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Your Guide to Foundries in Pakistan

2<sup>ND</sup> QUARTER 2019



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# PRESIDENT MESSAGE

One of the most important events for foundry industry is the upcoming GIFA in Dusseldorf, Germany from 25th to 28th June, 2019. It is an important international trade fair for foundry technology globally held after every 4 years. It provides opportunity for information exchange for the metallurgy industries covering the entire valued chain: from raw materials, machines and processes right to the end product.

Foundry planted machinery and technologies along with the entire production chain are exhibited. With more than 780 exhibitors, GIFA is the top event for innovations of foundry suppliers at the bright world of metals.

The Government of Pakistan is encouraging to shift from Trading to manufacturing.

I suggest PFA members' participation is important as we have the potential to export to European countries and can get business contacts from GIFA, 2019. We must find international customers to export our foundry products to improve economy of Pakistan.



Pakistan Foundry Association (PFA) has facilitated PFA members for participation in GIFA; and managed to gather members from leading foundries of Pakistan.

Our members will also participate in "China day celebrations" at the event and will meet representative from China Foundry Association Mr. Thomas Gao, Deputy Secretary General-CFA and more than 200 casting manufacturers. This can be an opportunity to find, collaborating partners from China to support our foundries.

Beside the above, one of the important responsibilities on PFA members is providing internships (on the job training) to the students of B.SC Metallurgical and Materials Engineering, UET, NED, Dawood Engineering, Punjab University and GIKI etc. I would emphasize that all our members should provide this opportunity to maximum number of students. This will build a secure future for our industry.

**Sikandar Mustafa Khan**  
**President-PFA**

## Table of Contents

- 04** Solving the Problems in Your Foundry
- 11** A Case-study to Eliminate The Shrinkage in Ductile Iron Through Modification of Solidification Pattern
- 16** Minimizing Casting Costs by Autonomously Simulating Different Gating Systems for Ductile Iron Castings
- 25** Future of Lightweight automotive construction Prospects for casting
- 31** Future of Lightweight automotive construction Prospects for casting
- 34** Future of Lightweight automotive construction Prospects for casting

## Chief Editor

**Mr. Fahad Iqbal**  
Joint Secretary  
Pakistan Foundry Association



## Editor / Publisher

**Mr. Abdul Rashid**  
Secretary  
Pakistan Foundry Association  
Foundry Service Center,  
University of Engineering & Technology,  
(Opposite Gate # 5, U.E.T) G.T Road, Lahore, Pakistan  
Ph:+92-42-36851559, Cell: +92-322-8487873 /  
+92-300-8673873  
E-mail: pakistanfoundryassociation@gmail.com/  
info@pfa.org.pk, Web: www.pfa.org.pk



# Solving the Problems in Your Foundry

A systematic approach to identifying problems and achieving solutions can help metalcasters meet customer expectations and avoid unnecessary costs of quality. A MODERN CASTING STAFF AND AFS INSTITUTE

Problem-solving in life and in business can seem like a complex and intimidating effort causing many to fall back to a hands-off approach. But problems must be solved in a metalcasting operation or they eventually lead to additional costs to your business and loss of profitability. Using structured problem solving, metalcasters take a systematic approach to identifying problems and finding a solution that addresses the problem's root cause. This general strategy includes a focus on process metrics and customer needs.

Structured problem solving includes defining, describing and establishing possible causes; testing the most probable cause; verifying the true cause; and implementing well-tested countermeasures. When integrated with existing records, such as shop floor incident reports, scrap reports, and customer feedback, quality assurance personnel can leverage proper questioning skills, critical and creative thinking skills, knowledge capturing skills, and diagnostic skills to solve incidents and problems efficiently and accurately. Structured problem solving is effective because it provides focus in



Fig. 1. The total cost of quality is more than the visible costs of rework, inspection and warranty payments. Hidden costs, like lost customer loyalty, are less obvious but can have a high penalty.

**Table 1. Sample Problem Definitions**

Typical	Better
Our plant has been seeing a big increase in porosity rejects lately.	Starting in February, porosity rejects for the R40 rotor increased to 5.4% from the normal 0.6%, increasing annual costs by \$230,000.
A customer complained about our cast housings breaking in the field.	In the last month, we've had 4 complaints of the 12" JK95 fracturing at the connecting flange during installation; there were no prior occurrences.
A malfunction in our heat treat furnace is causing finished parts to be out of spec.	On June 20, in-process tests showed the average hardness of our steel castings to be Rc36, below the specified range of Rc 40 – 43.

**Table 2. Key Points in Corrective Action Flow**

Key points:	Key points:
<b>Communication strategy starts at the top:</b>	<b>Identify and define the problem:</b>
Work from paper and electronic records	Examine the actual product defect where possible
Confirm facts	Verify proper defect identification
Determine requirements	Confirm understanding of corrective action requirements and timing
Centralize monitoring in QA	
Pass down good information	
<b>Isolate and contain:</b>	<b>Gather and analyze data:</b>
Limit the damage and isolate the customer from the problem	Collect information about the problem based on C & E diagrams or other root cause techniques
Quit sending defective parts	Test assumptions
	Rule out contributors
	Evaluate relationships
	Confirm the chain of cause and effect until systematic, root cause is identified
<b>Reduce or eliminate:</b>	<b>Monitor and document change:</b>
Identify a countermeasure that addresses the root cause	Check effectiveness and adjust (act) where necessary to ensure the problem goes away.
Implement the countermeasure(s) across all applicable lines, stations, mold, etc.	Use in-house documents to help manage the process
Anticipate cultural resistance to change	Don't make changes that are not documented and reviewed by all affected parties
Communicate and train	

problem definition and consistency of direction in investigating the problem. It coordinates collection and analysis of data, facilitates communication between team members, management, and the customer, and promotes countermeasures that address the root cause and not its symptoms.

## Costs of Quality

Quality is conforming to requirements at a cost the customer perceives as value. Four types of costs go into the total cost of quality: prevention costs, appraisal costs, internal failure costs, and external failure costs. Prevention costs includes activities specifically designed to prevent poor quality, such as quality planning, internal system audits, training and supplier quality work. Appraisal costs are associated with

measuring, evaluating, auditing products to ensure conformance to quality standards. Internal and external failure costs result from products not conforming to customer requirements, either occurring prior to or after shipment to the customer. Most costs, especially those associated with external failures, are not obvious and can be difficult to quantify, such as lost customer loyalty, increased inventory, expediting costs, and late deliveries (Figure 1).

Problems cost more the further they occur from the process where they were made. This is because added value increases as more processing has been done on the product. The customer may be directly affected, and customer impacts are the responsibility of the supplier.

***Short-term corrective actions or poor solutions to problems can sometimes add costs greater than the problem itself. Like a band-aid on a bad cut, it only lasts so long before the wound becomes worse and you have to pay for professional care.***

Attendant costs, such as shipping, damage to equipment the casting was in, or labor costs, go up, as well. Short-term corrective actions or poor solutions can sometimes add costs greater than the problem itself. Like a band-aid on a bad cut, it only lasts so long before the wound becomes worse and you have to pay for professional care. Poor quality always has some cost. At a minimum, some level of prevention and appraisal is necessary, but those costs will be far less than failure. The minimum cost is a significant dose of prevention, some appraisal costs and a minimal amount of internal failure. The implementation of preventive measures to control quality often takes a great deal of time and process knowledge. Appraisal measures are initially undertaken that cause internal failures to increase but external failures to decrease.

Quality maturity sees prevention costs increase and failure costs decrease. As problems are identified closer to the source of failure, fewer variables are at play, cause-and-effect relationships are better understood, and costs associated with correcting these failures decreases. Prevention activities, especially quality planning, auditing, error proofing, and training, can yield a 10 to 1 return on investment according to the American Society for Quality's Quality Cost Committee.

## Corrective Action

A good corrective action flow will start with problem communication and move to identifying and defining the problem (Figure 2). Once a problem arises, the personnel charged with solving it needs to write a clear and effective problem definition that details the issue the team wants to improve. It gives the primary metric, and if needed, a second metric, outlines the magnitude of the problem (usually with a financial impact) and sets the time frame. The problem definition should include a detailed, narrative description, be neutral to avoid jumping to solutions, and include a reference to a baseline measure. Table 1 lists sample problem definitions.

Every metalcasting facility has its own way of dealing with quality issues. Smaller facilities might only have a coordinator rather than a formal problem-solving team. But the coordinator and/or the team should involve quality assurance personnel for technical problem solving help, engineering/supervision for process help and implementation, maintenance for practical solutions, and operators for shop knowledge.

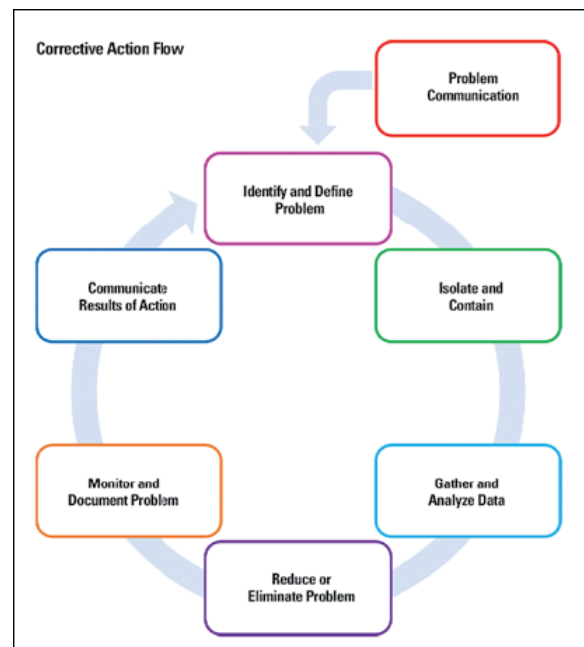


Fig. 2. A good corrective action flow will start with problem communication and move through a loop of defining the problem, isolating and containment, data analysis, problem reduction, monitoring and further communication.

