Martin Hartlieb

www.viami.ca

VIAMI INTERNATIONAL INC.

High Integrity Diecasting for Structural Applications

A holistic approach to improved die casting quality

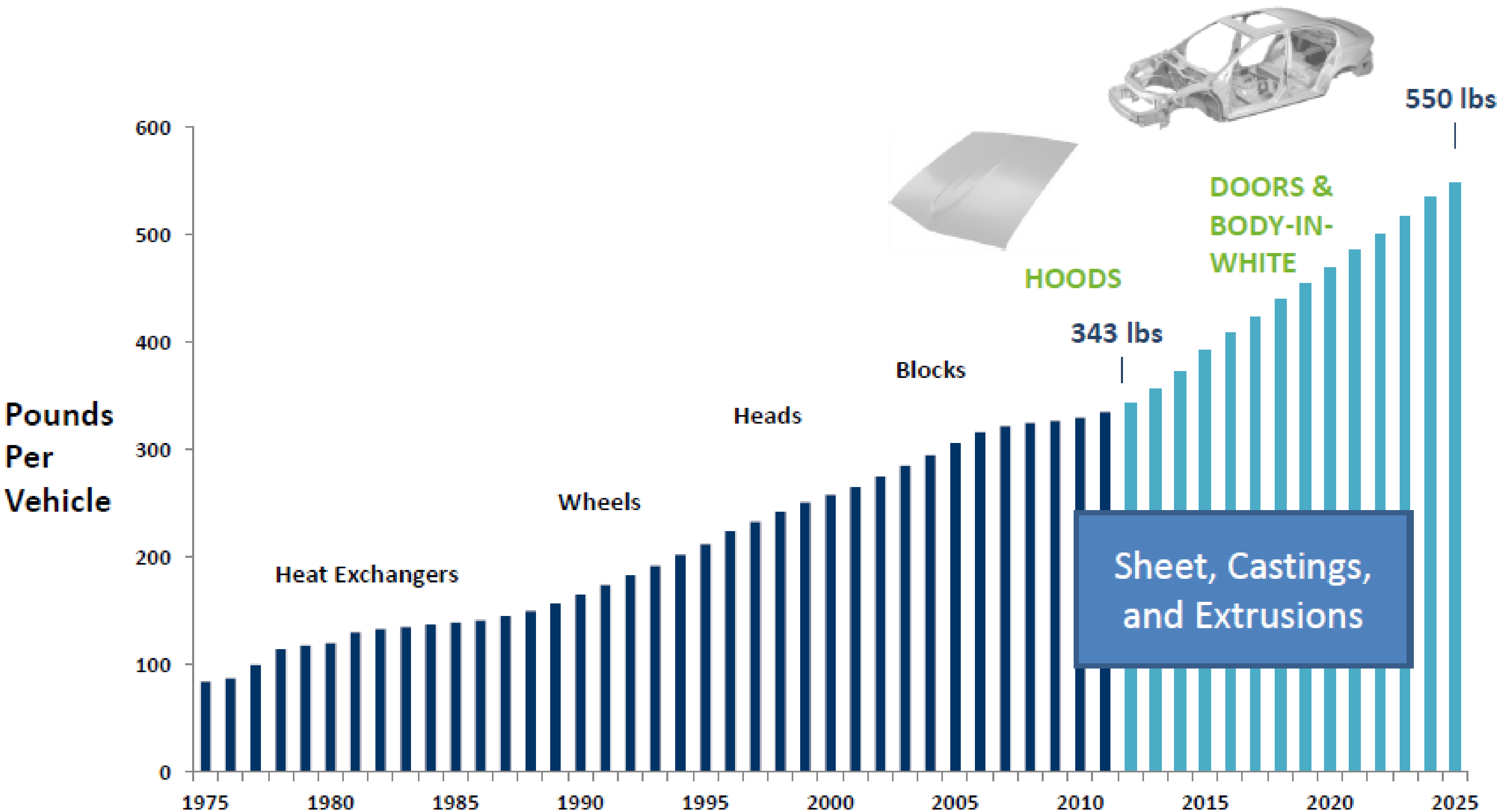
iMdc meeting, WPI, Worcester, MA December 12, 2013

VIAMI INTERNATIONAL INC.

Services offered

- Assistance in material, process/technology selection, implementation and optimization for specific application
- Assistance in sourcing metal/process/castings (supplier benchmarking and selection, supplier development)
- Assistance with part / system development, specifications, prototyping, testing, etc.
- (International) market development
- Trainings, seminars, workshops
- Project management (time, cost, quality)

Aluminum content in automotive



Source: Ducker Worldwide 2011

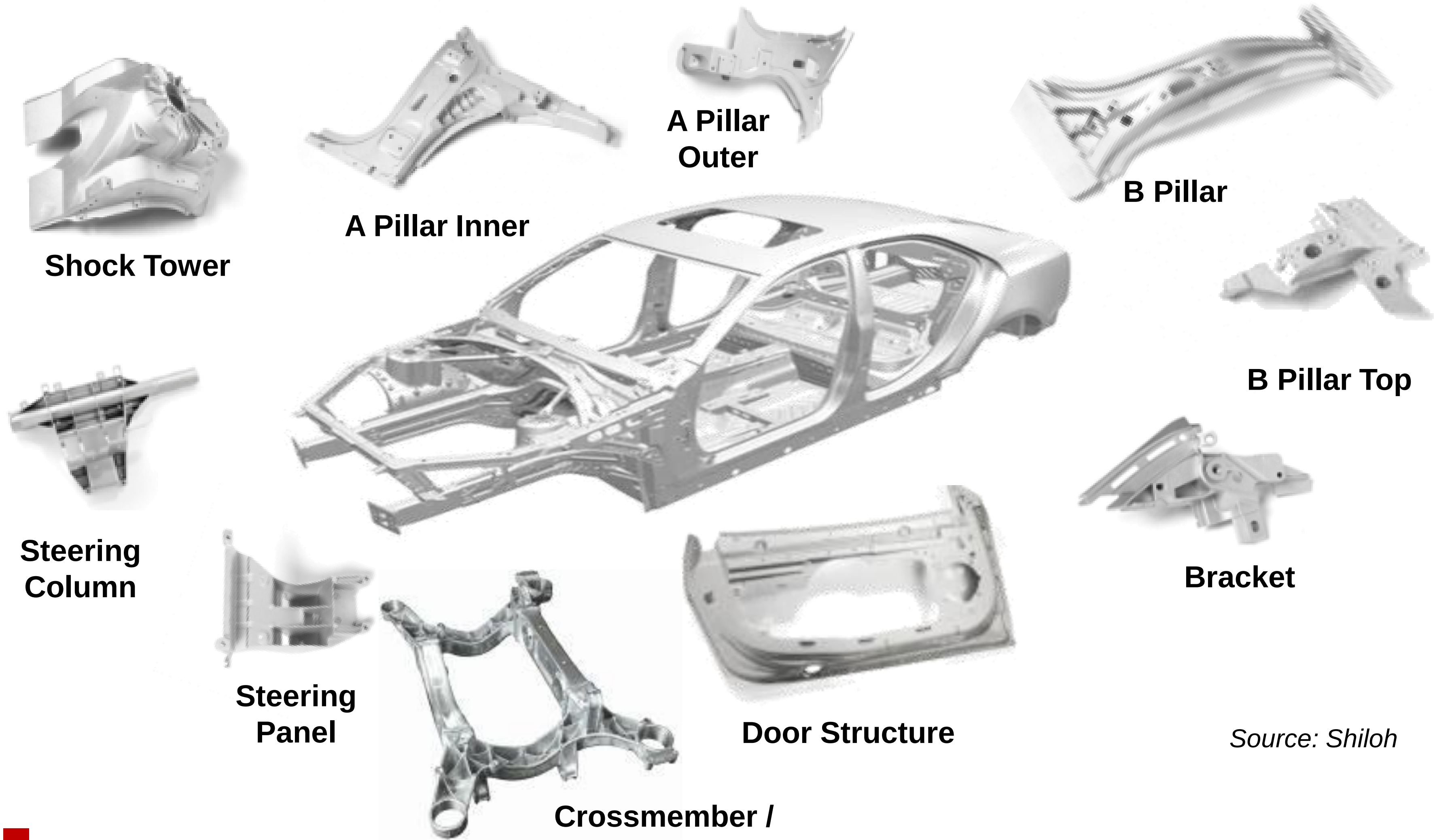
Structural aluminum die castings

… are being used for

- Saving weight & costs - replacing
  - Heavier materials
  - Thicker walled parts
  - Steel/Al assemblies and stampings
  - Higher cost materials and processes
  - …

- For performance increases
- For pressure tight parts
- …

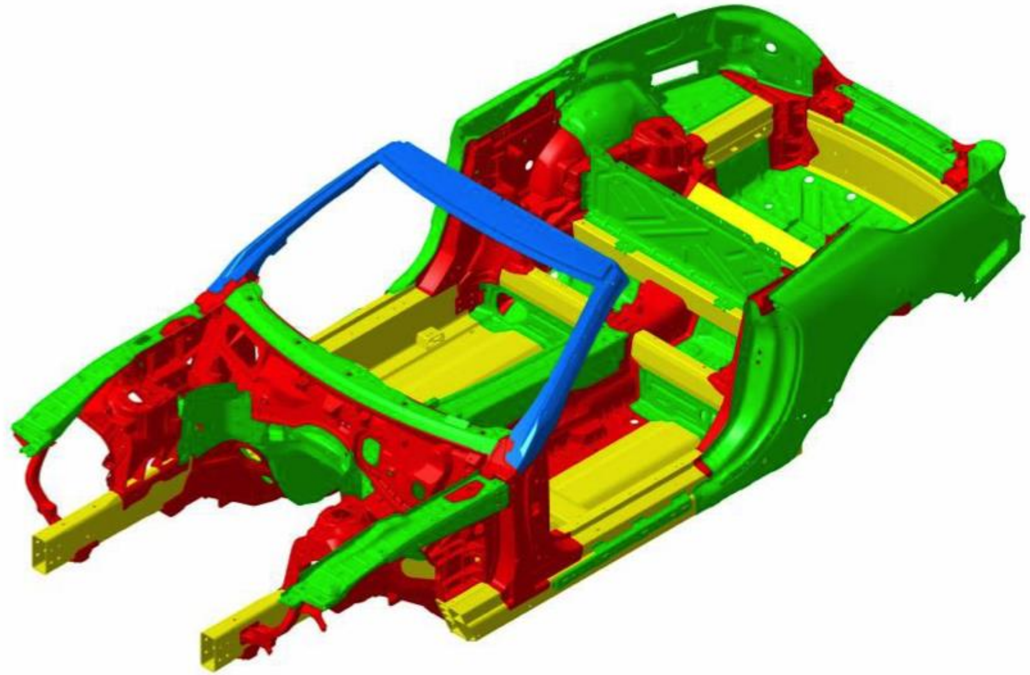
Applications for structural high integrity aluminum die castings

