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MOLTEN METAL FILTRATION

Molten Metal Filtration – An Engineered Balance.

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1–ABSTRACT
The use of molten metal filters is becoming established practice for an ever growing number of foundries. With this growth in use there is a need for an increased technical understanding of filtering technology in general. It is not enough for a filter to just have good filtration efficiency. It must also have a high and consistent flow rate, good strength, a high capacity and good dimensional accuracy. This must be achieved at the lowest possible cost. Some of these parameters are in conflict with each other, for example if a filter has a very large capacity, the filtration efficiency may be compromised. The most effective filters are therefore ones that have been engineered to give the optimum performance over all of these parameters.

The following paper aims to discuss the relative performance of three of the most popular filtering technologies against each of the above parameters. The filter types considered are pressed filters, extruded filters and foam filters. The results of several technical studies will be presented and discussed. It is hoped that a better understanding of the relative strengths and weaknesses of each filter type can be attained.

2–INTRODUCTION
With the ever increasing quality demands necessary for today's castings, the filtering of molten metal has become established practice for an ever increasing number of foundries around the world. Traditional methods to remove inclusions such as whirl gates and extensive running systems are now rarely seen. There is therefore a greater need for increased technical understanding of filtering technology. Experience has shown that characteristics other than just filtration efficiency are important properties of filters. The ability to remove inclusions is of course important, but a filter must also have a high and consistent flow rate, good strength, a high capacity, good dimensional accuracy, and a low cost.

Some of the above properties are in conflict with each other. For example if a filter has a very large capacity, this may be at the expense of filtration efficiency. The most effective foundry filters are engineered to give the optimum performance in all of the important areas.

There are several established filter technologies presently on the market. These include strainer cores, woven cloth or mesh, and ceramic tile filters. Ceramic tile filters are generally considered to be the most effective. The most popular of these are pressed cellular, extruded cellular and foam filters. Pressed cellular are generally characterized by their round cells, extruded filters generally have square cells, whilst foam filters have a random dodecahedron type structure.

The following paper aims to discuss the relative performance of these three filter types against each of the following parameters:

- Filtration Efficiency: efficiency is obviously an important property of filters. An effective filter must remove slag and dross from the melt in order to prevent non metallic inclusions from entering the mold cavity. How effectively a filter does this will depend on several factors.
- Metal Capacity: The capacity of a filter should of course be adequate for the casting but it should also be consistent. The capacity should not vary from filter to filter. This may lead to premature blockage in some cases.
- Flow Rate: The flow rate should be high and consistent. Wide variations in flow rate may in some cases lead to mold fill problems, or a requirement to use a larger filter thereby increasing cost and decreasing yield.
- Dimensional Accuracy: The filters should fit into their print cavity first time and every time. This performance criteria is more closely related to the manufacturer rather than the technology.
- Strength (hot and cold): The strength of a filter is classified in two ways, hot strength and cold strength. The cold strength of a filter is important for shipping and handling purposes. It is important that pieces don't break off or loosen as these may well end up in the casting. Hot strength is important so the filter remains intact when molten metal is poured onto it.
- Cost: The cost of a filter is obviously an important consideration. Today's modern foundries are highly competitive and ways to reduce costs are always being sought.
In all cases, the studies used filters that are generally recommended for use with ductile iron. All the foam filters tested are 10 ppi (pores per inch). The extruded filters are 100 csi (cells per square inch). The pressed filters have a cell diameter of 0.100 inches (2.5 mm).

3–FILTRATION EFFICIENCY
The ability of a filter to remove inclusions is obviously an important parameter. Ceramic tile filters are generally more efficient at removing micro inclusions than traditional methods such as extensive running systems and whirl gates. The removal of such inclusions will have a positive effect on the machinability of castings, (1), resulting in extended tool life. The fatigue strength will also be improved as a result of improved as cast surface finish.

3.1–FILTRATION MECHANISMS
Filters remove inclusions using a variety of mechanisms (2). Some may be more efficient at one mechanism than others. The following is a brief description of each of the mechanisms, using cellular filters as an example.

3.1.1–SCREENING
Filters will collect dross particles and inclusions that are larger than the filter hole or pore size on their upstream face. These particles are unable to pass through to the casting cavity due to their physical size. Figure 1 shows a diagram describing the screening mechanism. Figure 2 shows a large sand agglomerate retained on the filter surface by screening.

3.1.2–CAKE FILTRATION
The larger dross particles collected on the upstream face during the screening phase will form what is known as a "filter cake". This cake will itself act as an efficient filtration media. This phase is able to collect particles smaller than the cells of the filter. Figure 3 shows a diagram showing the mechanism of cake filtration.

In ductile iron, a more probable mechanism for the removal of micro-inclusions, (<1% of the cell size), is through the formation of "inclusion bridges". Small eddy currents, formed when the metal stream splits on the active face of the filter, are generated. These eddy currents will encourage small non-metallic particles to make contact with the edges of the cell. As the pour progresses these particles will continue to adhere to each other and will eventually form an "inclusion bridge". Figure 4 shows an inclusion bridge formed from minute sulfide and oxide particles in ductile iron. The phenomenon is regularly observed in both cellular and foam type filters. Figure 4 shows an inclusion bridge formed from minute sulfide and oxide particles in ductile iron. The phenomenon is regularly observed in both cellular and foam type filters.

3.1.3–DEEP BED FILTRATION
The internal structure of the filter is able to capture small particles of dross and slag. Small variations in flow will cause particles to touch the ceramic walls of the filter. Once contact is made, the inclusions will have a tendency to adhere to the ceramic material. Figure 5 shows a diagram of the mechanism. Figure 6 shows a sand grain retained by deep bed filtration in a pressed cellular filter.
3.2–RELATIVE FILTRATION EFFICIENCY

Many studies have been undertaken in an attempt to quantify and compare the filtration efficiency of filters. Such a study (3) was implemented to compare the three filter types under discussion. The study was also used to examine the effectiveness of filtration in general. Filtered and unfiltered castings were poured for the study. Quantitative and qualitative examinations were then performed.

For the tests to be valid it was necessary to keep parameters such as composition of the melt, pouring temperature and pouring time as consistent as possible. The melt composition can be kept constant by pouring each casting from the same melt. This, however, will inevitably lead to temperature losses between the first and last pours. To account for this variability, four series of castings were poured and the order of pouring was reversed between the first two heats and the last two. Each series started and ended with an unfiltered casting. The system choke was at the base of the sprue. This was done to ensure that pouring time did not vary with filter type.

A step block casing was designed for the study. A diagram of the complete system can be seen in Figure 7. The casting had a 3 inch, (75 mm), thick section and a 1/4 inch, (75 mm), thick section. The system was gated so that the iron flowed through a drag runner, up through the filter, and into a cope runner.

3.2.1–QUALITATIVE METALLOGRAPHY

The cope surface of each of the castings was examined visually for pit type defects. These defects are normally associated with macroscopic silicate inclusions. The castings were rated as "3" for a good surface finish, "2" for a fair surface finish, and "1" for a bad surface finish. Examples as to what was regarded as good, fair and bad can be seen in figures 8, 9 and 10.

All of the castings poured were scored using the above system. The average scores of each filter type can be seen in the graph in Figure 11.

As can be seen from the average ratings, the choice of filter does not seem to make any difference to the surface quality of the castings. All the filters tested produced good quality castings, and as such can be considered approximately equal in their ability to remove the exogenous silicate inclusions associated with the pitting defects.

3.2.2–QUANTITATIVE METALLOGRAPHY

The castings from one series underwent quantitative metallography. This basically involved counting the
number of micro-inclusions present in samples from each of the castings in the series.

Specimens from the three-inch portion of the casting were carefully polished to ensure that inclusions were not torn from the sample. Each specimen was divided up into a 10x10 grid pattern to give 100 fields. Each field measured 300µm x 350µm. Particles with an area greater than 160µm² were eliminated based on the assumption that these were graphite nodules. It is however inevitable that some particles included in the count will be graphite nodules, partially accounting for the relatively low efficiencies observed.

For the purposes of presentation, it is assumed that unfiltered castings have zero filtration efficiency. The number of inclusions found in the unfiltered casting can therefore be assumed to be 100%. The relative efficiencies of each filter type can therefore be calculated. A graph showing this can be seen in figure 12.

It cannot be claimed that this study represents an absolute figure for the relative filtration efficiency of each filter type. The castings are taken from one series only and, as stated earlier, differences from pour to pour will always occur. The study does show, however, that the effects of using filters in general are considerable in their ability to remove micro and macro-inclusions. This is shown in both the qualitative study and the quantitative study.

