.003	0.007	0.002
			[%]	22%	8%	12%	4%
	Large Carbide	Al_4C_3 > 3 µm	[mm²/kg]	0.005			
			[%]	2%	Trace	Trace	Trace
Magnesium Oxides	Magnesium Oxide	MgO	[mm²/kg]	0.012		0.002	0.0004
			[%]	5%		3%	1%
	Cuboid	$MgAl_2O_4$-Cuboid	[mm²/kg]				
			[%]	Trace			
	Metallurgical Spinel	$MgAl_2O_4$-Spinel	[mm²/kg]	0.005			
			[%]	2%			
Refractory Materials	Reacted Refractory	(Spinel-like)	[mm²/kg]			0.001	
			[%]	Trace		1%	
	Unreacted Refractory	α-Al_2O_3, CaO, SiO_2, ...	[mm²/kg]				
			[%]				
		C (Graphite)	[mm²/kg]				
			[%]				
Metal Treatments	Potential Chloride	$MgCl_2$, NaCl, $CaCl_2$,…	[mm²/kg]	0.037	0.015	0.013	0.014
			[%]	15%	36%	23%	32%
	Fluxing Salt [1]	Varies with flux type	[mm²/kg]		0.006	0.005	0.013
			[%]		13%	9%	29%
Additions	Boron Treatment	(Ti, V)B_2	[mm²/kg]				
			[%]				
	Phosphorus Modifier	AlP	[mm²/kg]	0.075			
			[%]	30%			
	Grain Refiner	TiB_2, TiC	[mm²/kg]	0.060	0.019	0.029	0.015
			[%]	24%	43%	52%	34%
Total Inclusion Content			**[mm²/kg]**	**0.249**	**0.043**	**0.056**	**0.044**
Total without Grain Refiner			**[mm²/kg]**	**0.189**	**0.025**	**0.027**	**0.029**
Comments:							
[1] Could also be Bone ash particles. Please refer to section Results Table Description at the end of the report.				Presence of primary crystals at the interface.	Presence of gas porosities at the interface.	Presence of gas porosities at the interface.	

Metallographic Parameters

Filtered weight	[kg]	0.86	1.42	1.48	1.25
Method		GRID	GRID	GRID	GRID
Magnification	[X]	200	200	200	200
Measured chord length	[mm]	12.7	12.6	12.4	12.7
Filter condition		GOOD	GOOD	GOOD	GOOD
Mould number		3020-3	3021-1	3021-2	3021-3