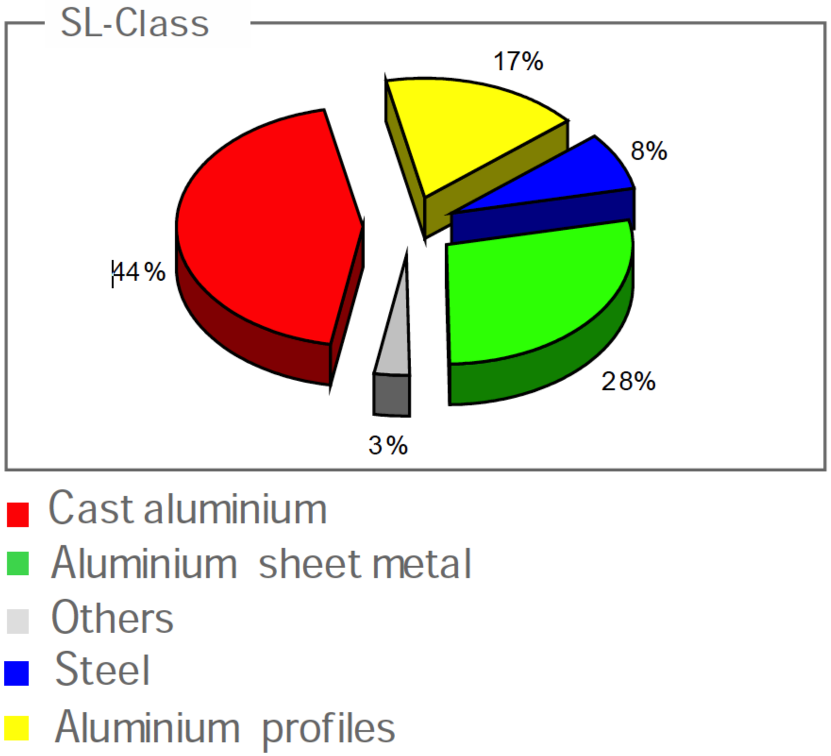


Source: Shiloh

Applications for structural high integrity aluminum die castings

BIW structures: It usually starts in very high-end vehicles before it spreads into high volume cars – example of Mercedes SL





- World premiere in January 2012 - Launch March 2012
- Aluminium and FRP detachable body components
- Weight advantage of approx. 110 kg versus conv. steel design

Source: Daimler AG, Dr. Lutz Storsberg, Mercedes-Benz Cars, Structural Symposium Bühler AG, Hamilton, Canada, October 1, 2013

Applications for structural high integrity aluminum die castings

BIW structure Mercedes SL

34 Vacuum-HPDC parts

2 low pressure diecasting parts

Total weight of castings:110 kg

Source: Daimler AG, Dr. Lutz Storsberg, Mercedes-Benz Cars, Structural Symposium Bühler AG, Hamilton, Canada, October 1, 2013

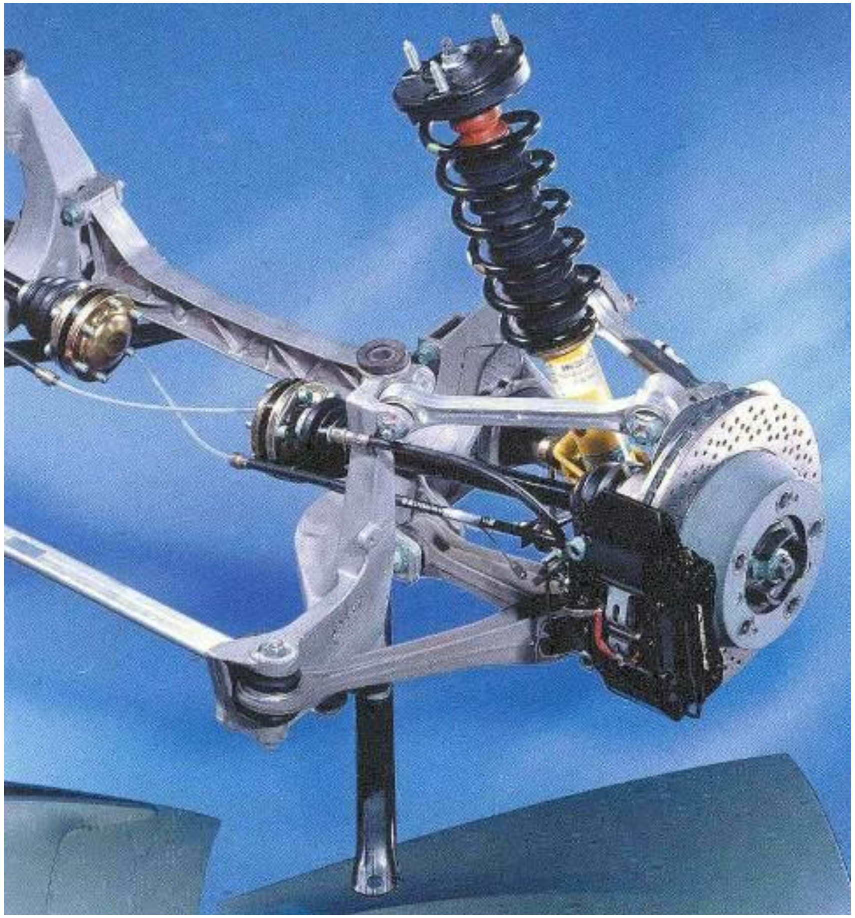
Applications for structural high integrity aluminum die castings

Suspension parts

Porsche
Side beam member, rear axle

Longitudinal Beam

Alloy: Aural-3
Heat Treatment: Auraltherm™



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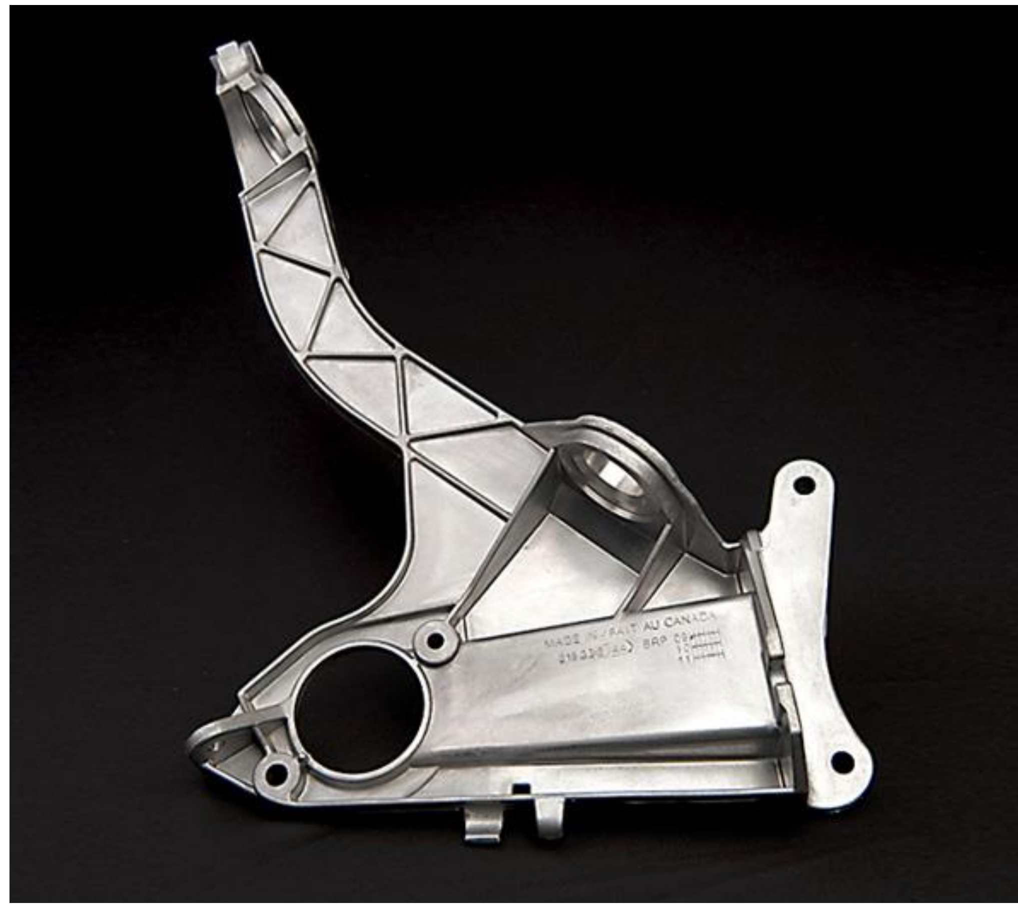
Applications for structural high integrity aluminum die castings

Yamaha motorbike main and seat frame in Silafont™ 36 in T5

Applications for structural high integrity aluminum die castings

- BRP part produced by AMT in Silafont 36 / Aural-2
- replaces two gravity cast parts.
- Significant reduction in machining costs