4–FLOW RATE

Consistency of flow is becoming an increasingly important property. Filters of a particular model should ideally have a high and consistent flow rate. The filter should have as little effect on the pour time as possible. Most ceramic filter manufacturers recommend that the active face of the filter should have a surface area of between 3 and 5 times that of the system choke, but even if these recommendations are followed, high variations in the flow rate can sometimes lead to problems.

Assuming factors such as melt cleanliness, metal temperature and chemistry are constant the consistency of flow rate through the filter will depend upon the consistency of properties such as percentage open area and porosity.

Studies were undertaken to compare the flow rate characteristics of the three filter types under review. The first study (4) was performed on water flow measuring equipment. The second study (5) used ductile iron.

4.1–WATER FLOW RATE

A water flow testing machine was constructed to compare the flow rate of the different types of filters. The filters studied were all 50 x 50 mm. The foam filters were 10 ppi, the extruded were 100 csi and the pressed had a cell diameter of 0.100 inches. These are generally the filter models recommended for use with ductile iron. The aim was to assess the consistency of flow from one filter to the next. One hundred pieces of each filter type were measured to get an accurate idea of any variation. The filters were the system choke. Figure 13 shows a graph of the first 25 filters to be measured. As can be seen there is a high variation in the flow rates of foam filters, whereas the cellular ceramic filters show negligible variation. This graph depicts the variation that would be expected from one filter to another in normal production. The difference in the filter types can be seen clearly in the distribution plots in figure 14. The distribution curves are normal and this indicates that the test samples are valid. It can be seen that the pressed filters and the extruded filters have almost exactly the same flow rate and consistency.

The reason for the inconsistency in the flow rates of the foam filters is due to their random nature. There will always be variations in their porosity and consequently in the amount of ceramic coating. This variation will occur within the structure of individual filters and from filter to filter. Also, due to the random nature of the foam there will always be "dead spots" were almost no flow occurs -- much like the water behind rocks in a fast flowing river. These inconsistencies will compound to give the variation seen on the graph. If a filter type has an inconsistent flow rate, it follows that they will also have an inconsistent capacity. Filters with areas of fine porosity and low percentage open area can lead to premature blockage and consequently short run problems.
Conversely, the structure of cellular filters is highly repeatable. As such, due to the filter design, there will almost be no inconsistencies in the flow rate and therefore negligible variation in capacity.

4.2—METAL FLOW RATE

Although water flow rate gives a good indication of the relative consistencies of filter types, it still does not exactly simulate the flow of iron. When iron is flowing through a filter, its rate will not be linear. It will get less over time, due to the non-metallic inclusions progressively blocking more and more of the filter.

Studies performed on the flow rate of iron through filters (5) mirror the results of the water flow study. Cellular filters have a significantly higher flow rate than foam filters. Only one filter of each type was used for the study. If many filters were tested the trend for foam filters observed in the water flow study, would likely be experienced in metal flow also.

5—CAPACITY

The capacity of a filter is closely related to flow rate and filtration efficiency. If a filter has a very high filtration efficiency, it may be at the expense of flow rate and capacity. Foundries would ideally like all of these properties to be high but it is no use having a filter that has an extremely high efficiency if it is prone to premature blockage. Conversely, if the capacity is too high then the filtration efficiency may be compromised.

Studies, (5), have found that at 2462°F, (1350°C), in ductile iron, extruded filters have a marginally higher capacity than pressed filters. Both types had a significantly higher capacity than foam filters. At 2642°F, (1450°C), however, the differences between the filter types are reduced.

In this study only one filter of each type was tested. Given the inconsistency observed in the water flow rate study, it could be expected that the foam filters would also display a similar trend for capacity. Variations in the capacity of filters is often masked by the use of large filter areas relative to the system choke.

6—DIMENSIONAL CAPABILITY

The dimensional tolerance of filters is becoming increasingly important. Filters must fit into their prints first time, every time with minimal danger of leakage around their edges. This is especially true when the filters are set automatically. To compare their dimensional capabilities, one hundred of each filter type were measured. The pressed filters and the foam filters were described as 50 mm x 50 mm x 22 mm. The extruded filters were 55 mm x 55 mm x 13 mm. These were the only filters that were available for analysis at the time. Although there are two different sizes of filter, it is still possible to get a good idea of their capabilities in terms of dimensional stability. The foam filters were the "free formed" type with non-machined edges.

The results are presented in figures 15, 16 & 17.

The most dimensionally consistent filter type measured are the pressed and extruded filters. The foam filters have almost twice the spread as the pressed and extruded. This is due mainly to their manufacturing processes. Pressed filters of a particular reference are individually made in identical steel dies. This ensures that each filter will have very close tolerances. Extruded filters are made by extruding a large log and then slicing them into individual pieces. Squareness can be a problem due to log twist before or during slicing. The foam filters analyzed are made using individually cut pieces of polyurethane foam. There is therefore a degree of variation from this cutting process before the ceramic is coated on the foam. Whilst being coated with ceramic, the filters will stretch and distort slightly due to the manufacturing process. The edges of the filters also contain a significant build up of ceramic material. This is again due to the forming process. The liquid ceramic slurry will squeeze out the sides of the foam causing the build up. Sharp edges can also be formed on the edges of foam filters. This can cause loose sand to be scraped away from the mold. This could then end up in the casting cavity.

7—COLD STRENGTH

The cold strength of filters is important for handling and shipping purposes. It is important that pieces of the filters don't loosen and break off, as these may well end up in the casting. The filter must also have adequate strength to survive the closing of the mold.
The cold strength of filters can be measured by subjecting them to a three point loading test. In this test, filters are supported on two horizontal pins. A load is applied from a third pin from above. The load is increased until the filter breaks and peak load is recorded. Twenty of each filter type were measured in this way. The results are reported in the graph in Figure 18.

In terms of cold strength, pressed cellular filters are by far the strongest. This is due to the inherent advantages of processing ceramics by pressing. The extruded filters are less than half the strength of the pressed. The foam filters are less than one third of their strength. The foam filters are also friable in nature, (small pieces of the strands tend to break away). There is a danger that these small pieces may get washed right through into the casting cavity. This can be especially dangerous during mold closing especially if the filters are not dimensionally accurate.

8–HOT STRENGTH

A filter must obviously have sufficient strength at molten metal temperatures. To compare the hot strengths of the filter types in question, a small furnace was heated to 2732°F (1500°C). Inside the furnace is a refractory tube measuring 1.60 inches in diameter. The filters are introduced into the hot furnace through a small opening at the front, and placed on top of the tube, simulating the thermal shock experienced in the mold. The furnace is then allowed to equilibrate for one minute back up to 2732°F, (1500°C), after which load is then applied to the center of the filter with a refractory rod, 0.705 inches in diameter. The load is increased until the filter breaks. The peak load is then recorded. Ten samples of each filter type were measured in this way. The results are illustrated in Figure 19.

As can be seen the pressed cellular filters are far stronger than both the extruded cellular and the foam filters. The hot strength of pressed cellular filters measured are on average over twice the strength of both extruded and foam. This is again due to the inherent strength advantages of pressed ceramics.

The test described above is only a static test designed to compare strengths at elevated temperatures. It is accepted that there are other factors to consider when iron is poured onto the filters.

9–COST

The actual cost of each filter type is impossible to give. Different manufacturers will have different costs and each foundry will purchase different volumes. However, it is generally accepted that at present foam filters are the most expensive type followed by extruded. Pressed cellular filters are generally regarded as the least expensive option of the three in types under review.

The price difference is due to processing costs. Foam filters go through a relatively complicated manufacturing cycle that involves coating a polyurethane precursor with a ceramic slurry. The filter then usually has to go through several spraying and drying stages before it is eventually fired in a kiln. Extruded filters are formed as a continuous log and individual filters are sliced from this. Pressed filters are less complicated to manufacture in that the filter is formed in one pressing operation after which it is dried and fired.

10–GENERAL DISCUSSION

The filtration efficiency study showed that all of the ceramic filters were effective in their ability to remove non metallic inclusions and to improve the surface quality of castings. The main differences between the filter types were found to be in the areas of strength, consistency of flow rate, dimensional stability, capacity and cost.

The water flow study was really aimed at comparing the consistency of filters rather than attempting to simulate the flow of iron. The flow rate of a filter will have an effect on its capacity and also its filtration efficiency. The higher the flow rate, the higher the capacity and the lower the filtration efficiency. This is, of course, also true in the opposite sense. Therefore, if a filter type has a highly inconsistent flow rate, it follows that its filtration efficiency and its capacity will also be variable. The gradual decrease in the flow rate marks the progressive blockage of the filter. Kahn et al. (6) studied the fatigue strength of castings produced from cellular filters and foam filters. It was found that cellular filters gave more consistently improved casting quality. Foam filters gave a more unpredictable casting quality ranging from the best quality castings to the worst.

