ALUMINIUM GDC TECH
GREAT DIE CASTING

GREAT DIE CASTING TECHNOLOGY FORUM

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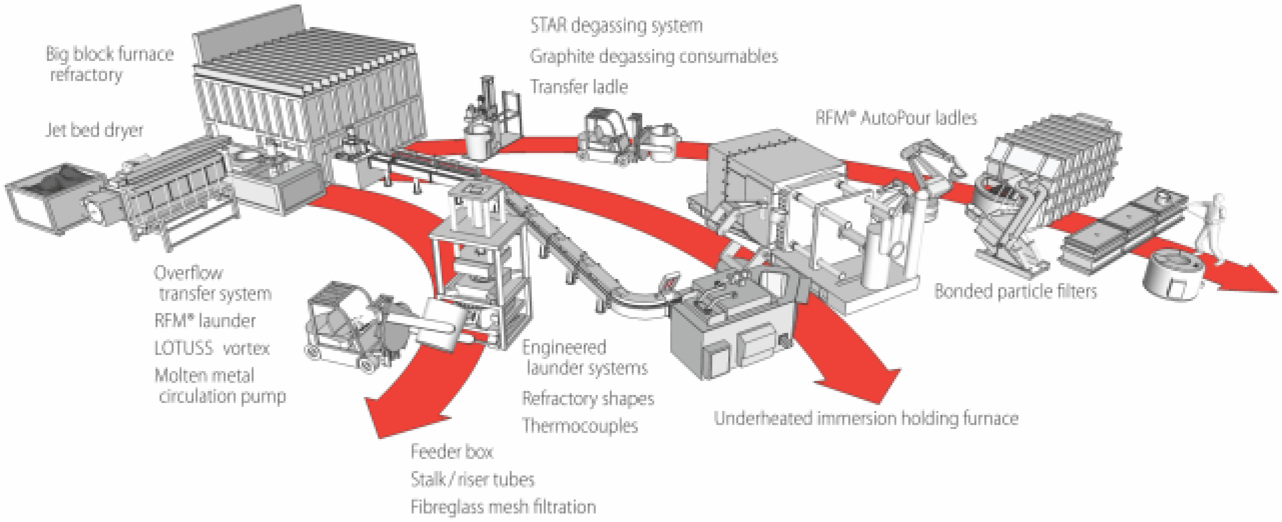

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Volume 49 - December 2021

ALUMINIUM GDC TECH
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SMARTT – An innovative process control for rotary degassing of aluminium alloys

Introduction

The production of aluminium castings globally is dominated by the automotive industry and the growing importance of emissions and fuel economy has resulted in a rapid increase in the use of aluminium castings. For these demanding applications many of the attributes in terms of mechanical strength, elongation and fatigue strength can no longer be satisfied by standard alloys and so new alloys with greater potential have been, and will continue to be, developed. To exploit the potential of these alloys completely then pore-free castings of high cleanliness and fine structure must be produced. Safety critical castings now require elongation in excess of 10 % from the casting itself and this is moving close to the limit for the alloy. The 'window' for melt properties to fulfill these requirements becomes smaller and smaller whilst the starting conditions such as ingot quality, melting and holding furnace condition, temperature control and melt transfer can become limiting factors. To ensure that the correct casting quality is achieved then a more effective and technically sound melt treatment is essential followed by a well-designed and controlled pouring practice.

Another important attribute required by the automotive industry is reproducibility and so any melt treatment adopted must be capable of achieving consistent levels of cleanliness and hydrogen control. Many quality management systems also require a 100 % record of production data so again a sophisticated melt treatment system with data storage becomes more attractive to the automotive industry.

An innovative process which can automatically achieve the same melt quality regardless of the external environmental conditions will be the key to the future production of truly high quality castings meeting the needs of this growing market segment.

Degassing simulation

Foseco's non-ferrous Marketing and Technology team have worked with tsc - Technology Strategy Consultants to develop a web-based batch degassing model. It has been designed as a tool to analyse quickly foundries' operations, and make suggestions for their improvement.

The mathematical model behind this software is based on the best available published information concerning the kinetics of hydrogen degassing (e.g. hydrogen solubility, diffusivity, mass transfer rates and stable bubble sizes). An extensive trial program was undertaken to provide specific information about individual rotors under different conditions.

To characterise different rotors the following trials were carried out:

- Power analysis of degasser rotors
- Mixing capabilities of degasser rotors
- Gas solubility tests in water
- Foundry trials in aluminium melts

A full description of the development work is given in Foundry Practice 256 (2011).

Parameters influencing degassing results

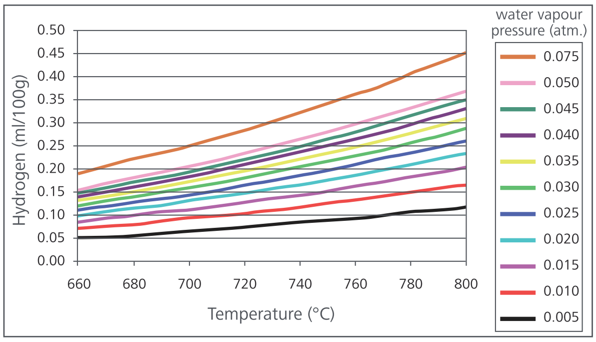
Three main groups of variables influence the degassing efficiency: ambient conditions, rotary degasser parameters, and melt properties. The hydrogen concentration in the melt has been calculated using the Degassing Simulation for the following widely common set of parameters (Table 1); and variations of the parameters illustrate the influence on the degassing result and the final hydrogen content in the melt after treatment.

ATL 1000 with 850 kg melt	XSR 220 rotor
AlSi7Mg	420 rpm
750 °C melt temperature	20 l/min inert gas
50 % relative humidity	0.30 ml H_2 / 100 g Al starting level
25 °C outside temperature	

Table 1. Model simulation parameters

1. Ambient conditions

The melt forms an equilibrium with the water in the surrounding atmosphere; a warm and humid climate gives much higher hydrogen content in the melt than a dry and cold climate (picture 1).



Picture 1. Influence of ambient conditions on hydrogen equilibrium (0.005 atm = 5 °C / 50 % rH; 0.050 atm = 35 °C / 90 % rH)

During rotary degassing the melt is in interaction with the atmosphere and picks up hydrogen again. The degassing simulation shows the effect of different ambient conditions (diagram 1):

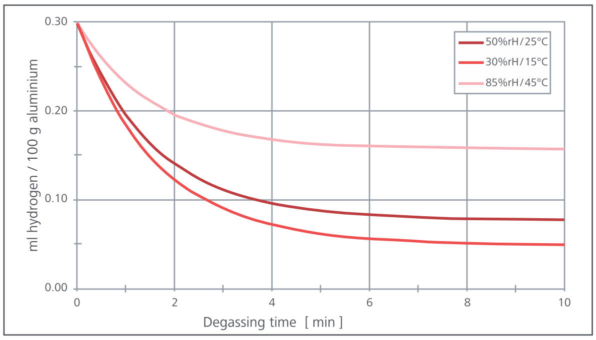


Diagram 1. Degassing curves for different ambient conditions

2. Rotary degasser parameters

The rotary degasser can run a treatment with different rotation speed and inert gas flow rates. Each rotor design has minimum and maximum values for those parameters – working conditions – for rotor speed and inert gas flow rate. It is important that both parameters are within the limits; running a treatment at very high rotation speed and extensive flow rates would create too much turbulences or in extreme cases an aeration of the rotor with a complete loss of degassing performance.

The diagrams 2 and 3 show degassing behaviour for typical parameters of an XSR 220 rotor under varying conditions:

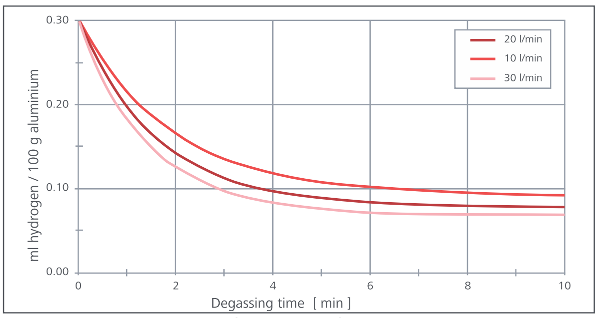


Diagram 2. Degassing curve for inert gas flow variations

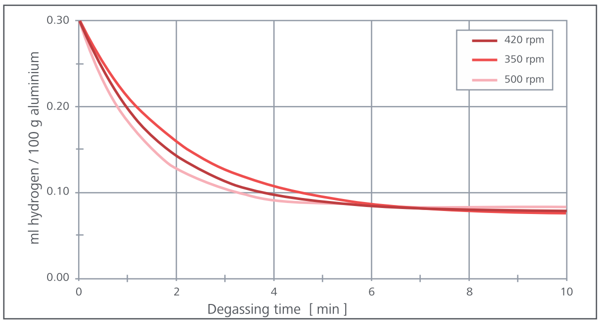


Diagram 3. Degassing curves for rotor speed variations

3. Melt properties before treatment

The alloys composition has a huge influence on the degassing performance. Elements like Magnesium increase hydrogen solubility whilst Silicon or Copper slightly decrease it (diagram 4). The melt temperature influences the equilibrium with the atmosphere; melt at higher temperature dissolves more hydrogen (diagram 5).

The starting hydrogen level is often unknown, but the diagram shows that variations in the initial hydrogen does not change the final result (diagram 6).

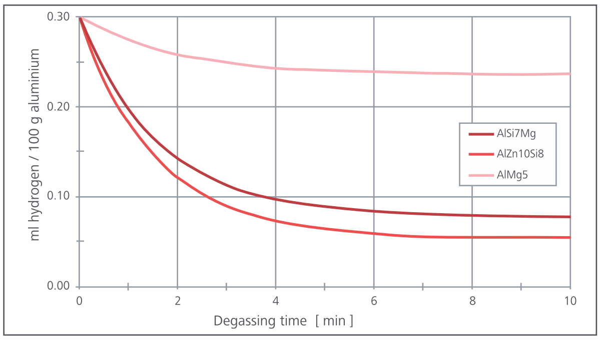


Diagram 4. Degassing curves for different alloys

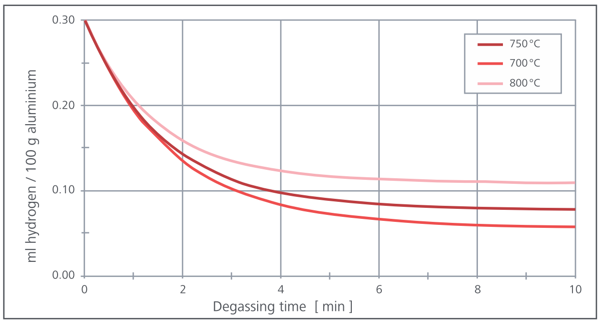


Diagram 5. Degassing curves for different melt temperatures

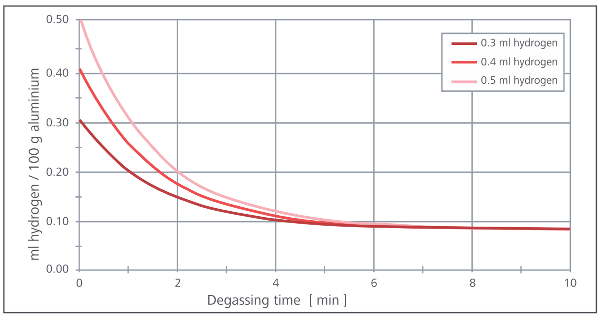
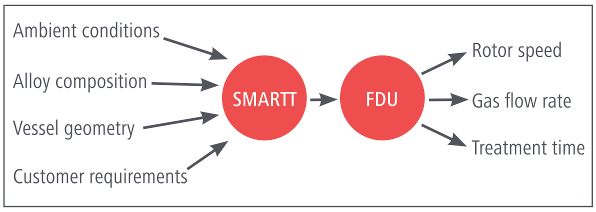


Diagram 6. Degassing curves for different initial hydrogen levels

SMARTT – an innovative process control

SMARTT is the acronym for self-monitoring adaptive recalculation treatment and an innovative process control that analyses all incoming parameters and calculates the treatment parameters for the rotary degassing process just before each treatment. The target for the optimisation is a constant melt quality after each treatment.