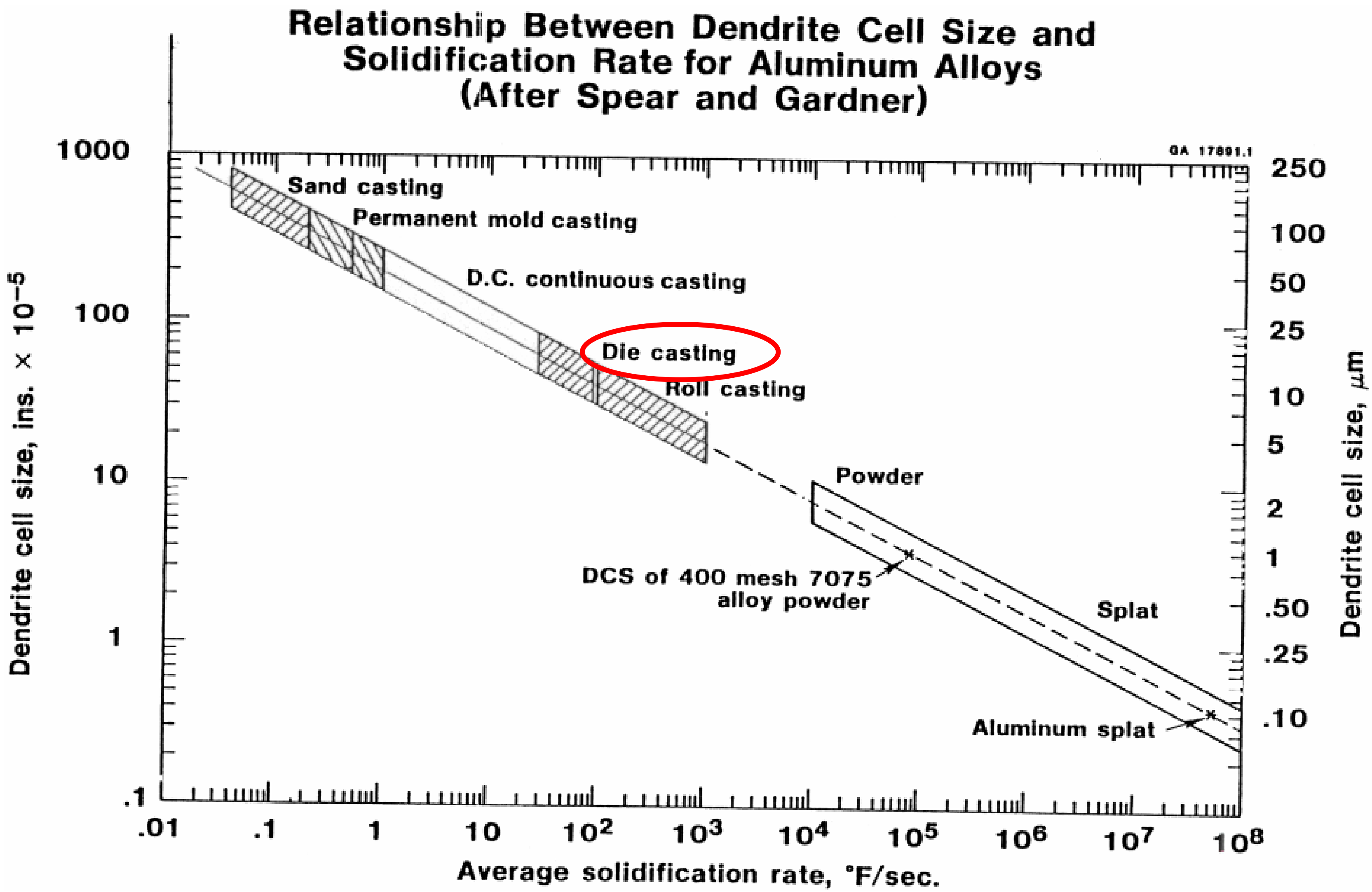


Why High Pressure Die Casting?

Advantages

- Lowest Cost mass production casting process
- Very easy to automate
- Very high dimensional tolerances are possible
- Very thin walls / complex shapes possible
- Excellent surface finish
- Very high solidification rate
- “Skin” effect can give very good fatigue performance

The effect of freezing rates



High Pressure Die Casting

Disadvantages

- Very expensive tooling - need high volumes to justify
- Usually high amounts of porosity / defects and
- Typical HPDC alloys are secondary (high Fe alloys – to avoid die soldering)

➢ which do not allow good mechanical properties and fatigue life!

Fatigue life of Al castings*

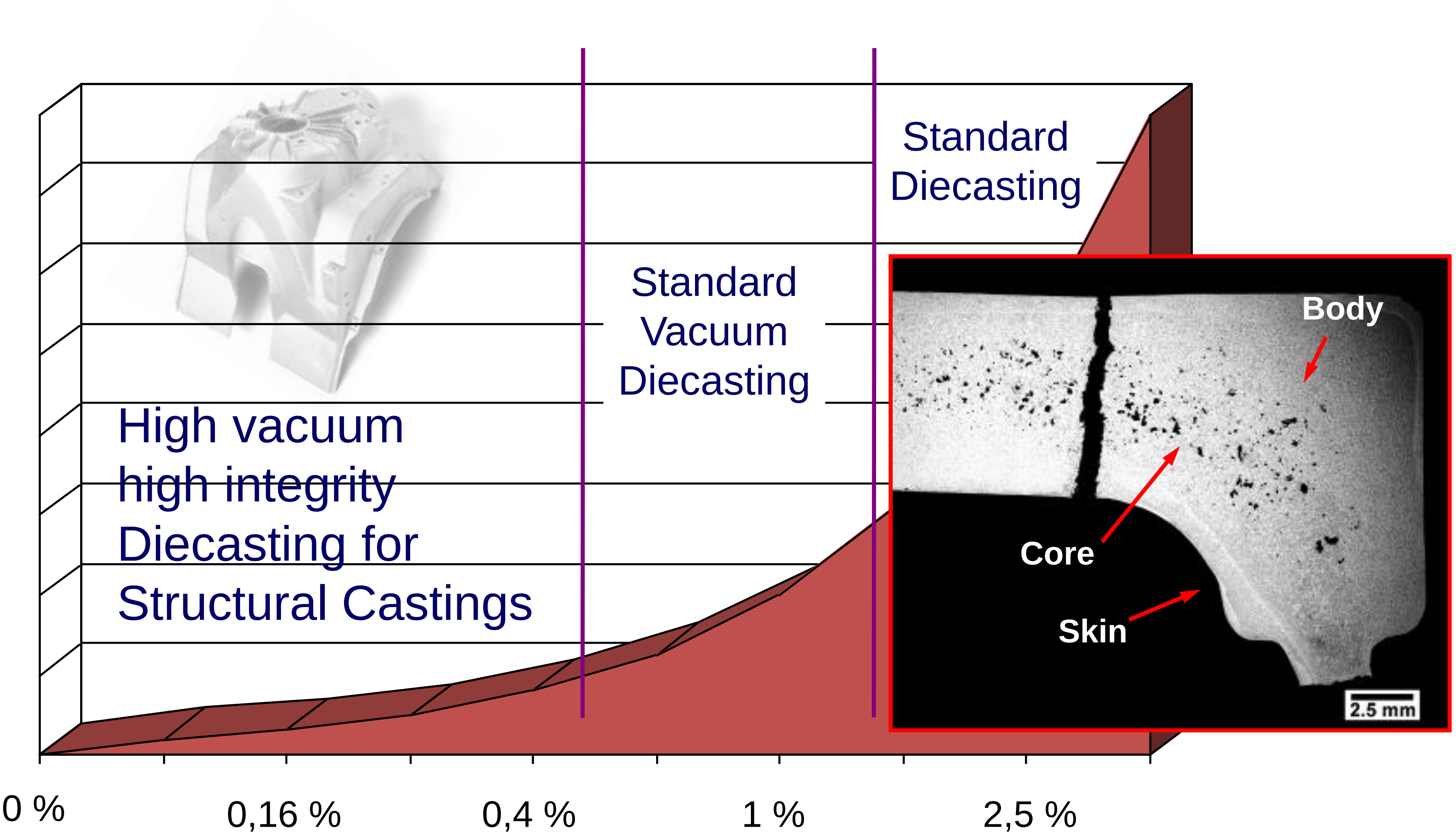
- Strongly depends on casting defects and inhomogeinities – those strongly reduce fatigue crack initiation life
- Absent of defects, crack initiation occurs at fatigue sensitive microstructural constituents.

➢ Porosity
➢ Oxides
➢ (Si, Fe, etc. rich) intermetallic particles
➢ …

- Maximum defect size determines fatigue life

*) See also Modern Casting Article "Predicting the Fatigue Life of Aluminum Castings (May 2013) based on research paper 13-1342 from P. Jones & Q. Wang (GM) presented at the 2013 AFS Metalcasting Congress

Porosity in High Pressure Die Casting



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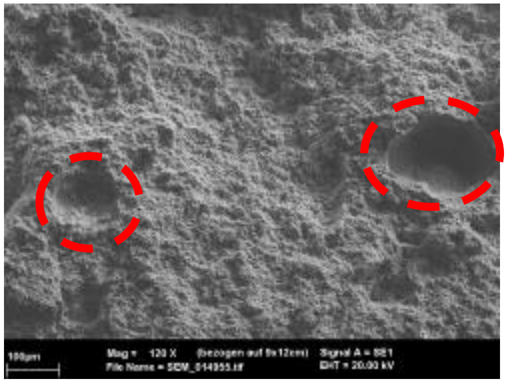
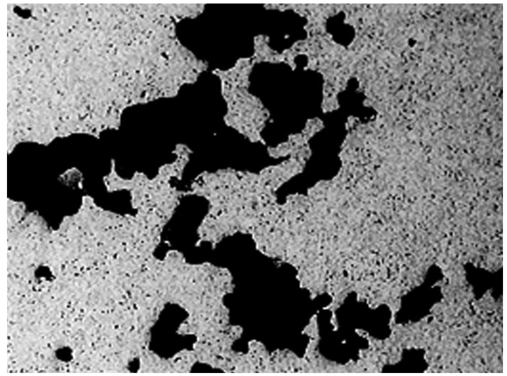
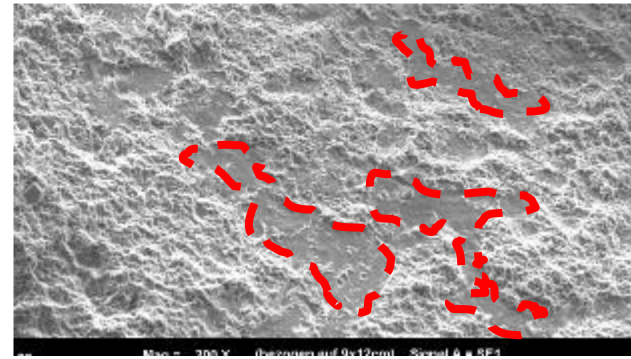
Typical Diecasting Defects