All foundries are different and some may not be so sensitive to some parameters than others, however in terms of an engineered balance, it is clear that the more consistent filter solutions are the cellular types. Foam filters offer good filtration efficiency but they
lack consistency, strength and are generally more expensive. The extruded filters offer good consistency in terms of flow rate and dimensional accuracy, but they tend to lack some strength. The pressed cellular filters give good filtration efficiency, good consistency in terms of flow rate and consequently capacity, have good hot and cold strength, have good dimensional stability and are generally the least expensive option. As such it is reasonable to conclude that in ductile iron, pressed cellular filters offer the best engineered balance of the performance parameters discussed.

References

2. Hamilton Porcelains' Technical Data sheet No 1/95
3. Hamilton Porcelains' Technical Data Sheet No 3/95
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EXPENDABLE MILLIS

EXPENDABLE MILLIS –
THE FATHER OF DUCTILE IRON

By Stephen K. Millis

Ladies and Gentlemen,

It was with great pleasure that I accepted Lyle Jenkin’s invitation to speak to you on behalf of my Dad, here at the Keith D. Millis Symposium celebrating the 50th anniversary of Ductile iron and the 40th anniversary of the Ductile Iron Society.

I wonder how many of you know what the "D" stands for in Keith D. Millis? I used to tell Dad that his parents were prophetic and the it stood for Ductile Iron! Actually it stands for Dwight but I always thought that he should have had it changed.

That aside, when I hung up with Lyle, I tried to formulate some type of outline for a memorial or tribute to Dad, that would be of general interest to the wide range of backgrounds of the many attendees here today, My problem is that in the sixties, I followed the advice in the movie, the graduate, and I went into plastics. Specifically, plastic packaging. Since I suspect that almost everyone here has a background based in metals, you can safely assume that I won't be boring you with any of the technical aspects of Ductile Iron. One look at the agenda tells me that there will be plenty of that available for those who want it.

So, what's left to talk about? Well, within the last three months I became a first time grandfather and I was thinking about what I might tell my granddaughter about her great grandfather. **What was he like?**

**What was important to him?**

**What did I remember about my childhood with him?**

**And finally, what was so great about this invention of his?**

I think I would start by telling her that her great-grandfather was loved and respected by most everyone with whom he came in contact. This gift was apparent even in his youth. In some files at the house I found copies of some correspondence written in 1932 when her great-grandfather was 17 and working In the Albany Savings Bank, Mr. Frederick Townsend was writing to the Director of Rensselaer Polytechnic Institute to solicit admissions information on behalf of my Dad. He wrote " the reason I asked for this information is because we have in the bank here a high school graduate who is anxious to go to RPI but cannot afford the tuition. He is an attractive, promising boy and I hope that later on he will be able to accomplish this ambition of his". In a subsequent letter, he states, "I have known the boy since February 1931 and he seems to be worthy of a college education. He attends strictly to business and strikes me as too serious, if anything, for I have never seen him fooling about as boys often do or in fact, doing anything but what he is expected to do." So, you can see the die was already cast. His personality and work ethic were already firmly established. And they were to become the standard by which he conducted his life.

Dad ultimately got into RPI and graduated in 1939 with his master's degree. He then joined the International Nickel Company in mid 1939. Interestingly enough, in going through some of the files at his house, I found a few of the Inco compensation records (now W-2's) for the years 1939, 1949,194*1 and 1942 (the year I was born). He grossed $900, $1800, $21 00 and $2500 respectively. I think my trip down here cost that much! His good friend, Bob Savage summed it up accurately when he said, "As is sometimes true of outstanding inventors, Keith never became rich from his discovery."

In fact, I recall in later years, kidding him about being a poor negotiator because if he had just negotiated a lousy $1.00/lb. or even settled for $1 .00/ton on all Ductile Iron production, we could have been having our conversation over cocktails on a veranda overlooking the ocean on some tropical island, that he owned! He always laughed at that because the financial rewards never really mattered to him.

He once revealed that he never even got the one dollar from Inco that was given to employees for patents. Therefore, if there is anyone from here today from Inco who wants to pay up, please see me after lunch.

I only saw Dad upset on a few occasions. Generally he was pretty cool. But I do remember a few. Three were business related and the other involved me.
Apparently early on in the development of Ductile Iron, there was a story circulating that the invention of Ductile Iron was "by accident". That is to say that Dad inadvertently dropped some magnesium into some molten iron and out came Ductile Iron. The second occasion was the patent infringement trial with Ford. This patent infringement hearing and trial occurred in the mid-fifties. This was also about the time that I began hearing the phrase: "expendable Millis". But it was not until after Dad's death in 1992 when I was reading through the 5 volumes of the transcript of the court case held in the U.S. District Court of New York in early 1956 between the International Nickel Company and the Ford Motor Company and Caswell Motor Company that the true meaning of "expendable Millis" came to light. Inco was suing Ford for "willful and deliberate infringement my manufacture, use and sale of Ductile Iron crankshafts." Caswell Motor was a Ford dealer in NYC and was accused of having infringed by using and selling Ford cars equipped with Ductile Iron crankshafts.

In a few minutes, I will be quoting from the exact testimony at the trial because, I think it may give those of you who are unaware of the details surrounding the invention and some interesting commentary on Ductile Iron and its initial development. It should also put to rest the "accidental discovery issue". But back to "expendable Millis"

Early in the trial, during the direct questioning of Dad, it came out that one of the last things told to him by one of his professors, a Dr. Scott MacKay, was that "he would forever be listening to experienced people telling him of their experiences and telling him what he should do according to their experiences, but he said 'don't pay any attention to them, find out for yourself. This led to the following line of questioning by the Inco lawyer.

Q. There came a time did there, when you were working in the Inco lab at Bayonne, New Jersey, when it was decided that you should attempt to introduce magnesium into cast iron?

A. (By Millis) - Yes

Q. Up to that time, what had your information been as to the possibility of doing so?

A. The information that I received from people who had, for various reasons, tried to add magnesium to iron, and also from references in the literature, was that magnesium had very little if any solubility in iron, and that when magnesium was added to iron, it was a very hazardous operation. The reaction was very violent and the probability was that the molten iron would b spread all over the area from the reaction.

Q. What were the circumstances under which this decision was made that you should attempt to introduce magnesium into cast iron?

A. Well, the task of finding a substitute for chromium in Ni-Hard was assigned to me, and about the first thing that I did was search the literature, looking for elements which would form carbides chemically, or which would promote carbides in iron. There were some of these known at the time. I made a list of the ones, which I found would do either one of these jobs, and we discussed - my superiors and I, discussed which one we should add.

Q. Who were these superiors with whom you discussed this matter?

A. Mr. Pilling and Mr. Gagnebin

Now I want to break into this testimony to take you forward to testimony given by one of the aforementioned superiors, a Mr. Norman Pilling. Mr. Pilling was asked by the Inco lawyer if he recalled any work that was done in the Inco laboratory in the early 1940's which was concerned with an effort to find a substitute for chromium in an alloy Inco made called Ni-Hard. He responded that "in the spring of 1942, Mr. Millis, who had been conducting this work on the development of a non-strategic substitute for chromium in Ni-Hard, had also written what we called a patent suggestion, covering the invention which he (Millis) thought he had made in that respect, which had come to me for perusal and to take action upon. As I read that patent suggestion, and its related report, I was very much interested with its facts. When Millis had prepared his program, which as he described it before in this hearing, had involved making experimental melts of nickel irons containing a variety of elements which he thought might have interest as carbide stabilizers. When I saw that list and found on it magnesium, I was first disposed to tell him to scratch it off and forget it. But perhaps a little charitable thought occurred; it seemed to me, well, we all have to learn, sometimes the hard way, and let him go ahead and do it. He did.... At this point the Master, Simon Rifkind interrupted and said to Pilling, "he was expendable?" and Pilling responded, "he was expendable and I was not." Voila! The origin of the term "expendable Millis" and my subsequent understanding of Dad's oft-referred-to pseudonym.
Now, I would like to return to that portion of the testimony that in Dad's words, describes the circumstances surrounding the birth of Ductile Iron. You will recall that Dad presented a proposal to his superiors and he was now ready to implement his plan. The testimony picks up with the following question from the Inco Lawyer:

**Q. Would you describe for the court the actual first addition of magnesium, which you make to cast iron?**

**A.** In view of all the warnings I had from various people, I was a little bit leery of the operation, but went ahead with it anyway, and rather than add pure magnesium, I decided that the best thing to do was to use it in a diluted form, rather like taking castor oil with orange juice. I hunted around the laboratory and finally found a supply of copper-magnesium alloy, 80% copper and 20% magnesium, which had been prepared by the people in the non-ferrous section for deoxidizing copper base melts of alloys. The magnesium additions were made along with various elements from a master heat. It was split a number of different ways, and these attains were all made, in view of the reactivity aspects, I took precautions not to be injured by the possible reaction.

