Installation of Porous Plug and Injection of Argon Gas Through the Bottom in Induction Furnaces at Matrix Metals – Acerlan Foundry

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Abstract. **A new Induction Furnace (IF) operation practice was implemented at Acerlan Matrix Metals (AMM) and laboratory results showed that there is a potential for increasing the quality of metal through Argon stirring using a porous plug installation ~~melting practice~~ in the IF. This study was part of the company continuous improvement projects as well as for our customers satisfaction.**

Keywords— induction furnace, argon stirring, argon bubbling, porous plugs, Gas diffusers, steel casting, electric induction melting, Gas purging.

I. Introduction

Gas diffusers have been available for foundry ladle applications but have never made the impact seen in the tonnage steel industries. 'Classical' steelmaking methods such as the electric arc has two distinct melt phases: oxidation in which harmful gases like hydrogen and nitrogen can be removed during the carbon/oxygen reaction and reduction where oxygen and oxidation products can be removed. [1]

Induction furnace melting does not promote these reactions, while Hydrogen, Nitrogen and Oxygen can be absorbed by the melt from the atmosphere. This pickup can be inhibited by processes that have been developed to shroud or blanket the melt, making use of the fact that inert argon gas is denser than air by blowing argon gas onto the melt. [1]

A present limitation is the inability to use refining techniques to efficiently reduce gas content. When carefully selected melt scrap is coupled with consistent and rapid melting, an acceptable steel can be produced as a "dead-melted" metal, without excess gas molecules such as nitrogen and oxygen that can cause defects. However, with this practice there is a gas content increase during melting because of exposure to the atmosphere.[2]

Steel foundries have attempted to modify large-ladle porous plug technology to the induction furnace in hopes of using argon gas bubbling to reduce the gas content of the steel. This has been done successfully and has been reported with furnace sizes of 1,000 lbs. or greater. or greater. Notably, these furnaces used a rammed lining that lends itself to the installation of the nozzle in the bottom of the furnace.[2]

The typical foundry practice must ensure that the gas diffuser is able to deliver small quantities of inert gas to the induction furnace melt in a controllable manner and be compatible with the induction furnace lining materials. The gas diffuser must be easy to install, operate and be able to last for the life of the induction furnace lining. Ultimately, it must be cost effective, too. Where possible, a diffuser should be installed in the center of the furnace base, or as close as possible to the center.[3] (see Figure 1).

Laboratory experiments showed that there is a potential for increased alloy recovery and control through argon stirring with a porous plug.[4]

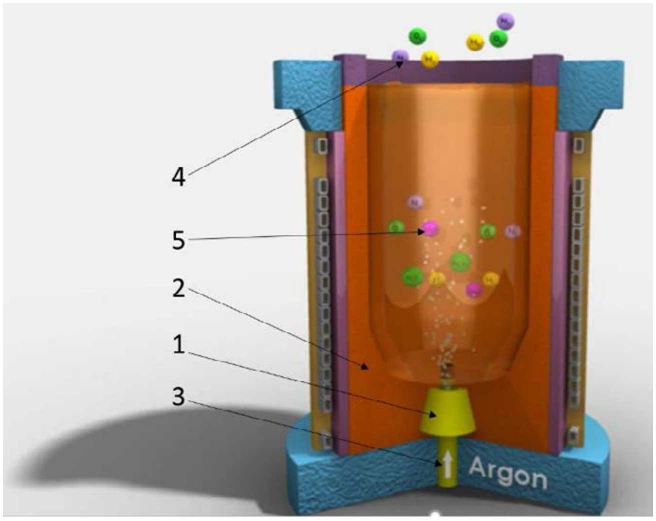

Figure 1. Porous Plug and Injection of Argon Gas Through the Bottom in Induction Furnaces configuration.

As illustrated in Figure 1, the furnace must have a gas supply to connect to the gas diffuser (1), and a there must be a suitable gas-flow control system. Such a system may be as simple as a pressure regulator on an argon-gas bottle with an inlet needle valve and flow meter.