***While short-term measures only address the immediate problem, to keep customers happy, sometimes these measures are necessary to do what's right for them and to meet contractual obligations.***

After the defining the problem, the coordinator should move the team through isolation and containment, data collection and analysis, problem elimination or reduction, monitoring and documentation, and communication of the results of action. See the chart in Table 2 for information on each step.

To help in the problem identification, definition and information collecting process, simple forms can be used to communicate with the customer. A trouble report is a means of “listening” to a customer’s complaint. It may not give all the information you need, but the report can ask some simple questions to help you understand the problem and the customer describe the problem in meaningful terms. Sample questions can ask for specific descriptions of the problem, conditions under which it occurred, and the quantity affected. The form can also include information about customer expectations for correcting the problem.

Another useful form is a corrective action request for internal follow-up by quality, engineering, maintenance and operations personnel. These departments document what short-term actions they have taken to document and stop the problem from recurring, and give directions to others about the next steps required. This document also asks the problem be categorized so any further action, such as longterm measures or a root cause analysis, can be taken.

Quality alerts are documents issued to communicate the necessary short-term

actions required by employees. It identifies the problem and shows key facts and should be posted where employees can access the information. Short-term and long-term measures can be used to solve a problem. Short-term actions may include:

- Containment
- Quarantine of suspect parts.
- Go/no-go gauges.
- Extra sampling and testing.
- Extra inspection, including lot control for scrap or rework.
- Training.
- Establishing acceptable (temporary) rework or salvage procedures, if possible.

A critical element in short-term action is communication with the customer so they know they are protected. Customers are key stakeholders, and they hate being in the dark when there’s an issue, whether quality or delivery. It’s important to make the distinction between acute and chronic problems. Chronic problems exist when performance is below standard but relatively stable over a long period of time. It is often related to the basic capability of the process, and fixing it requires fundamental process improvement. An example of a chronic problem is overall equipment efficiency of 65% over the past two years, which is below a target of 75%. An acute problem exists when performance worsens significantly from the normal level. This can be over a very short period of time or be sporadic and is often related to some undocumented deviation in the process.

An example of an acute problem is three field failures in the last three months after five years with zero failures. The full application of a program like Six Sigma is probably not appropriate for acute problems even when the root cause is a system issue. If there is a flaw at the system level, it doesn’t necessarily involve a fundamental change to the process except at a management level. While short-term measures only address the immediate problem, to keep customers





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happy, sometimes these measures are necessary to do what's right for them and to meet contractual obligations. If short-term measures are required repetitively, however, you haven't addressed the root cause or "real problem."

Long-term countermeasures are not necessarily complex or facility-wide, but they permanently alter the system of doing things. They address the root cause. Typically, long-term measures will involve a documented alteration of the process.

- Tips for success in long-term measures include:
- Take control of the problem-solving process and get management's buy-in.
- Have a standard response format in place for external customer complaints.
- Get started on the corrective action as soon as you have a reasonable idea of the problem. Don't wait for perfect information.
- Too frequent corrective action cycling overwhelms management systems. Don't issue unneeded CAR's.
- Tailor your effort to the true impact of the problem.
- Don't leave problem solving to the quality department. Practical input from the plant floor, supported by data, is essential in developing effective countermeasures.
- During the problem-solving process, have a communication plan to keep team members, customers, and management informed:
- Appropriate information and level of detail (edit carefully!)
- Preferred medium (e.g. emails, phone calls, meetings, one-on-ones, reports) for each stakeholder.
- Appropriate frequency of communication.
- Be pro-active! Ask stakeholders how they want to be kept in the loop.
- After a problem is solved, ask, "What have we learned?" Correlating data and positive customer feedback and positive feedback from those internally working to solve the problem will be indicators your corrective action measures are working.

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## CONTACT

### Mr. Abdul Rashid

Secretary  
Pakistan Foundry Association  
Foundry Service Center,  
University of Engineering & Technology,  
(Opposite Gate # 5, U.E.T) G.T Road, Lahore,  
Pakistan  
Ph:+92-42-36851559,  
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# A Case-study to Eliminate The Shrinkage in Ductile Iron Through Modification of Solidification Pattern

Khursheed Anwar, Plant Manager  
SaudiCast, Riyadh  
khursheed@saudicast.com

Mohammad Miftahuddin, Production Manager  
SaudiCast, Riyadh  
miftah@saudicast.com

## Abstract

Shrinkage at micro and macro level is the common casting defect which results in the poor quality of the cast products. Therefore in the present work an attempt has been made to minimize the shrinkage by controlling the solidification pattern of ductile iron. A cylindrical shape casting called stabilizer having wall thickness of 45 mm is used in the present work. To eliminate the shrinkage, we optimized our process parameters such as chemical composition, melt-conditioning, magnesium treatment, inoculation, temperature etc. but, still, the results was 35% rejection. Having done all that we decided to introduce a newly emerged Ce inoculant containing a trace amount of Sulfur and Oxygen which is supposed to give high powerful graphite nucleation thus reducing the shrinkage tendency of ductile iron. With addition of Ce inoculant nucleation continued till the end of solidification. This helped to overcome the high level of rejection which dropped to 3-5%.

**Keywords:** *Ductile Iron, Shrinkage, Cylindrical Casting, Composition Control, Inoculant*

## 1. Introduction

In the last few years Ductile iron is frequently

used in the production of heavy machinery parts to due high strength to weight ratio and range of properties associated with it [1, 3]. The ductile iron provides good combination of strength and ductility due to presence of spheroidal graphite. As a metallurgical view, ductile iron is one of the most complicated material for castings due to solidification behavior [2, 4]. During solidification there are several phases of nucleation and the interaction of these different phases has major impact on the final mechanical properties of casting [6, 7]. For the casting performance and solidification shrinkage control, a newly emerged Ceinoculant was introduced.

This inoculant contains a small and controlled amount of sulphur and oxygen in a form that make them available for reaction with calcium and cerium during addition to liquid metal and to give strong graphite nucleation [1]. Cerium will contribute in neutralizing the subversive trace elements in the base iron forming stable inter-metallic compounds. Cerium will also have strong affinity to sulphur and oxygen, resulting in the formation highly stable cerium oxides, sulphide and oxysulphides. This cerium compound appeared to be very beneficial in the inoculation process, resulting in improved nucleation effectiveness throughout the entire solidification range [1, 5].



This study is to eliminate the shrinkage defect occurring in many of our complex castings produced in Furan bonded mould. We had tried to optimize all the following parameters but failed to get shrinkage free castings.

1) Optimized the parameters of Furan Bonded Moulds.

2) Used proper weights on the mould during pouring.

3) Reduced Mn content to below 0.20%.

4) Used melt pre-conditioners.

5) Restricted Mg to 0.04%.

6) Pouring temperature controlled between 1320-1350°C.

7) Used all-round Chill.

8) Tried Riser and Riser-less gating system.

9) Used ladle and stream inoculation.

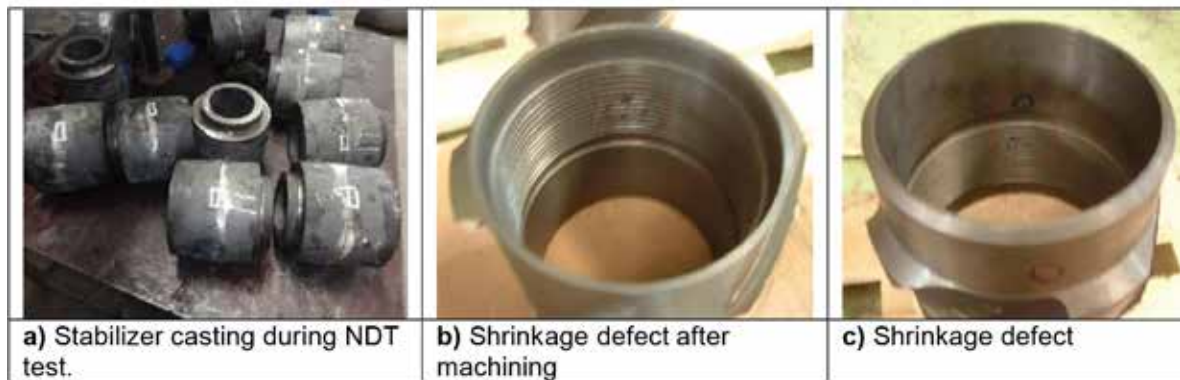


Fig. 1

## 2. Experimental Procedure

A cylindrical shape casting having wall thickness 45 mm is used. Producing a defect free casting of this shape and wall thickness is generally very difficult in sand molding process. This casting requires machining on all the surfaces.

The requirement of customer was full machining with no defect on machine surface. After all previous experiment we shifted our focus on solidification pattern. A thermal analyses equipment capable of plotting the Cooling curve and other

solidification data was used to study the solidification pattern of both inoculant i.e. Ba-inoculant & Ce-Inoculant. During this analysis we kept all other casting parameter unchanged. The spheroidizing process was carried out by applying the sandwich method and using nodulizer (Mg-6%, La -1.04%) and treatment temperature was 1500-1520 °C. The temperature of molten metal bath was measured by thermocouple. After the nodularizing treatment the melt was inoculated with 0.6% by weight of inoculants. The pouring temperature range from first mold to last mold were 1340-1350 °C and 1320-1330 °C, respectively.

Table-1 : Composition of Tested Liquid Iron

C	Si	Mn	Mg	S	P	Cu	Mo	RE
3.6-3.8	2.3-2.4	max-0.2	0.03-0.04	max-0.02	max-0.035	0.02	0.003	0.01

## 3. Experimental Results and Discussions

### 3.1 Thermal Analysis

The thermal analysis graph with both inoculants is shown in Fig. 2 and Fig.3. It is observed that lower eutectic undercooled

temperature (TEU) for base metal is 1121 °C and TER temperature is 1133 °C which shows the larger undercooling effect which gives larger recalescence degree. When the liquidus temperature is reached, the cooling curve shows a quasi-horizontal plateau. This point means the heat losses are exactly

balance by the amount of heat of solidification. The length of horizontal the heat losses are exactly balance by the amount of heat of solidification. The length of horizontal plateau is the total solidification time needed for graphite to grow. In other words, the increase in graphite growth increases the length of horizontal plateau.