Histogram of Results



Micrographs

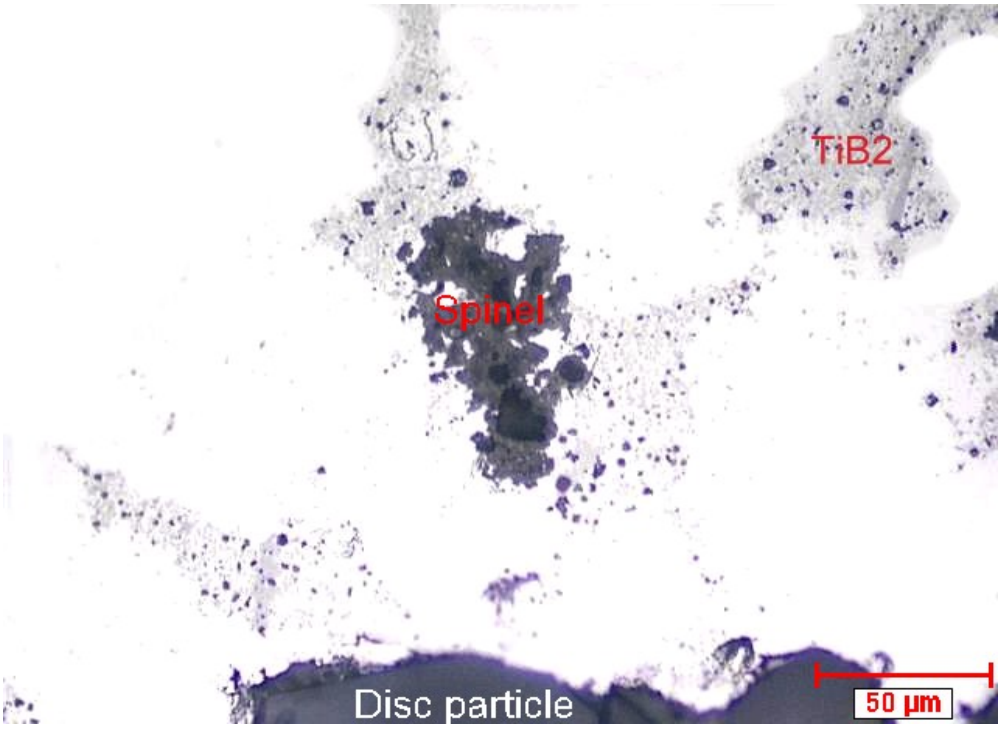
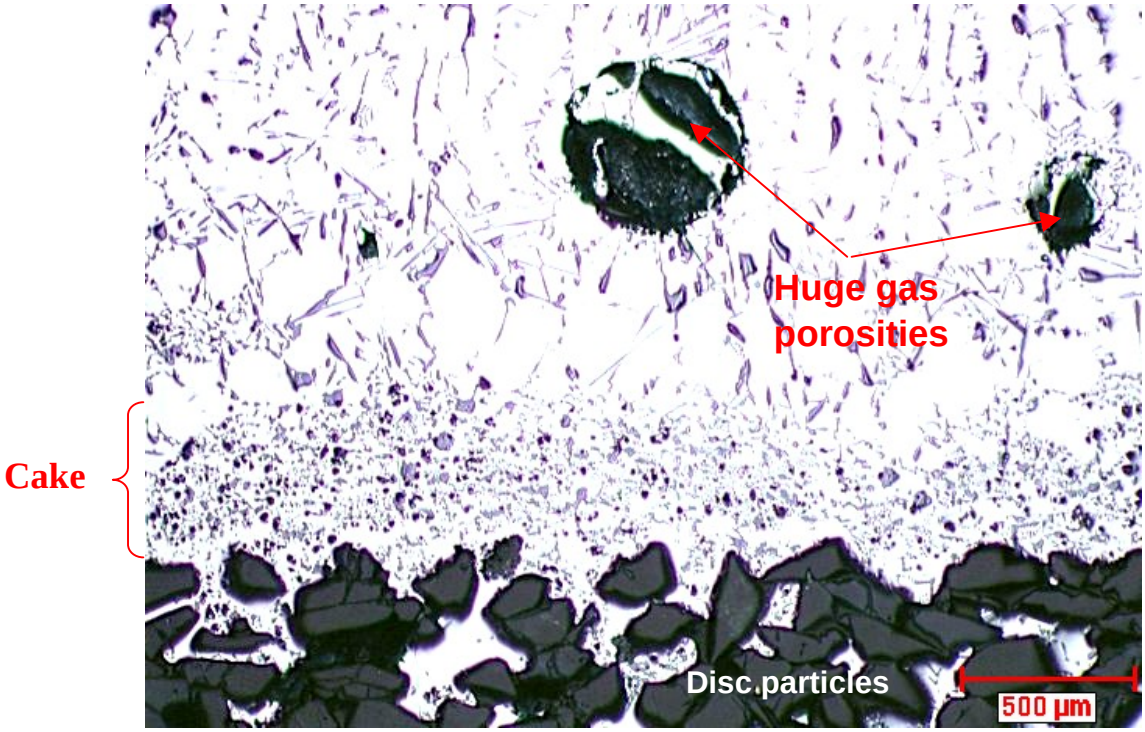


Figure 1 Sample #1 (500X) Presence of a metallurgical spinel particle at the interface.



interface – Presence of huge gas porosities.

