Understanding Key Factors to Improve Billet Surface Quality and Casting Mold Life

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ABSTRACT --- Billet surface quality is significantly influenced by both the type of casting mold and mold maintenance. Currently, the majority of billet producers use molds with graphite technology, where a mix of oil and gas is injected through a graphite ring into the mold to improve billet quality. The ability to maintain optimal surface quality, as well as extend the longevity of casting molds, can greatly benefit producers and end-users. Recently, a new measuring device has allowed several critical factors affecting billet quality and mold longevity (particularly the graphite rings) to be analyzed. This paper reviews multiple parameters that have been statistically analyzed under various conditions. The result of this analysis identifies the critical factors, such as oil type or graphite permeability and uniformity, which must be followed in order to produce billets of ideal surface quality while increasing mold longevity.

INTRODUCTION

For decades, successful billet casting was considered by many to be an art. Experienced operators and technical people made the difference between a good cast and a bad cast. Molds and table maintenance were governed by manufacturers' recommendations and practices developed in house. Preventive maintenance was implemented, but predictability was still not in sight.

The following paper will describe a model experiment run in one of the largest billet casthouses in North America. Through testing and measurements, a mold's behavior and lifespan can now be predicted, and billet quality improved.

Aluminerie de Bécancour Inc. (ABI) features a modern casthouse with four pits equipped to cast Wagstaff Air-Slip billets, a homogenization capacity of over 230,000 megatons (mt) per year, and a pit recovery in excess of 97 percent.

The current ABI practice regarding mold maintenance is as follows: upon reception, the graphite rings are assembled in the molds and are primed with oil; the molds are then wrapped in plastic and stored on a shelf for future installation; once in production, the mold will be cleaned and prepared between each drop. The molds will remain in production until they start producing surface defects. They are then taken out of service and the graphite ring is replaced. Figure 1 below illustrates the mold life cycle.

During this experiment, the location of each mold on the casting table was recorded. The flow through the graphite ring was measured when taken out of service, and compared with the initial measurement.

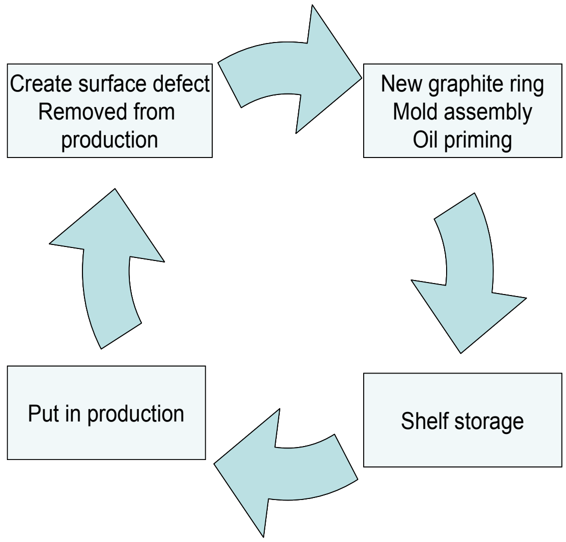

Figure 1. Mold life cycle.

PERMEABILITY MEASUREMENTS

Historically, graphite ring suppliers provided total flow recommendations from their own measuring apparatus. New measuring devices are now available that provide total flow and uniformity flow. The measurement device used for this experiment was the *RJ Collins Graphite Ring Tester* shown in Figure 2.

Figure 2. RJ Collins graphite ring tester.

The apparatus takes and records 20 measurements around the circumference of the molds under a specified pressure. Ring installation in the mold is done in such a way that each individual measurement can be tied to an exact location on the billet; a relationship between billet appearance and ring permeability can therefore be established. The total flow is also measured, and combined with the uniformity flow, they will provide a complete picture of the graphite ring quality.

The results are graphically represented using a radar graph as shown in Figure 3. This graph gives a 360-degree representation of the ring. The maximum flow at any point is topped at 0.8 liters per minute, and corresponds to the graph circumference. A dead spot would be equal to zero and be located at the graph's center. The light gray line represents the measured flow through each point; dotted lines are the boundaries within which the flow is expected to be. Apparatus repeatability was measured all along the experiment, and determined to be greater than 95 percent.

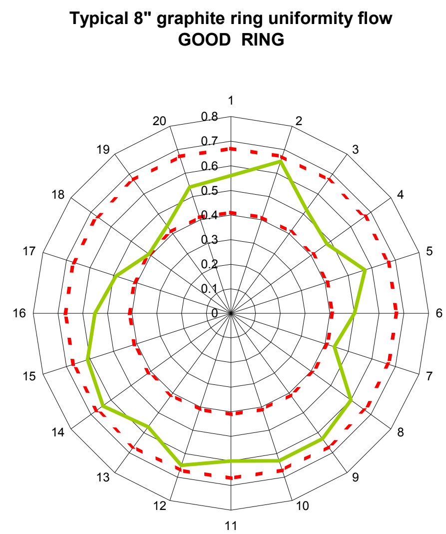

Figure 3. Uniformity flow measurement.