The SMARTT software is installed on a Windows PC, input and output of data is carried out on a comfortable touch screen panel. The SMARTT PC is LAN connected to the Siemens PLC that controls the degassing unit.



Picture 2. Schematic setting of SMARTT

The SQL data base system makes it to an open interface and enables the operator to define a nearly unlimited number of crucible or ladle shapes, alloy types and treatment programs

The target for all simulations is the hydrogen content in the melt and used for both degassing and upgassing procedures.

1. Ambient conditions

Relative humidity and outside temperature are measured by a standard sensor, mounted next to the control cabinet in the area where the treatment takes place. The actual readings are on-time transferred to SMARTT and recorded over time.

2. Alloy composition and vessel geometry

SMARTT comes with a number of pre-defined alloys and crucible or transfer ladle geometries. The user can easily modify, add or delete these. Alloy and treatment vessel become part of each program together with a recommended rotor type and diameter (picture 4).

3. Customer requirements

SMARTT offers four different treatment schemes to choose from. The calculation is based on a minimum and maximum gas flow rate and rotor speed depending on rotor type and diameter as well as on vessel size. The minimum degassing time is a parameter to ensure proper oxide removal.

High-speed degassing – shortest possible treatment time at highest possible rotor speed and inert gas flow rate. A minimum treatment time is observed to allow homogenisation and oxide removal.

Low gas degassing – runs the treatment for a given time at lowest gas consumption and correlative rotor speed to achieve the target.

Long life – runs at lowest possible rotation speed to reduce the shaft and rotor abrasion. The corresponding inert gas flow depends on the total treatment time.

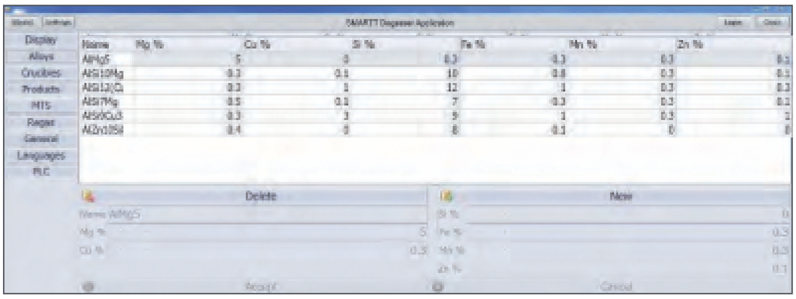
Standard degassing – the average of low gas and low speed provides a balance between the two extreme schemes.

The *high-speed* scheme is used if the degassing process is the bottleneck in the foundry and huge amounts of melt are needed for the following casting steps. The *high-speed* treatment can be used for certain time i.e. during morning shift with high melt demand or if the castings are heavy at short cycle time. The other schemes are depending on the local requirements.

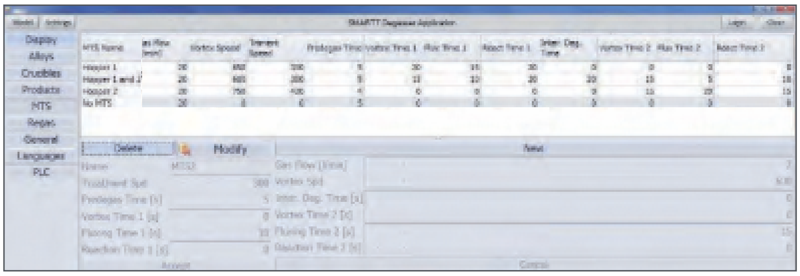
4. MTS 1500 settings

SMARTT is suitable for degassing machines with the optional MTS 1500 automated granulate addition as well. The MTS parameter setting is carried out on the touch screen in the conventional way, those parameters are not part of the optimisation. Nevertheless the different MTS programs are part of the treatment programs and combined with optimisation schemes and hydrogen targets (picture 5).

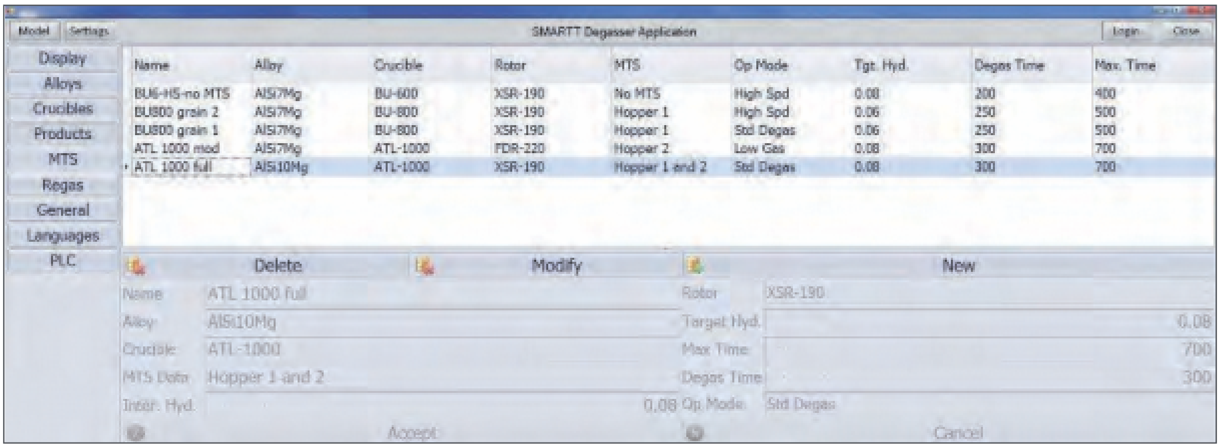
Picture 3. Touch screen interface in a FDU control cabinet door



Picture 4. Alloy screen



Picture 5. MTS parameter setting screen



Picture 6. Product screen

5. Product screen

The product menu brings all pre-defined program parameters together: treatment vessel geometry, alloy and MTS 1500. Additionally the limits for the degassing time are defined. The required hydrogen content in the melt is the target for the optimisation process (picture 6).

The different optimisation schemes enable the foundry to achieve the same degassing result in the same time using different parameter settings. The *low gas* options should be used for regions with high inert gas costs; the *long life* option reduces the erosion of shaft and rotor whilst *standard degassing* is a good balance between the two extremes. *High-speed* degassing is an option where the degassing procedure is the bottleneck in the melt shop.

A product name differentiates the different settings and makes it easy for the operator to choose the right one.

6. Operator screen

All previously described screens are accessible for the administrator only. The operator sees a specially designed interface to make an easy choice from 10 different administrator defined products. Additionally the ambient conditions and remaining treatment time are displayed (picture 7).

Picture 7. Operator screen

Results from field trials

During the foundry trial phase the SMARTT software was installed on a FDU Mark 10 mobile degassing unit with a 1 hopper MTS 1500 dosing system. The trials were started with a simple degassing procedure; the target was to achieve a standard melt quality with a minimum hydrogen level of 0.08 ml hydrogen per 100 g aluminium.

The parameters in table 2 - similar to the model simulation in the beginning of this paper (table 1) - were used for the SMARTT trials:

ATL 1000 with 850 kg melt	XSR 220 rotor
AlSi7Mg	0.30 ml H_2 / 100 g Al starting level
750 °C melt temperature (*)	300 s minimum treatment time (*)
50 % relative humidity (*)	25 °C outside temperature (*)

(*) – might vary for some examples

Table 2. SMARTT simulation parameters

The following tables compare the optimised SMARTT treatment parameters to reach the target under varying conditions and parameters. Table 3 illustrates the different optimisation schemes, table 4 compares the parameters for three different ambient conditions and table 5 provides parameters for different melt temperatures before treatment.

1. Optimisation schemes

The *standard degassing*, *low gas* and *long life* start their optimisation procedure at given minimum treatment time and try to find a logical result to reach the target. If no result is found the treatment time is increased. The *low gas* option runs with maximum rotor speed and according inert gas flow to reach the hydrogen target in time whilst the *long life* option is following the opposite strategy with lowest possible rotor speed and inert gas at maximum limit. The *standard degassing* scheme takes a result just between the two extremes. *High-speed* degassing runs the treatment close to the maximum for both rotor speed and inert gas flow and calculates the shortest possible treatment time to reach the hydrogen level at the end of the treatment (table 3).

Scheme	Melt	Rotor Speed (RPM)	Gas Flow (std. l/m)	Process Time (s)
Low gas consumption	750	500	29	300
Standard degassing	750	426	32	300
Long life for consumables	750	353	40	300
High-speed degassing	750	500	45	155

Table 3. Results for different optimisation schemes

The *low gas* option consumes 55 litres of inert gas less per treatment compared to the *long life* scheme. Foundries with 4 treatments per hour can save up to 1,500 Nm³ per year. This is an equivalent to more than 150 gas cylinders.

The reduced speed causes a reduced graphite shaft wearing. Based on customers experiences the lifetime of shaft and rotor increases by 25 % at 150 rpm lower speed. Depending on treatment conditions a foundry with 4 treatments an hour can save up to 15 sets of consumables – rotor and shaft – per year.

2. Ambient conditions

SMARTT measures the ambient conditions just before each treatment and starts the optimisation procedure based on the product settings. At higher humidity levels in the atmosphere the rotor speed and gas flow rate increase for *standard degassing* and vice versa. This is an expected result due to interactions of the melt surface with the atmosphere. The SMARTT software finds results up to ambient conditions of 75 %rH and 28 °C, for higher humidity levels the 0.08 ml hydrogen target is not achievable due to the regassing on the turbulent melt surface during the treatment.