Micrographs

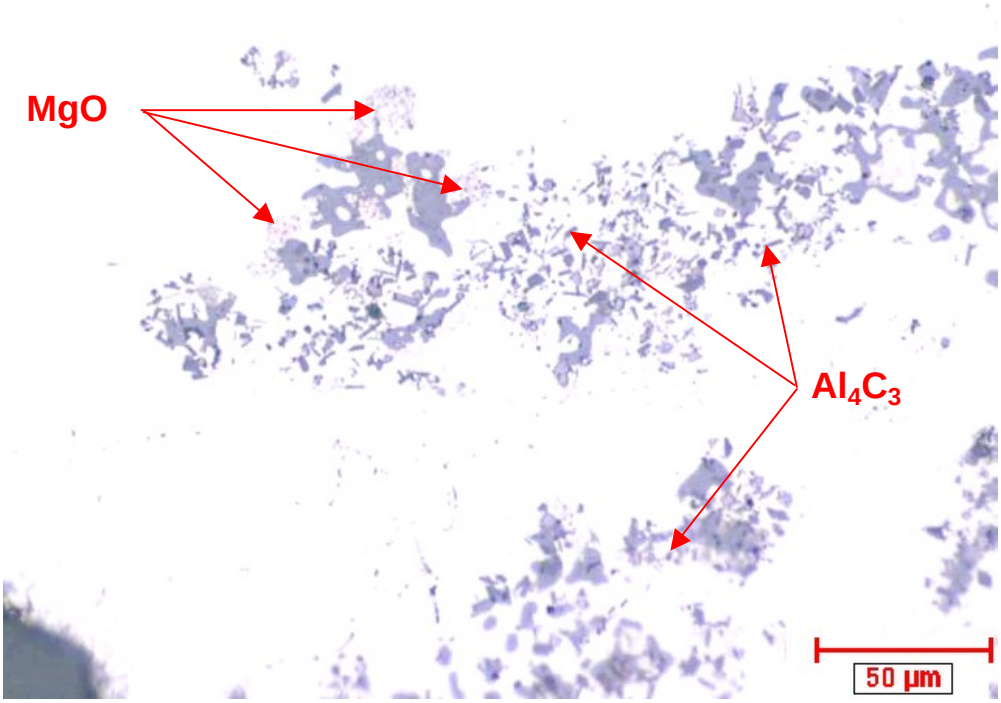


Figure 3 Sample #5 (500X) Presence of MgO and Al_4C_3 at the interface.

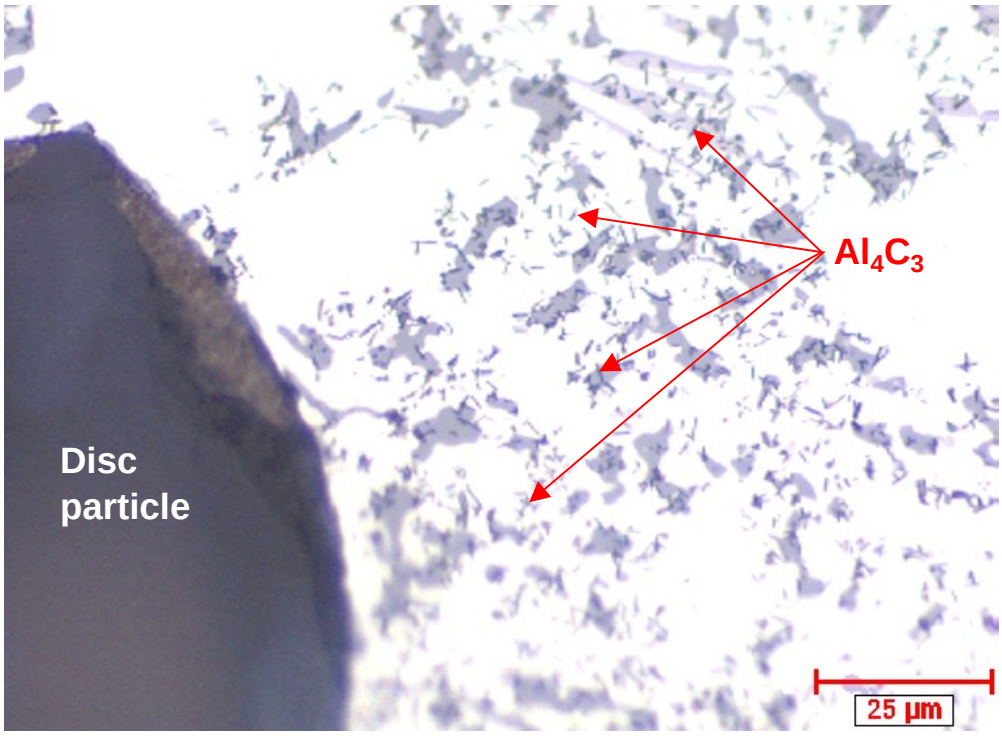


Figure 4 Sample #5 (1000X) Same as Figure 3 but at higher magnification.