$\Delta T_{EU}$  is the difference in temperature of eutectic undercooling of inoculated and a)

Stabilizer casting during NDT test.

b) Shrinkage defect after machining

c) Shrinkage defect un-inoculated iron and reported in Table-2. The  $\Delta T_{EU}$  was observed 15 °C in case of Ba-inoculant and 20 °C in case of Ce-inoculant. A higher TEU value indicates that the metal is more resistant to chill and shrinkage than a metal of lower TEU value. Similarly, a metal of lower Recalescence value has lower tendency of

Table-2 : Critical Temperature drive from Thermal Analysis

Specific Temperature	Temperature (°C)		
	Base Metal (Uninoculated)	Ba-inoculant	Ce-inoculant (Coated with S & O)
Lower eutectic temperature ( $T_{EU}$ )	1121	1136	1141
Eutectic Recalescence temp. ( $T_{ER}$ )	1133	1144	1144
$\Delta T_{EU} = T_{EU}(\text{Ino}) - T_{EU}(\text{Unino})$	----	15	20
$\Delta T_R = T_{ER} - T_{EU}$	12	8	3

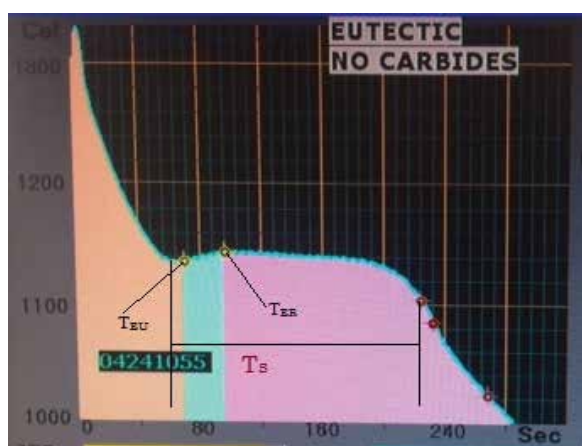


Fig. 2 : Cooling curve for Ba-inoculant

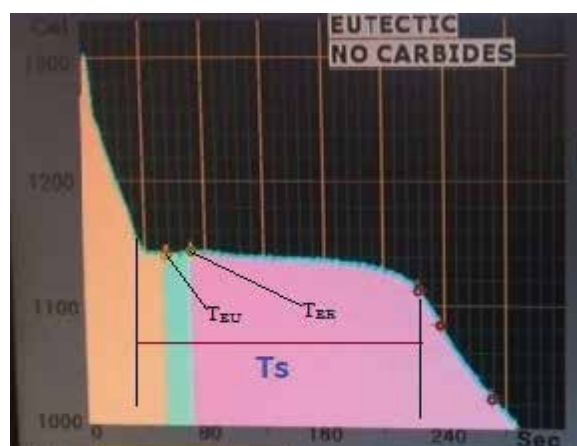


Fig. 3 : Cooling curve for Ce-inoculant

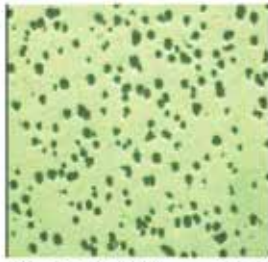
### 3.2 Microstructure Analysis

The sample for microstructure analysis was taken from casting lugs. The samples were polished and etched. An image analyzer software was used for metallographic examination. The high nodule count

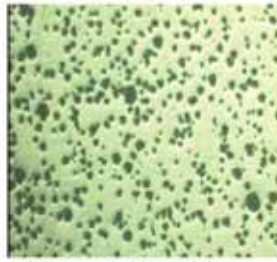
represent an inoculant condition where pronounced late graphite nodule formation is obtained, showing up as some big and numerous smaller nodules in the microstructure. Shrinkage formation is strongly reduced and almost eliminated by this wide nodule size distribution.

Table-3 : Analysis of Microstructure with Inoculants

Inoculant type	Nodule Count (mm <sup>2</sup> )	Nodularity (%)	Pearlite	Shrinkage Tendency
1) Ba-inoculant-0.6%	197	83	21	more
2) Ce-inoculant - (Coated with S & O) 0.6%	291	95	10	less



**Fig. 4:** (100X, Ba-Inoculant)



**Fig. 5:** (100X, Ce-Inoculant)



**Fig. 6:** Good casting

## Conclusion

The case-study was conducted on ductile iron casting by using of two different types of inoculants. Thermal analysis can be effectively used for measuring the performance of inoculant on solidification of ductile iron by plotting the cooling curve. During study the following conclusion were highlighted.

The use of Ce-based inoculant prolonged the graphite nucleation by providing extra nucleation site towards the end of solidification. In case of Babased inoculant, solidification time is less.

Ce-based inoculant increases the nodule count and nodularity and render a skewed microstructure. Thus the formation of pearlite is suppressed during the solidification of ductile iron.

Ce-based inoculant decrease the recalescence ( $\Delta TR$ ) and amount of undercooling, due to this reduce the shrinkage and micro shrinkage and improve the overall quality of casting.

While using a Ba-based inoculant, rejection was 35% annually due to shrinkage but use of Ce-based inoculant reduced the rejection up to 3-5 %

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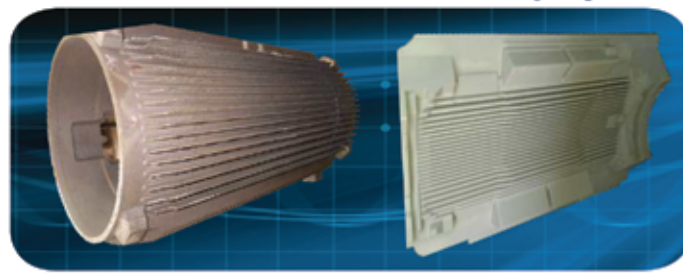
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Two part no bake acid cured system  
Two part no bake ester set system (steel, SG, NF)  
Phenolic urethane self setting system (steel, Iron, NF)  
Phenolic urethane gassing cold box  
Hot box system for ferrous & non ferrous  
Furan no bake (steel, SG, CI, NF)  
CO<sub>2</sub> cured phenolic  
Inorganic no bake system

### Coatings

Zircon spirit/water based  
Graphite spirit/water based  
Alumino-silicate mix refractory spirit/water based  
Magnesite spirit based  
Graphite water base for metallic trough  
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Coating for lost foam process  
Tellurium base coating  
Sulphur blocking coating  
Chill Coat

### Other Foundry Consumables

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- Release agent for green sand mould
- Release agent for alkaline phenolic no bake system
- Release agent for cold box
- Parting agent for shell (water / solvent based)
- Aluminum based release for no bake system

Core joining paste  
Mould sealing rope

Surface hardner for green sand mould  
Sealing compound for mould and core  
Silicon carbide, zirconia foam filters  
Ceramic sand  
Chromite sand  
Sand Additives (Sphereox) of Chesapeake Specialty Products, USA  
Furnace & refractory cleansing fluxes of ASI International, USA

- Redux EF40L briquettes

Additive for thermal reclamation of alkaline phenolic no bake resin  
Anti Veining solution from John Winter & Co., UK

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- Silicate based die coatings
- Aluminium based die coatings
- High pressure die coatings
- Zircon water base dressing
- Graphite based lubricant (plunger lubricant)

#### Forace degasser

- Forace degasser N<sub>2</sub> (nitrogen based)
- Forace degasser CF (chlorine free)

Forace grain refiner (powder & tablet)

Forace cover fluxes

Forace modifier

Forace mastic

Forbral

Forbruss

Master alloys

#### Shell Resin Coated Sand

Forsand AC (for anti cracking grade)

Forsand LN (for steel casting with low nitrogen)

Forsand GP (for heavy section iron casting)

Forsand NF/AL (for non ferrous casting)

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Email: [contact@foracepolymers.in](mailto:contact@foracepolymers.in), [mtg@foracepolymers.in](mailto:mtg@foracepolymers.in)  
Web: [www.foracepolymers.net](http://www.foracepolymers.net)



forace Industries

**forace Industries pvt. Ltd.**

E-29 Industrial Area, Haridwar – 249401, Uttarakhand, India  
Phone: +91 1334 334000, +91-9068907917-18 | Fax: +91 1334 334043  
Email: [mtg@foraceindustries.com](mailto:mtg@foraceindustries.com), [contact@foraceindustries.com](mailto:contact@foraceindustries.com)  
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# Minimizing Casting Costs by Autonomously Simulating Different Gating Systems for Ductile Iron Castings

Dan Coyle  
MAGMA Foundry Technologies, Inc. Schaumburg, IL

## Abstract

Once a riser configuration has been selected to meet the solidification demand of a casting, a gating system is typically developed to fill the casting and risers. The use of simulation is a well-established practice that helps engineers evaluate gating systems that can lead to improved filling or even yield improvements. This paper will show 2 examples where casting simulation software was used to calculate manufacturing costs for many different gating system configurations and the lowest casting price was autonomously realized. The runner, down-sprue, and gates were varied for the 1st vertically parted example which effectively changes the yield, production rate, and grinding hours, thus changing the cost to produce the casting. The 2nd vertically parted example also examines the casting cost as the runner, down-sprue, and gates change, but includes core costs and the costs associated with reducing porosity in the casting. By allowing the software to autonomously change the gating geometries and using casting cost as an objective for geometry selection, a foundry engineer can maximize profits for the foundry and casting buyers can evaluate the financial implications of changing the quality of a casting.

**Keywords:** simulation, cost, gating, optimization, ductile iron, yield, rise

## Introduction

Lowering manufacturing costs is generally a primary concern for foundries, casting designers, casting buyers, and virtually anyone involved with producing a casting. When designing gating systems the primary concern is often on quality with manufacturing costs as a secondary concern due to looming PPAP submission deadlines. If during this design phase hundreds or even thousands of different gating systems can quickly be evaluated, then both quality and manufacturing costs can be considered and even weighed against one another. Since pouring hundreds of sample castings with different gating systems is not practical, casting process simulation can be a practical solution. Even simulating hundreds of gating systems is not always practical, which is why autonomously optimizing gating systems was used in the subsequent examples.