The induction furnace lining (2) must be sintered before the gas diffuser is used, so that the gas can pass through the lining without disturbing it. Using a gas diffuser early in the melting process is not recommended; it's necessary for adequate sintering to take place first. Experience indicates that the best results are obtained from introducing gas to the diffuser during the third melt and onward.

Gas flow is turned on at "full melt" and the flow (3) is increased until a gentle bubbling motion is seen on the surface of the melt (4). This is generally at a rate of around 10 liters/minute, for example, in a one-metric-ton melt. Gas expands as the temperature rises, so there may be more bubbling as the temperature increases prior to tapping (5). Gas flow can be reduced at this stage to 6-8 liters/minute.

Gas purging should be continued for the duration of the melt, right up to the point of tapping. It is not necessary to purge fully for every melt. [3]

A gentle Ar rinse floats out nonmetallic inclusions (NMI) since the high-pressure bubbles of the Ar gas become the carrying agents which take the nonmetallic inclusions towards the surface of the slag and helps cleaning the liquid steel.

The fundamentals of Ar rinsing like other steel making processes are based on mass transport control. For mass transport control a convection current in the system is needed. Convection current is generated by the induction currents and due to the buoyancy of the inert gas introduced in the system at high temperature (around 1600 deg C).[5]

Installation and case studies [1]

Figures 2 to 5 shows the operation of an induction furnace porous plug.

Since the process was introduced, significant feedback has been received from users, those benefits identified include:

- Homogenization of bath temperature and composition
  - The introduction of argon gas via a gas diffuser immediately eliminated this problem.
- Improvement in casting quality
  - After the introduction of the gas diffuser and argon purging, scrap castings due to gas defects were eliminated and reworking was significantly reduced.
- Reduction in Nitrogen content
  - It is believed that this improvement (there were no other changes to the melting practice) was due to reduction of nitrogen in the metal.
- Cleaner metal
  - A significant reduction in nonmetallic inclusions since introducing the gas purging process to its induction furnace. The first indication of this came via the furnace operatives who reported that the volume of slag appeared to increase on melts treated with argon. Subsequent metallographic examination confirmed cleaner metal.
  - Showed improvements in impact strength of steel thus treated due to reduction in inclusion count.
- Increase lining life
  - Homogenizing in temperature (as previously described) would have a positive effect on the condition of the lining. A significant number of clients now report increase in lining life since introducing the process.

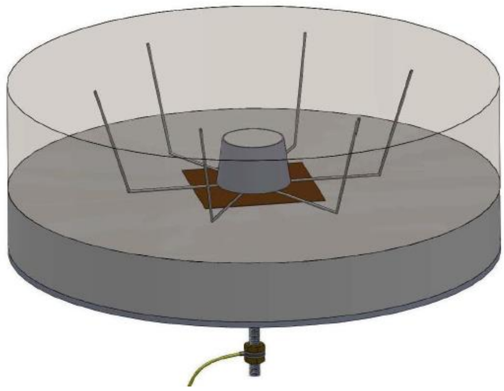

Figure 2. Typical diffuser installed in the center of the IF base (assembly)

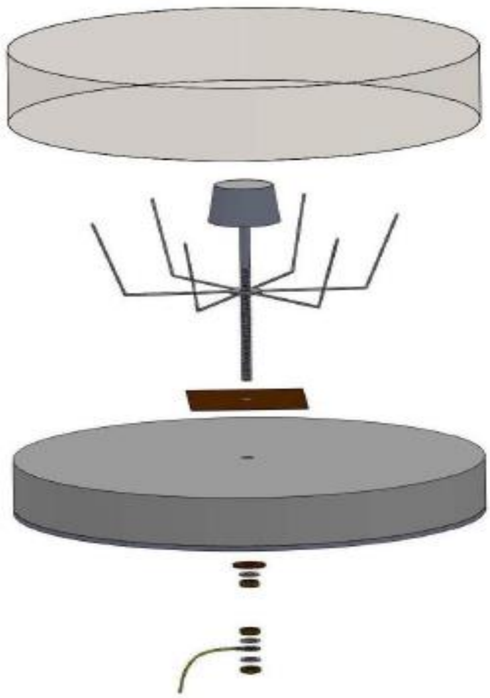

Figure 3. Typical diffuser installed in the center of the IF base (exploded view)