Micrographs

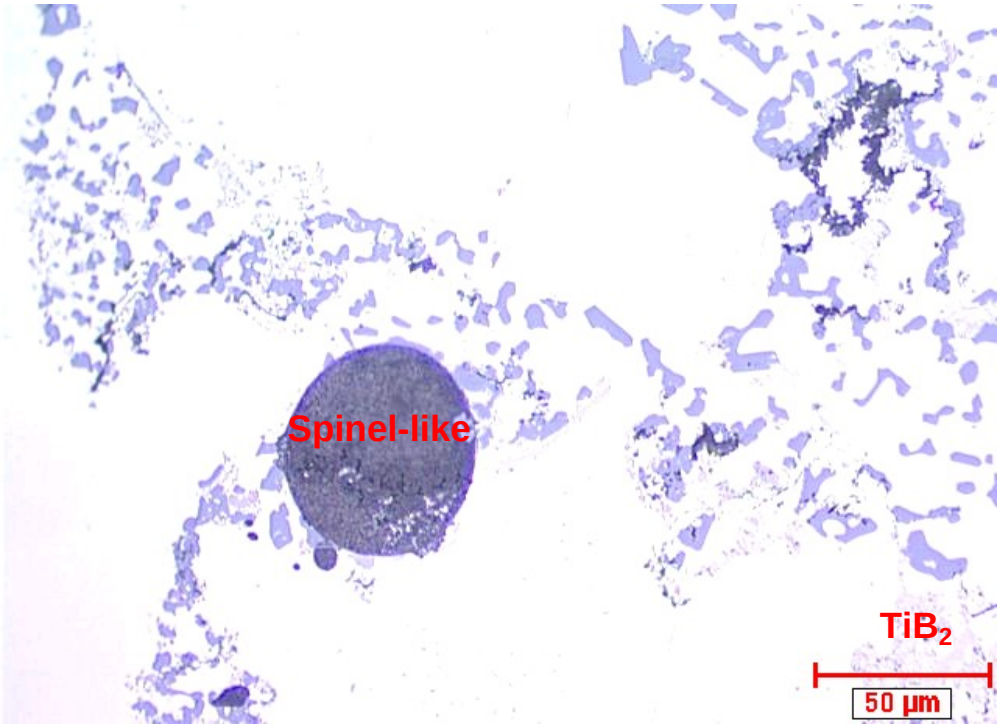


Figure 5 Sample #7 (500X) Presence of a spinel-like at the interface.

