World Academics Journal of Engineering Sciences
Vol.10, Issue.1, pp.14-18, March 2023
E-ISSN: 2348-635X
Available online at: www.isroset.org

Research Paper

Ceramic Filter Effect on Surface Defects in Nickel Based Superalloy

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Received: 14/Jan/2023; **Accepted**: 18/Feb/2023; **Published**: 31/Mar/2023

***Abstract*-**Surface defects are common defects in casting process and directly related to the purity of molten metal and using ceramic filter. In fact, producing a part in investment casting free of any defects is almost implausible. These defects are usually displayed as cluster or star at nights defects on surface of casting part and finally may lead the part to be rejected. In this study the effects of ceramic filter on reduction of surface defects in nickel based superalloy gas turbine blade has been studied. The mesh of filter was 10 ppi, and its thickness was 20 mm with two diameters of 40 and 70 mm for gate and cup filter respectively. To comparison of surface defects content, another ceramic mold without ceramic filter into the gate in vacuum induction melting furnace and with same casting condition was poured at 1420°C. After casting, fluorescent penetrant inspection was applied on each blade and also surface grain size of the blades was compared with each other. The results show that when ceramic filter is used into the gate, the surface defects are 4 times less. In addition, those blades that poured with filter had finer grain size. The reason for finer gran size can be related to the better temperature distribution in the mold.

***Keywords*-** Surface Defects, Ceramic Filter, Investment Casing, Nickel Based Superalloy.

1. Introduction

Generally, in all the investment casting processes, two of the common defects that are observed in casting process are dirty in molten metals and inclusions. These defects are generally originated from external source, usually non-metallic, such as slag. The inclusion may also be formed by missing areas of metal in the casting resulting in small, round, irregular or angular craters. Additionally inclusions may be depressions or cavities of various sizes, typically superficial with traces of ceramic and refractory material [1].

Usually, some causes of inclusions can occur early in the casting process such as cracks in the wax mold allowing bits of ceramic to get into mold cavity, in some circumstances over hanging ceramic material on the shell can break off during the casting process. One of the prevention methods for not allowing dirty and inclusion to enter into the ceramic mold is using cast ceramic filter. These defects are usually displayed as cluster shape and star at night on the surface. Figure 1 shows discussed defects in a superalloy Investment Casting [2].

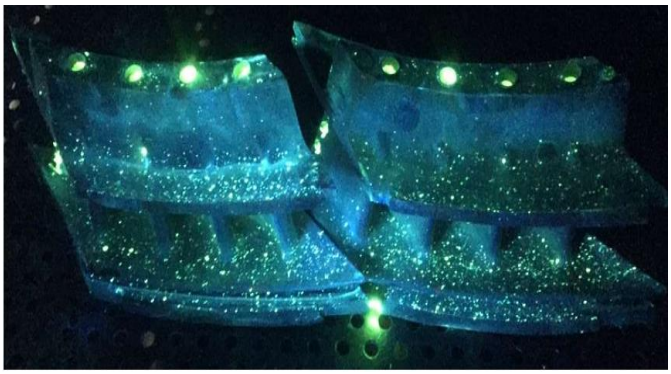

Figure 1. Surface defect in a superalloy Investment Casting [2].

Moreover, in the previous study it has concluded that non-metallic inclusions originated from filters may give us a lot of problems. The experiment carried out does not give us a definite answer which of filters with different mesh is the best for production, due to too long pouring time (too low flow rate). Different ceramic filters with various mesh are shown is figure 2. In this study different temperature profile determines surface defects (Fig 3). To achieve the final answer the experiment should be repeated with a reduced pouring time in the laboratory or using only a simulation by Procast software [3]. Ceramic filters can also be used within the gating system, before the runner, or before the gates to be more effective. Figure 4 shows that filters can be used in pouring cup, runner and gate simultaneously [4].