**Q. Did you put on a suit of armor for the occasion?**

**A.** Well, frankly yes.

**Q. What were the precautions?**

**A.** I rounded up from various sources, all kinds of protection. I had an asbestos jacket, which was probably 1/2 inch thick and which weighed anywhere from 25 to 50 pounds. An asbestos apron which went to my ankles, leggings and a welder's helmet with a hood to go over my head. I wasn't taking any chances.

**Q. How about your hands?**

**A.** I had gloves on. Actually when I made the addition, being a little leery of what might happen, I cleared everybody away from the area, put the addition alloy in a scoop and approached as close as I could to the ladle with my hand, with my body being back away from the ladle. I slid the magnesium alloy into the ladle and the backed away.

**Q. What happened?**

**A.** Not much. There was a magnesium flare and a few pellets of hot iron fell on the floor, just around the base of the ladle.

**Q. On what scale was this done? That is to say, how much iron was involved?**

**A.** There was about 20 pounds of metal in the ladle.

**Q. As time passed, Mr. Millis, did you continue to wear that asbestos armor that you described when you had occasion to put magnesium into molten iron?**

**A.** No. As with anything eventually I got rather contemptuous of it, and unless we were going to higher magnesium alloys for experimental purposes to determine the best alloys for the addition, I took no unusual precautions. I lost clumps of hair several times, and after that, when I was testing a new alloy, I made sure that I had my hair covered, at least.

So that was it! No fanfare, no explosions, just a man, in the words of his college professor, "finding out for himself. This persistence resulted in the birth of Ductile Iron, a new and separate material, different from gray and malleable iron and from cast steel. And as you heard, certainly not an accidental dropping of magnesium into molten iron.

By the way, just for the record, the decision rendered in February 1958 ruled in favor of Inco. I asked Dad how much Inco was awarded, but he said that he never asked or wanted to know, because whatever it was, it was not enough!

So, while the trial, the accidental discovery myth and the label "expendable Millis" were upsetting events in his professional life, I managed to take center stage in creating stress in his personal life.
In 1957, Dad bought a brand new Buick convertible. It was white with a red interior. While it was a beautiful car, it had no pep! Buick was selling its new Dynaflow transmission, touting its smooth, quiet acceleration. Unfortunately, for a teenage boy, smooth and quiet were not in! High torque, squealing tires, laying a strip of rubber, that was in! But with that Buick, even when you tromped on the accelerator, all you got was increased engine noise and slow smooth acceleration. In spite of that, it didn't take me long to figure out that if you put the car in park, put the accelerator to the floor, waited until the RPM's got near the red line, and then yanked the gear shift into drive, you could, if you were lucky and the road conditions were right, get the tires to spin and lay a nice patch of rubber! I guess I overdid this too many times for on this one occasion, there was this loud crash when I yanked it from park to drive. This was followed by a grinding and clunking sound, and that was followed by dead silence as the car stalled and rolled to a stop. I finally got it going again, but much to my surprise, the only gear that worked was reverse. I knew that I was in deep trouble. I figured that I was about to become the new "expendable Millis". I think that I tried to explain later to Dad, that the car suddenly stopped and as I was pulling away from the curb. I just didn't know what happened. I am sure that he didn't believe me, but we took the car back to the dealer and about a week later, Dad came into my room carrying a canvas bag. He dumped it out to reveal lots and lots of little pieces of broken metal parts. These were the remains of the Buick's shattered Dynaflow transmission. I think I told him that the metal must have been brittle or somehow stressed and it obviously wasn't Ductile Iron! He failed to see the humor, or buy my story and I was grounded for two weeks and couldn't use the car for a month. In hindsight, I must have sounded pretty pathetic telling the great metallurgist and Father of Ductile Iron that there must have been something wrong with the metal. Something tells me that my granddaughter would have liked this story best of all.

As I wrap up my time here, I would like to share with you some of the contents of a birthday card I received from Dad in August 1991. (My 49th) The significance of this for me was that Dad, while he was the kindest and warmest man I ever knew, he was not good at expressing his feelings. You sort of knew where you stood by his actions rather that by his comments. Typically, over the years, his greeting cards were just signed, "Love, Dad," and with any luck included a check! You can imagine my surprise when I found a few written paragraphs on what turned out to be the last birthday card he ever gave me. The message was as follows-.

"Dear Stephen,
I don't believe that I have ever written a message on you birthday card before. But this year, I wanted to tell you how very proud of you I am for the tremendous success you have made of your new venture in such a short time. Congratulations! It has afforded me the opportunity to become reacquainted with you and to understand why I love you so much."

As you can imagine, that card is very important to me. And while I am very happy with my life and career, my accomplishments pale when compared to his. When you consider the fact that since its inception 50 years ago, over 88 million tons of Ductile Iron have been produced in the U.S. alone. Using today's average price/ton ($1174) that works out to be over $103 billion dollars! Worldwide, the figure is in excess of 200 millions tons produced or a staggering $235 billion dollars. (See why I wanted that $1.00/ton deal I mentioned earlier!!!!) These figures, which originated from Ken Kirgin, were passed along to me by "Modern Casting's" Mike Lessiter. Mike, in his note to me, correctly pointed out that while the U.S. and global tonnage figures are impressive, they really only scratch the surface when you think about the wealth that Ductile Iron has meant to the end users, to the suppliers who sell the materials and equipment, to the foundries and all the way down to the nation's municipalities, families and employees who have benefited from the promise of this wonderful new material. I suppose that we all here today, in one way or another fall into the category of Ductile Iron beneficiaries. I know that I do.

When we lose a loved one, we all have regrets that we didn't do or tell him or her something before it was too late. My regret is that I never told Dad how proud I was of him. Not only for what his invention has done for mankind, but for what he did for me and the man I am today. I can only hope that he is here in spirit and that he has finally gotten my message.... and that he now knows the rest of the story about the Buick's transmission! Thank you for allowing me to share in this historic tribute to my Dad, Keith Ductile Iron Millis.
I am saddened to report the passing, on January 4th, of Dr. Bela Kovacs. Bela died suddenly while (apparently) in recovery from a long illness. He is survived by his wife Mary Jane (Jana), son Vic and daughter Jana Sue.

Bela was born in Hungary. His family survived being overrun by the Nazis in World War II and then occupation by the Russians after the war. His college education was interrupted by the Hungarian Revolution against the Soviets in 1956. History records that the revolution was crushed quickly by scores of Russian tank divisions. However, Bela was among several hundred young men who took to the hills and conducted guerrilla warfare against the Russians for almost two years.

Bela then escaped to Canada and then the US. He held a series of menial jobs while learning English and completing his education. Showing great technical capability he got a job at Ford and earned his Engineering degree from Wayne State. He spent many of his 30 years at Ford in the Scientific Research Laboratories working on advancements in ferrous metal technologies.

Bela then joined Applied Process in 1986 and was instrumental in many developments related to the commercialization of the Austempered Ductile Iron (ADI) process. After the collapse of the Soviet Union Bela wrote, and defended his doctorate at his old college in Hungary. (He went from being on their "Most Wanted" list to a celebrity of sorts). Of late, Bela had been consultant to Applied Process on several issues and was working on a corrosion study for us at the time of his death.

Bela's list of technical merits is long and impressive. Among them he was an ASM Fellow, an AFS Award Winner and Alumnus, a recipient of Ford's Edison Award for Technical Innovation, and author of numerous published works, holder of scores of patents and chairman and member of countless committees and technical organizations. He will be missed by his friends and family, the manufacturing and technical community and by his friends here at Applied Process. As I grew to know Bela he was first my technical mentor, then my peer in industry and, finally, my friend. An enthusiastic voice has been silenced with his loss.

Funeral services were held January 7, 1999 in Orchard Lake, MI.

Bela WAS NOT one to sit around and wring his hands, wondering what to do. Flowers are nice, but Bela was a man of action. He had great respect for an organization that DID something. The Campus Crusade for Christ is an organization that he loved and supported. This organization is trying to raise moral standards in young people in his home country of Hungary after nearly 50 years of Communist rule. In his memory, contributions can be made to:

Campus Crusade for Christ
100 Sunport Lane
Dept. 2400
Orlando, FL 32809

Attn.: Dave & Karen Robinson, 0111374 write "in memory of Bela V. Kovacs" on the check.
Modified "NiResist", "Nomag" Cast Irons and Technological Processes of their Manufacture

Sheyko A., Bondarevskyy V., Sluchovskyy O., Zeleny B.
(Note: Highlighted words are in place of Greek symbols)

"NiResist" and other austenitic class cast-irons allow us to obtain cast-iron castings with the complex of high physical, mechanical and working properties (high corrosion and erosion properties, heat resistance, cold resistance, non-magnetic, etc.)