Three different measurements will be used throughout this paper to describe the performance of the graphite ring.

- Uniformity flow average: average flow of the 20 measurements performed on the circumference of the ring, in liters per minute

- Total flow: total amount of gas that flows through a graphite ring

- Dead spot: an area of the ring with negligible gas flow.

The graphite ring behavior was also characterized under different production conditions such as oil type, oil viscosity, oil injector type, casting tables, and so on.

The Experiment

The experiment consists of measuring 100 percent of our graphite ring population before and after being put into production. The first objective of this experiment was to characterize a good graphite ring. Data analysis has proven that some of the as-received graphite rings were not fit to be used in production, or didn't last as long as expected. The number of graphite ring dead spots, average uniformity flow, and initial total flow are critical parameters that need to be established in order to meet graphite ring life expectancy.

The following figures present the Airslip tooling used for billet casting and a graphite ring close view near to the solidification point. The Airslip technology provides thinner shell zone, and the best surface quality available.

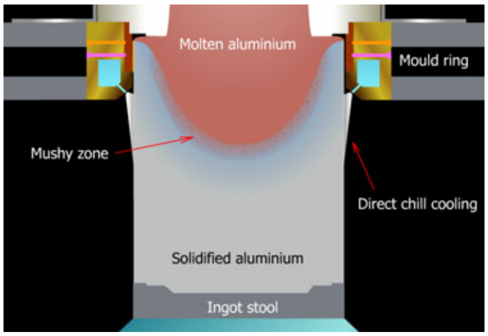

Figure 4. Casting mold and apparatus.

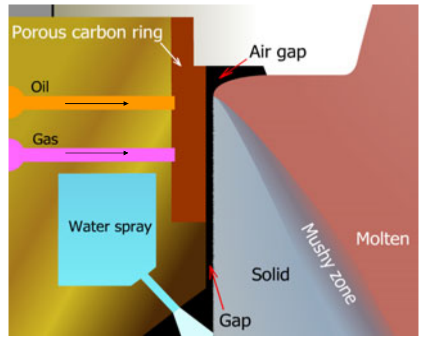

Figure 5. Graphite ring close view.

Graphite is known to be porous, per its fabrication process. Unfortunately, dead spot areas can occur, which will generate billet surface defects while decreasing ring life expectancy as shown in Figure 6.

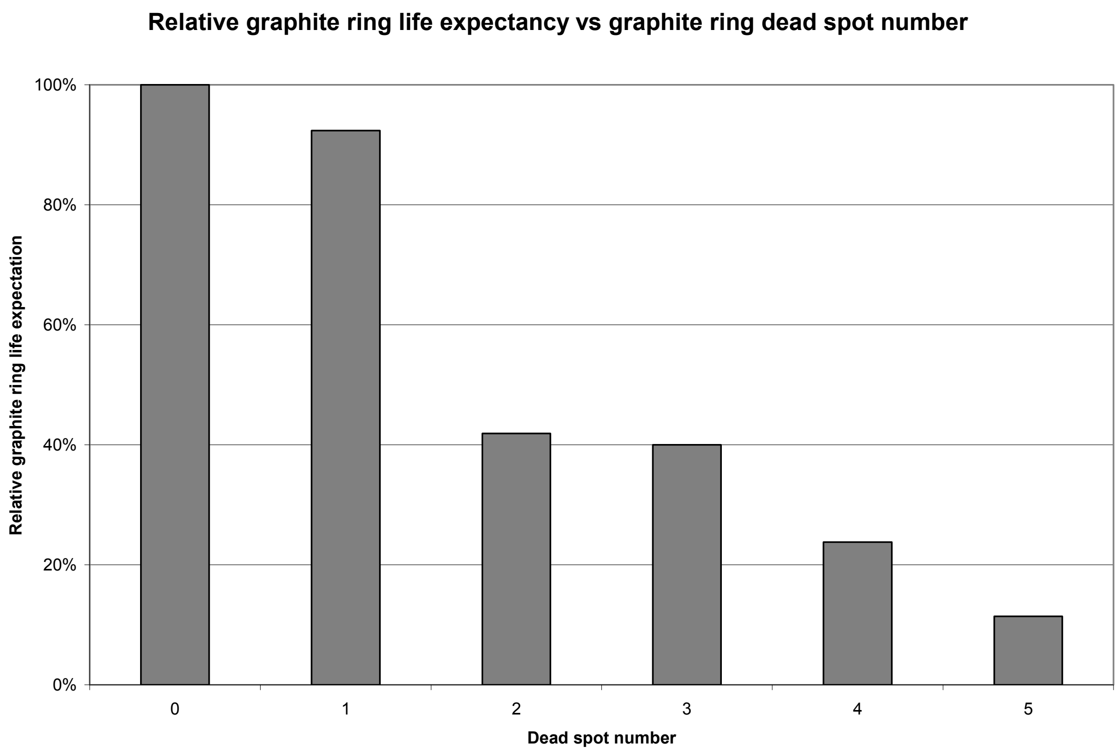

Figure 6. Graphite dead spot effect on life expectancy.