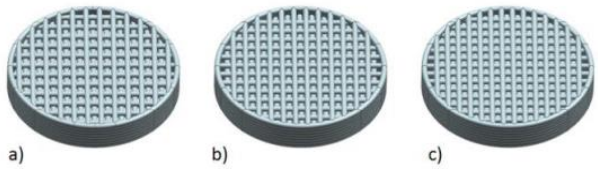

Figure 2. Printed filters with different level of the filtration: a) Fast, b) Medium, c) Slow [3].

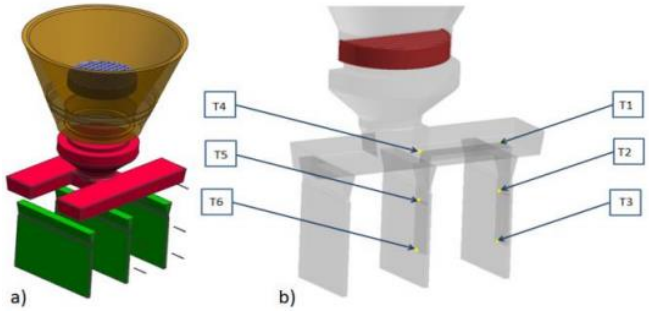

Figure 3. a) Wax assembly with pouring cup and ceramic filter b) location of thermocouples [3].

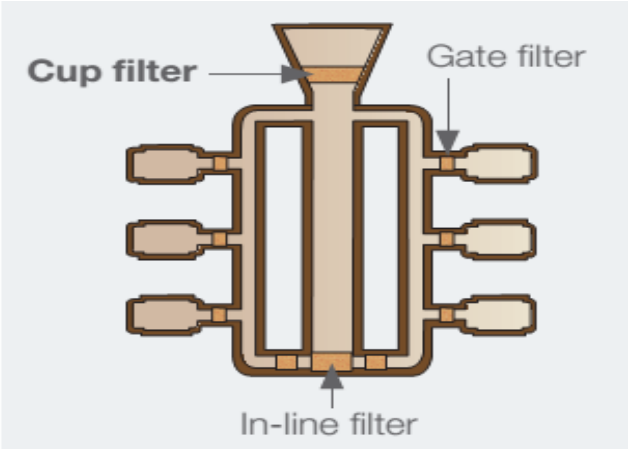

Figure 4. Different places of filter in ceramic mold [4].

In this study, shape of filters and their size of mesh are directly related to their influence in preventing inclusion. The benefits of the ceramic filters are providing laminar flow of the melt, filtrating nearer to casting, reducing molten metals splash by undulating the surfaces of filters and providing available space for melts to flow. Figure 5 displays shape and sizes of the discussed filters [4].

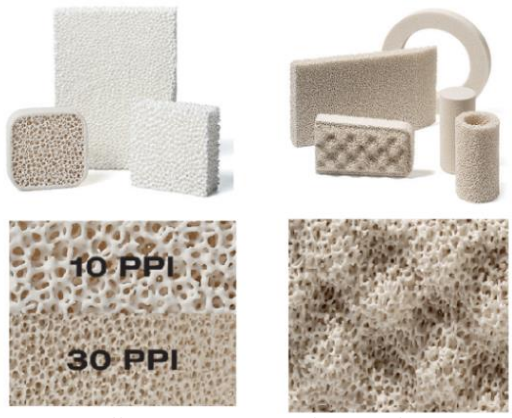

Figure 5. Different shape and size of ceramic filter [4].

To gather more information of the flow going through foam filters, Gebelin and Jolly used the computational modeling to simulate the flow through a filter. They found the temperature distribution in the region of the runner and the filter depended on the design of the runner system [5]. In other research, it demonstrated that optimum velocity of molten metal is very critical to prevent any turbulence. These turbulences can form bubbles and biofilms that might be displayed as surface or bulk defects after solidification [6].

In the other study, Hsu and Campbell emphasized that the shape of gating system by using filter can reduce some porosity defects on the surface of casting. In fact, in comparison of U shape system, L shape can reduce the defects increasingly. In the study, they showed that preventing melt from turbulences can drastically reduce biofilms which van be observed on surface due to the reducing the velocity of the melt [7].