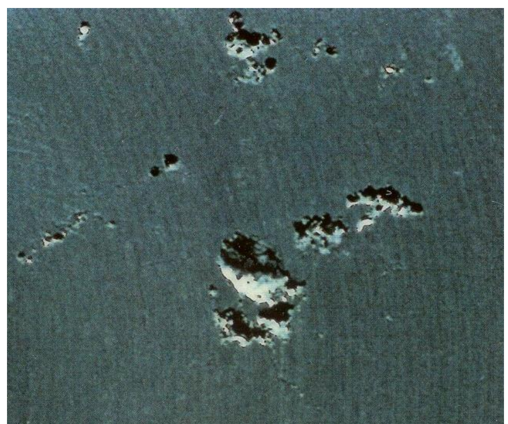




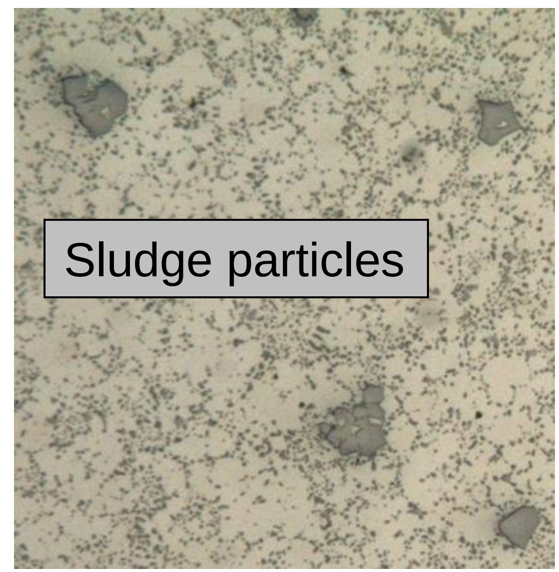


Oxide inclusions

Gas porosity



Shrinkage porosity

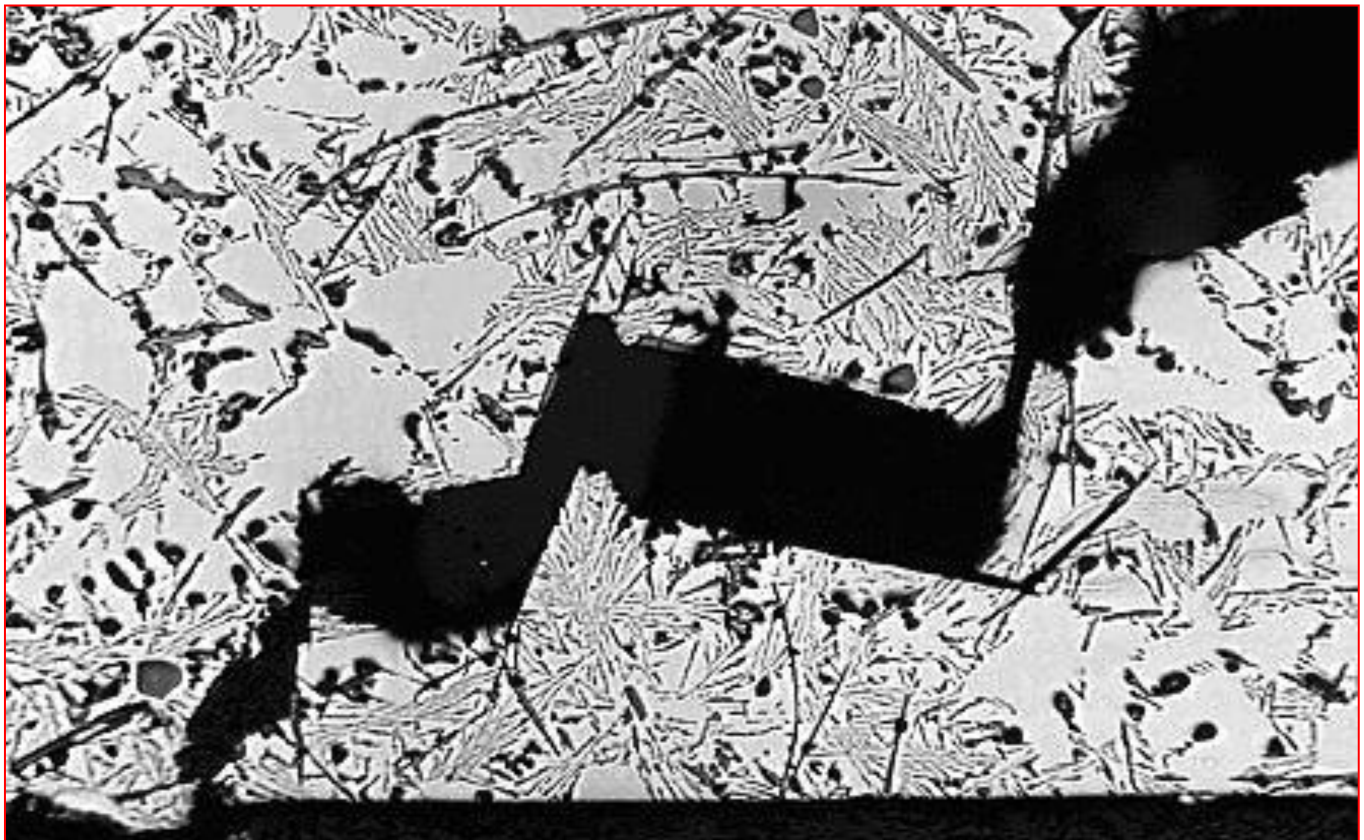


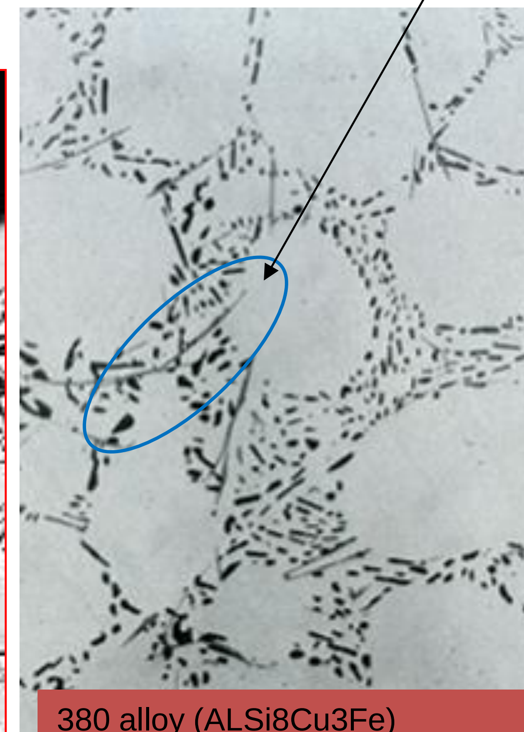
Sludge particles

Other inclusions, etc.

Al_5FeSi NEEDLE-LIKE PHASE

Very high Fe:
An extreme example





380 alloy (ALSi8Cu3Fe)

Requirements for structural high integrity aluminum die castings

- Weight reduction
- Part integration
- High mechanical properties
- Crash performance
- Corrosion resistance
- Weldable / heat treatable (blisters!)
- Surface quality (esp. joining / contact surfaces)
- Distortion free with tight tolerances
- Pressure tightness
- …

Example mechanical properties:

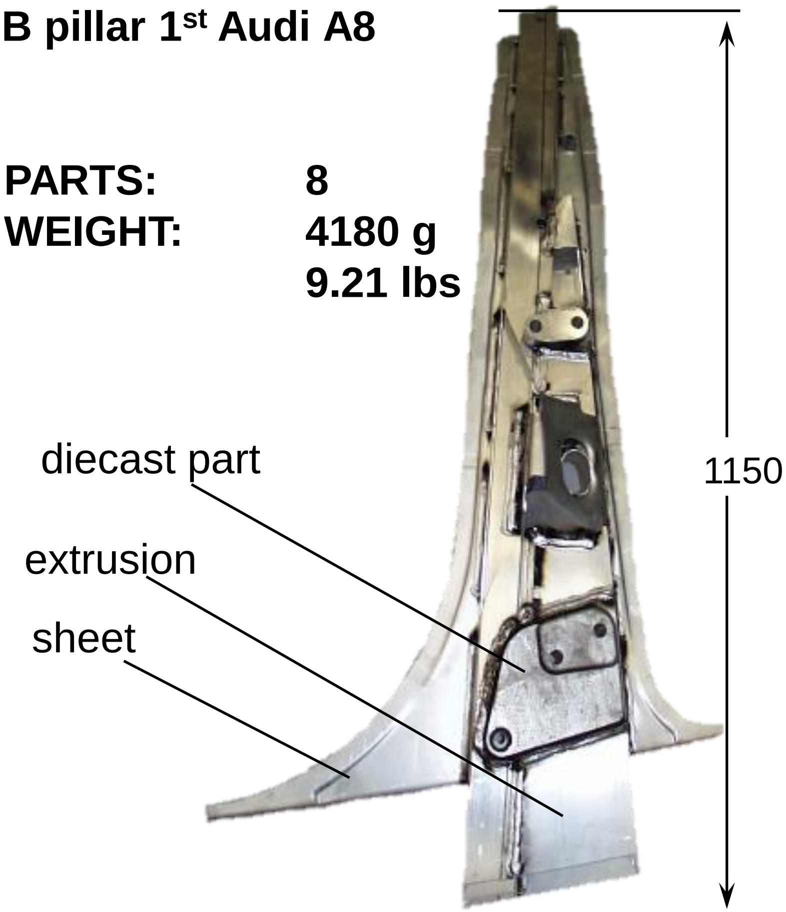
YS	100/120MPa
UTS	180MPa
El	≥10%
Bending angle	≥50/60° (d=2mm)