Scheme	Melt	Rotor Speed (RPM)	Gas Flow (std. l/m)	Process Time (s)
Standard degassing - 15 °C outside temperature / 30 % relative humidity	750	404	18	300
Standard degassing - 25 °C outside temperature / 50 % relative humidity	750	426	32	300
Standard degassing - 28 °C outside temperature / 75 % relative humidity	750	459	44	300

Table 4. Results for different ambient conditions

3. Melt temperature

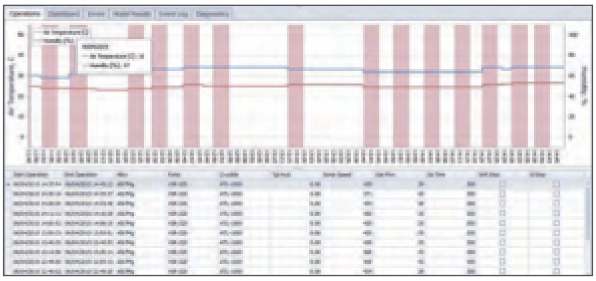
Aluminium dissolves more hydrogen at higher temperatures and takes even more hydrogen back at the melt surface from atmosphere. The treatment is carried out at faster rotor speed and higher inert gas flow rates with increasing temperature and conversely. SMARTT found a logical solution for up to 780 °C, no parameter setting could be predicted for 800 °C due to too high initial hydrogen content and the re-pick-up on the surface (table 5).

Scheme	Melt	Rotor Speed (RPM)	Gas Flow (std. l/m)	Process Time (s)
Standard degassing – 700 °C melt temperature	700	417	23	300
Standard degassing – 750 °C melt temperature	750	426	32	300
Standard degassing – 780 °C melt temperature	780	446	44	300

Table 5. Results for different optimisation schemes

4. Data logging

The SMARTT software runs a data logging system that enables a complete parameter tracking for date time and all pre-defined and optimised degassing functions. This very comfortable function replaces complex systems that run on external computers using 3rd party data logging software. The treatment data can be exported to standard office applications for further analysis.



Picture 8. Data logging screen

Summary

- Casting requires a melt on a constant hydrogen level.
- Inconsistent starting conditions in a foundry make it impossible to always reach this in the cost effective way.
- Foundries today compensate this effect in mostly overrunning the treatment which wastes inert gas and graphite consumables.
- SMARTT offers a comfortable interface to program all necessary treatment steps.
- The innovative degassing control predicts the best treatment parameters for different schemes under given conditions.
- SMARTT saves inert gas or extends graphite consumables lifetime.
- SMARTT records all treatment parameters.
- An innovative process control is the best solution for foundries that treat high melt volumes with a number of different castings that require the same or similar quality levels.

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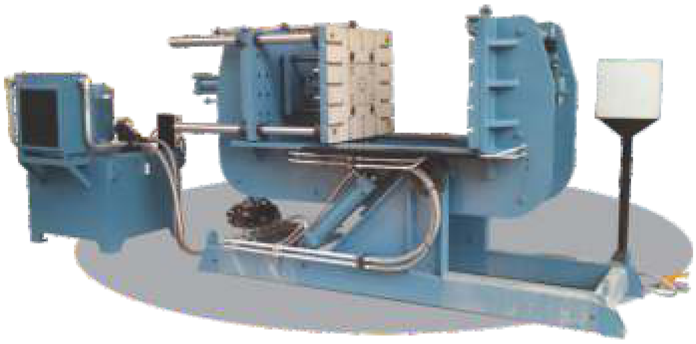

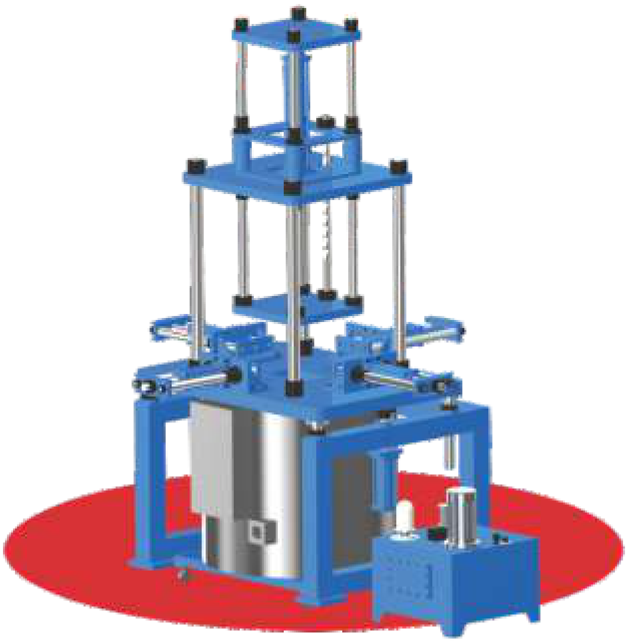

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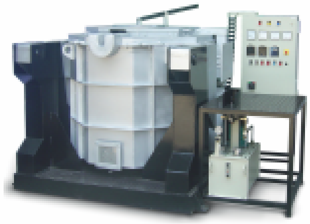
Inner View



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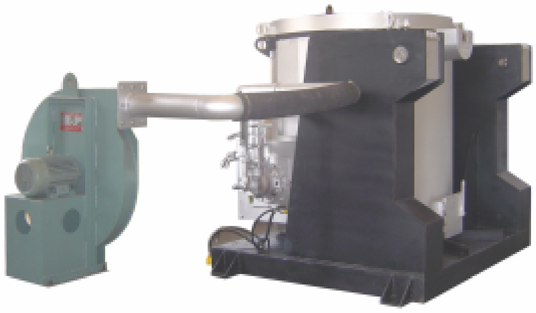

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KNOW MORE ABOUT SOLUTIONS CENTRE

Dear Sir,

In line with the organization's purpose, Great Die Casting Forum has decided to revive and strengthen the **"Solutions Centre"** platform to help the die casting foundries in solving their technical problems, thus enhancing their Casting capabilities.

Scope of the GDC Tech Solutions Centre is to help resolve technical issues and queries raised by the Aluminium Die casting foundries.

Services in the following areas will be a focus:

- o Productivity Improvement
- o Yield Improvement
- o Process Change
- o Simulation: Design Alternatives
- o Reduction in Rejection
- o Process Optimization

For this, GDC Tech is equipped with a panel of Experts in various fields of technologies who draw their expertise through their hands-on work and experience on the shop floors and their association with the die casting industry for years. The panellists from diverse fields ensure a 360^0 analysis of the problem and aim to provide a timely and fool-proof solution.

The panel of Experts from the following fields will cover various aspects and dimensions of the problem:

1. Production, Quality and Process control
2. NPD
3. Core making: Materials and equipment
4. Heat Treatment and furnaces
5. Simulation and Die Design and die maintenance
6. Machining
7. Instrumentation

The Solutions Centre is also willing to undertake Workshops and process audits in your foundry to uncover the irregularities in the processes leading to problems and rejections.

Also, the Centre, in collaboration with expertise available in the other committees can help your foundry in improving the workmen and supervisors' technical edge covering various areas of foundry operations and quality.

- **How can you reach the Centre:** You can connect with us in person at the Forum office or through emails, direct phone calls or WhatsApp numbers of GDC Tech Forum
- **What the Centre needs from you as a foundry:**
  - o Readiness to share data with full transparency
  - o Readiness to allocate resources for data collection
  - o Complete transparency in sharing problem details like
    - ▪ Nature of problem
    - ▪ What has been done so far
    - ▪ Implications of the problem
- **Will the information be confidential?**

o The GDC Tech Forum assures you that the data shared will be treated with complete confidentiality and will not be used or shared in part or full without the written permission from you

We look forward to hearing from you.

Shrikant Bhat
Head Non - Ferrous Foundry
Foseco India Ltd.
Chairman - Solutin Centre

Report on Annual Conference

"Casting Resilient Future"

Great Diecasting Technology Forum (GDCTECH FORUM) had organised Virtual Annual Conference GDCTECH 2021 – 5th & 6th October 2021.

Mr. SJR Kutty, Head, Chief Sustainability Officer, Tata Motors Limited, inaugurated the Virtual Conference.

Technical conference was held about one and half day with the following subjects:

- Extending AIMC1000: The World Class Fully Autonomous and Industry 4.0 Compliant Robotic Laser Cleaning technology for Glass Moulds to Aluminium HPDC, LPDC and GDC Mould Cleaning"
- Digitisation / Industry 4.0 / IOT in Diecasting
- Structural components opportunities
- Digitisation of Metal Casting Operation for Resilience in their Manufacturing set-up
- Government initiatives for Export Promotion
- Materials Science of Additive Manufacturing Metals
- Can Magnesium Challenge Aluminium castings in India - Future scope?".
- Multi Skilling & OHSAS Necessity for Resilience
- Operational Optimisation in Diecasting
- Operational Optimisation in Diecasting
- Six Sigma / DOE
- Special Technology for Structural components

Mr. Anand Joshi, Chairman Project Competition Committee, welcomed the participants and the delegates. In his introductory speech he briefly covered the objectives and people development aspect of the project competition. Total Projects received 13 Nos.

There were presentations from

- ASHLEY ALTEAMS INDIA LTD.
- MINDA CORPORATION LTD.
- MINDA INDUSTRIES LTD.
- POOJA CASTINGS PVT. LTD.
- SIGMA ELECTRIC MANUFACTURING CORPORATION PVT. LTD.
- UNITED METALLURGICALS PVT. LTD.

& the Award Winners

- ASHLEY ALTEAMS INDIA LTD.
- MINDA INDUSTRIES LTD.
- SIGMA ELECTRIC MANUFACTURING CORPORATION PVT. LTD.

All participants were given participation certificates and Trophies to the winners.

The competition is sponsored by OMR BAGLA AUTOMOTIVE SYSTEMS INDIA LTD., and the award is **Raj Narayan Bagla Award for Best Innovative Project.**

Mr. Pramod Gajare, Chairman Best Casting Competition Committee announced the Award Winners as follows:

- D. C. ENGINEERING INDUSTRIES
- NOBLE CAST COMP. PVT.LTD.
- POOJA CASTINGS PVT. LTD.
- MINDA INDUSTRIES

The Best Casting competition is sponsored by Aakar Foundry Pvt. Ltd.,

Along with the above two competition GDCTECH had conducted Die Design Competition.
There were 13 engineers participated in the competition following companies.

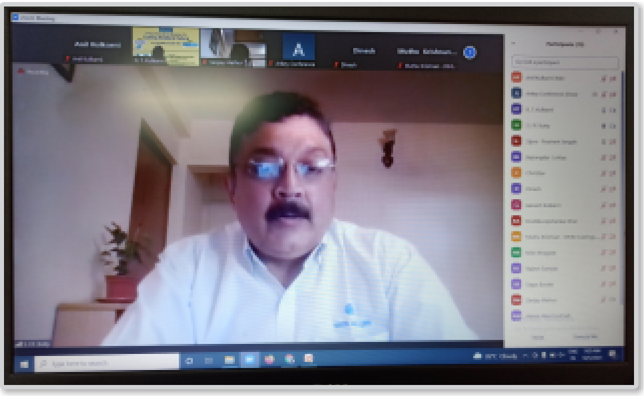
- AAKAR FOUNDRY PVT. LTD.
- ASHLEY ALTEAMS INDIA LIMITED
- CAPARO ENGINEERING INDIA LTD.
- DIETECH INDIA (P) LTD.