2. Experiments

In this research, the effect of ceramic filter on surface defects has been studied. For this purpose, two ceramic molds of gas turbine blade were produced by investment casting process. The alloy was IN738LC alloy and pouring temperature was selected 1420°C. Chemical composition of IN738LC is shown in table 1. The molds were poured in vacuum furnace and the amount of vacuum was 10^{-3} bar. Each ceramic mold had two blades. To comparison of filter effect, one of the molds only had one ceramic filter in pouring cup, while in the other two filters were put in pouring cup and gate. The wax cluster without filters is shown in figure 6 and Ceramic filter which is assembled into the gate is displayed in figure 7. The wax cluster with filters is shown in figure 8 and finally the ceramic molds for both systems are shown in figure 9. After casting to investigate surface defects and comparing them between casting parts, grain size and fluorescent penetrant test (FPI) have been done. The etching solution for detecting the grain sizes was composition of Hydrochloric acid (HCl), Ferric chloride $FeCl_3$ and water.

Figure 6. Wax cluster without filter.

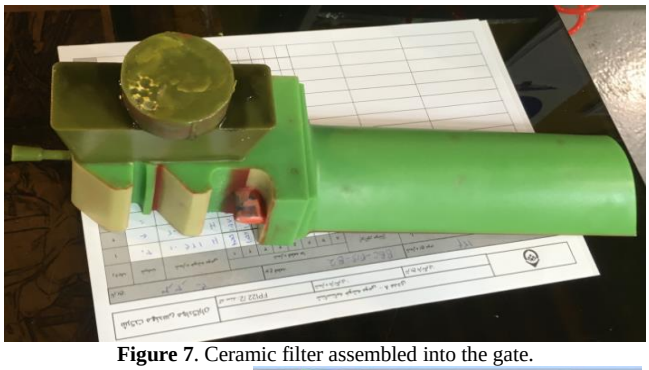

Figure 7. Ceramic filter assembled into the gate.

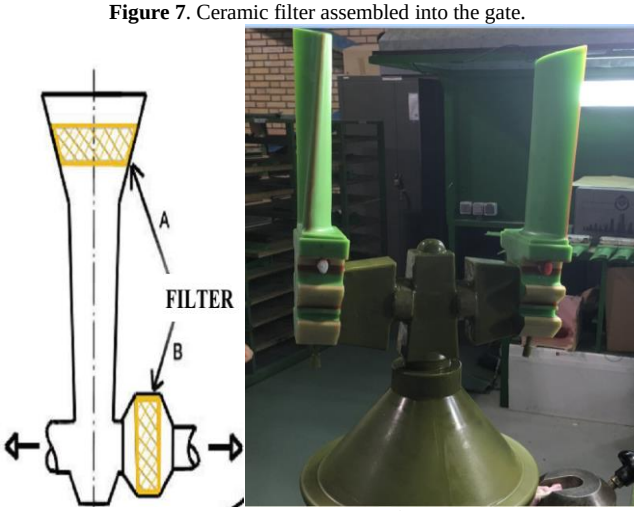

Figure 8. Wax cluster with ceramic filter into the gate.

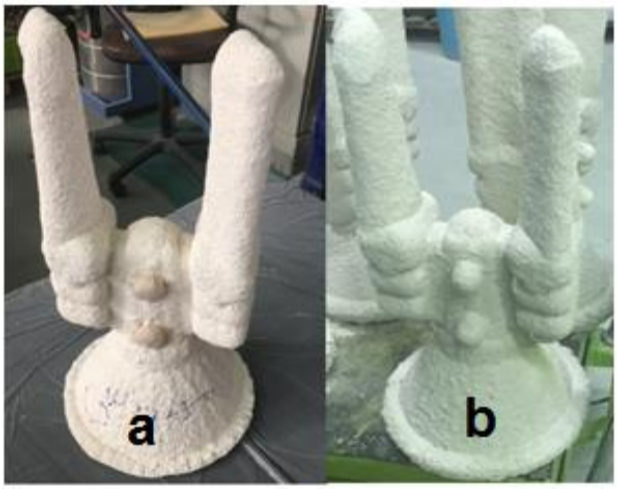

Figure 9. Ceramic molds: a) with and b) without filter

Table1. Chemical composition of IN738 LC (Weight Percentage).