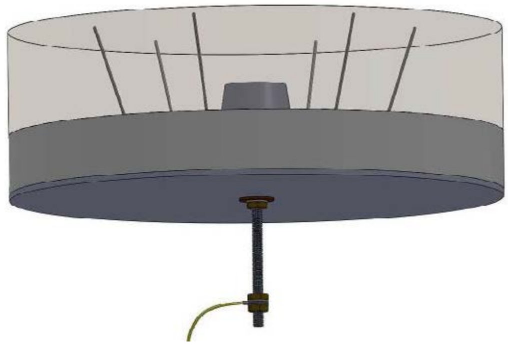

Figure 4. Typical diffuser installed in the center of the IF base (bottom)

II. BACKGROUND

In AMM case, a 90% alumina preformed crucible was used to line a nominal 2000-Kg. furnace. The crucible is backup-lined with a high Alumina (Al_2O_3) and dry magnesium oxide lining (MgO) to the induction coil.

A typical campaign life before using porous plugs was 80 heats. Casting defects associated with gas in the metal at times exceeded 20% which required significant reworking of in the finishing operation.

Heats produced in IF had high scrap rates on hydraulic seals castings and almost all castings were scrapped when nitrogen levels exceeded 0.012%. Prior to introducing the argon purge in the IF the average nitrogen was 0.010%.

Metallurgical Laboratory results showed a rejection of 3% to 5% on mechanicals and impact strength. Rejections of metallographic examination NMI were reported as well.

III. METHOD

The present operation provides an IF that utilizes a gas diffuser (see Figure 5), a crucible for a 2-Ton furnace, a method for preparing and using the crucible to promote the purity of a molten material

Methodology of results analysis described below:

a) Increase lining life
b) Gas reduction (Nitrogen and Oxygen results)
c) Test bars defects reduction - Tensile & Impact strength
d) NMI (no metallic inclusion) reduction – microstructure results.

With a high Al_2O_3 (85%) + MgO (12%) lining, the gas diffuser configuration described in below:

The porous plug placed in a crucible-lined furnace, and a safety ground fault wire (spider) was attached to the tube.

The validation for the installation of porous plug was one full lining campaign approx. 80 heats. Since the results came out very favorable, it was decided to install the porous plug in all induction furnaces at AMM.

The gas flow starts when the furnace is in liquid stage before final sample and is left on until the heat is poured. The flow rate needs to be adjusted by observation of the bubbles forming on the top of the bath. A typical flow is 7 liters/minute for 5-10 minutes before tapping.

It is understood that bubbles in the liquid metal become sites to remove Nitrogen and Hydrogen gases from it at ~1650°C [3000 F].

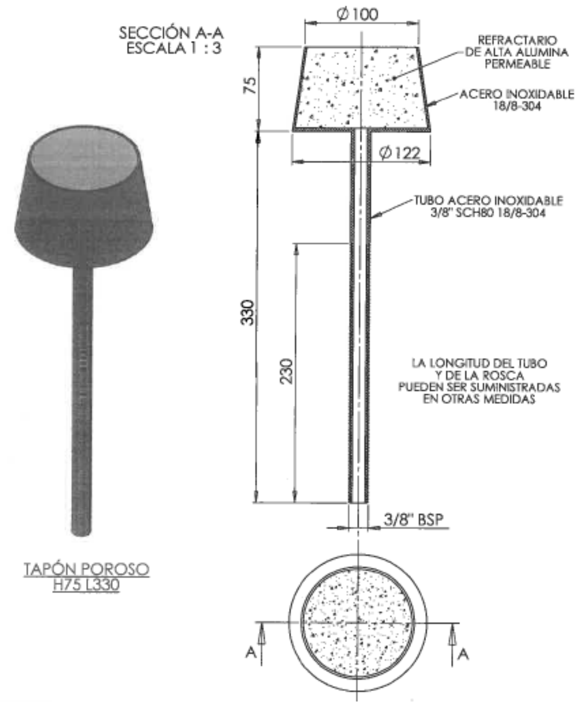

Figure 5. Porous plug components.Scale 1:3.