Requirements for structural high integrity aluminum die castings

Example: Part integration and weight reduction

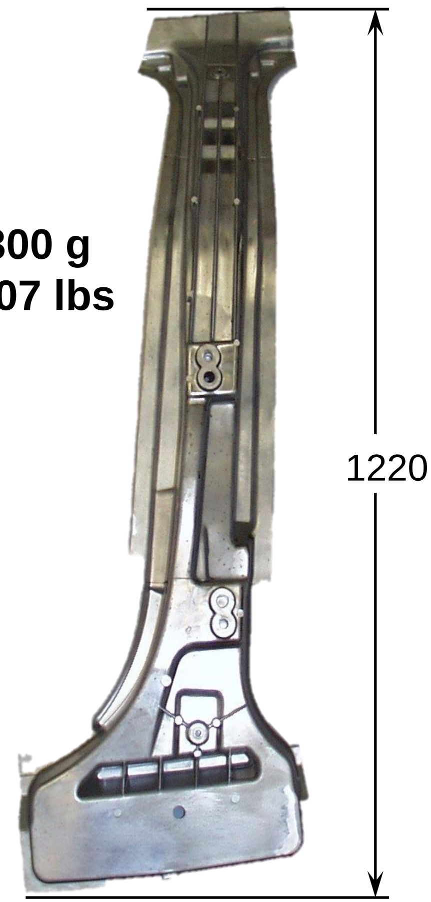
B pillar 1st Audi A8

PARTS: **8**
WEIGHT: **4180 g**
9.21 lbs



B pillar Audi A2

PARTS: **1**
WEIGHT: **2300 g**
5.07 lbs



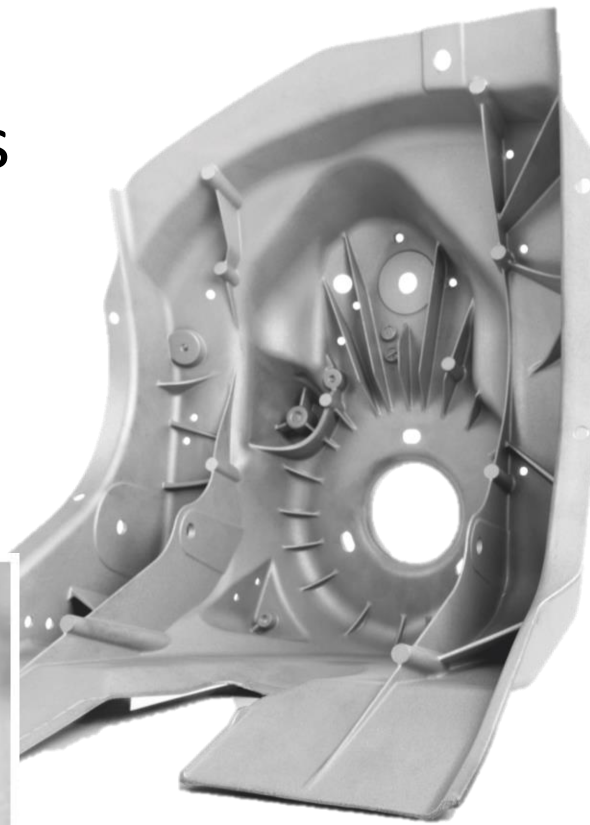
Requirements for structural high integrity aluminum die castings

Example: Part integration and weight reduction

BMW X5 shock tower

- Very low level of entrapped gasses allowing for subsequent heat treatment
- BMW part is 40% weight of traditional steel part and comparably priced.
- High strength and ductility

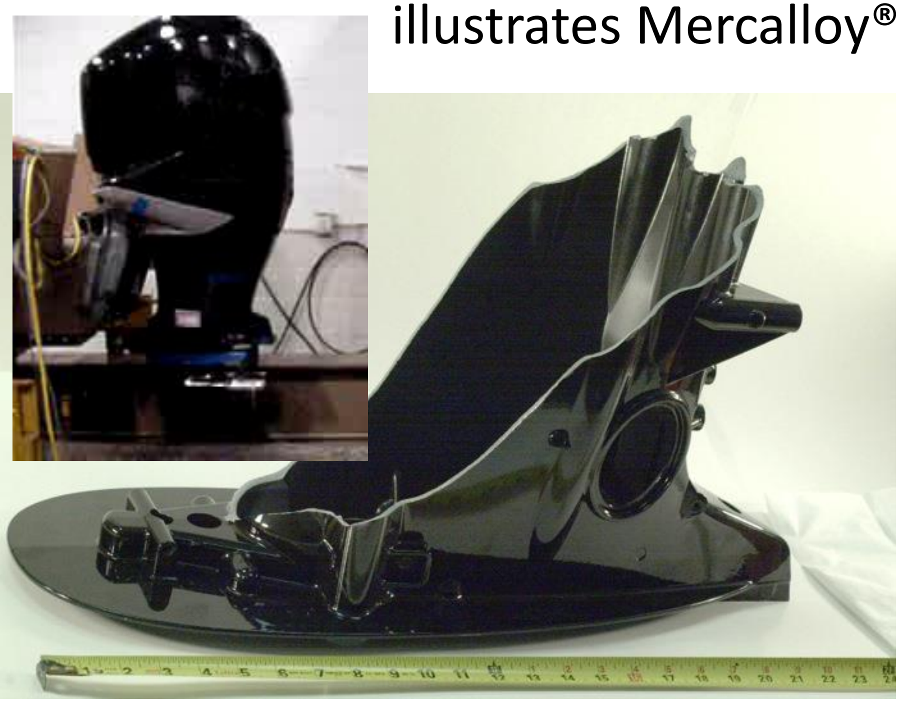
Before: required 5 welded steel stampings weighing 18 lbs.



After: One piece, 7.2 pounds or 40% of traditional steel fender well

Requirements for structural high integrity aluminum diecastings

Crash performance: Static loading of 25 Ib. drive shaft housings illustrates Mercalloy®'s far superior energy absorption

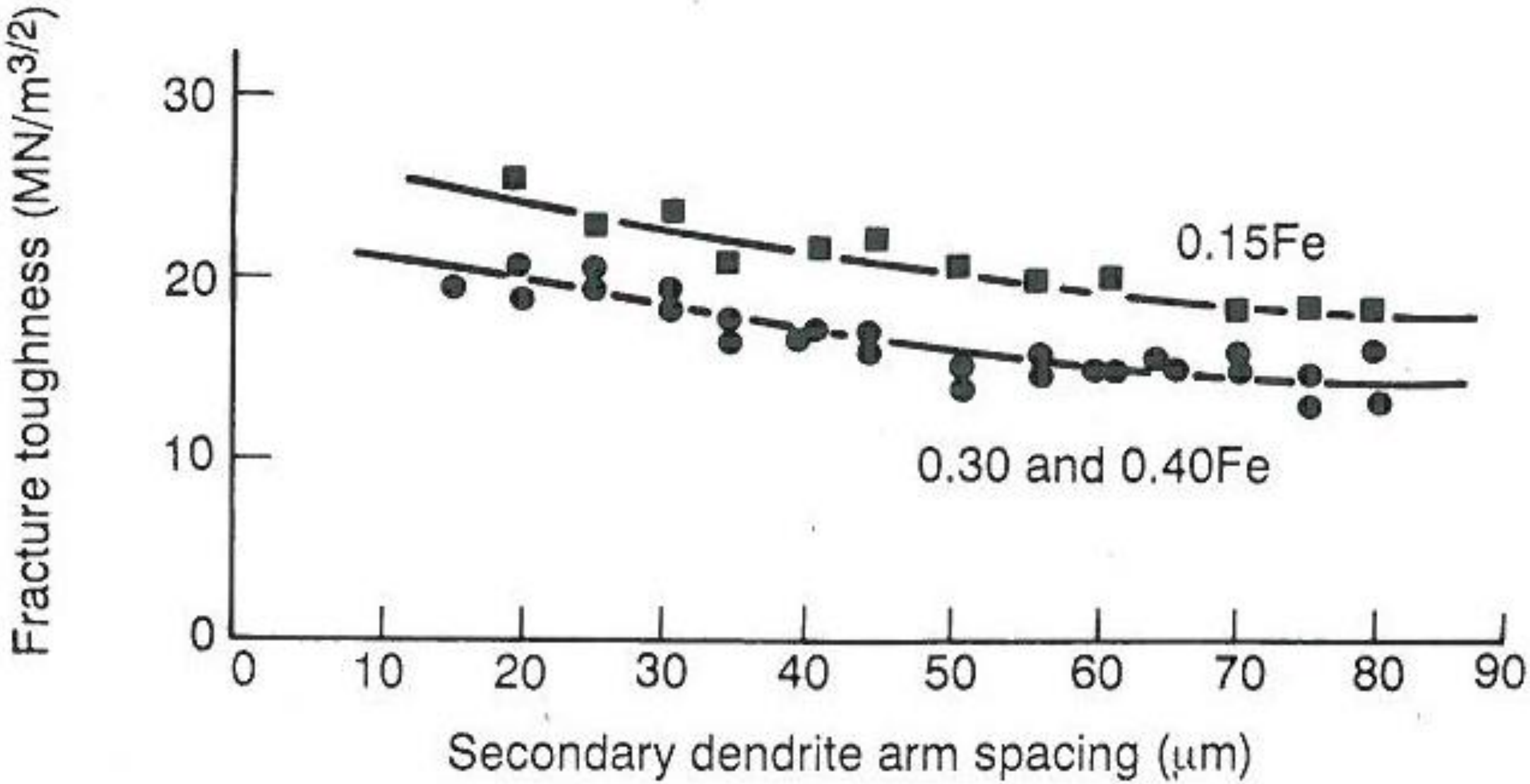


Alloy: XK 360 with 1.3% max Fe
One sudden, fast-propagating failure mode [in less than 100 milliseconds]

Alloy: **Mercalloy® 367** - Crush-like failure never splitting completely – Honorable Mention in 2010 NADCA Casting of the Year Competition

Courtesy of MERCURY MARINE, a division of BRUNSWICK CORPORATION

Fracture Toughness depends on Fe content & dendrite arm spacing



Source: John Campbell: CASTING [1991 edition], page 266, figure 8.3.