Data have been collected from 7-inch, 8-inch, and 9-inch graphite rings under various conditions such as casting tooling, alloys, oil type, and casting recipes. It has been proven that initial graphite conditions such as the total flow and uniformity flow through the ring are strongly related to the ring's life expectancy.

Initial total flow through the ring would ease the billet to get the best Airslip condition such as oxide release, and smooth billet surface finish. Figure 7 illustrates the impact of the initial total flow on ring life expectancy.

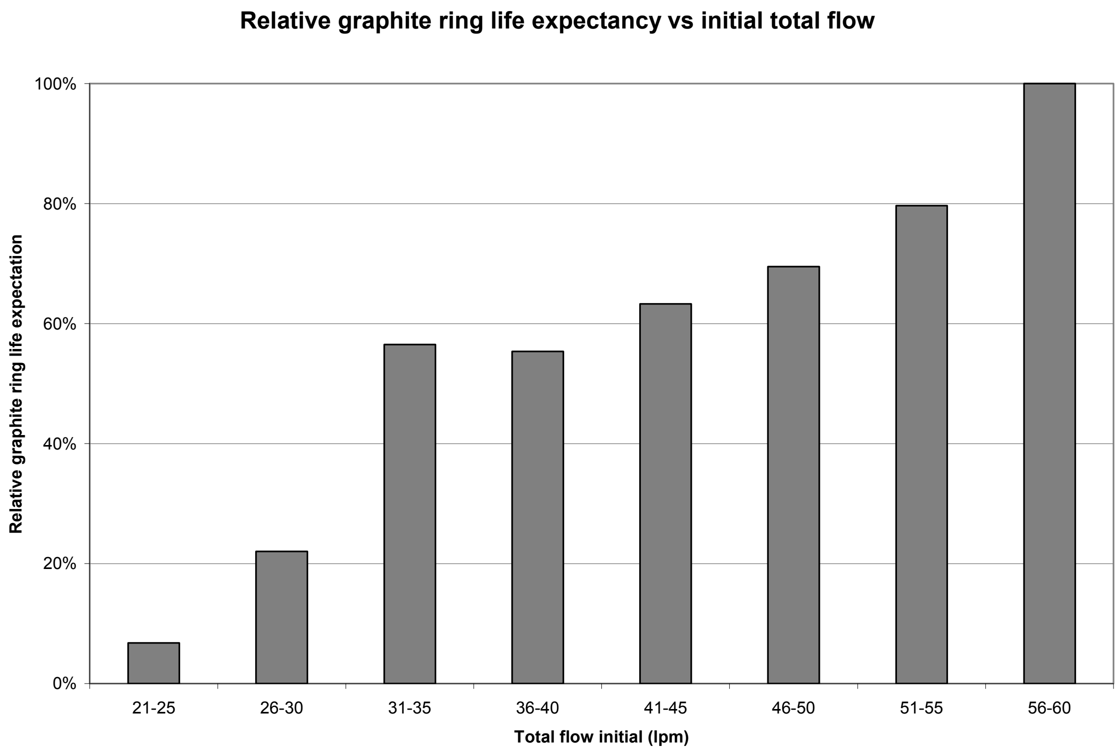

Figure 7. Initial total flow impact on graphite life expectancy.

Uniformity flow through the ring has been shown to be a key factor for surface defects, as well as graphite life expectancy, and is related to initial total flow, but both of them have to meet targeted conditions. While total flow will provide enough gas for the Airslip, it won't guarantee a smooth surface across the billet like uniformity flow does. A mold is usually removed from production as soon as it starts to produce any kind of surface defect. Figure 8 presents the uniformity flow on the ring life expectancy.