IV. RESULTS

A yearlong study of results is presented on this paper.

a) Increase lining life by 20%

More than a 100 heats were achieved poured using porous plug in the IF resulting in 14 weeks of operation and 20% increase of each lining campaing. See list of heats charge in Table 1.

ALLOY	HEATS	t, Mix (min)	POUR TEMP.	TAP TEMP.
CS	60	7.5	1590°C	1620°C
86xx	17	8.5	1585°C	1510°C
WC6/WC9	10	8.5	1580°C	1600°C
CFxx	18	8.0	1570°C	1590°C
Total.	105			

Table 1. Alloy average parameters of campaign with Ar treatment in IF

Melting summary report:

- Argon injection: 8 minutes Av.
- Tap temperature 1610°C [2930 F]
- Pour Temperature: 1585°C [2885 F]
- 105 Heats

b) Gas reduction (Nitrogen and Oxygen results)

Final Gas analysis in liquid metal was 70 PPMs of N for CS and low Alloy. Both Nitrogen (N) and Oxygen (O) were verified with LECO® equipment. See Table 2.

Av	CS	86xx	WC6/WC9	CFxx
N	0.0075	0.008	0.009	0.050
O	0.010	0.013	0.007	0.024

Table 2. Percentage of N & O analyzed via LECO

c) Test bars defects reduction - Tensile & Impact strength

After pouring the casting the remaining metal was poured into test bars for tensile & impact strength testing in our Metallurgical laboratory. An increase in mechanical properties from 98.5% to 99% accepted results and increase from 96 to 98.45% in impact strength. See Figure 6 & 7.

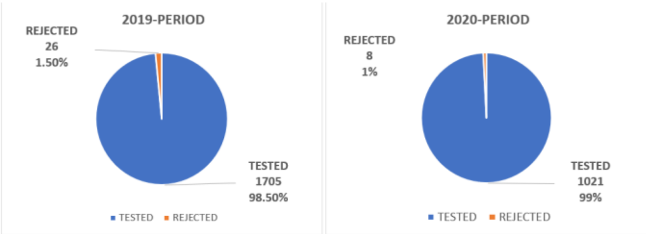

Figure 6. Tensile results 2019 vs 2020.

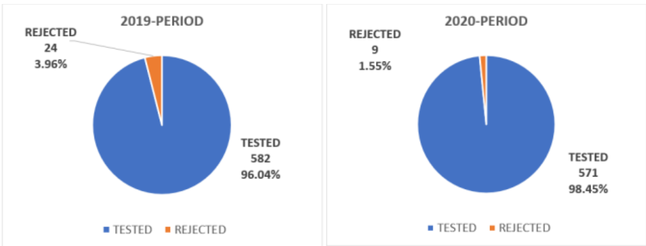

Figure 7. Impact strength 2019 vs 2020.

d) NMI (no metallic inclusion) reduction – microstructure results.

Metallographic results were compared from 2019 to 2020 for each type of alloy: CS N&T (WCB/WCC), CS Q&T (LCB/LCC), Low Alloy (86xx) Q&T, Martensitic (WC6), Austenitic SS (CF8C) at different magnifications: 100X, 200X, 500X and 1000X with and without etching to see the content of inclusions per alloy.

The results were favorable and significant NMI reductions were observed by microanalysis shown in Figures 10 to 20 only at 1000X magnification where a) is for 2019 and b) is for 2020.

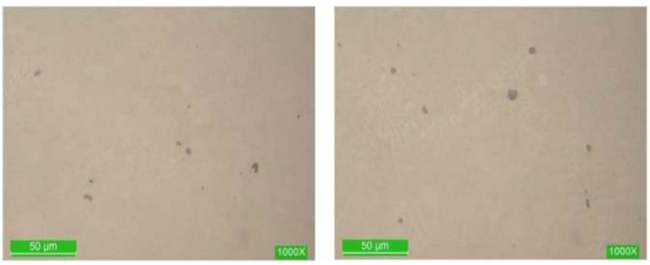

Figure 10 a) heat number 19K37H without etching at 1000X WCB/WCC material.