In order to autonomously optimize a gating system all of the possible geometries must be created in either a CAD program or within the

simulation software itself. Once all of the geometries are set up, a casting cost objective can be created that accounts for changes in yield, pouring time, and riser/gate contact area. With a large design space (100+ possible designs), the casting cost objective can be minimized by a multi objective genetic algorithm where only a small percentage of designs is simulated in order to arrive at an optimized solution.

Using autonomous optimization with the casting cost as an objective that is minimized proves to be a very useful way to evaluate a gating system, especially when different quality criteria are plotted against the casting cost. This can aid in the discussion about the costs for reducing/eliminating something like shrinkage.

## Example 1 – Set Up

The first example is a single cavity that is vertically parted and a 65-45-12 ductile iron was simulated. Solidification simulation was performed and the riser shapes were selected such that the risers effectively feed the casting and no porosity indications were seen in the casting. This casting/riser combination with 2 different size runners and 3 different size down-sprues were used as seen in figure 1 and figure 2. All of the runner and down-sprue geometries were created in a separate CAD package, imported into the simulation software, and were activated individually. The size of the pouring inlet, the pouring cup, the down-sprue overlap, and runner overlap remained constant throughout the experiment.

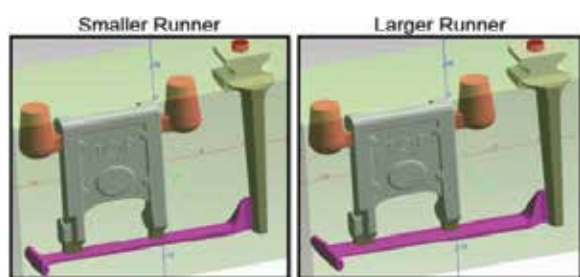


Fig. 1. 2 Different runners

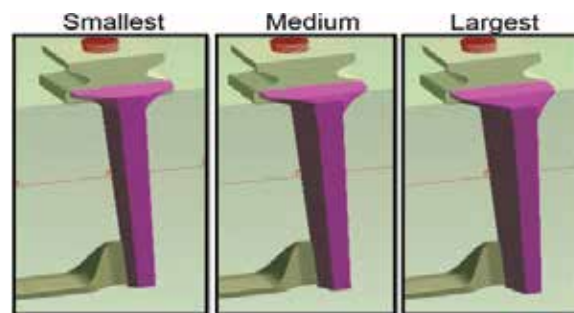


Fig. 2. 3 Different down-sprues

Two gates connecting the runner and the casting were created as parametric objects in the software and varied independently as seen in figure 3. The width of gate 1 was varied from 0.6" to 1.2" by 0.2" and the thickness was varied from 0.4" to 1.2" by 0.4". The width of gate 2 was varied from 0.4" to 1.2" by 0.2" and the thickness was varied from 0.4" to 1.2" by 0.4".

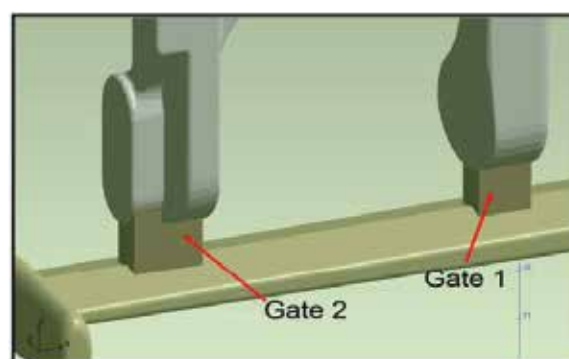


Fig. 3. Gate 1 & Gate 2

## Example 1 – Filling Analysis

Given these 6 variables, 1080 different combinations are possible. All 1080 different gating designs were simulated, which took 128.6 hours to run. Since solidification was already performed on the casting and risers, only filling was calculated for these 1080 designs. While different temperature distributions through different filling patterns can give rise to shrinkage issues (especially at the gates), this was not considered for this example.

As mentioned earlier the size of the inlet did not change, but more importantly, the level in the pouring cup was maintained at 70% full once the gating system backed up. This was done to ensure that the filling time was not



an input, but rather an output that changed as the geometry of the gating system changed. The free surface area of the melt was calculated at 100 different time steps during the filling and added up to give a very large number called total surface area. While the goal of this paper is not to talk about how to establish a quantifiable way to characterize a “Good” filling or a “Bad” filling, the total surface area appeared to be an effective way to analyze the filling pattern for each design. Figure 4 compares the velocity result of the design with the highest total surface area and the velocity result of the design that has the lowest total surface area.

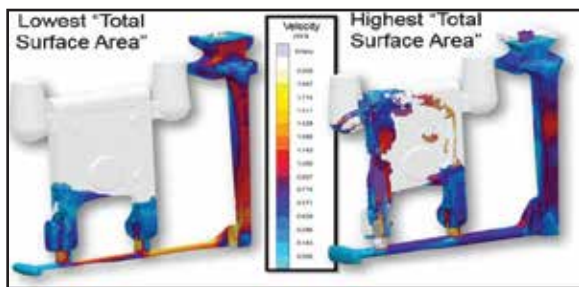


Fig. 4. Lowest vs. Highest “Total Surface Area”

A graph shown in figure 5 was then created for all of the designs where the filling time was plotted against the total surface area.

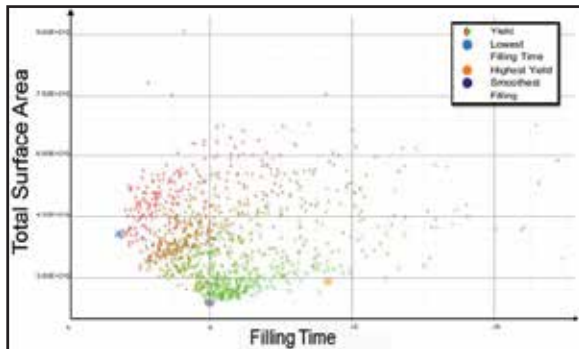


Fig. 5. “Filling Time” vs. “Total Surface Area”

Changes in yield are shown by varying the marker color such that green represents a higher or better yield whereas the red represents a lower yield or worse yield. The design with the highest yield is highlighted in orange and has a filling time of 11.4s with a relatively smooth filling pattern. If the yield was the primary concern this would be the most attractive design option. The design with the smoothest filling pattern is highlighted in purple and has a very good

yield with a filling time of 8.0s. If achieving the smoothest filling possible was the primary concern this would be the most attractive design option. The design with the lowest filling time is highlighted in blue and has a bad yield and an average filling pattern. If filling the mold as fast as possible was the primary concern this would be the most attractive design option.

## Example 1 – Cost Analysis

In order to determine what gating system should be selected as the best design, the financial impact of changing the yield, pouring time, and riser/gate contact area must be understood. Figure 6 is a chart with some typical numbers that are specific to the part and can be used in calculating the manufacturing costs for a single casting.

Casting Weight (lb)	30.61	CW
Castings per Mold	1	CPM
Yield	0.41	Y
Molds per hr	230	MPH
Grinding per hr	110	GPH
Scrap Rate	0.06	SR
Melt Loss	0.08	ML
Adjusted Mold Weight (lb)	81.15	AMW
Burden (Other Expenses)	0.09	B
* Varies with gating changes -		
* Does not vary with gating changes -		

Fig. 6. Part specific cost analysis data

Figure 7 is a chart with six different foundry specific costs that need to be calculated based on the foundry specific values highlighted in green. All of these foundry specific values are rough estimates for an iron foundry. For the sake of simplifying these costs, fixed overhead and variable overhead costs have been combined into one overhead cost (O.H.) for the different manufacturing processes.

MATERIAL COSTS		
Material Price (\$/lb)	0.12	MATP
Special Costs (\$): Filter, Sleeve	0.04	SC
MELTING COSTS		
Melting Labor (\$/lb)	0.05	MeltLab
Melting O.H. (\$/lb)	0.06	MeltOH
MOLDING COSTS		
Molding Labor (\$/hr)	600	MoldL
Molding O.H. (\$/hr)	850	MoldOH
SHOT BLAST COSTS		
Shot Blast Labor (\$/lb)	0.02	SBL
Shot Blast O.H. (\$/lb)	0.02	SBOH
GRINDING ROOM COSTS		
Grinding Labor (\$/hr)	55	GL
Grinding O.H. (\$/hr)	26	GOH
SHIPPING COSTS		
Shipping Labor (\$/lb)	0.005	SL
Shipping O.H. (\$/lb)	0.005	SOH

Fig. 7. Foundry specific cost analysis data

Once all of the part specific and foundry specific values have been entered, the costs for manufacturing a single casting can be calculated and a casting price realized as in figure 8[1].

Casting Weight (lb)	35.51	CW
Castings per Mold	1	CPM
Yield	0.41	Y
Molds per hr	250	MPH
Grinding per hr	300	GPH
Scrap Rate	0.04	SR
Melt Loss	0.06	ML
Adjusted Mold Weight (lb)	34.13	AMW
Burden (Other Expenses)	0.09	B
<b>MATERIAL COSTS</b>		
Material Price (\$/lb)	0.12	MATP
Special Costs (\$): Filter, Sleeve	0.04	SC
<b>MELTING COSTS</b>		
Melting Labor (\$/lb)	0.05	MeltLab
Melting O.H. (\$/lb)	0.06	MeltOH
<b>MOLDING COSTS</b>		
Molding Labor (\$/hr)	600	MoldL
Molding O.H. (\$/hr)	850	MoldOH
<b>SHOT BLAST COSTS</b>		
Shot Blast Labor (\$/lb)	0.02	SBL
Shot Blast O.H. (\$/lb)	0.02	SBOH
<b>GRINDING ROOM COSTS</b>		
Grinding Labor (\$/hr)	55	GL
Grinding O.H. (\$/hr)	26	GOH
<b>SHIPPING COSTS</b>		
Shipping Labor (\$/lb)	0.005	SL
Shipping O.H. (\$/lb)	0.005	SOH
<b>SCRAP COSTS</b>		
Scrap Rate	0.04	SR
<b>BURDEN COSTS</b>		
Burden (Other Expenses)	0.09	B
<b>CASTING COST: \$25.41</b>		

Fig. 8. Calculated Costs

Any changes to the gating indirectly effect all of the costs except for the shot blast costs and the shipping costs. A change to the gating effects the yield because the mold weight changes. A change to the gating can

affect the molds/hr if the pouring time changes (and the pouring process is a bottle neck for production). Changing the geometry of the gates has an effect on the yield and the molds/hr if the pouring time changes. Changing the geometry of the gates also effects how much material must be removed in the finishing room which is a function of the grinding/hr calculation. For this example it was assumed that the smallest gate area would result in 120 castings being ground per hour and 100 castings being ground if the largest gate area was used. This is how the linear equation  $123.2 - 8.1 * (\text{Gate Area})$  was derived for the grinding/hr value and how the gate area becomes a function of the grinding room costs.