Award Winners were as follows:

- CAPARO ENGINEERING INDIA LTD.
- AAKAR FOUNDRY PVT. LTD.
- DIETECH INDIA (P) LTD.

Total 30 Delegates Attended the Programme

Mr. R. T. Kulkarni, Vice Chairman, proposed vote of thanks to all participants and assured to meet this year again.



Mr. SJR Kutty, Head, Chief Sustainability Officer,
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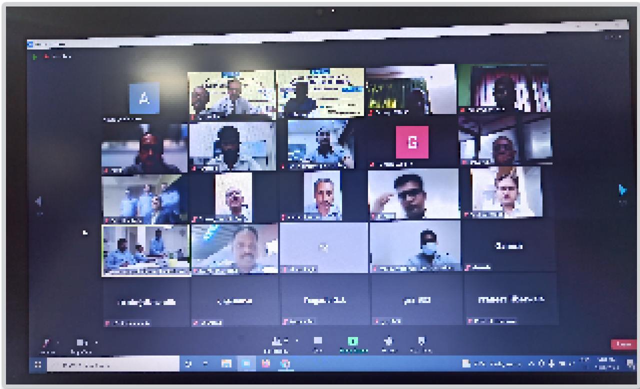

Participants

Certificates & Trophies for Competitions

Certificates & Trophies for Competitions

Integrated modelling of deformations and stresses in the die casting and heat treatment process chain

Structural high pressure die casting aluminum parts are widely used in the automotive industry. During casting and subsequent heat treatment, the casting experiences thermally induced stress formation and related distortion. The design of the part and the die, together with the process control and the choice of cooling and heat treatment parameters, have a significant impact on how the stresses and deformations evolve during the multiple manufacturing steps. The article pre- sents a fully integrated approach in Magmasoft, to predict casting stresses and distortions for the full manufacturing process chain, which has been applied to different industrial castings. The bene- fits are significant when dimensional tolerance problems are identified and resolved systematically in the design phase of the component or before tooling is manufactured.

Jesper Thorborg, Jörg Klinkhammer and Heinz-Jürgen Gaspers, Aachen

1. Introduction

Structural aluminum parts used in the automotive industry are widely produced by the High Pressure Die Casting process, HPDC. The process is mainly used because of the high produc- tion rate and the possibility to manufacture complex parts with high requirements to shape and tolerances. Due to microstructural requirements and mechanical performance of the alumi- num parts, the HPDC process is in many cases followed by a se- quence of heat treatment steps, which govern the final prop- erties of the parts before assembling into larger structures.

During casting and heat treatment the cast material is ther- mally loaded in a wide temperature range, starting from the casting temperature going through the solidification interval and during solid state cooling down to room temperature. De- pending on the chosen heat treatment process, the temperature is subsequently changed in several steps by reheating the parts and holding the temperature for some time before finally cooling down to room temperature again. Depending on the design of the part, the process control, and the choice of cooling and quench parameters, the level and change in temperature lead to thermal gradients and conditions which have a high influence on how the stresses and deformations evolve during the multiple manufacturing steps.

To analyze and predict the evolution of stresses and deformations quantitatively, it is important to simulate the full sequence of manufacturing steps in a coherent and consistent way, where the full load history of the material is considered.

Today, casting process simulation is widely used and accept- ed to be an efficient way of optimizing the casting process. Industry is showing an increased interest in extending the simulation capabilities to also analyze the subsequent heat treatment process.

This article presents a state of the art modelling approach where results from the casting process are considered in the subsequent heat treatment calculation. This fully integrated approach in Magmasoft supports the workflow of Autonomous Engineering, where virtual experiments are used to op- timize mechanical properties and performance, to improve quality and to reduce costs and production time. The benefits from analyzing the full manufacturing process chain are significant when dimensional tolerance problems are identified or can be resolved before tooling is manufactured or even in the design phase of the component.

2 Process steps and distortion control of structural parts

In the HPDC process, the majority of the aluminum solidifies in- side the die and even cools down below the solidus tempera- ture before it is removed from the die. Therefore a considerable level of stresses due to constrained contraction is formed in the cast material before ejection. The result is a complex in teraction between the cast material and the die, i. e. some regions shrink onto the die and other regions open up gaps with no contact, [1]. Depending on the cooling conditions and how long the part stays in the die, the constrained contraction will lead to stresses and permanent deformations in different regions of the part. During the die opening sequence and ejection, some of the stresses will be released due to elastic spring- back, and the part will deform as a consequence of removing the constraints due to the die. The part will freely contract during the final cooling/quenching step until it reaches room temperature. At room temperature, the total amount of deformation is a sum of the full thermal contraction from solidus to room temperature plus the permanent deformations which were mainly generated during cooling in the die. The casting process is schematically shown in **Figure 1**, where the different process steps are indi- cated by small icons.

Casting of aluminum structural parts for the automotive industry is often followed by a heat treatment process, where the main objective is to improve the mechanical properties by modifying the as-cast-mi- crostructure in a sequence of ther- mal steps. In this way, it is possible to obtain a material with increased ductility and higher strength compared to the as-cast-state. The heat treatment steps can also have a significant influence on the stress level and the distortion that builds up during e. g. solution treatment. To predict the final distortion of a structural part, it is necessary to consider all relevant steps of the manufacturing process. This imposes some challenges for the simulation of the integrated process. The importance for having an appro- priate simulation technique originates from a relatively new trend in the automotive industry to apply distortion engineering to structural parts. Relevant process stages and the related temperature history imposing stresses and distortion during the heat treatment process are illustrated in **Figure 2.**

The following three alternatives to reduce/avoid possible final distortion of the part are usually pursued in practice:

- Design support frames used during heat treatment to allow the part to distort back to the desired shape.
- Trim or straighten the part after casting or heat treatment.
- Compensate expected as-cast-dis- tortion by modifying the die cavity.

3 Simulation approach

Thermo-mechanical modeling of the casting and heat treat- ment processes is a challenge. The main concern is to model the mechanical response of the material at different tempera- ture levels, on different time scales and sometimes with differ- ent strain rates. A unified creep model has been chosen as an appropriate constitutive mode, [2] and [3]; further details can be found in the "Thermo-mechanical constitutive model" box **(Appendix 1)**.

The simulated stresses results depend on a prior compre- hensive thermal analysis of the entire casting setup, including filling of the die cavity, cooling and heating of the die, spraying of die lubricants, etc. Furthermore, different process conditions have to be

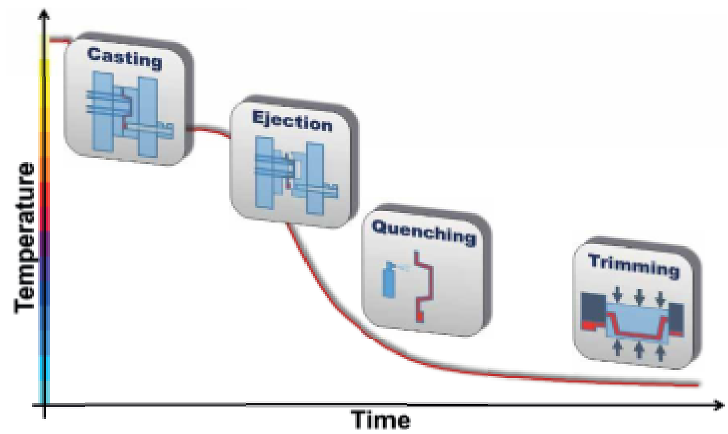

Figure 1: Schematic temperature profile of the HPDC process with illustrations of the associated process events resulting in stress formation.

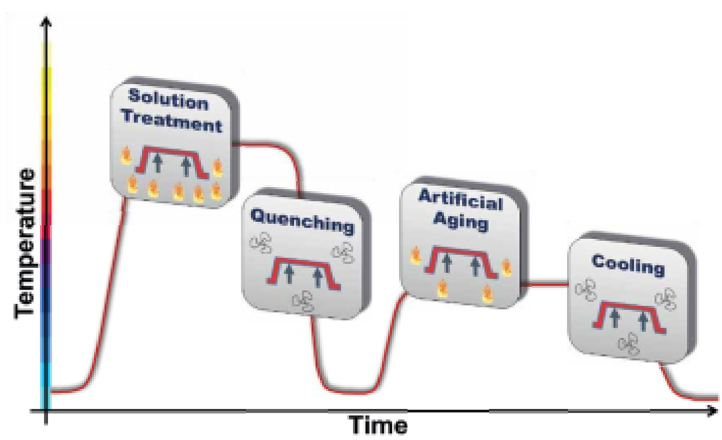

Figure 2: Temperature profile for the different heat treatment steps in a typical T7 treat- ment after casting of aluminum parts.

PHOTOS AND GRAPHICS SOURCE: MAGMA

considered such as die open temperatures, die constraints, shakeout conditions and trimming operations. While simulating stresses and distortion for the HPDC process is a rather well known procedure, it is not frequently done for the subsequent heat treatment process. In the integrated approach presented here, parts are placed in the heat treatment support frame after casting. This requires an additional step in the simulation where the already deformed as-cast-part is positioned onto a support frame. When the structural part is heated while positioned in the support frame, it can experience a considerable amount of deformation due to gravitational forces and creep in the solution treatment step. During the final artificial aging step, the temperature level is only in-creased to allow precipitation hardening to take place, [2]. See further comments on the mechanical behavior during casting and heat treatment in **Appendix 2** and **Appendix 3**, respectively. Typical observations in the different process steps are indicated with a small icon of an eye, and interesting be- havior/fields to check and validate are indicated by an excla- mation mark,! .

4 Application of the simulation approach

The integrated simulation approach of Magmasoft has been applied to different industrial castings. The primary example is a shock tower, which illustrates how simulated distortion from the casting process is used to design a support frame for subsequent heat treatment. The objective is to reduce the deviations in shape compared to the reference geometry by using the distortion from solution treatment to correct the overall shape of the part. The results are compared to results from a straightening simulation, where corrections are obtained by applying a correctional force at room temperature. The simulated results are compared to measurements.

Secondly, a space frame connection node is simulated and virtually measured distortion after shake-out and cooling is used as information to pre-shape the die cavity dimensions to pre-compensate for and to reduce distortion.

Thirdly, the ejection process is evaluated on the same space frame connection node. Simulated ejection forces are used to evaluate the number and layout of the ejector pins. Based on the results, a reduced number of pins are used for an optimized layout and the ejection forces are compared to the initial layout. Finally, a virtual Design of Experiments (DOE) has been applied to a third example, which is another space frame connection part. Several layouts of the heat treatment support frame and different process conditions are automatically calculated and evaluated to minimize the distortion during solution treatment.