In Physico-Technological Institute of Metals and Alloys in Kiev in Ukraine since 1960 we had been occupied for a long time with problems of ductile cast irons of an austenitic class. Moreover, we have been investigating not only "NiResist" and "Nomag" cast irons but also austenitic cast irons with lower Ni content including Ni-free and manganese-copper austenitic cast irons.

Here we shall report some aspects of obtaining and properties of "NiResist" and "Nomag" cast irons that, as we consider, have theoretical and practical interest.

In our investigations of "NiResist" ductile cast-iron the content of Ni in it ranged from 12 to 20%, Mn content from 0.5 to 4%, Cu content up to 6%, Cr content from 0 to 2%.

Cast irons of pre-eutectic, eutectic and post-eutectic compositions were investigated.

From this cast iron the thick-walled castings were manufactured. For example, centrifugal castings, weighing from 8 to 25 tons with the thickness of the wall up to 120mm for the parts of pulp and paper equipment. The thin-walled castings weighting from 0.5 to 4 kg were also manufactured for oil pumps.

Cast iron was modified by Ni-Mg alloying composition or by alloying composition containing Mg, Ca, REM, Si and Fe.

In modification of "NiResist" and more rarely "Nomag" cast irons we could often observe occurrence of their demodification. This is the occurrence when together with globular graphite in separate areas of the casting the graphite of eutectic-like shape takes place. Hence all negative consequences for the properties of cast iron. This occurrence is specific for high-alloyed cast irons. In modification of austenitic cast-irons by the modifier of Ni-Mg alloying composition type (or complex Fe-Si-Mg-Ca-4REM modifier containing Mg, Ca, Ce) the instability of modification process was considered to be one of different reasons independent on the melting conditions. The modification instability showed itself in the fact that in austenitic cast iron structure together with globular graphite the numerous colonies of so-called frame-type eutectic graphite have formed, that on 1/3 reduced strength properties and on 2/3 reduced plastic properties of modified cast iron.

We connect this occurrence with peculiarities of microinhomogeneous structure of the melt of cast iron before modification and crystallization and, first of all, with the character of micro-distribution of C atoms in the melt. Structural state of the melt, in its turn, to a great extent is determined by the technological parameters of metallurgical process (by the state of initial charge materials and sequence of their melting, heat and time conditions of the manufacture).

Our conducted diffractional investigations liquid cast iron structures obtained in different technological conditions of melting allow us to make this conclusion. The investigations were conducted on X-ray v-v diffractometer in neutral atmosphere of helium. The measuring of intensity of monochromatized Mo-Kalpha emission, scattered by free surface of the melt, was conducted in the interval of magnitude of dispersion vector S from 1.0 to 12.0 Å [4pi/lambda sin v], lambda-length of wave of Mo-Kalpha 2v-angle of dispersion]. The interfering functions and functions of radial distribution of atoms [4pi^2 lambda(ν)] (integral Furies-analysis) were calculated from the obtained diffraction patterns (pictures). Beforehand the investigations of alloy (when Fe content 75.4%, Ni content 21.4%, C content 3.35%) was conducted. Obtained results show that the process of micro-distribution of graphite depends on sequence of charge components and heat and time conditions of the melting. Graphite dissolution simultaneously with carbide formation and its dissolution. This process proceeds at about liquidus temperature for continuous time [from 6 to 8 hours at a temperature of 30-50° above liquidus line].

At a certain sequence of injection of C and Ni into the melt the process of graphite dissolution in this melt can be accompanied by the formation of intermediate phase - carbide with equal atom composition with MeC type hexagonal lattice (the analogue of WC or
MoC carbides). We suppose that Ni carbide formation takes place.

The metastable double-phased state (carbide + fluide) on balanced liquidus line stays preserved for continuous time (8 hours and more). Under crystallization of this double-phased system the decomposition of MeC carbide with precipitation of graphite occurs.

The increase in a temperature on 200-300°C (higher than T_{lg}) quickly brings the system to homogeneous liquid state. At the same time microheterogeneous structure of the melt is characterized by essentially inhomogeneous distribution of C atoms in microvolumes of the melt. All the above-mentioned is illustrated by Figure 1. On this figure some of sequentially-obtained diffractograms of the triple alloy at a temperature of 1260°C are represented. We found out that in time the intensity of graphite lines reduces (at S=18.5 mm⁻¹, and 37 mm⁻¹), and intensity of reflections from MeC carbide lattice increases.

At continuous enough isothermal holding the X-ray pattern becomes typical for the liquid state. The character of microinhomogeneity of liquid alloy in essentially caused by uneven atom distribution on the melt microvolumes.

Microareas, strongly enriched by C, have carbide-like type of package (atom distribution in this sort of microareas is like their distribution in hexagonal lattice of the MeC carbide). Microareas, consisting mainly of metal atoms (with small C content) have BCC or FCC-like type of atom package (austenite or cementite-like type of package). The results of modeling of the melt structure within the framework of quasi-poly-crystal model.

Thus, if at a high temperature the complete melting of the Ni carbide formed, didn't occurred, and we cool the melt, so, in the area of liquid-solid state complete decomposition of this melt will occur. In a solid of cast iron this carbide isn't observed. We suppose that this occurrence affects the process of cast iron demodification. This process can't be eliminated by the increased content of Mg and other modifying elements in cast iron.

For the investigation of Fe-Ni- Mn-C alloy, two samples of metal of the same composition Fe=70.4%; Ni=9.8%; Mn=5.9%; C=3.8% were smelted. Main differences in the melting were in the sequence of charge components, injected into the melt. During the melting of sample 1 mn charge component was injected into the melt the last, and during the melting of sample 2 Ni was injected the last.

X-ray structure investigations were conducted about liquidus line. First diffractograms were measured after 20 minutes isothermal holding, second ones - after 2 hours.

For conduction of the integral analysis (the calculation of the functions of atom distribution) the second curves of typical liquid sort (without additional sharp side tenons) first diffractograms of sample 1 and 2 (curve 1 and 2) and one of diffractograms of above-mentioned Fe-Ni-C alloy are presented on Figure 1.

The comparison of diffractograms shows, that the most expressed diffraction effects (sample 2) [at 1.6; 2.2; 4.0Å ], observed for the investigated alloy correspond to the most intensive lines of reflection of MeC carbide hexagonal lattice in liquid-solid triple alloy (curve 3). Unlike triple alloy, in this case we can observe only separate diffraction effects. These effects are marked feebly, and in sample 1 they are completely absent. Nevertheless by them we can estimate parameter "a" hexagonal lattice of MeC carbide which small fraction is typical for the melt of sample 2 of investigated alloy. Parameter "a" for Fe-Ni-Mn-C alloy is equal 0.3-031 mm. For triple alloy parameters "a" and "c" were equal to (0.315 ± 0.004 mm) and (0.38 ± 0.005 mm) accordingly.

It this lattice the shortest is the distance between atoms of metal and carbon and it is equal to 0.263 mm. The distance between metal atoms [6 nearest neighbors] is equal to parameter "a" of the lattice (0.3-315 mm).

In liquid state, owing to the weak despersive ability C atoms, the coordination of MeC makes just a small contribution to the curve of radial atom distribution. [This is a peculiarity of X-ray structure analysis.] Therefore the curve of atom distribution 4πr⁻² S(r) (Figure 2) reflects on the whole the distribution of metal atoms. [In this very figure i(s) of the second diffractograms of samples 1 and 2 are also represented].

It can be seen from the 4πr⁻² S(r) that for second sample the distance (when r =0.3 mm) which is correspondent to the distance between Me-Me atoms in the hexagonal lattice of MeC carbide.

We suppose, that a melt of sample 2 contains a considerable part (share) of carbide-like-typed microclusterings and microclusterings consisting mainly of metal atoms with lambda-solution type package (GammaLIK-like type) [maximum at r=0.26 mm].

The melt of sample 1 consist mainly of the micro-clusterings of second type lambda-solution type, more saturated with C. Longer
the most probably distance between atoms $-r_1$, for the first sample in comparison with the second one (0.265 mm in comparison 0.260 mm). [Here is different 2% when error is 0.5%].

Hence, the method of melting of Fe-Ni-Mn-C alloy influence considerably micro-distribution of C atoms in the melt. For Fe-Ni-Mn-C alloy (70.4%Fe, 9.8%Ni, 5.9%Mn, 3.8%C) the order of input of charge materials in furnace crucible essentially influences the micro decomposition of C atoms in this alloy. In a liquid state the part of microareas strongly enriched (saturated) with carbon atoms is much bigger in case, when the last from charge materials Ni is injected into liquid melt. When injecting Mn as a last from charge materials, the microdistribution of C atoms is more homogenous.