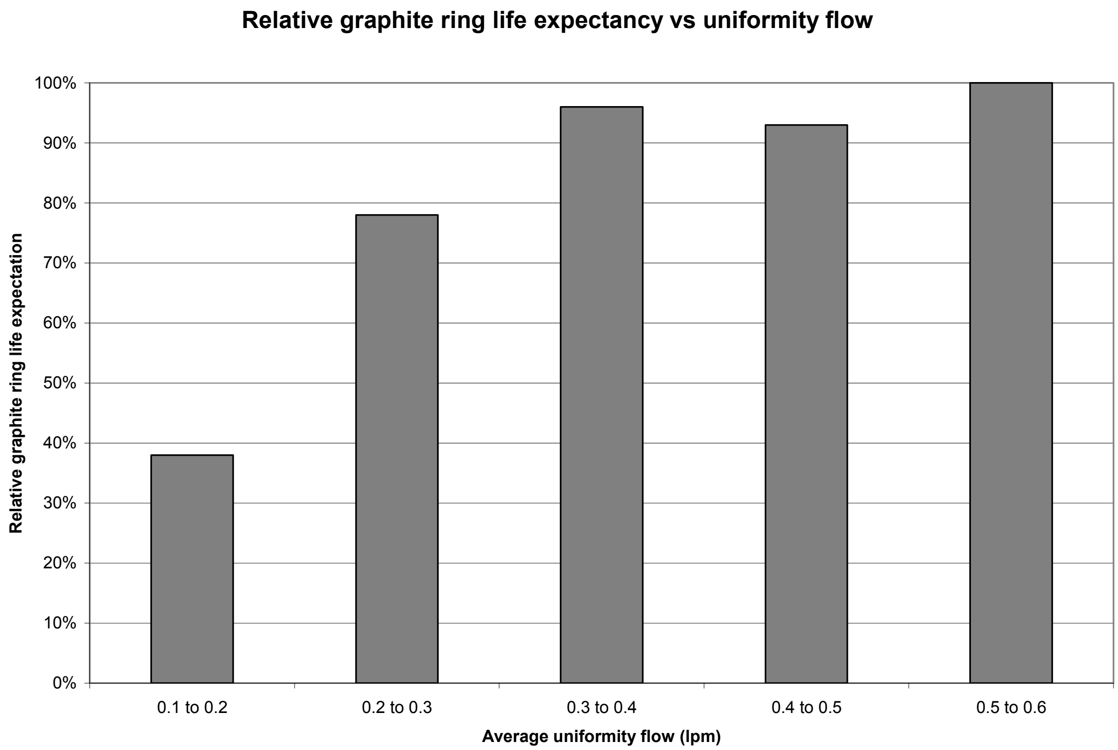

Figure 8. Uniformity flow on graphite life expectancy.

Mold to Mold Comparison

By studying the results of the uniformity flow, it became obvious that there was a relationship between the scrap rate generated by the ring and the uniformity flow at different points. Dead spots would create some types of scrap; a series of consecutive low flow points would also create some types of defects. Figure 9 illustrates the link between the billet surface and the state of the graphite ring.

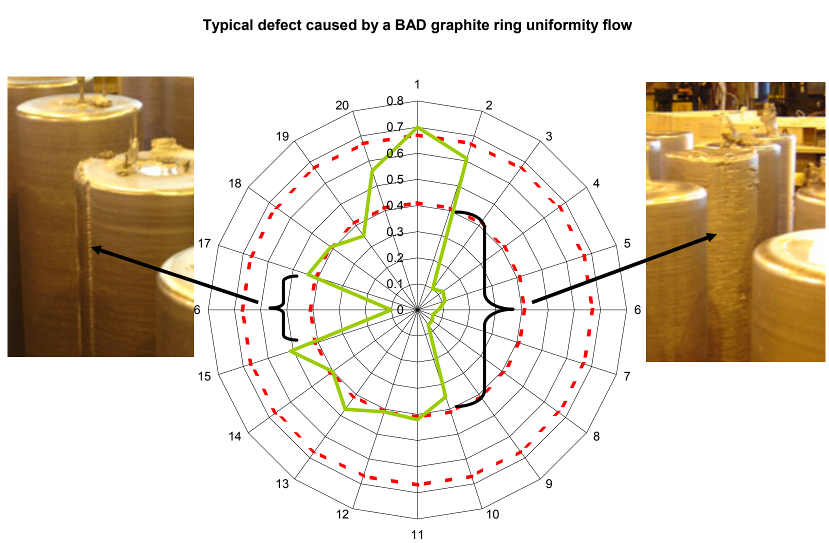

Figure 9. Billet surface defect versus uniformity flow.

Having measured hundreds of rings, the profile of what a good ring should look like has been established. Figure 10 represents an as-received ring qualified as "good."

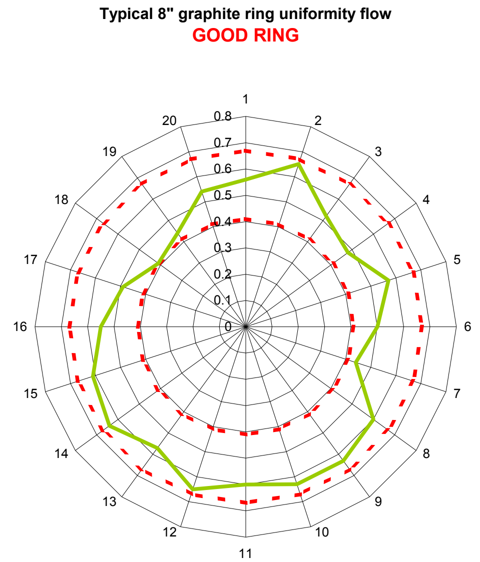

Figure10. Good ring graph representation.