C	Si	Mn	P	S	Cr	Mo	W	Co
0.12	<0.05	<0.005	0.0003	0.0003	15.7	1.7	2.5	8.4
Nb	**Fe**	**Ti**	**Al**	**Al+Ti**	**B**	**Ta**	Zr	**Ni**
0.9	0.08	3.4	3.5	6.9	0.01	1.7	0.02	Bal.

3. Results and Discussion

In general, moreover the reducing turbulence effect when ceramic filter is used, its main purpose is the separation of non-metallic contaminants from the molten metal. As a result, the open cross-section of the filter medium is decreased continually throughout the pour. Depending on the type and quantity of non-metallic contaminants that are to be removed from the molten metal via the filter, this process can result in the filter becoming blocked. This is reflected in the casting results in the form of increased pouring times, cold lapping or incomplete casting. And, such processes depend on the respective flow rate in each specific case and they exercise a direct influence on the capacity of the filter medium. With regard to the flow rate and capacity of ceramic foam filters, the parameters of filters are weight, porosity, filter surface area, filter thickness and flow rate [8].

In many cases, however, the process of analyzing the causes of filter blockages is significantly more complex. From the point of view of failure prevention, the analysis and investigation should not be restricted to the characteristics of the filter medium used. The filter-related characteristics mentioned above represent only some of the factors which need to be considered. The type and quantity of non-metallic contaminants in the melt are influenced by a large number of foundry-specific process parameters, and they are difficult to quantify. These process parameters can be categorized into the areas of charge make-up, aggregates, melting technology, metal treatment, and chemical composition and casting technology [8].

Although casting in vacuum atmosphere can reduce some metallurgical defects, surface defects in investment casting in vacuum induction melting (VIM) furnace are usual and inevitable. As a result, if the cleanliness of ingot and crucible are not controlled, these defects will elongate the time of finishing process or even worse, would cause the rejection of casting parts. For instance, by investigation of some specimen by scanning electron microscope (SEM) can be conclude that the inclusions observed in these images may relate to the reaction between the aluminum in the crucible walls and melt. The result revealed that the inclusions are mostly aluminum (Al) element and its oxides (Fig. 10) [9].

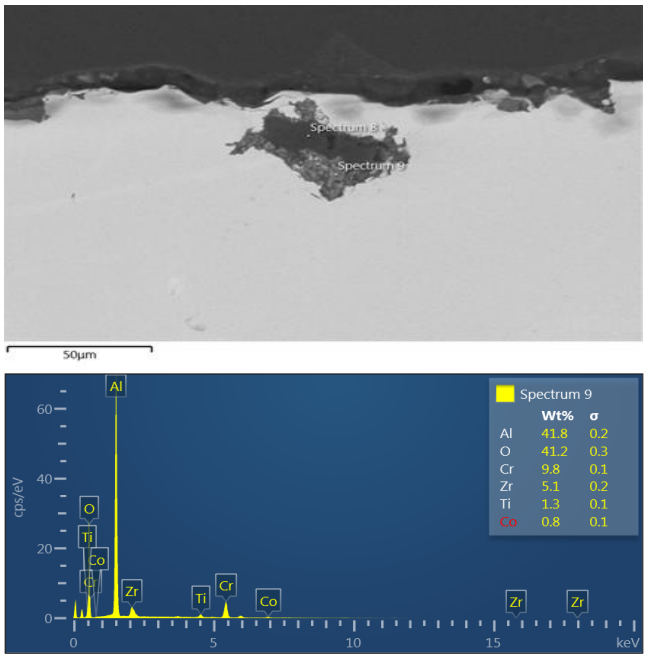

Figure 10 . Different inclusions in SEM results [8].