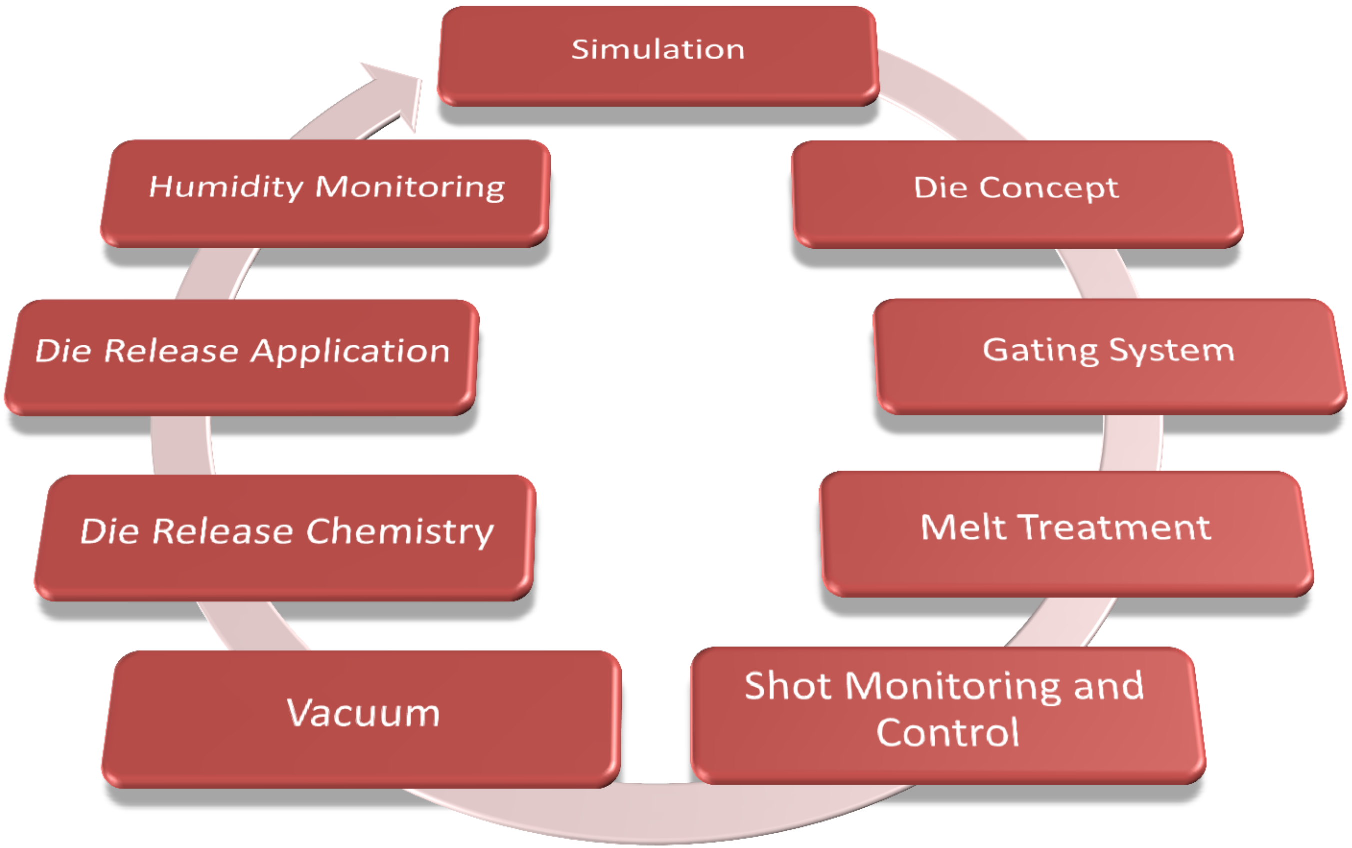
Factors affecting die-casting quality

- Alloy composition and impurities
- Metal quality (oxides, hydrogen content, sludge, dross, other inclusions)
- Metal temperature, treatment, transfer, delivery to shot sleeve
- Die-casting machine (size, type, equipment)
  - Clamp/platen: clamp pressure/platen programmable
  - Shot end: shot speeds/profile, pressure, closed loop control
- Monitoring/Control system:
  - for all critical process parameters / full machine diagnostics
  - graphical user interface (HMI) provide SPC

Factors affecting die-casting quality

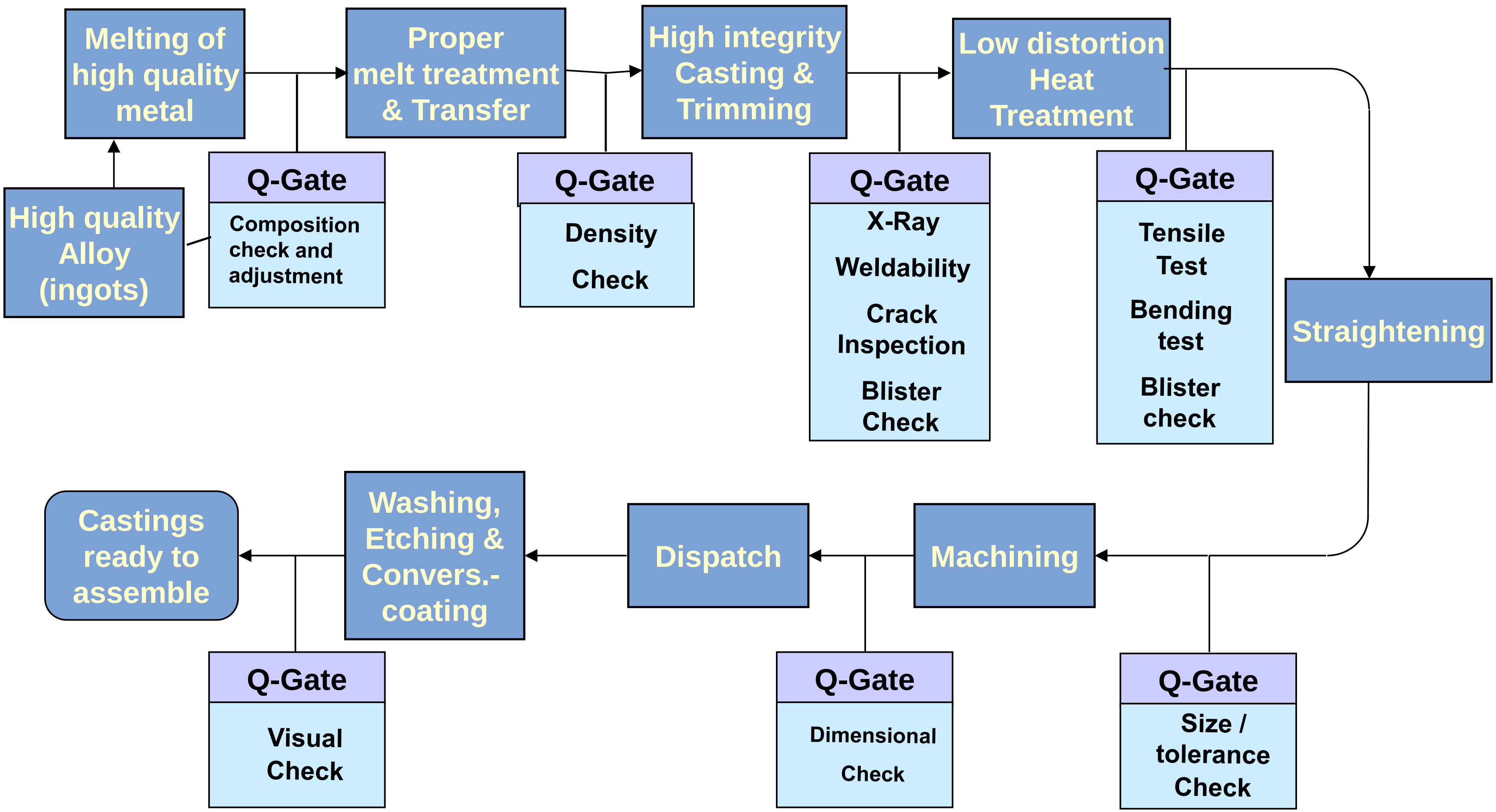
- Shot tooling:
  - Cold chamber (proper size, temperature control, etc.)
  - Shot tip (with ring to create seal and internal cooling)
  - Plunger lube (type and application)
- Die-casting dies / gating design / overflow design
- Part design (wall thickness, changes, etc.)
- Die temperature
- Lubricant type, application and efficiency
- Vacuum system: level & type / cavity pressure / control
- Part extraction and quench system
- Trimming
- Heat treatment and other process steps

A „holistic“ approach is needed!
Complete Die Casting Process Technology



Courtesy of Magna BDW GmbH & Co. KG, Markt Schwaben, Germany

Typical process chain for structural high integrity die castings



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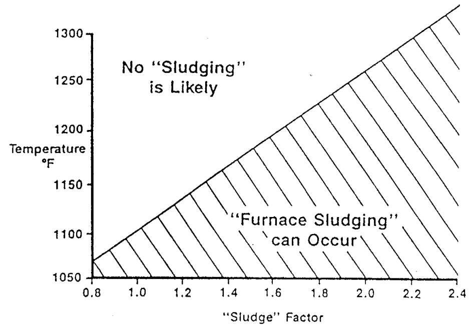
Melting, melt treatment & transfer

Items to pay attention to:

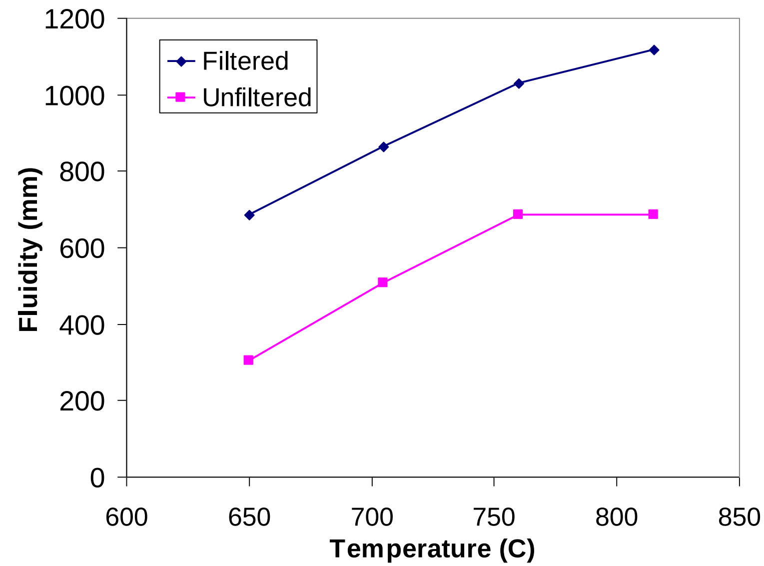
- Oxides
- Hydrogen
- Sludge
- Dross
- Other inclusions