## Example 1 - Analyzing the Casting Price for Every Simulated Gating System

Once the variables filling time, mold weight, and gate area become a function of the casting price an expression can be created in the software that calculates the casting cost as these variables change. This casting cost objective can then be calculated and plotted against any simulation objective or variable. If the total surface area is plotted against the casting cost as in figure 9, selecting the best gating design can become a matter of selecting the design with the lowest casting cost.

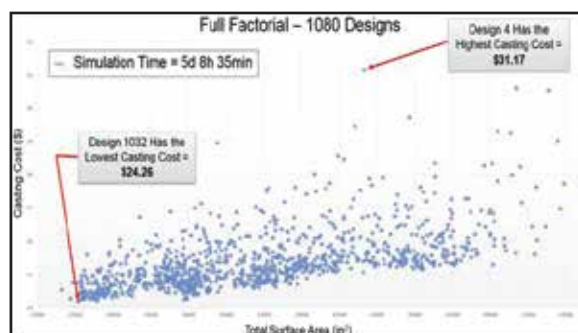


Fig. 9. Total Surface Area vs. Casting Cost

Changes in the gating system geometry had a significant impact on the total surface area and the casting cost. This particular example shows a trend where the total surface area gets smaller as the casting cost gets lower. This is not always the case and was an

interesting and unexpected result. In order to gain more insight into what is truly influencing the casting cost, the grind/hr, yield, and molds/hr values for every design were plotted on a “Parallel Coordinates” graph. As seen in figure 10, each design is represented by a line and the color scale is assigned to the casting cost to help determine which of the three variables had the biggest impact on the casting cost.

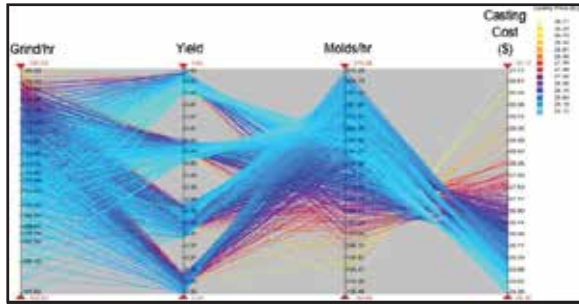


Fig. 10. Parallel Coordinates Graph

Figure 10 is a very busy graph when all 1080 designs are plotted and it is hard to draw any conclusions from, but if the majority of “expensive” designs are filtered out from this graph, some trends become clear as seen in figure 11.

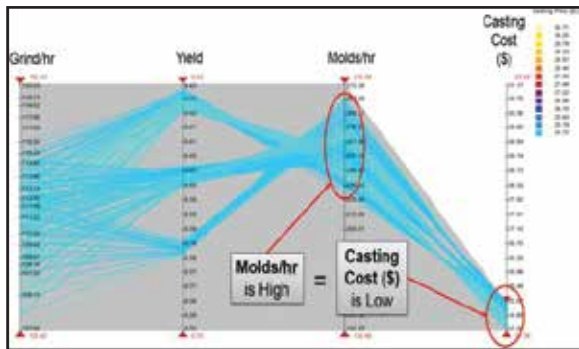


Fig. 11. Filtered Parallel Coordinates Graph

When the filling time is low the molds/hr value is high and the casting cost is low. The molds/hr is not the only variable driving down the casting cost, a higher yield and a higher grind/hr value also help drive down the casting cost. It is worth pointing out that the designs with the highest molds/hr values did not give the lowest casting cost. Therefore, all three variables must be considered when looking at lowering the casting cost. The relationship between grind/hr and molds/hr is illustrated in Figure

12 where the two variables are plotted against each other.

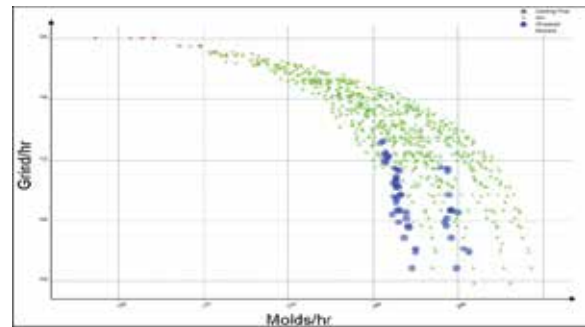


Fig. 12. Molds/hr vs. Grind/hr

In figure 12 the green color represents a lower casting cost and red represents a higher casting cost with the 45 cheapest designs highlighted in blue. Increasing the surface area of the gates lowers the grind/hr value, but increases the molds/hr value which is a result of a decrease in the filling time. Increasing the gate area has a two-fold affect where the finishing room costs increase, but the molding costs decrease because the molds/hr number increases. The images in figure 13 show the gating geometries for the cheapest design and the most expensive design.



Fig. 13. Lowest Casting Cost & Highest Casting Cost

The cheapest gating design uses the smallest down sprue and runner which increases the yield and the largest gates which increases the molds/hr. The most expensive gating design uses the largest down sprue and largest runner which decreases the yield and the smallest gates which decreases the molds/hr. With such small gates this is a highly pressurized gating system that results in very high velocities at the gates and leads to a “Bad” filling and possibly mold erosion at



the gates. Since all of the possible gating geometries were simulated, any filling result written by the software can be loaded and used to further analyze the filling. The velocity result for both of these designs is shown in figure 14.

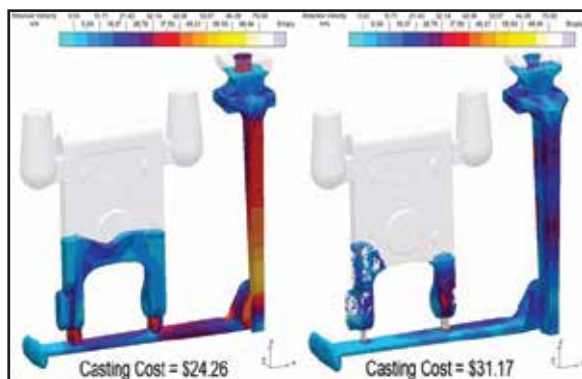


Fig. 14. Velocity of the Lowest Casting Cost & Highest Casting Cost

With such a large difference in casting cost knowing this value is very important and can be compared to different quality related results in order to select an optimum design. Simulating every possible design enables the foundry engineer to scrutinize every gating system if need be, but 128.6 hours was needed for the computer to run all 1080 designs and approximately 30 minutes to set up.

## Example 1 – Autonomous Optimization

With a design space of 1080 possible designs, using autonomous optimization with the objective set to minimize the casting cost can save a significant amount of simulation time. In this example, the software's genetic algorithm automatically assesses what combination of geometric variables will minimize the casting cost objective after a "generation" of simulations is run.

This same simulation was rerun, but an initial start sequence of 16 designs was created for the first generation using a Sobol algorithm. Once the first generation of simulations finished, the genetic algorithm then selected another 16 designs from the reduced design space and this process repeated for another 2 generations. A total of 4 generations was run

with the casting cost set as the objective to be minimized. This gives a total of 64 designs that could be simulated, or about 6% of the total design space. If a design has been selected that has already been run, this design is not run and recorded as a duplicate design. After each generation the design space becomes smaller and smaller which increases the possibility of duplicate designs. For this particular autonomous optimization example there were 64 possible designs, but only 48 designs were actually simulated because 16 designs were duplicate designs that were never simulated. This resulted in reducing the simulation time from 128.6 hours to 6.3 hours. Figure 15 is a graph of total surface area vs casting cost for this autonomous optimization simulation.

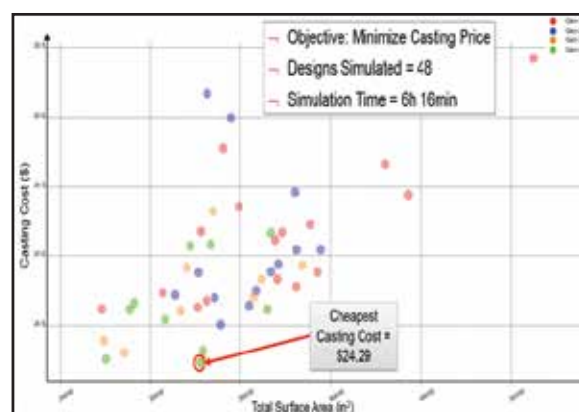


Fig. 15. Total Surface Area vs. Casting Cost - Autonomous Optimization

Each generation was given a different color to show the progression towards minimizing the casting cost. The cheapest casting cost was found in generation 4 with a cost of \$24.29 and this design is highlighted in figure 16 on the full factorial graph.