From Nomag ductile cast iron the large-sized castings of pressure (forcing) rings for turbogenerator stators, castings for electrotechnical industry and ets were manufactured.

We investigated the influence of Ni (from 6 to 12%), Ni-Mg alloying composition and Fe-Si-Ca-Mg-2REM alloying composition on the proportion of structural components at cooling rate of from 0.41 to 4.1 K/s and mechanical properties of these cast-iron when Cu content in them was 3%. On increasing the rate of austenitic ductile cast iron by Ni, the total amount of carbide component is decreased. The same happens on decreasing the speed of crystallization. The increase in Si content decreases the carbide component in cast irons, but it increases the quantity of graphite inclusions that especially shows itself at high cooling speeds. With reduction in cooling speed the quantity of graphite inclusions in the volume decreases, which is explained by the increase in carbon solubility in austenite.

Austenitic cast irons contain both the elements promoting graphitization (Ni, Cu, Si) and those preventing it (carbide-forming element Mn).

Taking into account complex influence of the above-mentioned elements on graphitization processes and cast iron structure formation, first of all it was necessary to define an optimal content of Si and Mn and their influence on the stability of an austenitic base.

As a result of conducted investigations we found out that destabilizing influence of Si shows itself in the interval of cooling speeds from 3 to 25 K/min. Upon increasing cooling speed the concentration-kinetic threshold of Si destabilizing influence moves in the direction of higher Si concentrations (Figure 3.)

The study of Mn influence on obtaining austenitic structure showed that under the conditions when the cooling speeds ranged from 12 to 0.5 K/s, the minimum amount of decomposition products of austenite could be recorded when Mn content was 6-6.5%. (Figure 4.)

Lower content of Mn leads to destabilization of austenitic matrix, while its higher content leads to a considerable increase in the amount of carbide-austenite component and a pearlite-like component, impoverished austenite of which is instable. (Figure 5)

It is well known that cast irons are the alloys with developed segregation processes on the grain level. The investigation showed that the microdistribution of alloying elements in grains of austenitic cast irons is uneven. Segregation of Ni and Cu is inverse and reaches 2% for each element. Mn segregation is direct and reaches 4-4.5%. (Figure 6.)

We discovered that the distribution of C and Si indicates the direct segregation of these elements. The obtained data allows us to explain the existence of a pearlite-like component on grain periphery. The consideration of the combined influence of a cooling speed, the alloying by Ni and the content of Si allowed us to discover some objective laws in correlation of structure components in lean-alloyed austenitic cast irons:

- Increase in Ni and Si content reduces the volume fraction of carbides and increases the fraction of free carbon;
- Increase in cooling speed results in simultaneous increase in both carbide inclusions and free carbon in the whole interval of alloying by Ni and Si. (Figure 7).

The investigation of mechanical properties of austenite cast iron in cast and heat-treated conditions was conducted under their modification NiMgREM and FeSiMgCa-2REM alloying composition with Ni content from 6 to 12%, Si content from 2 to 3% and constant Mn content.

Stable and plastic properties of lean-alloyed austenitic cast iron showed their evident dependence on above-mentioned factors. (Figure 8.)
The tendency of alloys with austenitic structure to distorting transformations (any kind of mechanical tests and mechanical treatment are considered to be deformation) and also to plasticity caused by transformation and plasticity caused by twinning takes place in austenitic cast irons.

We also investigated mechanical properties of "Nomag" cast iron under the conditions of compound stressed state at a complex force-temperature influence. On figure 9, you can see general result at a temperature a 173 K, 293 K, 473 K. Rather high isotropy of cast iron mechanical properties attracts the attention at the positive temperatures. The proximity of experimental points and rated value $\sigma_{b}$ (by Colon's criterion) and $\sigma_{02}$ (By Myzes criterion) testify to it.

The investigations were performed on tubular samples under 7 variants of state of major stresses. It was achieved by the combination of using axis load and its direction (compression or tension) and tangential load (internal pressure) and their relation.

We should emphasize the correlation $K= -I$ (simultaneous axis contraction and tangential tension). Under this correlation of major stresses the level of values of $\sigma_{02}$ is equal to 50-60% from the level of $\sigma_{02}$ at mono-axis tension $K=0$. Using this technique as a macromodel of the stressed state at the grain level at the interaction of II type with the applied load one can suggest the possibility of deformational transformations at lower stresses. (Figure 9.)

The expediency of using austenitic cast irons for castings can be defined not only by high mechanical properties but also by opportunity to obtain the complex of special properties (cyclic ductility, low magnetic penetrability, hydroabrading and corrosion resistance).

We found out certain dependencies of magnetic permeability bath on the degree of alloying by Ni and content of Si and on cooling speed in the interval from 0.4 to 4.1 k/s. These dependencies belong to cast state. The increase in cooling speed and increase in Ni content reduce magnetic permeability. With the rise of Si content in cast-iron the magnetic permeability will increase. (Figure 10.)

Heat treatment allows us to improve magnetic permeability of austenitic cast-iron of alloying degree. This permeability doesn't exceed $\mu=1.3 \times 10^{-6}$ H/m.

Increased demands of hydroabrading resistance of lean-alloying austenitic cast iron are made on materials of different function pumps. The influence austenitic cast-iron structure and angle of attack of abrading particles on hydroabrading was investigated. The structure with 10-15% of isolated carbide inclusions in austenitic matrix was found as optimal one.

The comparative tests, conducted in laboratory and on special stand, showed 1.3-1.6 times higher hydroabrading resistance of developed austenitic cast iron in comparison with alloyed steels. (Figure 11.)

"Nomag" cast iron has a high corrosion resistance in a number of corrosive mediums (iodine-bromide water, layer liquid, ammonia water, etc.).

Corrosion resistance in seawater under continuous nature tests ranges from 0.045-0.055 mm/year.

We have developed and mastered technological processes of manufacture the casting of high technological complication from ductile austenitic cast iron for pumps, compressors, energetic machines, etc.
Experimental diagrams

Graphite

Carbide MeC

0.5 hour

2.5 hour

6.5 hour

Scattered radiation intensity, I 10
Interference vector value, $S \text{ nm}^{-1}$

fig.1.
Cooling speed, K/s

Si content

+ 2% Si  
■ 2,5% Si  
● 3% Si

fig.10.
fig.11.
Interferential functions (a) and functions of atom radial distribution (b) of liquid alloy Fe-Ni-Mn-C (1- sample 1; 2- sample 2)
fig.2.

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The influence Si and rated cooling speeds on the quantity of martensite in austenite cast iron structure.

The influence of Si on the quantity of ferromagnetic phase in the structure of austenitic cast iron when cooling speeds are rated.

Fig. 3.
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The influence of manganese on the quantity of ferromagnetic phase in structure of austenite cast iron when cooling speeds are different.

![The influence of manganese on the quantity of ferromagnetic phase in structure of austenite cast iron when cooling speeds are different.](image)

**Fig. 4.**

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The type and the placing of carbide in austenitic cast-iron structure

The placing of pearlite-like (a) and its structure (b) in austenitic cast-iron with Mn content 7-8%
The distribution of elements in a grain of metal matrix of austenitic cast iron.
The distance from graphite inclusions, mkm

Fig. 6.
The influence of Ni and Si on correlation of structural components in austenitic cast iron with different cooling speeds, modified by complex modifier FMC-2R and NiMgREN alloying composition.

a) Complex modifier FeSiMgCa-2R

6) Ni-Mg-REN alloying component

Fig. 7.
Mechanical properties

Cast state

Heat treatment state

Ni content, %

- tensile strength
- 0.2% proof stress
- elongation
- narrowing

fig.8.

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The influence of the correlation (k) of axial stress ($\sigma_1$), tangential stress ($\sigma_2$) and temperature under complex load on the parameters of limiting state of austenitic ductile iron.

$T=173K$

$T=293K$

$T=473K$

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Japan Malleable Casting Association (JMCA) Visit to Inductotherm

Below are photographs from the JMCA trip.

The "Spirit of Philadelphia." The group on boarding the cruise ship for dinner and entertainment on the evening of October 15, 1998. Y. Tada, the president of Inductotherm Japan, is on the far left of the picture. From the right is Bernard Raffner (VP of Sales) and John Thorpe.

The JMCA being welcomed to Inductotherm on October 16, 1998. Y. Tada is second from the right. On the extreme left is Bernard Raffner with Al Ferrari in the center.