5 Casting distortion and design strategies for the heat treatment support frame

Significant distortion and unwanted stresses can be a conse- quence of the casting process. Even though the final distor- tion is relatively simple to measure, it is very hard to control and tackle in production. Simulation and careful analysis of the conditions after casting can be used as input to design strategies for the support frame, to actively ‘correct’ deformations during solution treatment.

Figure 3: Front wheel shock tower of a passenger car. Initial problems with distortion being out of tolerance after casting and heat treatment were analyzed virtually.

The front wheel shock tower **(Figure 3)** of a passenger car had initial problems with distortion being out of the allowed tolerances after heat treatment, [5]. Therefore it was decided to analyse the process with Magmasoft.

6 Casting process

The casting process was simulated as a first step, to predict the distortion before heat treatment. **Figure 4** shows the evolution of the stress levels during the casting process and how the displacements build up at the same time. The von Mises stress distribution is shown above the process view and the displacements are shown below the process view. Starting from left, the results show the conditions just before die open, just after ejection, at ambient temperature and finally after trimming.

In the first result the stress level is governed by the constraints from the die and the chosen die open time, Figure 4a. Evaluating this result makes it possible to analyze, if critical stress levels are reached, which could promote large permanent deformations or even affect the ejection process. After ejection the stress level is significantly reduced, which is seen in the second result, Figure 4b. During the subsequent cooling step to room temperature moderate stresses are generated due to the thermal gradients, see the third result, Figure 4c, and only small changes are seen in the subsequent trimming step, Figure 4d.

Evaluating the distortion at the same points in time shows how the main distortion evolves during the cooling step from die open to room temperature. Only a limited amount of distortion is observed just before die open, Figure 4a, due to the constraints from the die. Just after the ejection process some distortion is seen, mainly due to elastic spring back when the constraints from the die are removed, Figure 4b. The free thermal contraction from die open to ambient temperature generates a significant amount of distortion, Figure 4c. For this reason it can be useful to make variations in the die open time to investigate how much the free contraction affects the final distortion level. For this example, the final trimming step does not change the distortion significantly, Figure 4d. However, depending on the gating system and the design of the part, this final step can contribute to the distortion level.

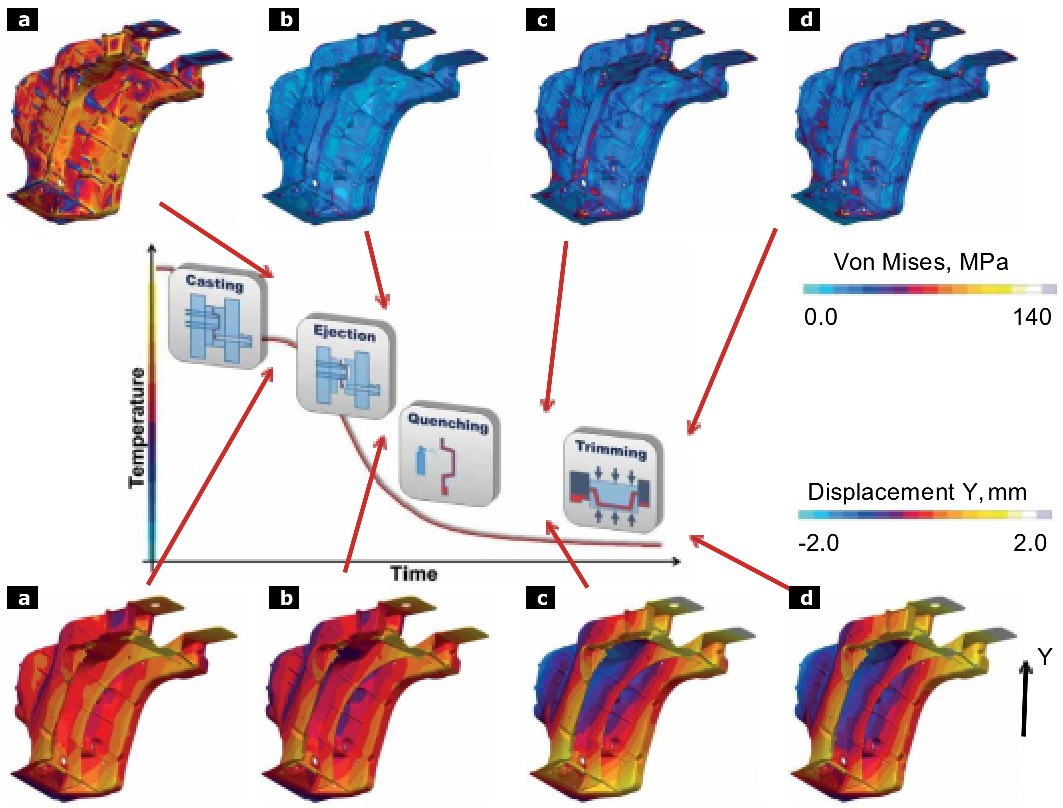

Figure 4: Evolution of von Mises stress (upper row of results) and displacement in Y-direction (lower row of results) during the different HPDC process steps. From left, the results are shown at different process times just before die open (a), just after ejection (b), at ambient temperature (c) and finally after trimming of the gating system (d).

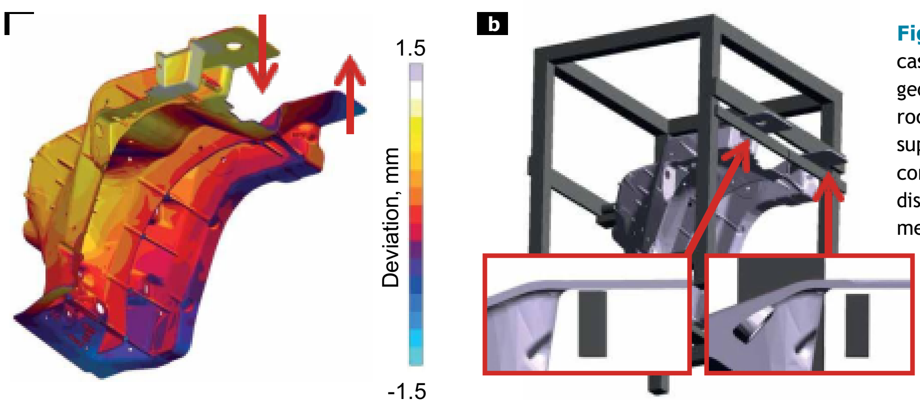

Figure 5: Deviation of the casting from the reference geometry after trimming at room temperature (a) and support frame designed to compensate for the casting distortion during heat treatment (b).

7 Heat treatment and support structure design

The final distortion after casting was used to design the support frame for the subsequent heat treatment steps. It was clear from the calculated distortion, Figure 5a, that the upper left corner bends downwards whereas the upper right corner bends up wards compared to the reference geometry. The directions of bending are indicated by the two arrows.

This type of unwanted distortion can in most cases be reduced by allowing the structure to deform in a controlled way during solution treatment. As the temperatures are close to solidus, small forces from gravity promote creep in regions where the support frame does not restrict the deformation. The amount of obtained creep, and by that distortion, in the structure depends on the temperature level and the process time. The temperature must be suflciently high to activate creep and the frame must be carefully designed to allow wanted distor- tion and restrict unwanted distortion.

For the considered example the frame was designed as shown in Figure 5b. The zoomed-in view in the box at the right shows how the part initially has a gap between the upper right plate and the bar in the frame just below it. This freedom to deform is designed to allow the two plates to align at the end of solution treatment.

Results from the casting process are mapped to the position of the part in the support frame, Figure 5b. This step is done automatically in Magmasoft, i. e. all relevant mechanical fields are transferred from the orientation in the casting process to the orientation in the heat treatment process.

8 Stress development during heat treatment

During the heat treatment process, the stress level in the part significantly changes due to the elevated temperature levels and the cooling conditions. To illustrate the influence on the considered part, several von Mises stress results are shown in Figure 6, where the initial stress level is based on the mapped results from the casting simulation. As expected, the stresses are relaxed to almost zero during solution treatment, where the temperature level is approximately 460 °C. The subsequent cooling only leads to a small increase in the stress level, and in the final aging step, at approximately 220 °C, the stresses are again relaxed to an even lower level at the end of the entire heat treatment process.

9 Distortion evaluation after heat treatment

The results in **Figure 7** show the obtained distortion after heat treatment and the deviation from the reference geometry after casting and after heat treatment. The designed gap in the support frame clearly allows the wanted deformation to develop during solution treatment and by that to actively compensate for the casting distortion. The level in deviation from the reference geometry was reduced by approximately
1.5 mm, see Figure 7 below.

10 Validation of results using optical measurements

The obtained correction to the casting distortion was com- pared to measurements. **Figure 8** shows the distortion of the cast part after the full process chain of casting and heat treatment. The curves show the deviation at multiple measurement points from the reference geometry. The red curve shows the Magmasoft-simulation result, where the blue, yel- low and green curves show measurement results for 3 differ- ent specimens of the part.

The predicted results show a very good agreement to the measurements in almost all areas. Differences mainly appear in the red marked areas, where the measurement points are lo- cated very close to the outer bounds of the geometry. In these outer regions, mechanical influences from e. g. handling and trimming are very likely to have influenced the measured re- sults. In one case (detail on the right) an artificial indentation in the imported stl-geometry, containing the measured shape, is responsible for the shown deviation to the simulation result.

Overall, the agreement between simulation and measure- ments is very good and the applied simulation approach has been useful to analyze the distortion problem during casting and the subsequent heat treatment processes.

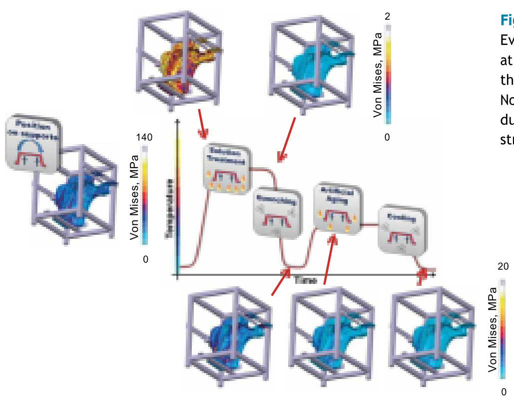

Figure 6: Evolution of von Mises stress at different points in time during the heat treatment process. Notice the different stress scales due to the different ranges of the stress levels.