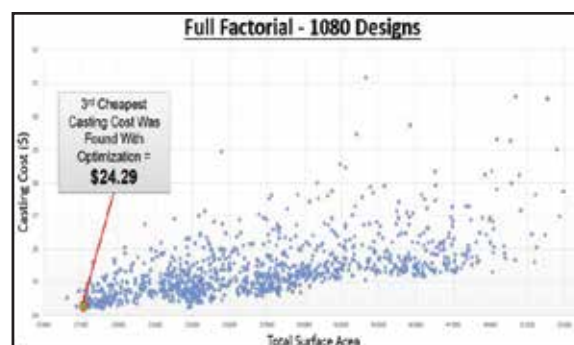


Fig. 16. Total Surface Area vs. Casting Cost – Full Factorial

At \$24.29, this design has the third cheapest cost when compared to the cheapest cost of \$24.26 found by running the full factorial. When using autonomous optimization, more generations could have been used to find the cheapest design, but 6.3 hours to find the 3rd cheapest design out of 1080 designs would be a great compromise in most situations. This example shows a very strong trend where reducing the casting cost reduces the total surface area thus improving the quality of the casting. This is not always the case when comparing casting costs with quality related objectives. The next example uses casting cost as an objective and compares it to the level of shrinkage in the casting.

## Conclusion

Using autonomous optimization is a quick way to minimize things like pouring time, contact area, the weight of the gating system, surface area during filling, or shrinkage porosity. If all of the relevant production costs are known, the casting cost for any gating design can be calculated for any and every simulated design and used as an objective that is minimized. This approach enables a foundry engineer to design a gating system that will maximize the profits for the foundry. When something like shrinkage porosity is analyzed in conjunction with the casting cost, the cost of reducing the shrinkage porosity can be quantified and discussed between casting buyers and foundries.

## References

[1] Robert C. Creese, M. Adithan, B.S. Pabla, "Estimating and Costing for the Metal Manufacturing Industries", CRC Press, 1992

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**Mr. Abdul Rashid** - Secretary  
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# Nodular Graphite Iron production without Magnesium Treatment

Anjan Prodhon

CSIR–National Metallurgical Laboratory, Jamshedpur 831 007, Jharkhand, India.

## Abstract

This study reports (a) the effect of Electric Current Treatment (ECT) on degassing of molten iron and (b) how ECT treatment forms nodular graphite iron during freezing in a sand mould. It is observed that ECT modifies the shape of flake to nodular graphite due to removal of dissolved gases (esp nitrogen) from molten iron. ECT changes cast microstructure from pearlitic to ferrite-pearlitic. It means, that the ECT changes equilibrium diagram of Fe - Fe-Carbide.

**Keywords:** *Electric current treatment, Ductile iron, Degassing of iron, Magnesium treatment*

## Introduction

Cast irons, mainly used as construction material, are still maintaining the standard of usability. They provide a wide range of usable properties and also require less expensive metallurgy. Ductile or spheroidal graphite (SG) / nodular graphite cast iron was discovered in 1943 by Keith Millis. While, most varieties of cast iron are low tensile strength and brittle. Ductile iron has much more impact and fatigue resistance, due to its nodular shaped graphite.

Ductile iron is used in the form of ductile iron pipe for water and sewer lines. It is also used in many automotive components; where strength must surpass that of aluminium but

do not necessarily require steel. Other major industrial applications include diesel trucks, agricultural tractors, and oil well pumps. In wind power industry nodular cast iron is used for hubs and structural parts like machine frames. Nodular cast iron is suitable for large and complex shapes and high (fatigue) loads.

## Literatures:

According to Goodrich(1), nitrogen (N) level in gray cast iron normally has equilibrium of 70 ppm. When the dissolved N increases to 150 ppm, fat flake graphite is produced. Nitrogen is generally controlled by Ti. At high N content, if Ti is present, the graphite structure will be normal flake graphite.

Ten(2) established that oxygen (O) influences on the structure and properties of cast iron. Oxygen, initially present in molten iron in chemically combined state (as non-metallic inclusion), does not have a significant effect on the cast iron crystallisation. It acts as a graphite crystallisation substrate and also increases the graphitisation degree of the cast iron. Dissolved O deactivates the potential graphitisation centres that increases chilling tendency of cast iron. At the same time, the more cast iron is saturated by O, the higher its tendency for graphite modification.

Yamamoto et al(3) conducted extensive trials to verify the hypothesis of the formation of nodular graphite inside gas bubbles to

establish it as a gas bubble theory of nodularisation of graphite. It was found that graphite nodules can be obtained by four methods:

- (a) addition of deleterious elements such as S, Se, Te, Pb, and Bi
- (b) addition of Ce, La, Y, Ti, and Zr which have absorbed a large amount of hydrogen
- (c) direct injection of gases into the melts
- (d) precipitation of nitrogen from super-saturated molten cast iron.

The formation of gas cavities and hollow graphite nodules was observed and attributed to the dearth of graphite in bubbles or to its absence. Some characteristics of graphite nodules could be best explained by the proposed gas-bubble theory.

Vondrak et al<sup>(4)</sup> reported variation of dissolved gas content in molten cast iron in different melting conditions has been given in the Table 1 below:

Table 1: Approximate content of gases in molten cast iron

Melting aggregate	material	oxygen ppm	hydrogen ppm	nitrogen ppm
cold-blast cupola	Blackheat CITG	64 – 104	1.0 – 1.1	101 – 103
cold-blast cupola	CILG for automobiles	14 – 26		
cold-blast cupola	CILG	42 – 86		
hot-blast cupola	Whiteheat CITG	23 – 52	1.0 – 2.0	111 – 114
hot-blast cupola	Coquille – centrifugal casting	5 – 7	0.8 – 0.9	11 – 17
Cupola lined with acidic material	CILG for automobiles	10 – 14		
Cupola lined with fireclay	CILG for automobiles	5 – 6	1.0 – 1.3	58 – 63
duplex – electric furnace	Blackheat CITO	14	0.9	100
duplex – electric furnace	CITG	35 – 43	1.8 – 2.0	80 – 94
Induction furnace	Alloyed CILG	120	5.2 – 6.6	110
Induction furnace	CILG	10 – 34		
Electric arc furnace	Austemite cast irons	4	0.9	1700 – 1800
Electric arc furnace	CILG	29 – 63		
Electric arc furnace	CISG	9 – 64		
Blast furnace	PI	5 – 15	1.1 – 2.7	18 – 105
Drum rotary furnace	CILG	133 – 148		

CILG – cast iron with lamellar graphite

CISG – cast iron with spheroidal graphite

CITG – cast iron with tempered graphite

PI – pig-iron

Prodhan<sup>(5)</sup> has established that the dissolved gases in molten metal / alloys can be removed by electric current treatment (ECT).

## Experimental:

This report consisted of two parts: (a) degassing of iron melt by ECT and thus (b) formation of graphite nodule by ECT treatment of molten iron in sand mould.

### Part – I: Electric Degassing of Molten steel

In this study, mild steel scrap was taken as charge material. It was melted in an air induction furnace. Iron ore was added in the melt to increase its oxygen content in heats 2 & 3. Castings were made in the shape of block (150 X 150 X 125 mm). ECT was conducted during freezing in a sand mould in samples 3 & 5 till the melt is in liquid state. Therefore, the treatment time is very less to complete the degassing process. The experimental details are given in Table 2.

Table 2: Electric degassing of molten iron – experimental details

Sample No	Material	Weight, kg	Addition, kg	Treatment	Duration	Energy
1	Mild steel scrap	—	—	—	—	—
2	Do	21.5	Iron ore: 3.5	Nil	Nil	Nil
3	Do	21.5	Iron ore: 3.5	Electric current	~ 45 sec	~ 1.5 Wh
4	Do	Nil	Nil	Nil	Nil	Nil
5	Do	25.0	Nil	Electric current	~ 100 sec	~ 4.0 Wh

### Part – II: Nodular graphite formation by ECT during sand casting

In the first set of trials, cast iron scrap (~ 5 kg) was melted and superheated to 1300o C in an air induction furnace. Proportionate amount of ferro-silicon and broken graphite pieces were added to compensate melting losses. Test castings (40 X 40 X 150 mm) were made in sodium-silicate & CO<sub>2</sub> bonded sand moulds with and without ECT. Sections were cut from the cast samples for micro-structural studies.

In the second set of trials, cupola melt at ~1280o C was used. Samples were cast in the form of rod (40 mm dia X 300 mm long) made in sand moulds. Castings were made with and without ECT. Metallographic samples were prepared and etched with Nital to reveal the microstructure.



## Results

### Part – I: Electric Degassing of Molten Steel

Fig 1 shows the variation of nitrogen in solid castings (a) treated with / without ECT and (b) with / without iron ore addition (to increase oxygen in the melt). The as received mild steel scrap (sample 1) contains nitrogen 55 – 90 ppm. But, during induction furnace melting (with iron ore), it increases to 135 – 165 ppm (sample 2). The ECT (sample 3) reduces the nitrogen level to 60 – 65 ppm. Sample 4, (without iron oxide), contains ~ 75 ppm nitrogen, but, the ECT (sample 5) reduces nitrogen to 45 ppm.

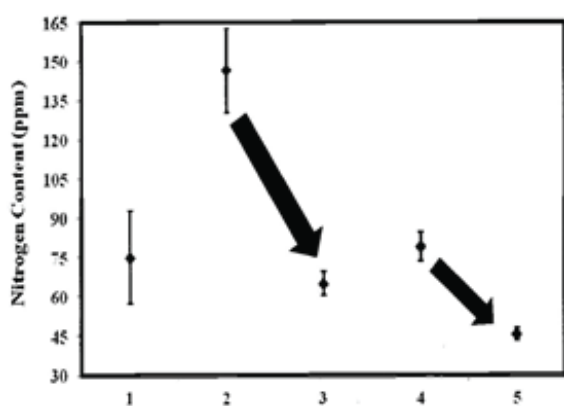


Fig 1: Removal of Nitrogen by Electric Degassing

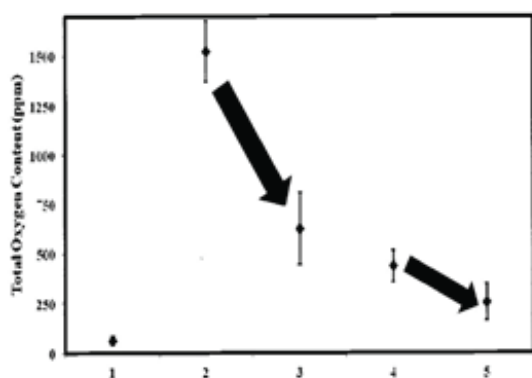


Fig 2: Removal of Oxygen by Electric Degassing

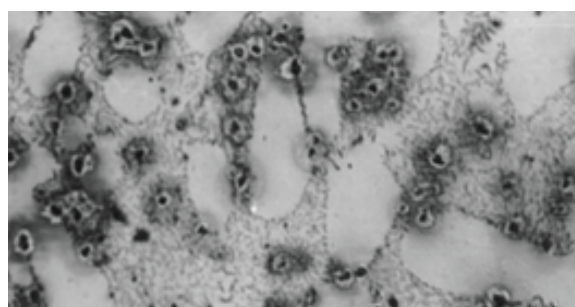
Fig. 2 shows variation of oxygen in solid castings (a) treated with / without ECT and (b) with / without addition of iron ore in melt. The as received mild steel scrap (sample 1) contains negligible amount of oxygen. But, induction furnace melting with iron ore, it

increases more than 1500 ppm (sample 2). The ECT (sample 3) reduces the oxygen level to around 600 ppm. Sample 4 (without iron ore) shows the oxygen content in solid steel casting is ~ 500 ppm. However, ECT reduces oxygen level to ~ 250 ppm (sample 5).