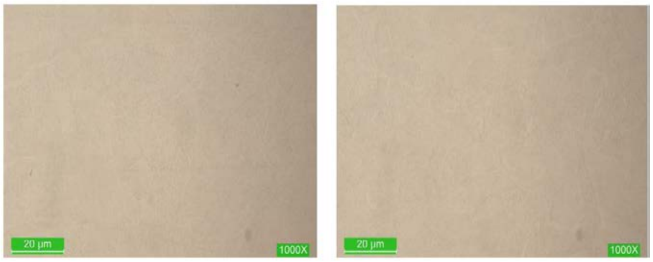

Figure 10 b). heat number 20N18H without etching at 1000X WCB/WCC material.

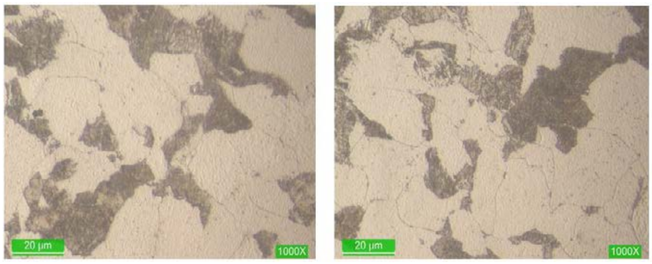

Figure 11 a). heat number 19K37H with etching at 1000X WCB/WCC material – Nital 5%.

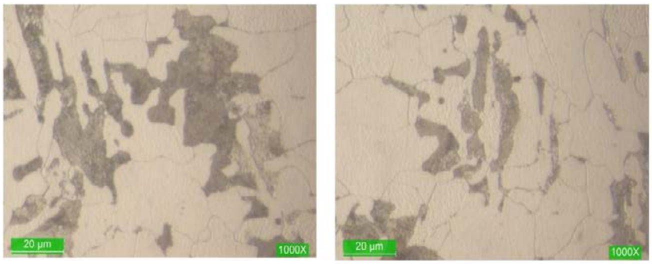

Figure 11 b). heat number 20N18H with etching at 1000X WCB/WCC material – Nital 5%.

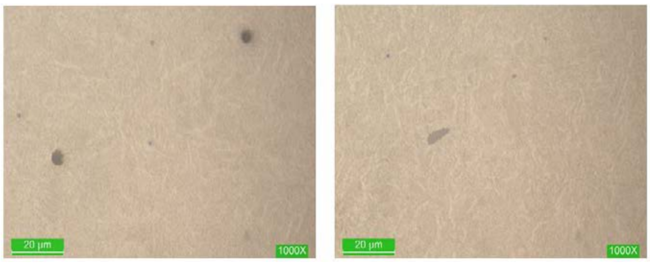

Figure 12 a). heat number 19S37H without etching at 1000X LCB/LCC material.

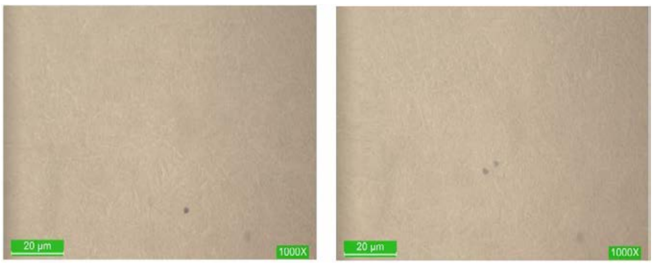

Figure 12 b). heat number 20N16H without etching at 1000X LCB/LCC material.

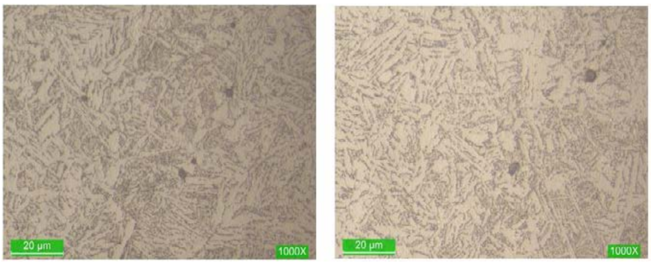

Figure 13 a). heat number 19S37H with etching at 1000X LCB/LCC material – Nital 5%.