More than a thousand graphite rings have been measured in the course of this experiment. Figure 11 shows the graphite permeability evolution of a ring after 273 casts. Many factors have been identified as having a significant impact on a ring's clogging rate. These factors will not be discussed here.

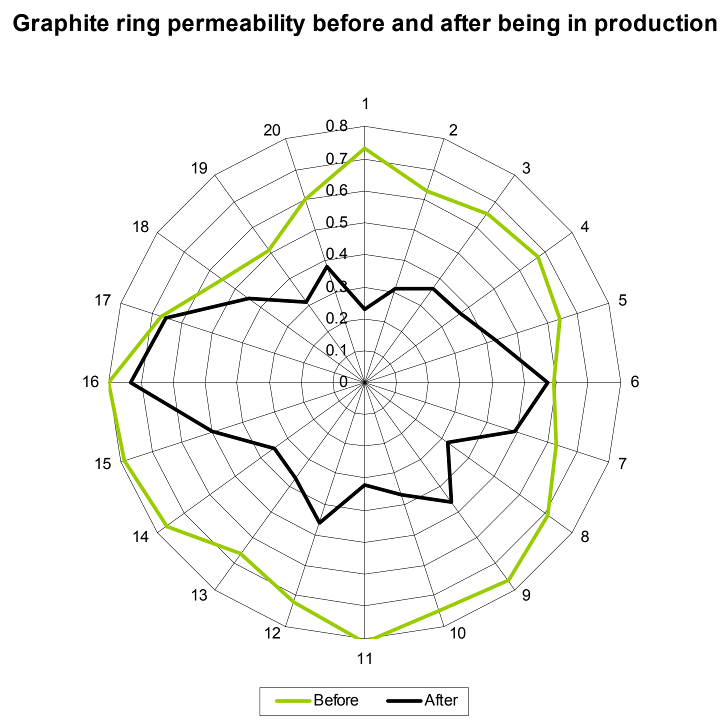

Figure11. Ring permeability before and after being in production.

Table 1 shows each diameter, the total flow, and uniformity flow, along with their respective standard deviation. These measurements were the basis for our definition of what a good ring should be.

Table 1. Ring properties per diameter.

	7"	8"	9"
Total flow (lpm)	33.90	38.04	47.90
Standard deviation Total flow	6.63	6.35	6.89
Uniformity flow (lpm)	0.52	0.54	0.49
Standard deviation Uniformity flow	0.12	0.13	0.08

One point of importance: the standard deviation on the uniformity flow is related to the material used to manufacture the rings. Graphite has been identified as the material of choice for this application so far. Graphite permeability is shown to be inconsistent around the circumference of the ring. This inconsistency must be related to the fabrication process, as this phenomenon was observed in a fairly large number of rings when comparing rings with each other, as presented in Figure 12.