### Part – II: Nodular iron formation by electric current treatment on molten iron



(a) Without treatment



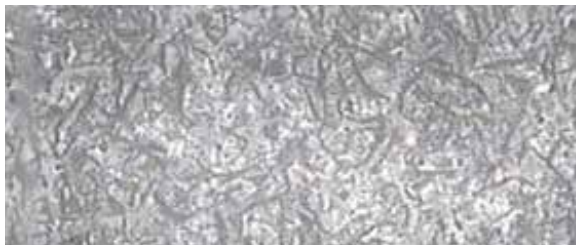
(b) With electric current treatment (ECT)  
Magnification: 100X (Unetched)

### Figure 3: Effect of ECT on flake to nodular graphite formation in cast iron.

Figure 3 shows the effect of ECT on nodular graphite formation in castings made from induction furnace melt. The untreated sample (Fig. 3a) shows graphite flakes but ECT (Fig. 3b) favours nodular graphite formation.

Figure 4 shows the effect of ECT on cupola melt in etched condition. The untreated sample (Fig. 4a) contains flake graphite in pearlitic matrix. However, the ECT treatment (Fig. 4b) modifies (i) flake graphite to nodular graphite and (ii) pearlitic matrix to ferrite-pearlitic matrix.

Figure 4: Modification of matrix phase with ECT



(a) Without treatment



(b) With electric current treatment(ECT)

## Discussion:

The above result indicates that the ECT when applied into molten iron / steel removes dissolved gases like N (Fig. 1) and O (Fig. 2) in melt. The author(5) reported this phenomenon to remove dissolved hydrogen (H) from molten aluminium. In another study at RAPSRI Industry, Bangalore, the ECT process has been successfully implemented to remove dissolved O from molten copper to make oxygen free high conductivity (OFHC) copper. The ECT process eliminates N-purging to remove dissolved O in melt. Normally, degassing by ECT (5) takes 5 - 6 min time. However, in degassing of steel by ECT is quite less 45 - 100 sec (Table 2), so, this process is incomplete. So, it is recommended to make ECT degassing on steel / iron in a higher volume molten bath (to retain the melt in liquid) to complete degassing. ECT degassing is cheaper than N-degassing process and pollution free also.

It is evident from the literatures (1-3) that the dissolved gases like N and O play a pivotal role in formation of flake or nodular iron. Vondrak et al(4) has given the details of dissolved gases present in molten cast iron (Table 1). The author feels that the ECT process removes the dissolved nitrogen and oxygen gases significantly, however, due to shortage of time of treatment, the degassing process is incomplete. Magnesium, when plunged into cast iron melt, produces high vapour pressure and flushes out dissolved N and reacts with O. The rare earth elements form their oxides / oxy-nitrides and reduce activity of N & O in molten iron. The graphite nucleates on oxide or oxy-nitride substrate to form globular graphite. In ECT, the surface active gaseous elements (N & O)

is been removed from molten iron. The graphite (having sublimation point >3000°C) separated from melt and form nodules due lowest surface area / volume ratio (Fig 3b). Fig 3b also shows that the bright phase (ferrite) and the dull phase containing under cooled graphite phase probably converted eutectic phase. The etched samples from Cupola melt (Fig. 4a), shows the untreated sample contains 100% pearlite along with flake graphite. However, ECT sample (Fig 4b) shows that flake graphite has been changed to nodule and the volume fraction of pearlite has been reduced to 60%. This is evident during chilling of samples. This phenomena has been observed by the author in his study with Cu-Sn alloy <sup>(6)</sup>.

## Conclusions:

This study reveals that flake graphite in cast iron can be converted to nodular iron by electric current treatment during sand casting. This study was conducted both in laboratory (induction furnace melt), as well as in a foundry (cupola furnace melt). This process does not require any magnesium treatment. It is a low cost and pollution-free process. Post inoculation is not required for this process.

## Acknowledgement:

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# Pakistan Aerospace Council Hosts CERN Team

Explores Pakistan Hi-Tech Manufacture Sector For Sourcing From Pakistan  
Islamabad June 15, 2019.

Pakistan Aerospace Council (PAeC) in collaboration with National Centre of Physics (NCP) hosted a four member, senior team from European Organization for Nuclear Research (CERN) including their head of procurement Dr. Anders Unnervik, in Pakistan.



Mr. Imtiaz Rastgar, Founder of Pakistan Aerospace Council, visited CERN in October 2018 to present to them possibilities of sourcing from Pakistan's High Tech Cluster. As a result, a four member senior team from CERN visited Pakistan to interact with private high tech manufacturing industry. More than 25 high tech manufacturing companies from Pakistan Aerospace Council cluster attended the event, organized at National Centre for Physics. and gave presentations about their companies, products, skills and expertise. Some companies displayed their products in stalls which were highly appreciated by CERN and other industrialists.

Dr. Andres Unnervik, Director Procurement at CERN gave a talk on, "Doing Business with CERN". In which he explained the whole process of procurement at CERN. He explained the future projects of CERN and the resources they require. He also explained the process of assigning projects to companies. Subsequently Dr. Francisco Sanchez Galan gave presentation on the upcoming High Luminous-Large Hadron Collider (HL-LHC). He explained the timeline of the project and equipment being used there and what products and services will be required in future. He also answered the queries from the audience about CERN procurement process.

Dr. Haroon Javed Qureshi, President Pakistan Aerospace Council summed up the presentations of the Pakistani Private sector Industry with his talk, highlighting Pakistan's young, intelligent and innovative engineering

workforce, supported by the number of excellent engineering universities, giving Pakistan the potential of becoming a leading knowledge based engineering, industrial hub, exporting high tech assemblies worldwide. Exporting Pakistani products to CERN is a unique opportunity, also for Pakistani high tech sector



to participate in a prestigious project like CERN and work together with the worlds leading scientist and engineers on the exciting possibilities emanating from CERN. Companies which start to make supplies can also use CERN logo, a great status for engineering companies. CERN Team also spent two packed days at Lahore where they visited QadBros Engineering on May 23, 2019, to review processes leading upto successful deliveries from that company. In Lahore the team also visited Pakistan Electron Ltd (PEL) which produces power transformers and high tension equipment. AE Design, next on the list, uses modern design tools for serving their, mainly, European Customers. They also manufacture light engineering products for their European customers under the name BECO. Last visit of the day was to EMCO, who manufacture EHT insulators. The CERN team was impressed about quality as well as international standard production by all these companies and showed keen interest for future procurement possibilities in CERN projects. Pakistan Aerospace Council (PAeC) is a platform of Pakistan's high-tech manufacturing industry, providing networking and business growth possibilities to its members as well a window for customers and government bodies to discuss policy and technology issues. . For more information please visit our website [www.pakaero.com.pk](http://www.pakaero.com.pk) .



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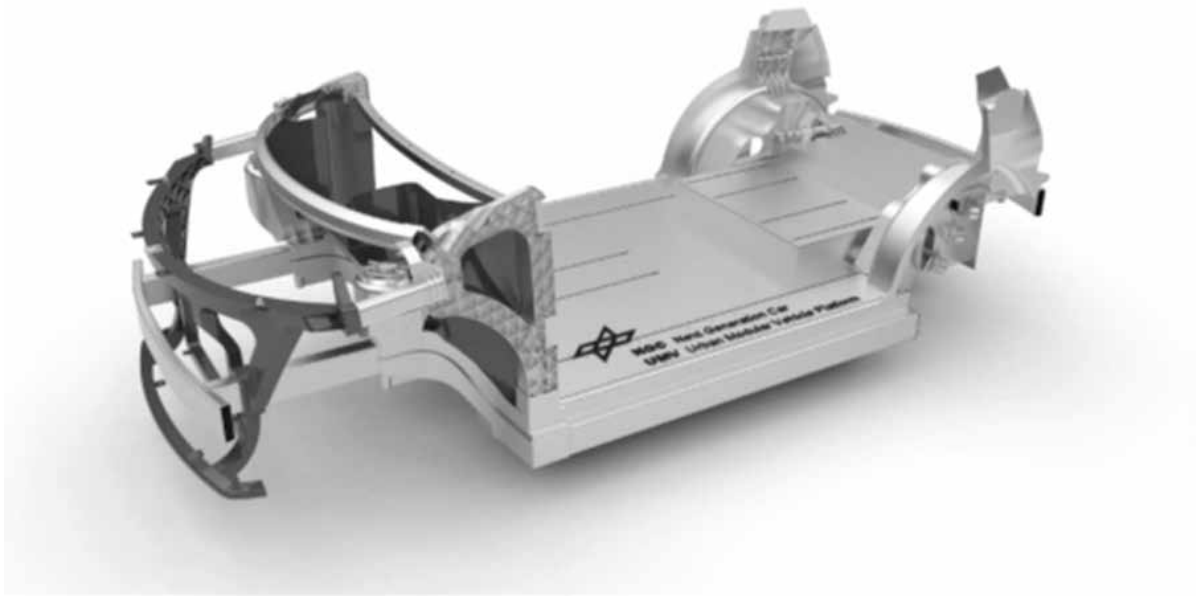
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# Future of Lightweight automotive construction Prospects for casting

The DLR Institute for Vehicle-Concepts has been researching for many years for innovative casting designs and provides an insight into future casting applications in lightweight automotive construction.