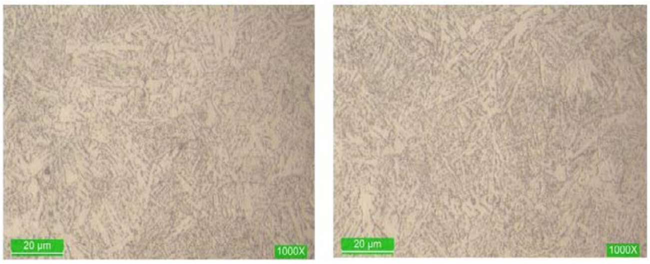

Figure 13 b). heat number 20N16H with etching at 1000X LCB/LCC material – Nital 5%.

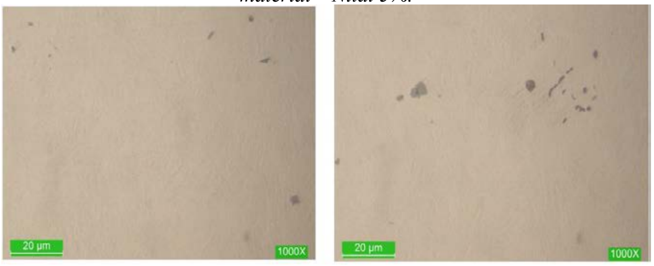

Figure 14 a). heat number 19T14F without etching at 1000X 86xx material.

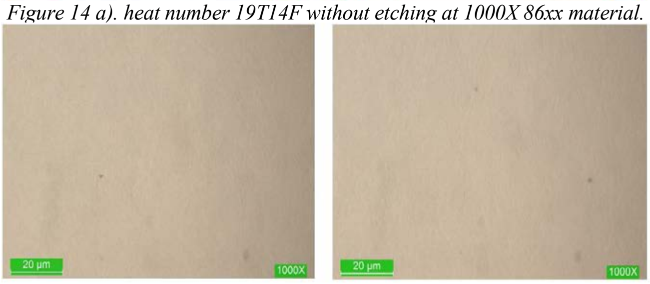

Figure 14 b). heat number 20K42H without etching at 1000X 86xx material.

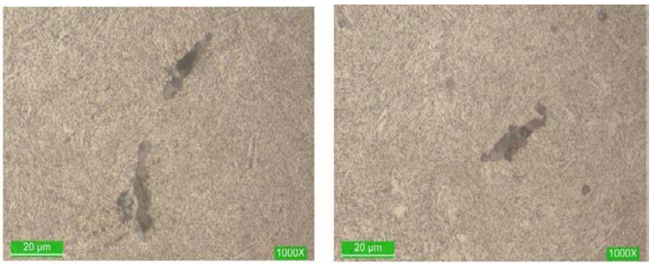

Figure 15 a). heat number 19T14F with etching at 1000X 86xx material - Nital 5%.

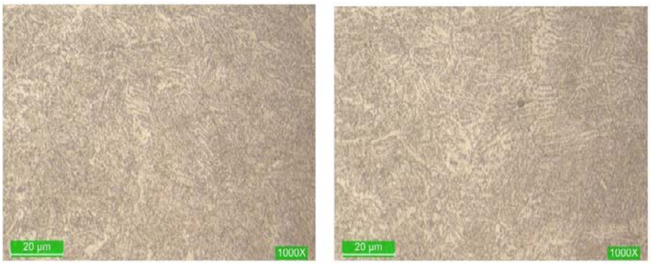

Figure 15 b). heat number 20K42H with etching at 1000X 86xx material – Nital 5%.