In this study, however the filter blockage was not observed due to the right selection of casting factors which were included optimum flow rate in good gating system, proper pouring temperature and enough preheat time for ceramic mold. Grain size in both casting condition is shown in figure 11. According to the fluorescent penetrant test and calculation based on formula (1), surface defects in root of the blades when filter was used were much lower than the other state. As a matter of fact, filter in gate reduced the cluster and star at night defects drastically. The amount of this reduction was four times, based on the calculation of formula (1). Figure 12 show FPI result test.

Figure 11. Grain size: a) filter is used and b)filter is not used.

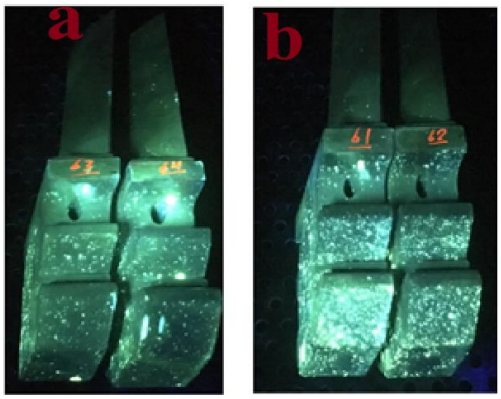

Figure 12. Fluorescent penetrant test: a) filter is used and b) filter is not used.

$$\%Defect = \frac{Defects \times Surface\ Area\ of\ Defects}{Total\ Surface\ Area} \times 100 \quad (1)$$

If average area each defect is considered 7.2 mm^2 (a circle with diameter of 3 mm). The defect here means non-acceptable defect according to the quality control criteria. Therefore, the percentage of surface area for each casting condition in a specific root area can be calculated like below:
With filter:

$$\%Defect = \frac{10 \times 7.2}{38 \times 22} \times 100 = 8.6\%$$

Without filter:

$$\%Defect = \frac{40 \times 7.2}{38 \times 22} \times 100 = 34\%$$

Figure 13 demonstrate above results:

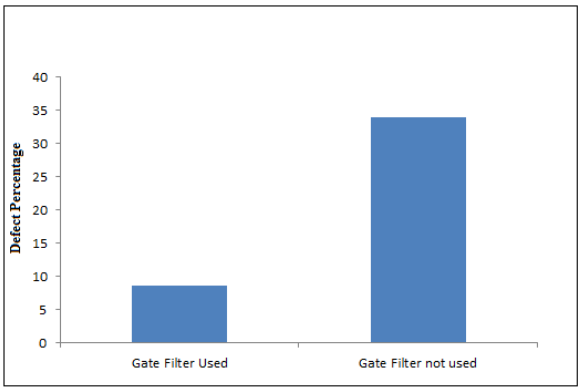

Figure 13. Surface defects content in the casting parts.

4. Conclusion

According to this paper, surface defects on the blades were significantly reduced when a ceramic filter was used in gate. As a matter of the fact, the most important region before the melt enters into the mold cavity is the gate. That is, this place is the last places in gating system that molten metal passes. In this study, it concluded that the effect of using ceramic filter is very important to reduce surface defects. In effect, it helped temperature of molten metal to be distributed universally amongst the mold cavity and conformed fined and a more equi-axed grains. Moreover, as the results show, some surface defects such as cluster and star at night defects were reduced greatly when filter used. The calculation and diagram showed that once filter used the surface defects reduced 4 times in comparison with the no-filter-in-gate.

Conflict of Interest

All authors are requested to disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence, their work. Otherwise, Authors declare that they do not have any conflict of interest.

Acknowledgements

This work was prepared with the support of the Casting Foundry and Engineering Unit of the Mavadkaran that is one of the subsidiaries of MAPNA Group. The Authors would like to thank Experts of Mavadkaran. Their suggestions and guidance in this work were helpful and appreciable.

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