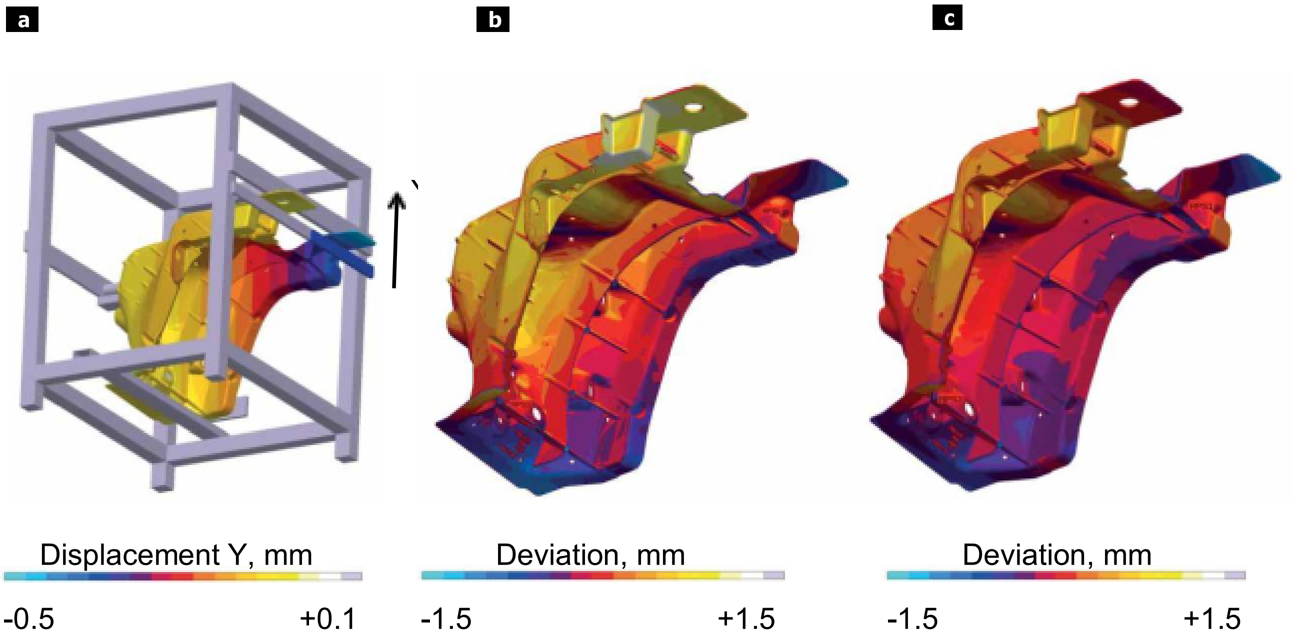

Figure 7: Distortion in the direction of gravity (a), deviation from the reference geometry after casting (b) and deviation from the reference geometry after heat treatment (c).

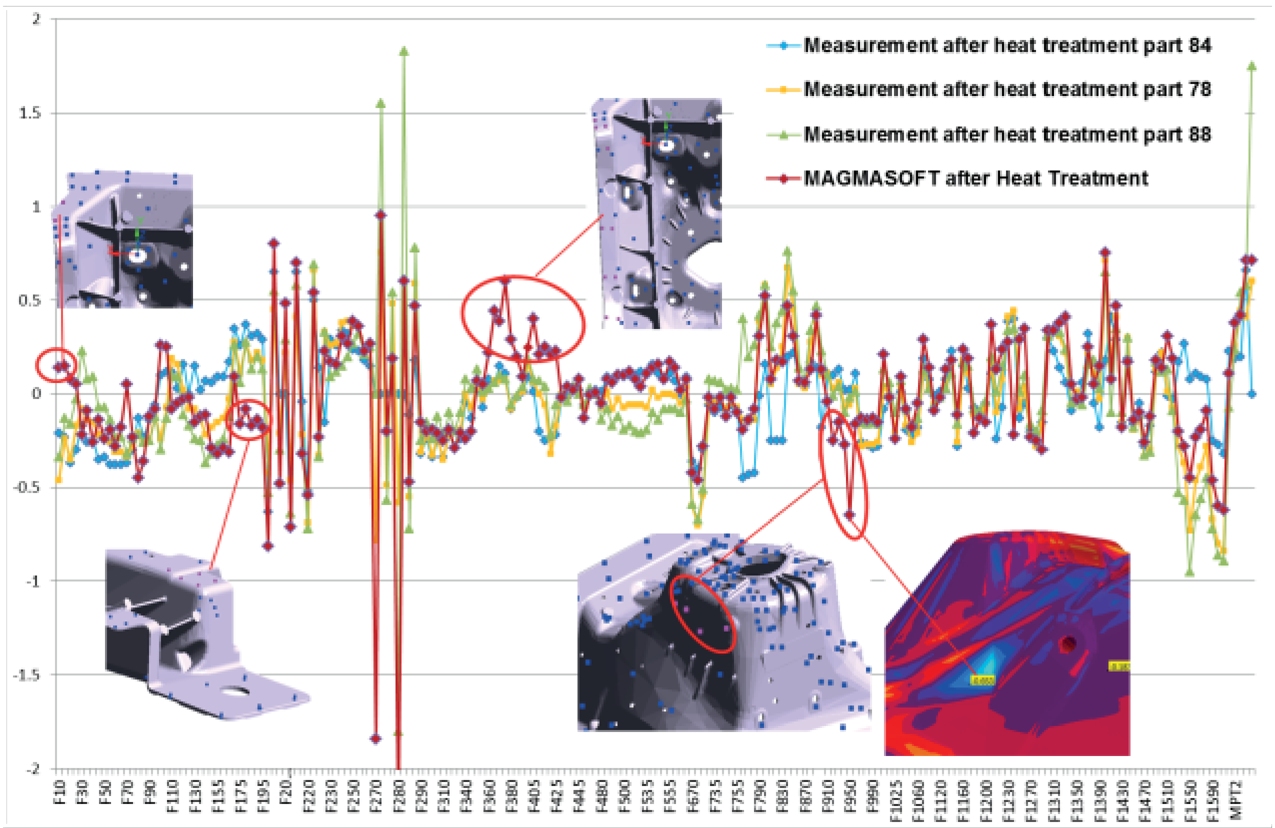

Figure 8: Measurements compared to results of the simulated deviation from the reference geometry for more than 50 measurement positions. Notice the measurements contain a spread in the level for the three considered parts.

11 Straightening and the risk of deforming the part at room temperature

Distortion after casting and heat treatment is typically corrected by different types of straightening processes. The needed corrections to get sufficient accuracy in the final shape are obtained by applying high mechanical loading to produce localized permanent deformation in different regions of the structure. Today, state-of-the-art straightening is done in a fully automatic process where several steps of pushing, pulling and twisting can be applied to the part in different directions. The most advanced systems are based on self-learning algorithms to reduce and optimize the required number of correction steps. The straightening process provides a high level of freedom to correct the part, but the mechanism be- hind the process is to plastically deform the material at room temperature, which in the worst case can influence the mechanical performance during service loading. Especially if several big correction steps are needed to obtain the required tolerances, the risk of provoking cracks and defects increases.

To illustrate the impact of the straightening process, a force is applied to the shock-tower to compensate for the uneven bending of the two upper plates. The setup is illustrated in **Figure 9**, where the dark gray cylinders are mechanical constraints and the red cylinder indicates the location of the ap- plied load.

The displacement result in Figure 10a shows the distortion during loading, which is approximately 9 mm in the area close to the applied load. The obtained distortion after unloading is shown in Figure 10b and is approximately 1.1 mm. During loading significant stresses build up in the part, which can be seen in Figure 11. Stress results during and after loading are shown in Figure 11a and Figure 11b, respectively. As a conse- quence of the high loading, localized permanent deformation is generated inside the part, which can clearly be seen in the highlighted regions in **Figure 12**.

The initial deviation to the reference geometry after casting is shown in **Figure 13**a. The deviation which was possible to obtain by designing the support frame for heat treatment is shown in Figure 13b, and the deviation obtained from the straightening process is shown in Figure 13c.

Figure 9: Setup for modeling the straightening process. The dark gray cylinders are constraints and the red cylinder indicates the location and direction of the applied load.

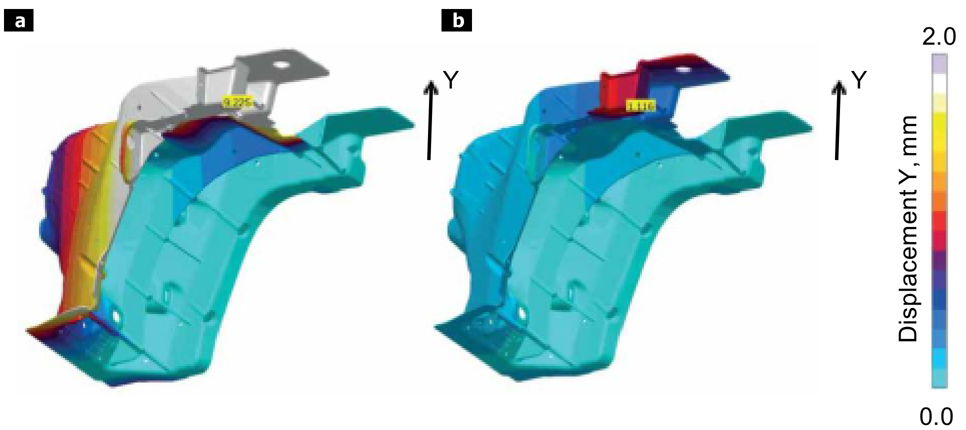

Figure 10: Deformation during straight- ening (a), obtained deformation after straightening (b).

The deviation in the two results Figure 13b and Figure 13c are to a large extent in the same range.

The example shows how simulated distortion can be used in the design strategy of the heat treatment support frame to promote distortion during solution treatment, which actively compensate for casting distortion. This approach can be used to reduce the required amount of straightening steps at the end of the process chain, which reduces costs and the risk of gener- ating defects and increased residual stresses in the final part.

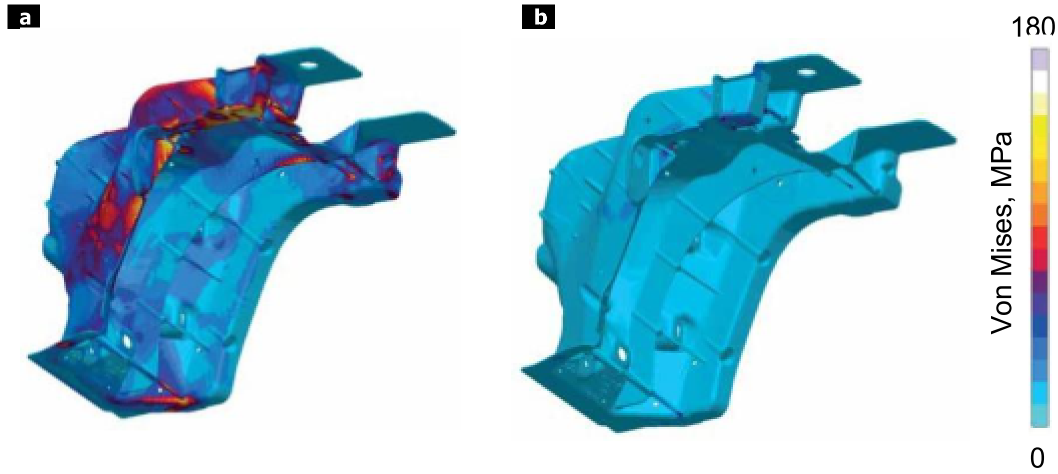

Figure 11: Von Mises stress during straightening (a), von Mises stress after straightening (b).