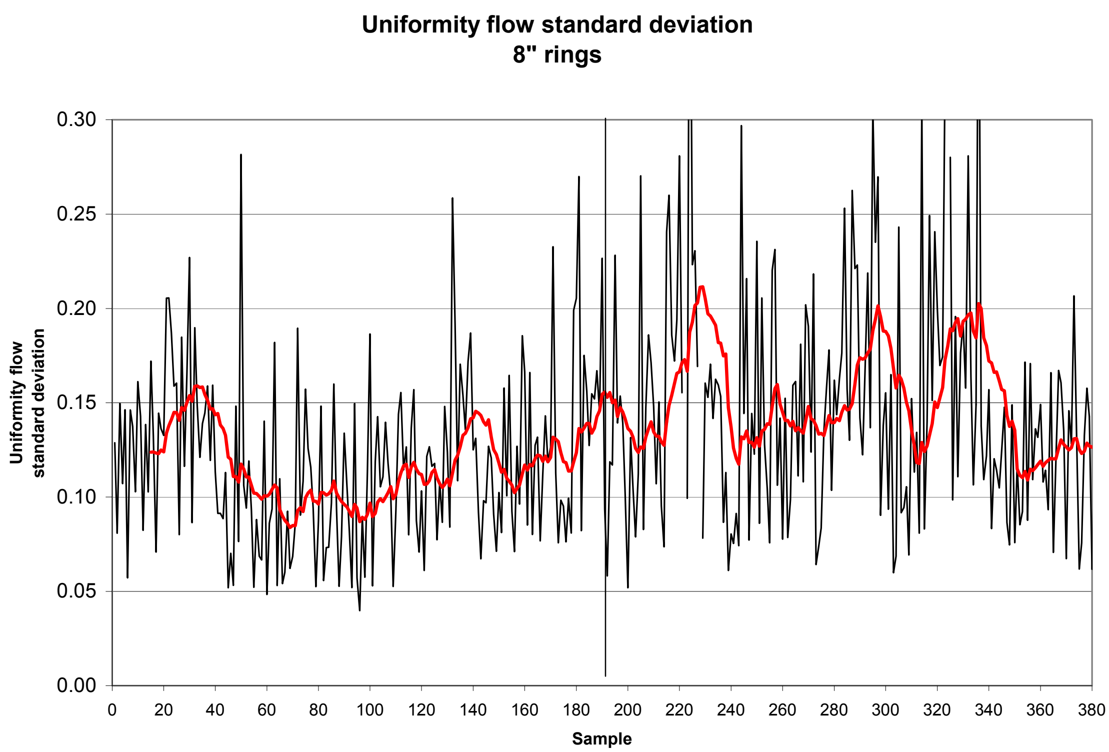

Figure 12. Uniformity flow standard deviation.

Batch-to-Batch Comparison

Graphite rings arrive at the plant in batches. Different measurements taken on all received rings during a period of more than six months were compared, and significant differences were found between the batches. Figures 13 and 14 show variation in uniformity flow and total flow for a given diameter. The uniformity flow variation from batch to batch leads to early billet surface defects, as well as decreased ring life expectancy. The initial total flow for this part is proportional to the life expectancy as shown previously in Figure 7.

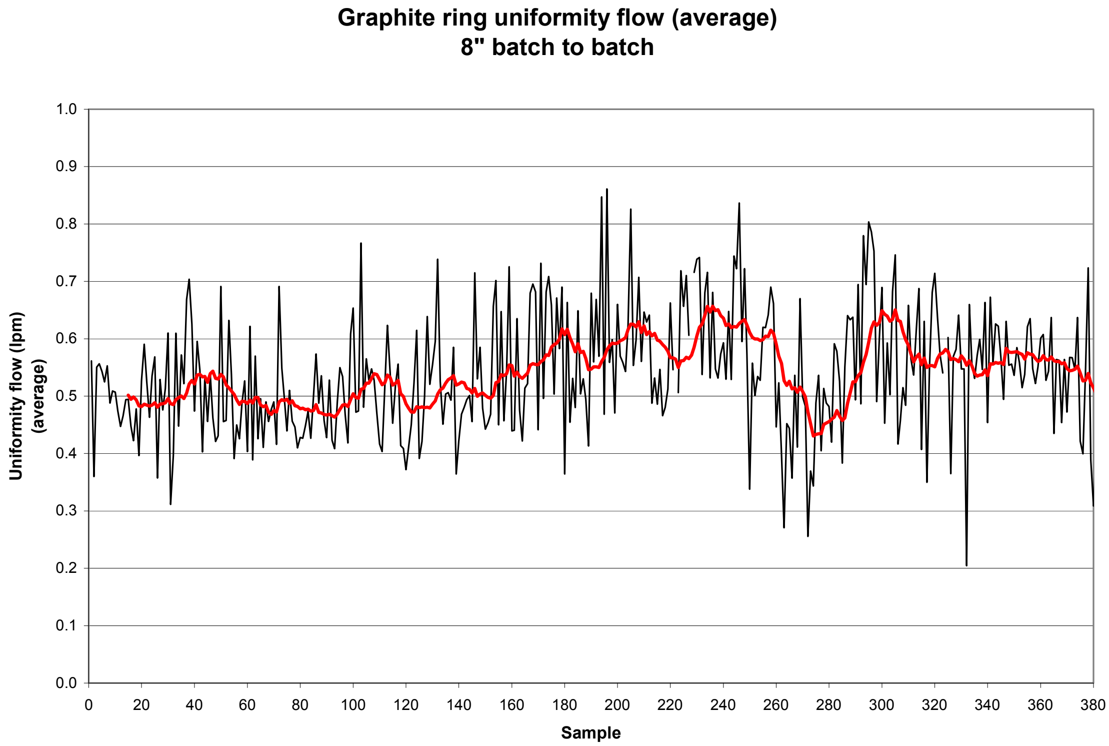

Figure 13. Average uniformity flow, eight inches.