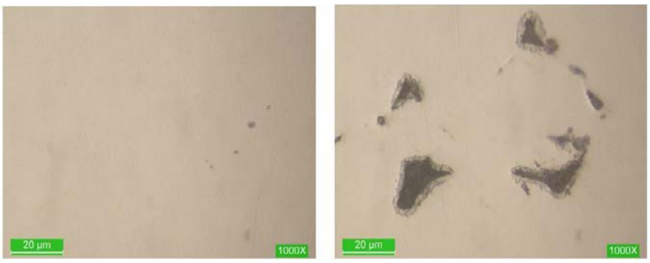

Figure 16 a). heat number 19S54H without etching at 1000X WC6 material.

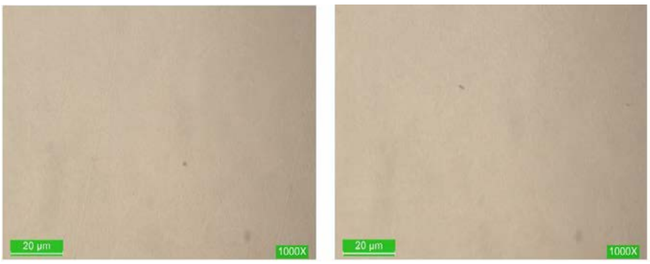

Figure 16 b). heat number 20K37H without etching at 1000X WC6 material.

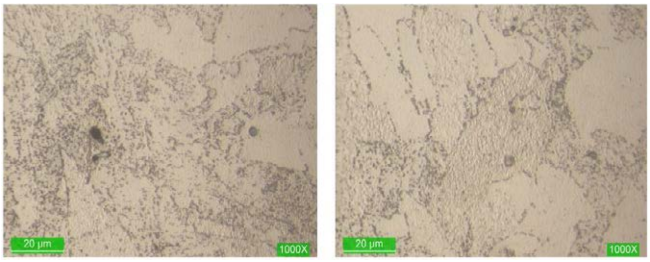

Figure 17 a). heat number 19S54H with etching at 1000X WC6 material – Vilella.

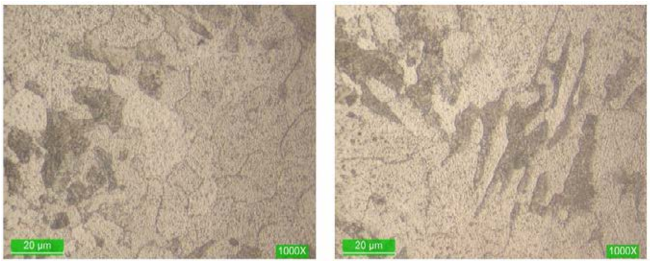

Figure 17 b). heat number 20K37H with etching at 1000X WC6 material – Vilella.

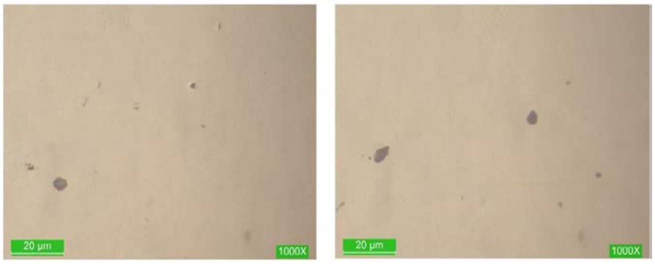

Figure 18 a) heat number 19J87F without etching at 1000X CF8C material.

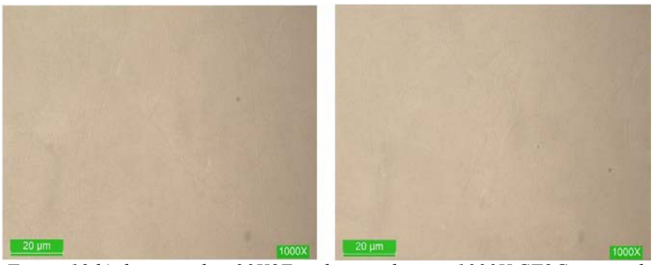

Figure 19 b). heat number 20K8E without etching at 1000X CF8C material.