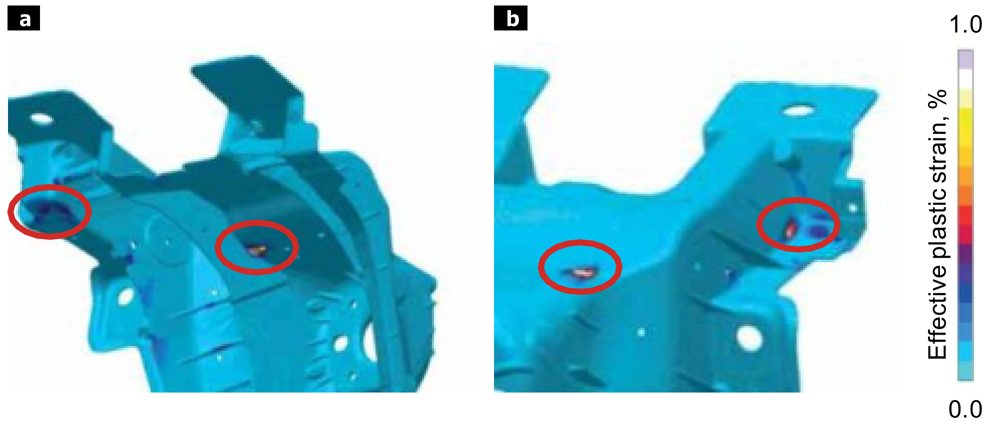

Figure 12: Effective plastic strain on the inner side (a), effective plastic strain on the outer side (b), both after straightening. The results show the localized permanent deformation which was generated during straightening.

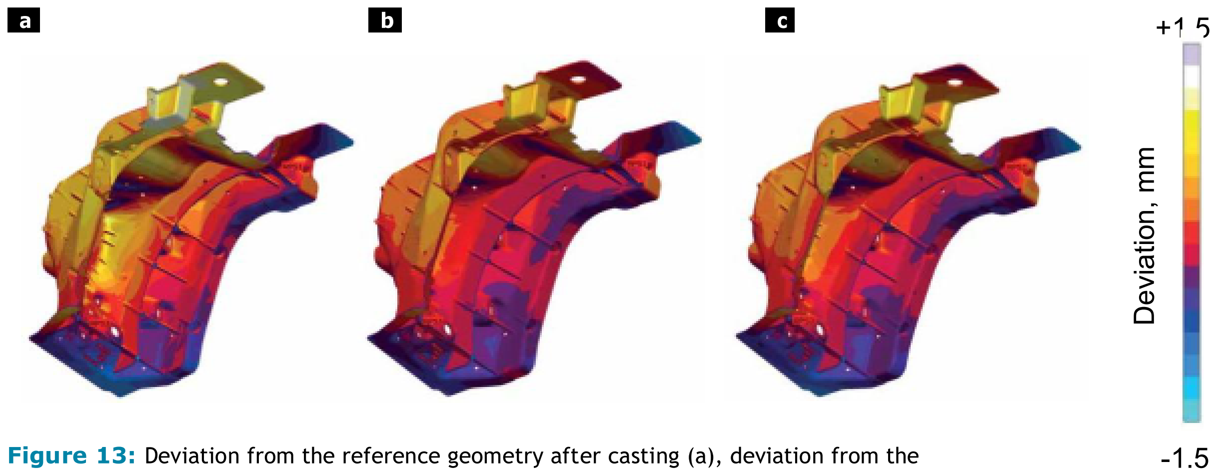

Figure 13: Deviation from the reference geometry after casting (a), deviation from the reference geometry after heat treatment (b) and deviation from the reference geometry after straightening (c).

To be continued in next issue...

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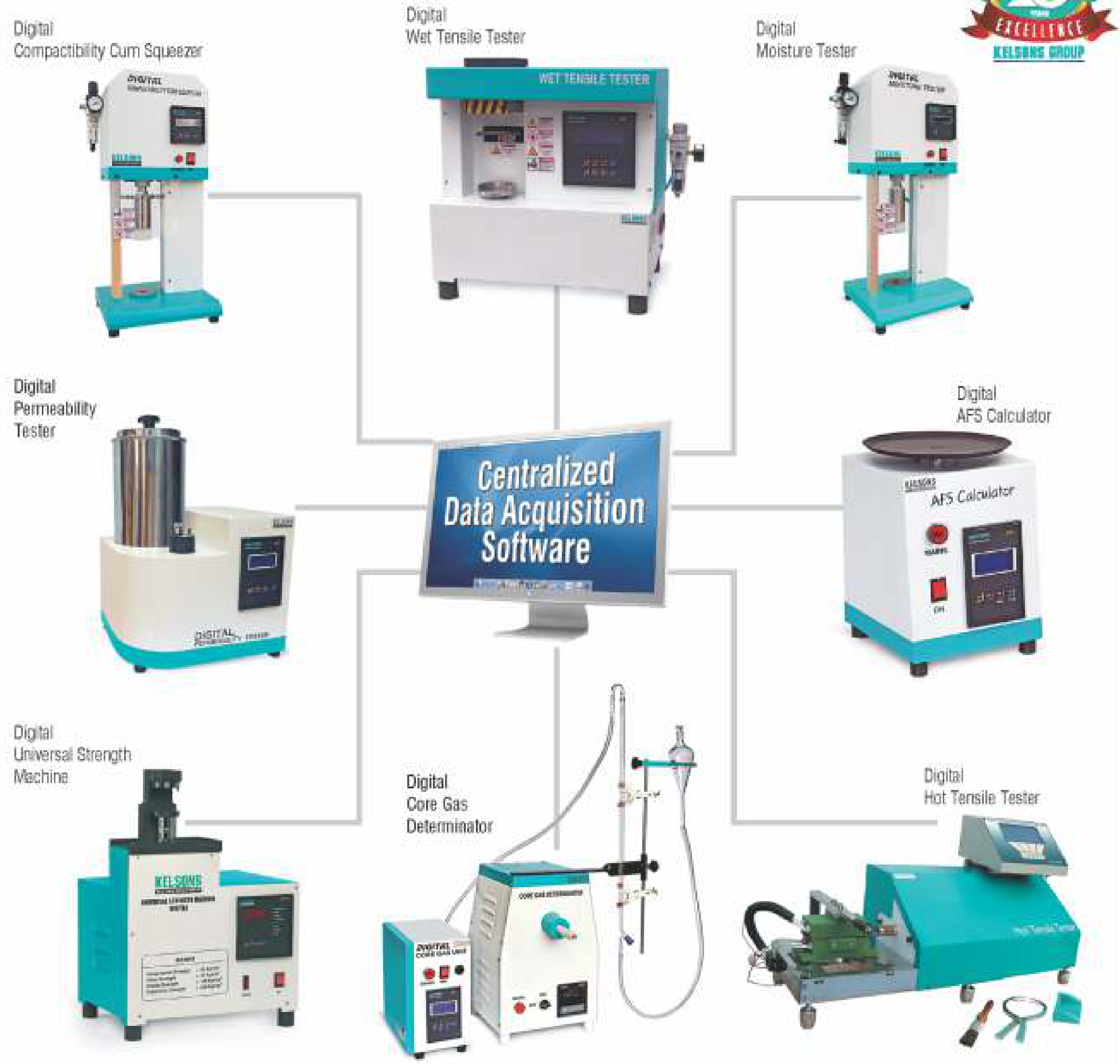

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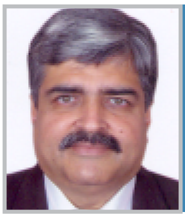


IMPORTANCE OF DIE LUBRICANTS IN HIGH PRESSURE DIECASTING OF ALUMINIUM ALLOYS

Madhav Athavale - Consultant, Email : athavalemadhav@gmail.com

Continued from October 2021...

5.0 How to select proper Die Lubricant?

Four step procedure is recommended by North American Die Casters Association (NADCA)

I. Understanding the need of the die caster – "Process Mapping"

Following information should be gathered about the process -

What is the operating philosophy of the die caster?

- Hot die and shorter cycle time – Higher production/productivity, may be slightly higher scrap rate but meet the customer requirement.
- Cooler die with longer cycle time – Lower production/lower productivity but lower scrap rate and meet the customer requirement.
- Recycling of die lubricants – Some do some do not depending on facilities available and associated costs

What are the casting types produced?

- Casting type: Thick or thin walled, how many inserts in castings, alloys used
- Die design: What are thermal patterns & infrared pictures, cooling line layout, die lube spray patterns?
- Casting defects: What are Primary defects with each casting?
- Finish Requirements: Are castings Powder coated or Chrome Plated?

What are the machine systems?

- Die Heating/Cooling system: Type of heating and cooling system and Maintenance program impact die thermals and how they will change in operation.
- Die lube spray equipment: Manual spay gun- Depends on operator skill, Reciprocators- Series of spray heads directed at different locations in the die,
- Robot: Most accurate, Air/die lubricant pressure and differential between them as it impacts atomization

Other important aspects of process mapping

- Have a format/s to capture the complete process details
- Try and gather as much quantitative details as possible in each part of the process
- Have clarity on what is the current status and what is the desired status in terms die or plunger lubricant performance
- Understand the details of what has been already done by the caster to reach the new status

II. Product Selection:

Primary Objectives – What issue needs to be addressed?

Operating Temperature Range – Use infrared scanners to check highest and lowest temperature and its location

Surface Finish Requirement – Is casting going to be used with as cast finish or its going to be coated/painted?

Above criteria help decide the formulation/type of die lubricant

III. Product Evaluation

Following things should be adhered to when doing evaluation of selected die lubricant.

Good base line data:

What is the current performance with current die lube against which new lube needs to be evaluated?

Properly maintained machine:

Casting machine should be in proper working order. It should not be the variable.

Proper Technical Support:

Die lube supplier and caster must assign dedicated persons for evaluation trials to ensure proper evaluation.

Detailed documentation:

Both parties must decide on method of conducting the trial such as dilution rates to be used, choice of casting for trial, die areas to be sprayed, spray pressure and duration of spray, assessment of die lube consumption, casting release assessment criteria, cycle time etc. what data will be captured to evaluate lube performance and review the same.

Extension of use:
After successful use on one item run the lube on other items with different operating conditions (previously known to lube maker) to ensure it works across the casting range as agreed.

IV. CANI – Continuous & Never-ending Improvement

This has to be part of operating philosophy. Many foundries in India following Kaizen technique for this purpose.

6.0 Use of Die lubricants – Mixing and Application

Die lubricant Suppliers give the storage, mixing and application recommendations.

Lubricant Mixers

There are many suppliers for such equipment. The choice depends on each die caster depending on the number of machines and type of castings that are being produced. There are two options. Some die casters use mixing system dedicated to individual machine or a common mixing tank that supplies to multiple machines.