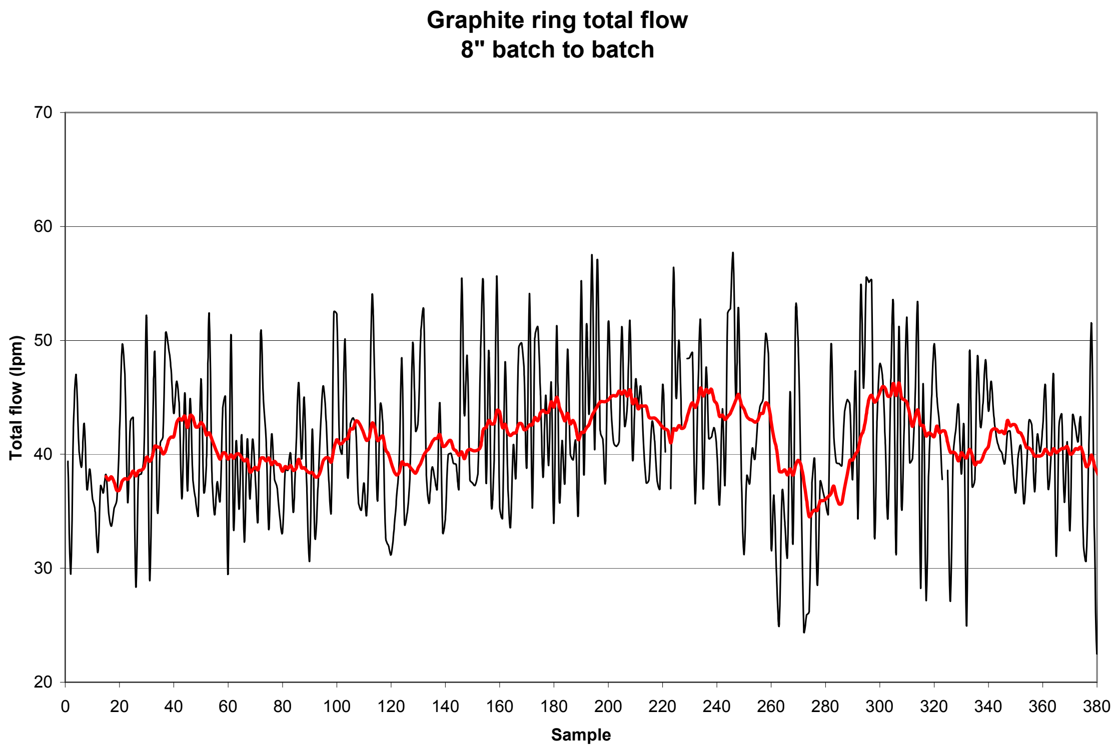

Figure 14. Total flow, eight inches.

Oil Type Experiment

Oil type may vary from one billet producer to another because of background, casting knowledge, and billet recovery. Typically, mineral oil is used, which tends to plug graphite pores. Oil tends to create varnish as it burns while casting, which will reduce ring life expectancy. Oil properties such as viscosity are related to casting conditions and in-house temperature. See Figure 15 for viscosity chart. It is important to select oil that promotes process stability and meets tooling capability.

Historically, type A oil was used. A first trial was performed with type B oil. Due to cold in-house conditions, billet surface defects have shown up early, due to oil injection system limitation. Type C oil has been selected, and can be processed as easily as type A oil.