BY ELMAR Beeh, STUTTGART

Castings offer a variety of ways to contribute to the mass reduction of vehicles. The electrification of the powertrain and the concentrated market growth, especially in China, lead to the question, which prospects arise here for the foundry.

## Global trends and challenges

Germany is still one of the leading exporter in the automotive sector. But the future trends in this troubled time are set by other regions of the world. For example, in Shenzhen, China, a city of 12.5 million inhabitants, now more than 16,000 electric buses, produced in China, are moving on roads. However, unlike

in the Western world, the government in China intervenes much more in development trends, particularly in the product portfolio of the car manufacturers.

In Germany, the economy is still buzzing - and that may be more dangerous than some people think. Studies are predicting that today's global auto market will see continued growth of approximately 90 million vehicles to approximately 110 million vehicles per year in 2025. The combustion engine market, which is important for the foundry industry, will at least be maintained despite electric mobility [2]. In the area of internal combustion engines, however, it is probable

that there will be fewer new developments and investments in this area due to the diesel scandal, but above all due to hybridization and electrification. Reduced innovation pressure makes it easier to implement shifts in the supply chains for standard technologies for customers, so that market shares can be lost, despite the good overall economic situation.

What role does lightweight construction play in the automotive future - and what did that mean for the use of cast parts? Lightweight construction is important today because cost-effective lightweight construction will continue to become important in the future. Only then the mass of heavy hybrid and electric vehicles can be kept within reasonable limits. And of course, the mass of a vehicle plays an important role when it comes to energy consumption. Castings can make important contributions here in the vehicle structure and in the chassis. In this context, structural cast iron has great growth potential. In addition to mass reduction, there are often good opportunities for functional integration and improvements in structural rigidity. Solutions from the premium segment are increasingly being used in the larger mid-range series. This can benefit in particular pressure pourers. The prospects are therefore good - it is now important to set the course so that we can continue to benefit from this development in the future.

## Prospects for the casting, in particular die-casting

The DLR Institute for Vehicle-Concepts works on concepts and technologies for innovative aluminum and magnesium castings as well as on process combinations of casting with additive manufacturing and has therefore intensively dealt with the potential of casting solutions in vehicle structures. Three areas were identified in which future prospects in the field of light automotive construction are seen for die-casting:

> Structure cast components

> Increase component complexity

> Electrification in the automotive industry:

## Structural cast components

Of course, in today's conventionally powered vehicles, most cast components are in the powertrain. However, a relatively limited field of application for cast components is still in the vehicle structure. Here it is possible to replace conventional assemblies that consist of several deformed and joined sheets by a larger, complex cast component. Castings for the vehicle structure were usually used in the premium vehicle segment until a few years ago - pioneered by Audi with its cast-intensive aluminum space frame. Meanwhile, aluminum die casting solutions for the strut dome are also in use for medium to large number of items such as in the current Mercedes-Benz C-Class, and other large castings, especially in the transition from the sill and rear side member, in turn spread over the Premium segment. Back in 2006, the DLR Institute for Vehicle-Concepts developed an A-pillar casting node, which demonstrated the great potential of intelligent and targeted functional integration. By integrating the upper suspension strut section into an A-pillar structure in the load-bearing manner, it was possible to create a component that reduces the mass by more than 40% compared to the steel reference structure at almost the same price per part [3] more than 4 kg per part and 8 kg per vehicle

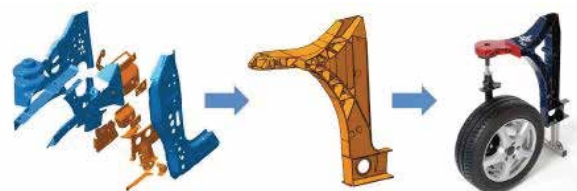


Fig. 1

The relevance of structural castings is recognized by the die casting industry and technically one is able to manufacture excellently designed and high quality components. However, the attractiveness of this growing application segment is also



arousing the interest of new competitors who, especially in China, are ready to enter the market with large investments. In the area of structural casting, the established die-casting suppliers have gone through a learning curve with regard to component design, integration of the parts in the structure (joining technology, corrosion protection), repair concepts and much more in cooperation with the automotive industry. Wherever it is only about the supply of such parts and not about specific unique selling points, now, however, increased cost pressure must be expected. Here, it is important to consistently tap and exploit savings potential.

The optimization of the casting costs starts with the selection of the components to be integrated. Therefore, it is important to look at the cost structure of reference assemblies in sheet metal design to pursue the right integration strategy. Depending on the prioritization, structurally optimized components and best mechanical properties will often look different from a cost-optimized component. An interesting way to optimize the cost of structural cast components via the manufacturing process chain, is the use of new natural die-cast aluminum alloys, which have good strength values and high ductility in cast condition 'F'. Particularly in the case of the large components in the structural castings, the costs for heat treatment, for straightening the components and for the associated logistics are not to be underestimated. Therefore, it can be expected that use of such alloys brings economic benefits in many applications. The DLR Institute for Vehicle-Concepts has investigated such alloys in cooperation with a supplier with regard to crash behavior and the suitability for different mechanical joining methods [3] and, due to the interesting combination of several positive properties, such as comparatively high fatigue strength coupled with a very good ductility and good joining suitability brings high potential for different applications such as the strut dome. components via the manufacturing process chain, is the use of new natural die-cast aluminum alloys, which have good strength values and high ductility in cast condition 'F'.

Particularly in the case of the large components in the structural castings, the costs for heat treatment, for straightening the components and for the associated logistics are not to be underestimated. Therefore, it can be expected that use of such alloys brings economic benefits in many applications. The DLR Institute for Vehicle-Concepts has investigated such alloys in cooperation with a supplier with regard to crash behavior and the suitability for different mechanical joining methods [3] and, due to the interesting combination of several positive properties, such as comparatively high fatigue strength coupled with a very good ductility and good joining suitability brings high potential for different applications such as the strut dome.

## Increase in component complexity

In addition to a focus on cost savings potential in the cast components already in use, it is important to set technological limits, especially at a time of high workload and utilization, e.g. by increasing component complexity, to expand steadily and to address future enabler technologies in their own research and development. Interesting topics here include, for example, the different technology routes for the production of channels and cavities in die-cast parts. In addition to the work on salt core depositors, there is also the possibility of producing ducts by means of the blow-out process (Fig. 2).

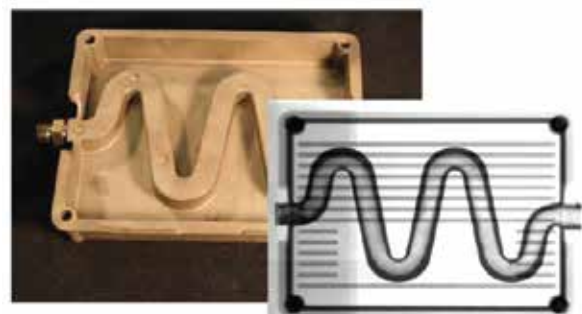


Fig. 2

Here, the Aalen University of Applied Sciences has succeeded in demonstrating that blow-out processes, as already used in the field of plastics, can also be used in the metallic die-casting process [4]. However, the technical challenges are great due to the very rapid solidification of the melt. However,

mastering such litigation has the potential to provide relevant technical and economic benefits in many applications.

Lightweight construction solutions in automobiles tend to lead to a more intensive mix of materials and thus to challenges in the field of joining technology and corrosion protection. In order to facilitate integration of aluminum and magnesium castings in vehicle structures, cast-in inserts that provide compatibility with the environmental structure would be of great benefit. Pressure cast parts with, for example, cast-in steel mounting flanges could thus be integrated directly into the established spot welding systems in steel structures. In this case, the casting may already be suitably protected against corrosion. Wherever such solutions are out of the question, it is important to understand the potentials and limitations of possible joining techniques, e.g. the punch rivets or flow forming screws, to know and to address in the construction.

## Electrification in the automotive industry

The electrification of the powertrain leads to significant changes in the parts spectrum of a vehicle. When components of the internal



Fig. 3

combustion engine will be eliminated, then sometimes other complex components are needed. New highly integrated cast components, for example, the housing for electric motor, gearbox and differential have integrated combined water cooling. connection points, lower positional tolerances) and reducing the risk of corrosion in the battery box can be addressed. For stiff

battery box covers, castings with well-sealable flange areas can also be used as advantage, as shown, for example, by Daimler on the battery module of the new EQ models (Fig. 3).

## Recognize and use potential

In addition to the fields of application mentioned, in which potentials can be tapped by technological capabilities and unique selling points, it is important from the point of view of the DLR Institute of Vehicle-Concepts to address the manifold possibilities of digitization in the production process chain of castings, e.g. through intelligent combinations of casting processes and additive manufacturing or the better use of data for process control, to recognize and make the best possible use of it. This can increase the efficiency of the processes, improve quality and reduce costs. This, in combination with a global delivery capability that is important for many vehicle manufacturers, is an important component for competitiveness in the global market environment.

## Conclusions

Even in times of technological change, castings have considerable potential for use in future vehicles. At the same time, it is becoming increasingly important to have technological capabilities and unique selling points in global competition that give the vehicle manufacturer the decisive advantage in the respective field of application. The DLR Institute for Vehicle-Concepts not only supports its customers in the research and development of innovative casting designs, but also offers a platform for recognizing technological requirements and trends in new vehicle concepts with its specialist conference "MaterialPlus Auto" in Stuttgart.

*Dr.-Ing. Elmar Beeh, DLR Institute for Vehicle Concepts, Department Head of Materials and Processes Application zeug, Pfaffenwaldring 38-40, 70569 Stuttgart, Tel.: 0711-6862-8311, E-Mail: [elmar.beeh@dlr.de](mailto:elmar.beeh@dlr.de)*





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