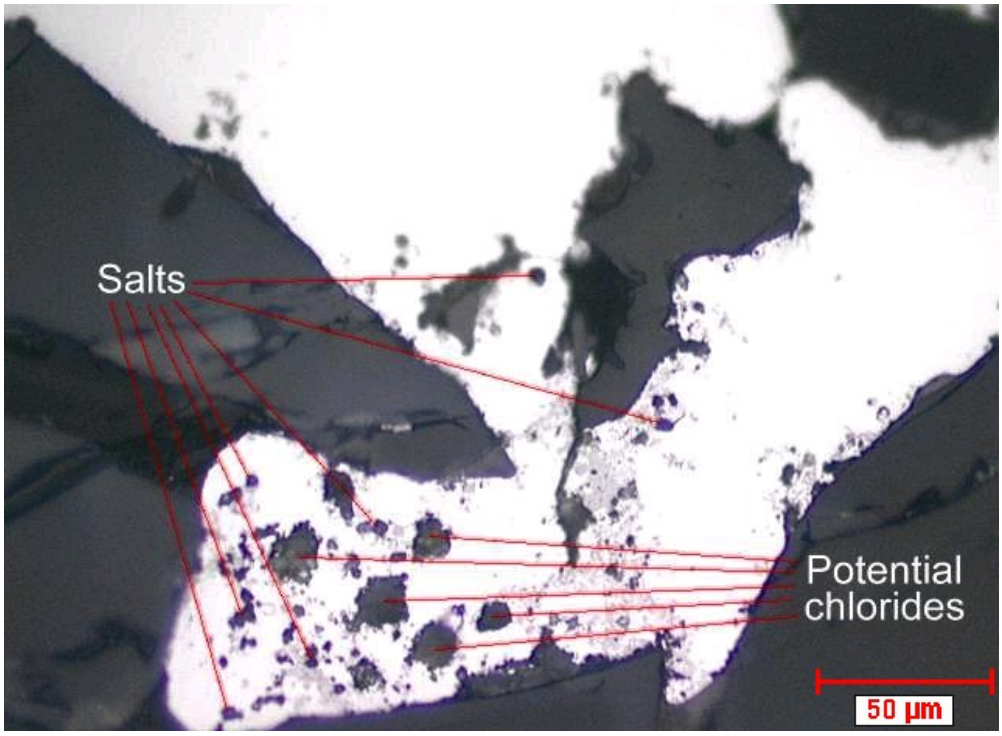


Figure 6 Sample #8 (500X) Presence of fluxing salt particles and potential chlorides.

Discussion

There were many types of inclusions found in these 8 PoDFA samples. The main inclusions found were grain refiner (TiB_2), aluminum carbides (Al_4C_3), magnesium oxides, potential fluxing salts and potential chlorides (or micro-gas). Please note that all samples contained aluminum carbide and grain refiner particles. We also noticed the presence of graphites, spinel-likes, iron or manganese oxides, aluminum phosphides and refractory materials. Sample #3.3 was the dirtiest with an inclusion content of 0.810 mm^2/kg and 21 oxide films per kilogram.

Spinel-likes are formed from the reaction between liquid aluminum and the refractory materials. This reaction is faster in alloys with higher magnesium content. Spinel-like inclusions are highly detrimental to the process.

Metallurgical spinels ($MgAl_2O_4$) are the most detrimental inclusions in the aluminum process because of their large size and hardness. The rate of formation increases as the melt temperature rises. Spinel (and cuboid) inclusions are generally formed from the reaction between MgO patches and aluminum oxides. Because of their large dimensions, both spinel-likes and metallurgical spinels can easily be filtered out of the metal.

Another type of inclusion that was found is magnesium oxide (mostly MgO). MgO is created by contact with the atmosphere. Because of their small size, these magnesium oxide inclusions are detrimental to the process only in large patches. Furthermore, they are often present with oxide films or worse with magnesium oxide spinel inclusions which are highly detrimental to the process.

Small amounts of potential chlorides or micro-gas were also found in all samples. Most chloride inclusions originate from fluxing devices using chlorine gas as an inclusion floating agent. Other chloride inclusions may also form when salt is added in the furnace as a metal cleanliness process. Chloride inclusions are very soft and should not cause any problems in most aluminum products except for thin foil and lithographic products. A dry polishing and a SEM analysis is necessary to differentiate chloride inclusions from micro-gas as chlorine dissolves in water.

Please note that one sample contained refractory materials. Refractory types of inclusions are introduced into the metal when the furnace lining becomes damaged during the stirring process. After degradation in contact with magnesium containing alloys, the refractory particles become similar in texture and color as a metallurgical spinel, but due to their larger size they are easily identified. Usually, refractory inclusions are large hard particles which may be extremely detrimental to the process.