During the tour, Bernard Raffner explains the operation of Inductotherm's test department.
INTERMET STUDY REVEALS THE ADVANTAGES OF CAST DUCTILE IRON CRANKSHAFTS

Significant Cost and Weight Savings with Positive NVH Characteristics

TROY, MICHIGAN, March 4, 1999 - Intermet Corporation (NSADAQ: INMT) will present a paper today to the Society of Automotive Engineers that demonstrates the lower-cost, weight-saving, and positive NVH (noise, vibration and harshness) characteristic advantages of utilizing cast ductile iron crankshafts in an aluminum block, V-6 engine.

The results of the joint study conducted by Intermet Corporation, Ricardo Inc. and Simpson Industries Inc., found that the NVH characteristics of a modern, aluminum block, V-6 engine were as good or better when a cast ductile iron crankshaft with a multi-mode damper was substituted for the production, forged steel crankshaft with a conventional, single torsional mode damper.

Dr. Alan P. Druschitz, Intermet corporate director of materials development, says that the recent trend in automotive crankshaft design to replace cast ductile iron with forged steel has often been based on an anticipated NVH benefit brought on by the higher elastic modulus (stiffness) of steel. However, not only do cast ductile iron crankshafts weigh and cost less due to their lower material, production and machining costs, they also produce comparable NVH performance to steel forged crankshafts when certain key system elements are addressed.

Much of the long-standing perception that steel components perform better than those cast in ductile iron has to do with the belief that there will be greater torsional and bending vibrations in the iron component. Druschitz says, though, that this claim ignores the effects of rotating mass and vibration dampers. "To begin with, a cast ductile iron crankshaft can be cast with hollow pins, mains and counterweights, which allow further reductions in rotating mass. Torsional vibration dampers are commonly used to reduce the effect of critical vibrations by absorbing and dissipating torsional vibration energy. However, dampers can also be designed to reduce bending vibrations.

Druschitz says, that none of the previous studies in this area took into account the significant effect dampers can have on NVH characteristics. The Intermet study, for the first time, included suitably designed dampers for each crankshaft as part of its comparison.

Results of the new study concluded:

- Sound pressure measurements for an engine with a cast ductile iron crankshaft with a multimode damper tuned to torsional frequencies of 209 and 309 Hz produced similar noise levels over an rpm range of 1000-6500 compared to the same engine with production, forged steel crankshaft and a single torsional mode damper.
- Bedplate acceleration measurements using the cast ductile iron crankshaft also produced very similar or even slightly lower accelerations over a rpm range of 1000-6500 compared to the production part.
- And, engine mount acceleration measurements produced similar results over the same rpm range.

Druschitz presented his findings on the influence of crankshaft material and design on the NVH characteristics of a modern aluminum block, V-6 engine at this week's 1999 Society of Automotive Engineers Expo at Cobo Conference and Exposition Center in Detroit, Michigan. The presentation was one of two given this year by Intermet at the annual SAE event.

With headquarters in Troy, Michigan, Intermet Corporation and its subsidiaries design and manufacture precision iron and aluminum cast components for automotive and industrial equipment manufacturers worldwide. Intermet also produces precision-machined components and manufactures cranes and specialty service vehicles. The company has more than 6,900 employees at 19 operating locations in North America and Europe. The company's internet address is www.intermet.com.
INTERMET LEADS JOINT DEVELOPMENT OF ENHANCED COMPACTED GRAPHITE IRON

TROY, MICHIGAN, March 1, 1999 - Intermet Corporation (NASDAQ: INMT) and DaimlerChrysler presented findings today on the development of a new modified compacted graphite iron which combines much of the strength, ductility and toughness of ductile iron with the better damping and machinability of gray iron. The new product, Enhanced Compacted Graphite Iron (ECG), was developed, evaluated and launched in production as a joint Intermet and DaimlerChrysler Corporation project for use in the new 4.7 L, V-8 engine introduced in the 1999 Jeep Grand Cherokee.

According to Dr. Robert J. Warrick, Intermet vice president of Materials Research and Development, the development of ECG came about when Daimler Chrysler engineers found they needed a bedplate material for their engines that was significantly stronger and stiffer than gray iron to help meet engine weight objectives. The material also had to provide good NVH (noise, vibration and harshness) characteristics, be cost effective and machinable.

"As their casting supplier," Warrick explains, "we saw the need for an additional material that was significantly tougher than gray iron, could be cast sound in complex sections and could be reliably produced on a cost effective basis."

Although ductile irons are stronger and tougher than gray irons, the gray irons were superior in the areas of damping capacity, casting soundness, mold yield and machinability. The other choice, compacted graphite iron, unfortunately didn't have as much ductility, toughness or stiffness as desired. As a result, Intermet suggested evaluating a modified compacted graphite iron with an increased nodularity of up to 50 percent. This material proved to be a winner.

"The major factor in developing ECG was taking a new look at the ratio of nodular to compacted graphite forms in the iron," says Warrick. "The 'normal' limits of 20 to 30 percent maximum nodularity for compacted graphite and 80 percent minimum nodularity for ductile iron have been set by individuals, not by nature. Materials in this 20 to 80 percent nodularity range can certainly be produced. So, working with DaimlerChrysler, we decided, rather than work with some preset definition, we would first let the engine decide what nodularity range it needed from the iron and then follow up with the best limits for the foundry and engine plants consistent with those engine requirements."

The resulting ECG has met and/or exceeded the project requirements:

ECG has been shown to have much higher strength, stiffness and toughness than Class 30 gray iron.

This enhanced strength and stiffness aided in meeting engine weight objectives and provided superior engine characteristics. It has eliminated the need for 100 percent magnetic-particle inspection for cracks common for gray iron bedplates.

The material has now been shown to be "production feasible" for a high-volume automotive application.

And, in its 4.7L V-8 engine bedplate application, ECG casts sound without risers and has a high mold yield.

Warrick presented an overview of the development and application of ECG at this week's 1999 Society of Automotive Engineers Expo at Cobo Conference and Exposition Center in Detroit, Michigan. The presentation was one of two given this year by Intermet at the annual SAE event.

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THE "Magic" of Applied Process

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Some might consider it a form of magic, but the Austempering process involves no prestidigitation—just specialized equipment and a thorough understanding of time and temperature and their affect on ferrous metals during the heat-treating process. Austempering, a specialized heat-treating process performed by Applied Process, produces steel and iron parts that are stronger, tougher, lighter, quieter, more wear resistant and have greater dimensional repeatability than conventionally heat-treated parts.

History
In 1962 W. R. Keough, with several partners, established what would grow to be Atmosphere Group Inc. (AG). AG based its growth on the austempering process, a specialized heat-treating method. The company grew to include Atmosphere Furnace Company (AFC) and several commercial heat treaters that specialized in the Austempering of small stampings and formed parts.

AG grew as the merits of the austempering process became evident to producers. The need existed for a facility that could Austemper larger parts efficiently. AFC spawned an experimental heat treat unit in 1978 to develop the processes and equipment necessary for that effort. The result was a unique integral-quench batch furnace with enhanced quenching capabilities for processing different (and larger) parts and applying new techniques. That experiment became Applied Process Inc., a different kind of heat treat.

Applied Process Inc., Livonia, Michigan
Applied Process Inc. was incorporated in 1984. AP quickly outgrew its Wixom, Michigan facility and moved to a 30,000-sq. ft. facility in Livonia, Michigan in 1985. AP has led the industry in the application of the austempering process to heavier stampings, forgings and castings, especially ductile iron castings. From 1984 to 1996 AP grew at a remarkable rate of over 14% annually. In 1993, as the result of a friendly spin off, Applied Process Inc. became a stand-alone company with John R. (Chip) Keough as President and majority stockholder. Additionally, Mr. Keough continually and enthusiastically promotes the benefits and applications of Austempering.

AP Westshore, Inc., Oshkosh, Wisconsin
In 1994, as demand started to outpace capacity at the Livonia facility a new company, AP Westshore Inc. was commissioned in Oshkosh, Wisconsin. This 32,000-sq. ft., green-field plant utilizes state-of-the-art austempering equipment with 100% recycling of quenchants, water and alloy. In fact, the AP Westshore facility is the only heat treat plant in Wisconsin that does not require a wastewater permit; a first that AP is proud of. In 1998 both Applied Process and AP Westshore became QS9000 and ISO9002 certified.

Licensees

Elizabethtown, Kentucky—The most advanced
As Austempering sales continued to grow, the need for additional capacity became apparent and construction was begun on a new, 36,000-sq. ft. facility in Elizabethtown, Kentucky. That facility, AP Southridge Inc., opened for business in December of 1998. The AP Southridge facility integrates the best designs and practices from both Livonia and Oshkosh facilities and adds to that complete automation for the most advanced austempering facility in the world.