"Sludge" Factor = (1 × %Fe) + (2 × %Mn) + (3 × %Cr)



Measures to be taken:

- Proper temperature control of melt
- Avoiding excessive turbulences/splashing
- Degassing
- Fluxing
- Filtering
- Settling



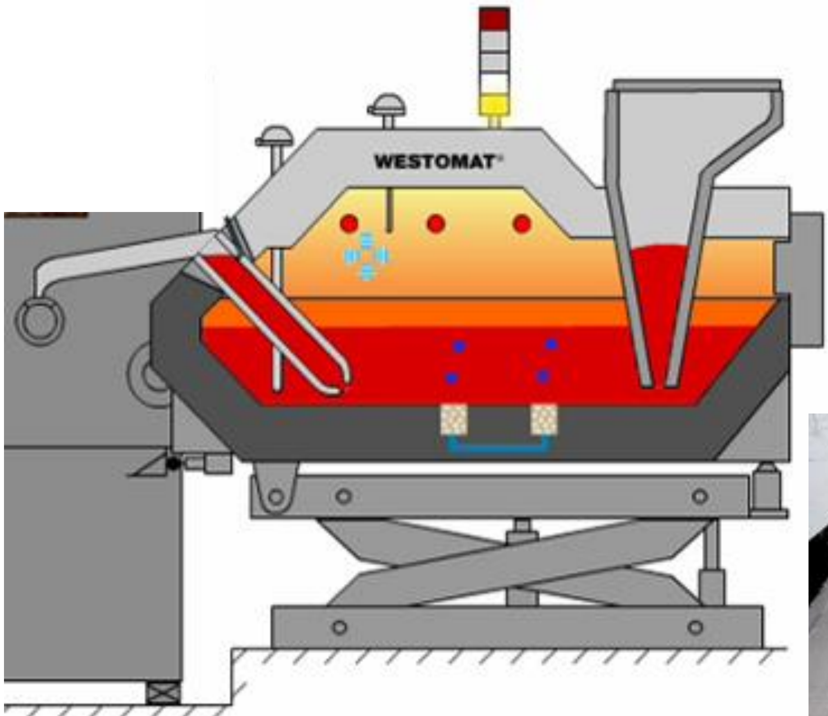
Melting, melt treatment & transfer

Any metal “waterfall” in the metal transfer will generate oxide inclusions!

Melting, melt treatment & transfer

Examples: StrikoWestofen dosing furnace

Pressurized dosing furnace with transfer launder and integrated porous plugs for continuous degassing.



Støtek DosoTherm

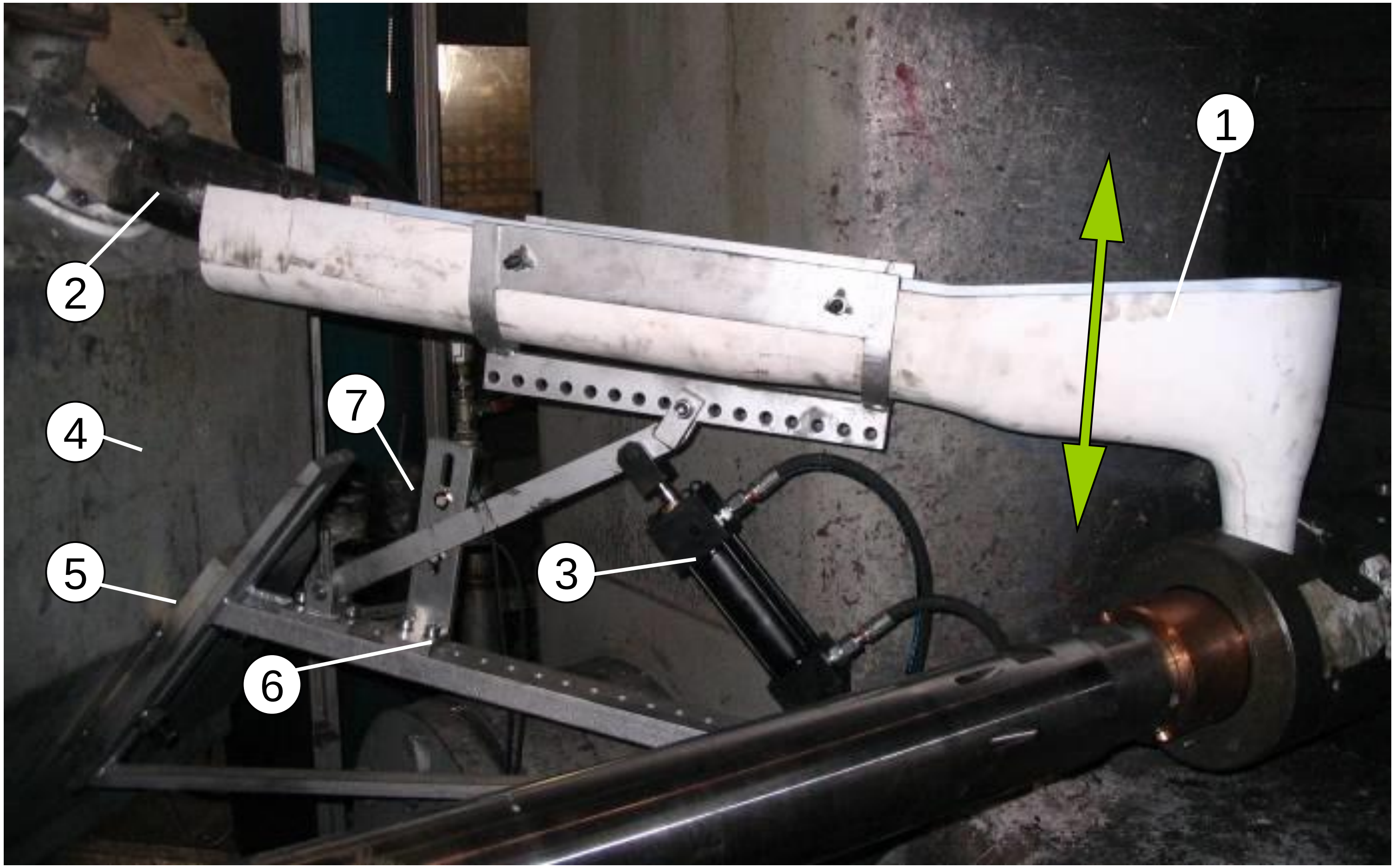
Un-pressurized dosing furnace with integrated metal filter, featuring Støtek patented pump technology.

Melting, melt treatment & transfer

Melt transfer into the shot sleeve: Swivel Launder

BDW technologies

…has developed the design of the launder and the swivel jig in order to achieve a high melt quality level for high integrity diecastings.

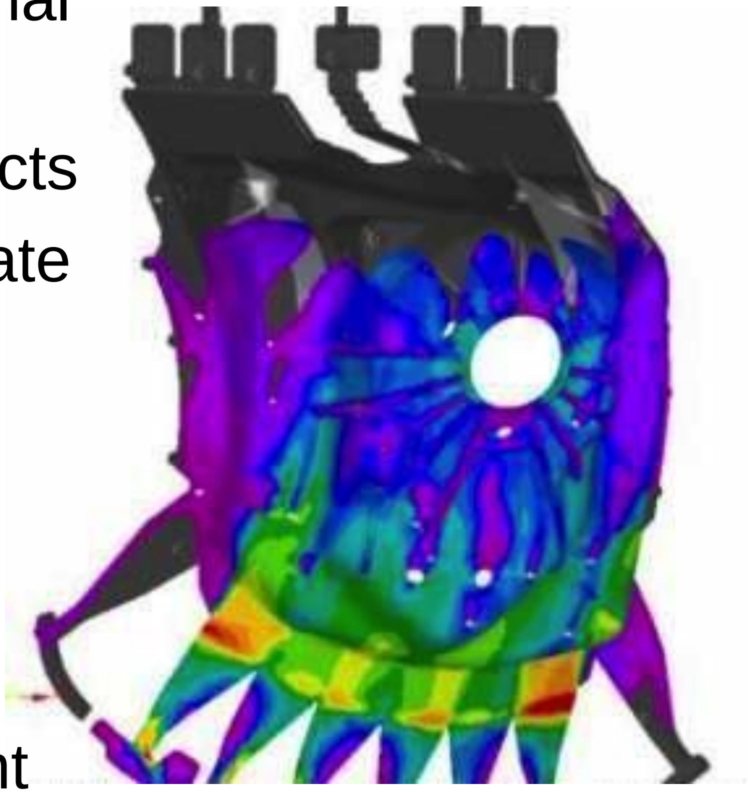


- Ceramic launder (1); Furnace spout (2); Hydraulic cylinder (3); Holding furnace (4); Swivel jig height adjustment (5); Mechanical swivel jig (6); Position sensors (7)

Courtesy of Magna BDW GmbH & Co. KG, Markt Schwaben, Germany

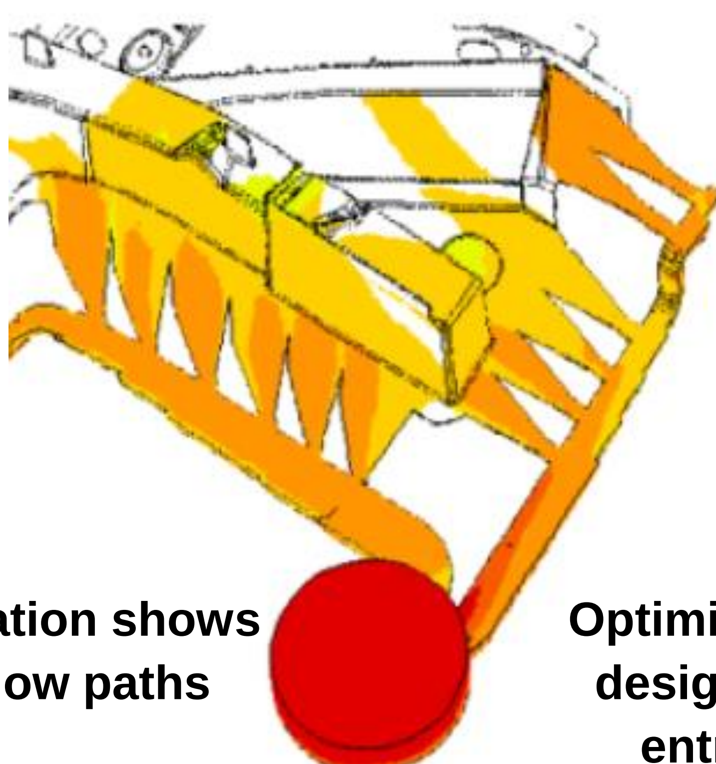
Product Development

- Component Design
  - Robust designs meet both functional & manufacturing requirements …
  - …and lead to higher quality products
  - Design engineers should collaborate with casting engineers in the early stages of product development
- Gating and Die Design
  - Simulation is a must
  - Gating and overflow (including vacuum gating) design is important
  - Utilization of gates along nearly entire front edge of part