The mixer in the picture (below left) is intended for permanent stirring with recirculation of a WATER based product (with or without graphite) which is aspirated by a 52l/min membrane pump to put the system under pressure. At the outlet, a pneumatic pressure controller smooths the jolts of the membrane pump to provide a regular output of product. A spray gun and hoses are also supplied with this distribution tank.

Centralized Die Coat System, Die Coat Tank, Die Lubrication

Die Lubricant Application

- ➢ Manual Brush/Swab: Here an oil-based lubricant is directly applied on the die face by using a brush or a swab. It is used for small dies and also for spot touching on large dies in hot spot or deep draw difficult release areas.

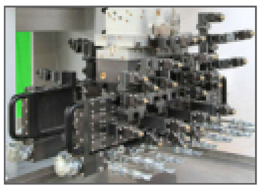
Die Spraying Important Common Points

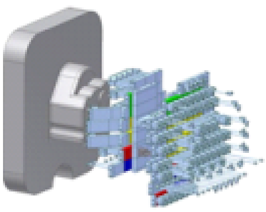
- ➢ Aim is to improve the temperature uniformity and create a film that facilitates the filling and the extraction of cast components
- ➢ Controlling the die surfaces temperature during the lubricant spraying within a narrower band around 200 ºC is beneficial for increasing the useful die life and the surface quality of the casting.
- ➢ Spray gun should be perpendicular to die surface
- ➢ Spray pressure, dilution ratio, nozzle size, spray pattern, spraying time is arrived at for each die with bit of trial and error.
- ➢ Die lubricant chemistry affects the cooling of the dies, particularly at elevated temperatures (more than 220°C).

Spray Application Techniques

- ➢ Manual Spray: A number of suppliers are available for lube mixing and spraying equipment. They would recommend method of mixing and application.

- ➢ Reciprocators: Use of spray heads where spray nozzles can be directed towards different parts of the die cavity as shown in the pictures below





Different individually switchable spraying circuits allow targeted spraying on critical die areas – without unnecessary separating agent consumption.

Robots offer high dynamics, high drive power, precise positioning and a freely programmable control. Most accurate, programmable, flexible but expensive

- Robotic Application: Toshiba Robotic Spray

- Pulsed Spray: Faster cooling of die face and better control of die face temperature

In the studies it has been found that the lubricant applied using pulse spray can achieve identical cooling efficiency as continuous spray with a pulse frequency of 100 Hz and a duty cycle of 50% when the pressure is higher than 0.2 MPa. Moreover, the use of pulse spray can reduce the consumption of lube and runoff by several times during lube spray, leading to significant cost saving, decreased environmental footprint, and leaner work environment. Annexure 4 gives details of another study by NADCA that shows similar results.

7.0 Plunger Lubricants

Plunger Lubricant Service Requirements

- In high-pressure die-casting the molten metal is injected into the die cavity through a cylindrical sleeve by a piston (or plunger) that forces the molten metal through a narrow orifice at high speed and pressure.
- Proper lubrication of the plunger is essential to provide smooth filling of the cavity, reduce energy consumption during the shot and extend the life of the plunger tip and sleeve to ensure productivity and quality.

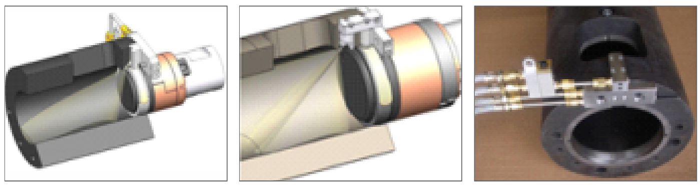
Plunger Lubricant Constituents

- Graphite is a key functional material in many plunger lubricants. It can be supplied in a variety of carriers including oil, water and waxes.
- The carrier serves not only as a lubricant itself, but also to help distribute the additives over the surface of the shot sleeve, and, depending on the method of application, to hold the additives in place once applied.
- Oil-borne plunger lubricants are similar in function but, as they are liquids, they may be applied with or without atomization to enhance surface coverage.
- Solid plunger lubes are most frequently supplied as small pellets that are introduced by an automated device through the pour hole into the shot sleeve.
- The carrier is designed to melt and then assist in the distribution of additives over the surface of the tip and shot sleeve.

Application of Plunger Lubricants

These can be applied manually by brush in the shot hole or now a days with modern machines automatic plunger lubricant dosing systems are available for oil graphite or blends as well as Pallets are available.

Pictures below show 3 of them for oil blends. They will lubricate plunger tip as well as shot sleeve.



- Lubrication Unit: Consisting of a lubricant reservoir made of stainless steel, equipped with solenoid valves and volumetric metering pump. Designed to mount on the wall or on the machine near injection area.
- Control: PLC with integrated HMI to control valves, metering pump and the specified cycle, from the signal received from the injection machine.
- Lubricant Tank: Tank with appropriate capacity with superior lid and visual detector level.

System for dosing of Pallets

Photographs below show the sequence of operation of dosing system

8.0 Testing of Die Lubricants

Usually Lube Supplier will recommend tests to be done.

Color & Appearance: Check against specs

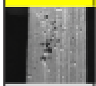
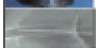
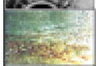
Specific gravity: Specific Gravity Bottle

Solids Content: Evaporation at 100 Dec C

Emulsion Stability: It is evaluated by diluting the lube with caster's water in pre agreed proportion like say 1Part Lube: 100 Parts Water keep it in a stoppered measuring cylinder for 24 hrs. and visually check for Separation or creaming.

Wettability: A hot plate can be used to assess wettability of the die lube in ready to use concentration by applying it on a steel plate to a pre-determined temperature and visually checking for adhesion of the lube film. The test temperature has to be just below LFT.

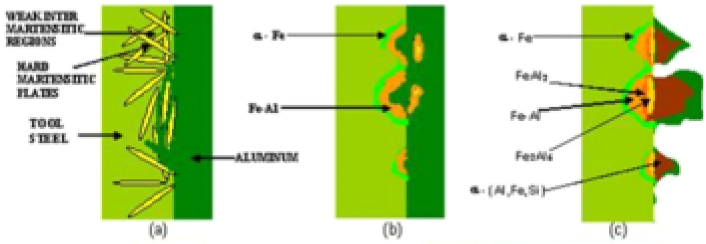
9.0 Typical Casting Defects Connected with use of Die Lubricants

Defect	Type	Cause	Remedy
	Gas Porosity	Gases from excessive die or plunger lube give dark appearance to cavity surface	Adjust lube quantities appropriately
	Soldering	Insufficient die lube	Adjust the lube quantity
	Drag Marks	Soldering or die erosion	Adjust die lube practice
	Cracks or distorsion	Soldering and or cracks	Change lube type or used anti solder paste and check die surface condition and do necessary corrections
	Die crazing	Excessive lube spraying	Adjust die lube practice
	Stained surface or discolouration of casting	Excessive use of die lube	Choose right type and quantity of die lube
	Wave or Lake	Excessive die temperature at a specific location	Adjust die lube spray pattern appropriately

10.0 Summary

- Die Lubricants perform 3 important functions in HPDC process
- Protection of Die material from chemical attack of Aluminium Alloy
- Easy release of casting from the die to ensure quality & productivity
- Water based lubricant spray also cools the die surface
- It is vital to understand production process details before deciding on selection of type of die lubricant and how to apply the same
- Working in close co-ordination with suppliers, designers in all areas is vital for best out come
- Improper use of lubricants can lead to casting defects
- New waterless lubricants with micro-spraying equipment and good fume extraction can improve die life by lowering the thermal stresses on the die.
- Automation in die lubricant application helps improve the productivity, quality & reduces costs

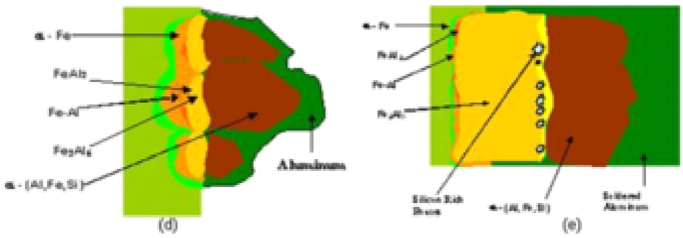
ANNEXURE 1
Schematic of Soldering Mechanism



(a) Initial attack of the grain boundaries by aluminium to loosen up the hard grains and martensitic plates to cause pitting on the die surface.

(b) Formation of the iron-aluminium intermetallic phases inside the pits and around the broken grains close the die surface.

(c) "Pyramid' growth of the ternary - (Al,Fe,Si) phase on the pits over the -Fe2Al5. In addition, the pits expand laterally and in depth. Aluminium begins to stick after this layer structure is formed resulting in the beginning of soldering.



(d) Shows the growth of intermetallic layers and merging of neighboring pits. Molten aluminium encounters the die surface only through the cracks and gaps present between adjacent pits.

(e) Straightening out of the pits and closing of the gaps between the adjacent pits. The ratio of the intermetallic layer thickness and the soldered aluminium is ~1:5. The reaction mechanism becomes very slow. Silicon is precipitated in the grain boundaries of the -Fe2Al5 phase and at the intersection boundaries between the two intermetallic phase layers.

ANNEXURE 2
Few examples of water-based die lubricant formulations

Polypropylene Aqueous Emulsion (Emrel 7 40% solids)	13.1 %
Mineral Oil Aqueous Emulsion (26.2% mineral oil)	86.7%
Preservative	0.2%
Total	100.00%

Polypropylene Aqueous Emulsion (Emrel 7, 40% solids)	16.0%
Natural Oil Aqueous Emulsion, e.g., Soya or Lard oil (40% solids oil content)	80.0%
Preservative	0.2%
Water	3.8%
Total	100.00%

Polypropylene Dispersed Powder 0.2 to 2 microns average diameter particles Molecular weight 4,000 to 20,000 D.	1 .80%
Silicone Oil Aqueous Emulsion (50% solids) (DC 290)	15.30%
Ethoxylated Alcohol Emulsifier Nonionic dispersing and wetting agent	0.18%
Anti-corrosion Agent (Becrosan BTO)	2.00%
Preservative	0.20%
Water	80.52%
Total	100.00%

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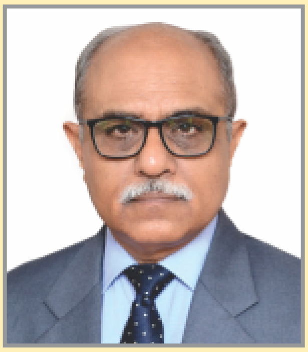

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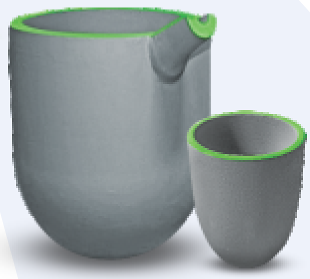

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