AP’s customers include several General Motors Divisions, John Deere, Caterpillar, Dana, Meritor, Purolator, Eaton, Citation Corporation, Thyssen/Budd, Freightliner, Ford, Vermeer, Masco, Intermet, Oshkosh Truck, Navistar and hundreds of other OEM’s,
and first- and second-tier suppliers in 38 states and five Canadian provinces. Austempered ductile iron alone accounts for nearly 20,000 tons per year of production.

**AP's Future**
AP and its U. S. affiliates are now an $8 million company employing about 50 people and operating seven days a week. They will continue to grow by focusing on their strength—Austempering of steels and cast irons. They are committed to supplying their customers with the highest quality services and technical support, on time, at competitive prices. AP’s future lies in continually improving their processes AND people to meet the ever-changing demands of their customers. *AP and its employees are meeting the challenge!*

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NEWS BRIEFS

Meetings

The 1999 annual meeting of the Ductile Iron Society is scheduled for May 19-21, 1999, and will be held at the Holiday Inn City Centre in South Bend, IN.

Business

Time Sensitive Material

Globe Metallurgical, Inc., the world's leading manufacturer of foundry alloys and the country's largest producer of silicon metal, today announced it is accepting applications for the 1999 Globe Challenge High School Scholarship Program. The deadline for applications is April 16, 1999.

Now entering its seventh year, the Globe Challenge Scholarship Program recognizes outstanding high school students who have overcome unique challenges or helped others to do so. High school seniors in the four communities in which Globe has production facilities are eligible: Beverly/Waterford, OH; Niagara Falls, NY; Selma AL; and Springfield, OR. Forty-six scholarships have been awarded to date.

"The scholarship theme is in line with Globe's corporate motto, 'The Challenge Never Ends,'” said Arden Sims, president and CEO. "It reminds us that we must constantly strive to reach new heights in quality improvement. Through the Scholarship program, we challenge students to reach new heights in their academic and personal endeavors."

Winners are judged by an independent panel based on their submission of a 500-word essay in which they describe a challenge they have overcome, or helped someone else overcome. In addition to their essays, applicants are evaluated on their academic performance, participation in extracurricular activities and letters of reference.

"Last year, our essays described how students overcame a variety of challenges--from helping parents get a home of their own to re-uniting broken families,” said Sims. "It is gratifying to see the ingenuity and maturity of these students. We are proud to help support them as they pursue their high education."

The award consists of a one-time $1,250 tuition payment to the student's college, trade or technical school of choice. Winners will also have their names engraved on a plaque placed at Globe's plant and the participating school.

The deadline for scholarship entries is Friday, April 16, 1999. For complete details and scholarship application, eligible students in participating school districts should contact their high school guidance counselors.

In addition to its Challenge Scholarship Program, Globe offers scholarships specifically for the children of Globe employees. Applications for these scholarships are available directly through the Company.

Globe Metallurgical, Inc., is a privately-held Company, with headquarters in Cleveland, OH. The Company maintains four domestic production facilities, and one in Norway. Globe also owns a subsidiary in West Sussex, England, and is a major shareholder in Fesil, a leading Norwegian alloy producer. Recognized internationally for its high-quality products, Globe has received numerous awards, including the 1988 Malcolm Baldridge National Quality Award and the 1989 Shiego Shingo Award for Manufacturing Excellence.

AMCOL International Corp. (NYSE:ACO) announced that the Latin America Sales Group of its Chemdal subsidiary and the Metalcasting Products Group of its American Colloid Co. subsidiary are "Operations of the Year."

Ashland Chemical Company, a division of Ashland, Inc. (NYSE:ASH), recently broke ground on its first manufacturing plant in China. The plant will formally operate as Ashland (Changzhou) Chemical Co., Ltd. and will be located in the Changzhou New District near Shanghai, China.

The office, blending, and manufacturing plant will service Ashland Chemical's Foundry Products Division. The facility will initially
have approximately 20 employees and is expected to be operational by the Spring of next year.

Superior Graphite's newest Chicago plant--built to accommodate the company's growing presence in the battery industry--has begun large-scale production, officials announced today. The plant, located on the city's Southwest side, houses a cutting-edge laboratory for testing and developing value-added graphite materials for the battery industry. Using special sizing and processing technology, workers will focus on alkaline and lithium ion applications.

Intermet Corporation today announced that it has signed a definitive agreement with Quadion Corporation for the purchase of its Tool Products Division. Tool Products is a North American manufacturer of precision engineered, close-tolerance, aluminum die castings. The company also manufactures for other broad applications in the motor vehicle, electronics, communications, power tool and recreation industries. Intermet Chairman and CEO, John Doddrige, said "It is Intermet's fundamental strategy to offer metal castings in multiple materials, so logically we have been looking for opportunities to grow our aluminum casting business to compliment our iron casting business."

The Foundry Division of the John Deere Waterloo Works, Waterloo, Iowa, the leading manufacturer of farming machinery, has placed an order with Inductotherm for what will be the largest, solid state, medium frequency induction melting installation in the world. John Deere's new induction melt shop will include three 16,000 kw Inductotherm VIP Power-Trak units powering three 20 metric ton steel shell coreless furnaces. The furnaces, which will include back-tilting for easy slag removal, integral fume collection covers and lining removal mechanisms, will set new standards for high operational efficiency. The new induction furnaces also will provide a cleaner and quieter working environment because they will generate minimal effluences and will produce substantially less noise than the six existing arc furnaces which they will replace. Inductotherm also is supplying integrated and automated alloy makeup and charge delivery equipment for this installation. An Inductotherm Meltminder 200 computer system will provide overall melt shop control via a central, elevated control room with line-of-sight monitoring of each furnace. The full project will be completed in June 2000.

People

Richard W. Carriker
AMCOL International Corp. (NYSE:ACO) recently announced the promotion of Richard W. Carriker to the position of managing director for Volclay Ltd., its U.K. minerals operation.

Jack Smith
Citation Corporation has appointed Jack Smith to the newly created position of vice president operations within the company's automotive group.

Smith will oversee the operations of three Citation divisions, Alabama Ductile, Camden Casting Center, and Citation-Marion.

David Laughton
David Laughton, a 13-year Superior Graphite Co. veteran, has been named product manager for the company's beta silicon group, officials recently announced. He comes to the position from Western United States Sales. As product manager, his chief duties are to oversee production and marketing of beta silicon carbide, manufactured in Hopkinsville, Kentucky.

Byron O. Pond, Jr.
Byron O. Pond, Jr., Chairman of Indiana based Arvin Industries, Inc., was elected to the Board of Directors of Intermet. Pond also serves on the Board of Directors of Cooper Tire and Rubber Company and is the current chairman of the Motor Equipment Manufacturer Association.

Laurence Vine-Chatterton
Intermet Corporation Chairman and CEO John Doddridge recently announced the appointment of Laurence Vine-Chatterton as President of Intermet Europe.

**Board of Directors**
At a recent Hickman, Williams & Company Stockholders' Meeting the following were elected to the Board of Directors:

Robert Damschroeder, Chm/CEO
Arthur Haack, President/COO
Paul Kjelstrom, Exec. VP, Oper.
Robert Greason, VP; Chm./Pres. of Hickman, Williams Canada, Inc. and Chm./Pres. of Hickman, Williams de Mexico, S. A. de C. V.
Richard Lambrecht, Senior VP
Robert Simons, VP
William Snyder, VP
James Wood, VP

**George Kitkowski**
Citation Corporation has appointed George Kitkowski director of continuous improvement.

Kitkowski was previously with Southern Aluminum, a Citation division. He will now share his manufacturing experience with all of the divisions within the automotive group.

Citation Corporation is a manufacturer of castings, as well as forged and machined components for the capital and durable goods industries. At its 22 divisions in 10 states, its approximately 7,000 employees produce steel, aluminum, and iron castings, steel forgings, steel and aluminum investment castings, and machined and assembled components for automobiles, light, medium and heavy trucks, off-highway construction equipment, agricultural equipment, aircraft and aerospace, pumps, compressors, and industrial valves, machine tools, and other durable goods. The company's stock is traded on the NASDAQ exchange under the symbol 'Cast'. Citation Corporation can be found on the World Wide Web at www.gotocast.com.

**Bytha Mills**
Intermet Corporation (Nasdaq: INMT) announced today that Bytha Mills has been named Director of Corporate Affairs. In a newly created position, Mills will assume responsibility for senior management compensation administration and the employee benefits department.

Mills most recently was Manager of Investor Relations with responsibilities for Corporate Office investor relations, human resources and public relations - duties she will retain in her new position.

She joined the company in 1997 from Dana Corporation, where she served in numerous positions in various locations, including human resources manager and accounting supervisor.

Mills holds a Bachelor of Science degree in accounting from Arkansas State University and a Master of Science degree in human resources from Indiana Wesleyan University.

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