Results Table Description

	Inclusion	*Chemical Symbol*	*Note*
Oxide Films	Number Length Thickness	γ-Al_2O_3	Number of oxide films counted under microscope divided by the weight of metal filtered. Short (< 250 µm), Medium (250 to 500 µm) or Long (> 500 µm). Thin (< 1 µm), Medium (1 to 3 µm) or Thick (> 3 µm)
Carbides	Small Carbide	Al_4C_3 < 3 µm	Aluminum carbide particles that have at least one dimension smaller than 3 µm and usually originating from the reduction of alumina or any other source of carbon contamination.
	Large Carbide	Al_4C_3 > 3 µm	Aluminum carbide particles that have at least one dimension greater than 3 µm and usually originating from graphite deterioration or any other source of carbon contamination (counted separately as carbides are very hard and because of their size, they are detrimental).
Magnesium Oxides	Magnesium Oxide	MgO	Reaction between magnesium and oxygen in the melt.
	Cuboid	$MgAl_2O_4$ - Cuboid	Forms after significant time and temperature in magnesium alloys.
	Metallurgical Spinel	$MgAl_2O_4$ - Spinel	Forms after significant time and temperature in magnesium alloys. Highly detrimental because of its big size and high hardness.
Refractory Materials	Reacted Refractory	(Spinel-like)	Hard and usually large inclusions coming from the reaction of refractories with magnesium alloys.
	Unreacted Refractory	α-Al_2O_3, CaO, SiO_2, ...	Unreacted refractory particles coming from the degradation of refractory materials which comes in contact with the melt.
		C (Graphite)	Graphite refractory particles in molten aluminum. After some time, graphite will react with molten aluminum to create aluminum carbides (harder inclusions).
Metal Treatments	Potential Chloride	$MgCl_2$, NaCl, $CaCl_2$,…	Inclusions that leave spherical shaped voids under optical microscope. Chloride crystals are dissolved by the polishing fluids. A dry polishing is necessary to differentiate between micro-gas porosity and chlorides.
	Fluxing Salt	Varies with flux type	Particles coming from flux treatments.
Uncommon Inclusions	Bone ash	$Ca_3(PO_4)_2$	Sometimes added on trough linings. Bone ash particles will be identified as fluxing salts as they have the same aspect under the microscope. SEM analysis is necessary to differentiate between them.
	Alumina Needle	Al_2O_3	From recycled metal.
	Nitride	AlN	Chemical reaction between aluminum and air (or nitrogen cover gas) after significant time and temperature. SEM analysis is necessary to confirm identification.
	Iron / Manganese Oxide	FeO / MnO	Inclusions coming from alloying powder additions.
	Silicon Particle	Si	Small particle probably coming from silicon addition in the melt.
	Fluoride	Na_3AlF_6, NaF, CaF_2…	Inclusions coming from cryolite during the electrolysis process.
	Aluminum Boride	AlB_2, AlB_{12}	Found in boron treated alloys.
	Borocarbide	Al_4C_4B	Forms with an excess of boron in the melt that reacts with aluminum carbides.
	Gamma Alumina Dispersed	γ-Al_2O_3	Forms in pure aluminum.
Additions	Boron Treatment	(Ti, V)B_2	Forms when boron is added to the melt to increase conductivity by precipitating vanadium and titanium.
	Phosphorus Modifier	AlP	Usually forms when phosphorus is added to the melt.
	Grain Refiner	TiB_2 / TiC	Deliberately added for grain refining.
Total Inclusion Content **Total Without Grain Refiner**			**Gives the total quantity of inclusions (except for aluminum oxide films).** **Gives the total quantity of inclusions excluding Grain Refiner (TiB_2).**
Comments:			Show some specific comments on samples.

Metallographic Parameters

Filtered weight	Weight of metal that passed through the filter.
Method	Counting method used (GRID or ESTIMATE).
Magnification	Magnification used for the counting under optical microscope (50X, 100X or 200X).
Measured chord length	Length of the analyzed section.
Filter condition	Good, Porous, Detached, Partially Detached, Rejected, No Filter.
Mould number	Mould identification number.

Note:

Analysis data reflect the metallurgical cleanliness of material actually sampled. Results are reproducible but long-term metallurgical quality will depend on the standard procedures and starting stocks employed in the manufacturing process. The value of any conclusions drawn from the data presented here will depend on the extent to which the material evaluated in this study is representative. In no event will ABB Bomem Inc. be liable for any damage whatsoever resulting from loss of use, data or profits, arising out of or about the use of the results in this report.

It was established that the repeatability of metallographic analysis is ± 16% for an inclusion content over 1.25 mm^2/kg. The precision of the metallographic analysis decreases with an increase of the metal cleanliness. When the inclusion content is less than 0.07 mm^2/kg, repeatability is ± 40%.

[Ref.: Metallographic Evaluation of PoDFA Inclusions Residue, Alcan, ARDC, Method # 2012-96]