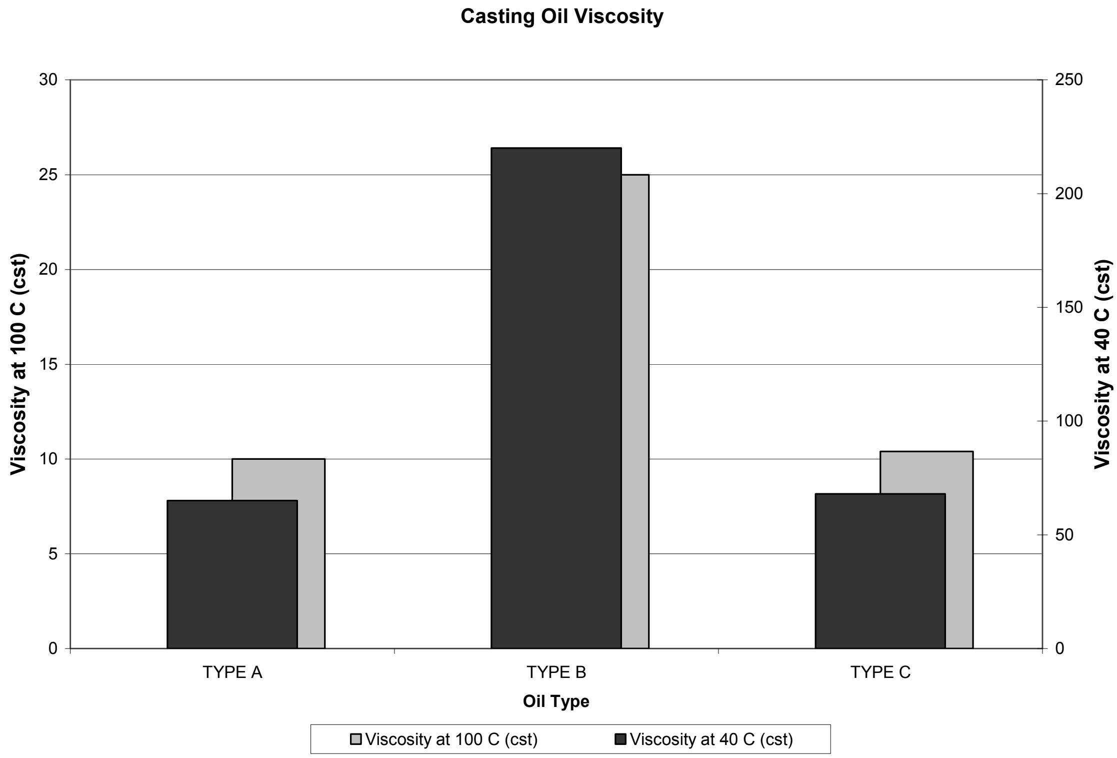

Figure 15. Oil viscosity versus oil type.

Type C oil provides no system limitation and supports long life expectancy, as it prevents early clogging of the graphite ring as shown in Figure 16. Life expectancy is still being monitored and still increasing. As shown, graphite ring life has been drastically extended, and surface defects are significantly reduced. The latest oils benefit end-users, providing billet of ideal surface quality.

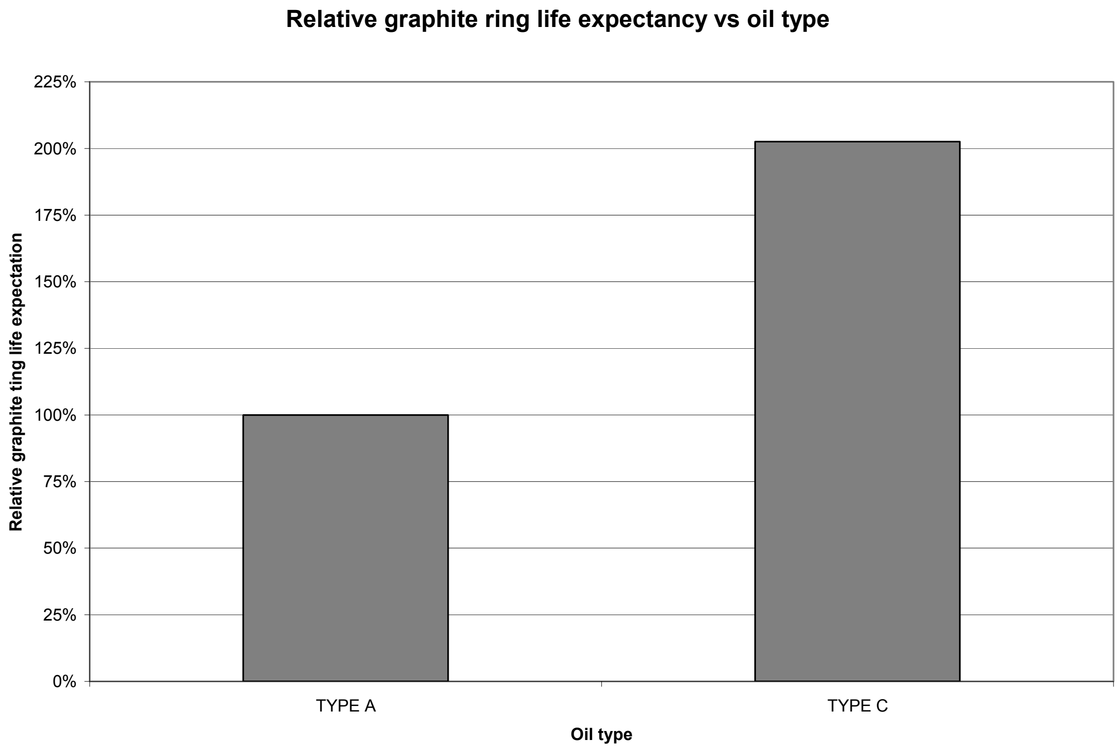

Figure 16. Life expectancy versus oil type.

CONCLUSION

Graphite ring life can vary because of key parameters such as oil type, graphite ring permeability, mold maintenance, and casting tooling. Gas flow measurement through the ring leads us to define critical factors and new performance standards. It is now possible to predict how long a graphite ring will last in production. By improving the understanding of graphite ring behavior in production, it was possible to improve key factors such as billet surface quality, mold life, and maintenance, as well as pit recovery.

Future steps will allow us to implement predictive models where each mold will be tracked individually, and maintenance performed in accordance with initial conditions. New performance standards will then be generated.