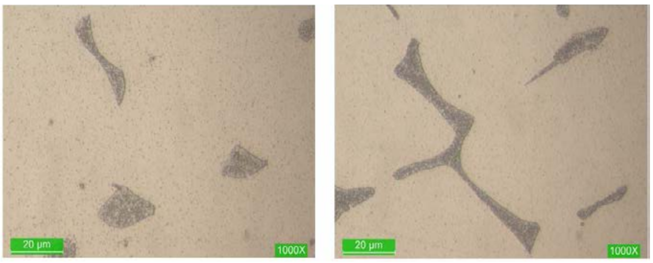

Figure 20 a). heat number 19J87F with etching at 1000X CF8C material.

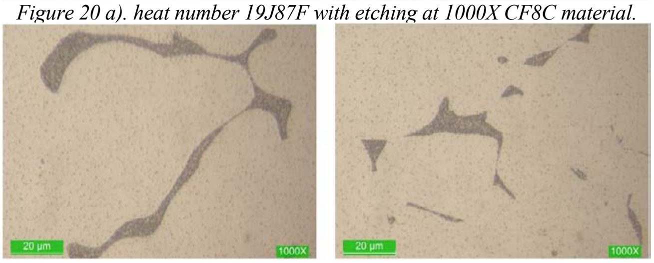

Figure 20 b). heat number 20K8E with etching at 1000X CF8C material.

V. CONCLUSIONS

Changing the old Induction melting practice to newly developed melting practice with Ar injection through a porous plug for 5-10 min purging at a 7-8 liter/minute flow in the 2-Ton crucible, the author reached the following conclusions:

1. The gas diffuser is easy to install and operate with safety ground fault wire (spider). The diffuser lasted with the life of the induction furnace lining.

2. Since Ar stirring improves the homogenization in the bath, AMM experienced an increase lining life by 20%. By controlling the liquid metal temperature range between 1590°C - 1620°C [2876 F to 2948 F] the lining life increased from 80 heats to average 105 heats for all type of alloys.

3. The Oxygen values were in the (~70 to 90 PPM) range which helped reducing the oxides inclusions.

4. Compared to the (90 PPM) Nitrogen content for "standard foundry melting practice" the newly Ar stirring practice reduced the Nitrogen in the (60 to 80 PPM) range.

5. Argon stirring with the porous plug in the IF is a proven melting treatment method which improved the mechanical properties from 98.5% to 99%. High energy Charpy impact testing values were observed ranging from 8 to 12 Joules [10 to 16 ft-lbs.] and an increase from 96 to 98.45%.

6. The surface area covered by inclusions in samples with Ar stirring was substantially lower than the untreated old practice shown at 1000X magnification on the surface area scanned.

7. Argon stirring with a porous plug in 2-Ton IF improved inclusion flotation and steel cleanliness by reducing levels of oxides i.e. SiO_2, Al_2O_3 and MgO. This was validated by quantitative inclusion measurements (micrography), Tensile and Charpy impact results.

To achieve similar results, the author has implemented this melting practice for all furnaces at AMM. and for the small induction furnace.

ACKNOWLEDGMENTS

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REFERENCES

[1] www.capital-refractories.com Capital Refractories Ltd "Gas purging in the induction furnace"; Furnace Technology, FTJ December 2007. Pp 350-351

[2] S. Boyd, R. Boyd "Nova Precision Casting Installed A Porous Plug in A Crucible Lined Induction Furnace To Treat Steel With Argon Gas" Nova Precision Casting Corp. Steel Founders Society of America (SFSA) T&O Conference, Auburn, Pa, December 2013.p1.

[3] "Installations Demonstrate Gas Diffusers Improve Induction Melting". https://www.foundrymag.com/issues-and-deas/article/21925137/installations-demonstrate-gas-diffusers-improve-induction-melting, Jun 24, 2007

[4] K. D. Peaslee et al., "Alloy Recovery and Control in Steel Melting," Proceedings of the SFSA Technical and Operating Conference, Steel Founders' Society of America (SFSA), Jan 2005. p1.

[5] https://www.ispatguru.com/argon-rinsing-of-steels, "Argon Rinsing of Steels", October 26. 2014.

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