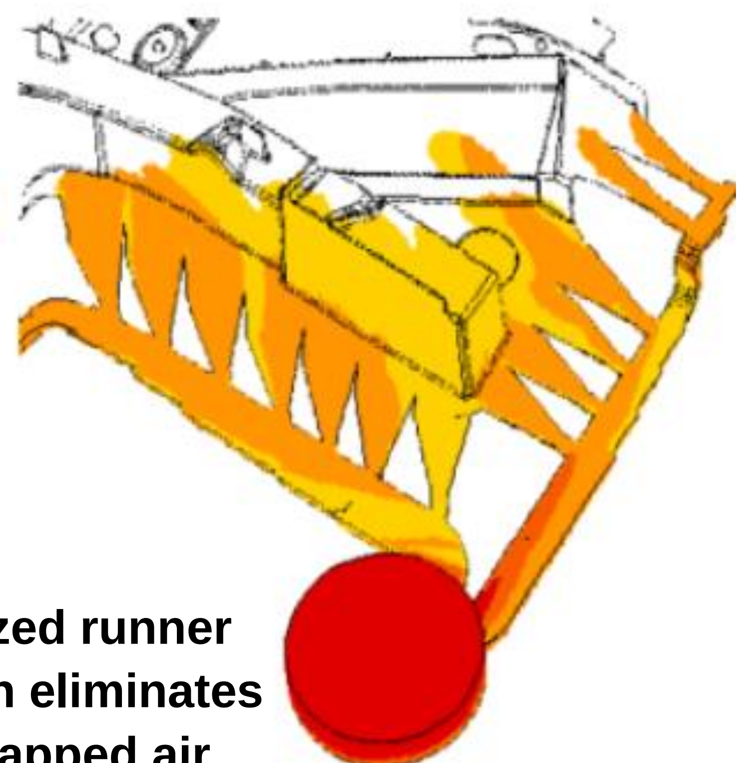


Numerical simulation

- Runner design optimization - provide a continuous flow path into and through the part
- Casting defects prediction
- Temperature distribution at surface of the cavity
- Velocity field in the liquid metal during die filling



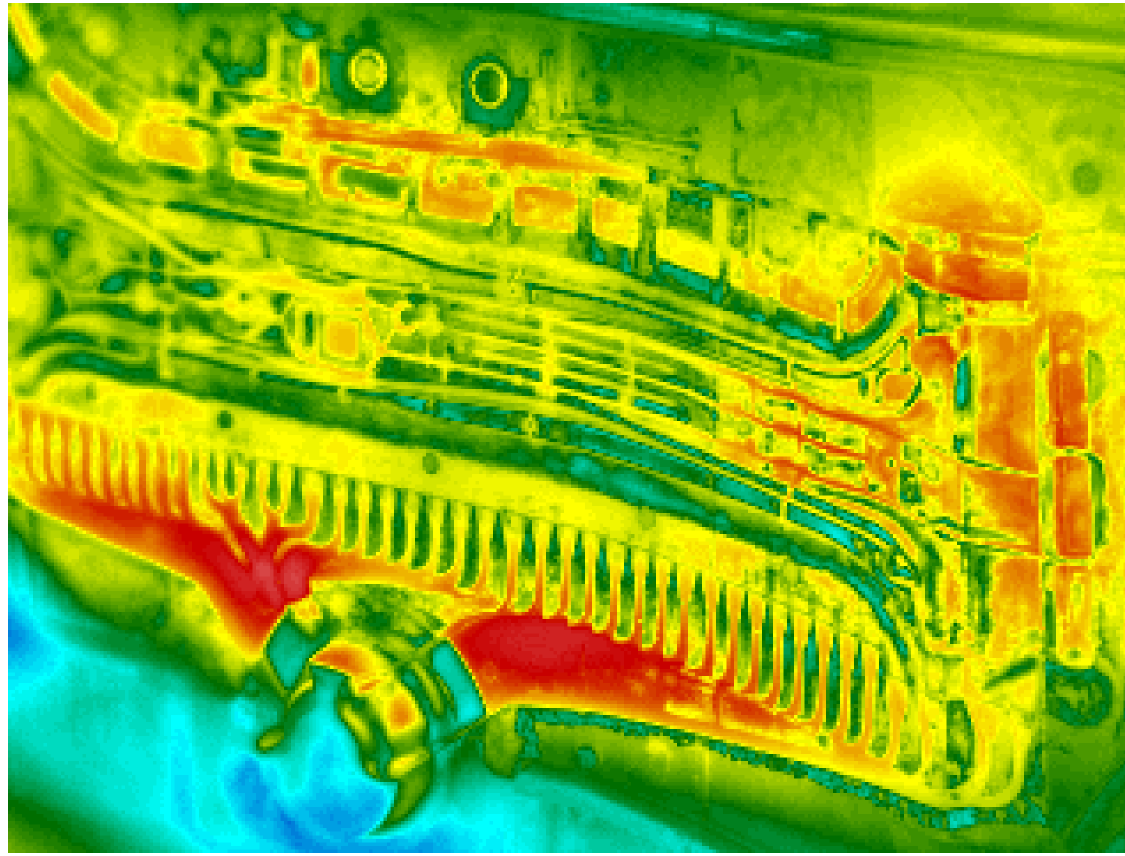
1st flow simulation shows Overlapping flow paths



Optimized runner design eliminates entrapped air

Die design, thermal balance and process control

Process Control – Die Temperature



- Real-time cycle-to-cycle die surface temperature monitoring with cycle-to-cycle adaptive control
- Read and store the die skin temperature at each cycle of the machine. It can monitor the die (outlined by laser pointers) with an IR camera mounted in a protective stainless steel case.
- High/Low limits can be set to alert the robot or unloading device to segregate a casting with an out of spec reading.

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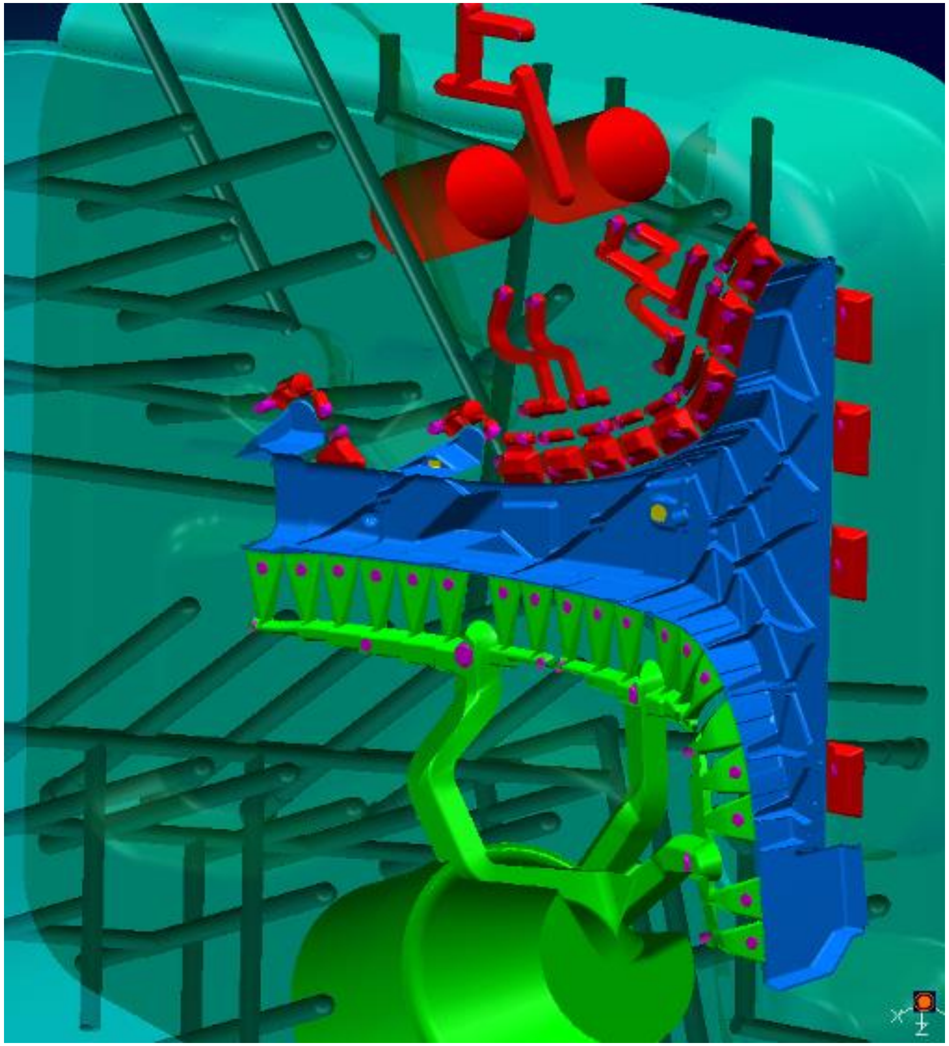
Courtesy of Visi-Trak Worldwide, LLC
https://www.diecasting.org/imis/scriptcontent/transactions/details.cfm?ID=13041

Die design and sealing



Moving half of die with gating system (green) and overflow/vacuum system (red)
Part contour (blue)
position of ejector pins (purple)
cooling/heating systems (dark green)

O-Rings are used extensively on tooling to prevent leaks

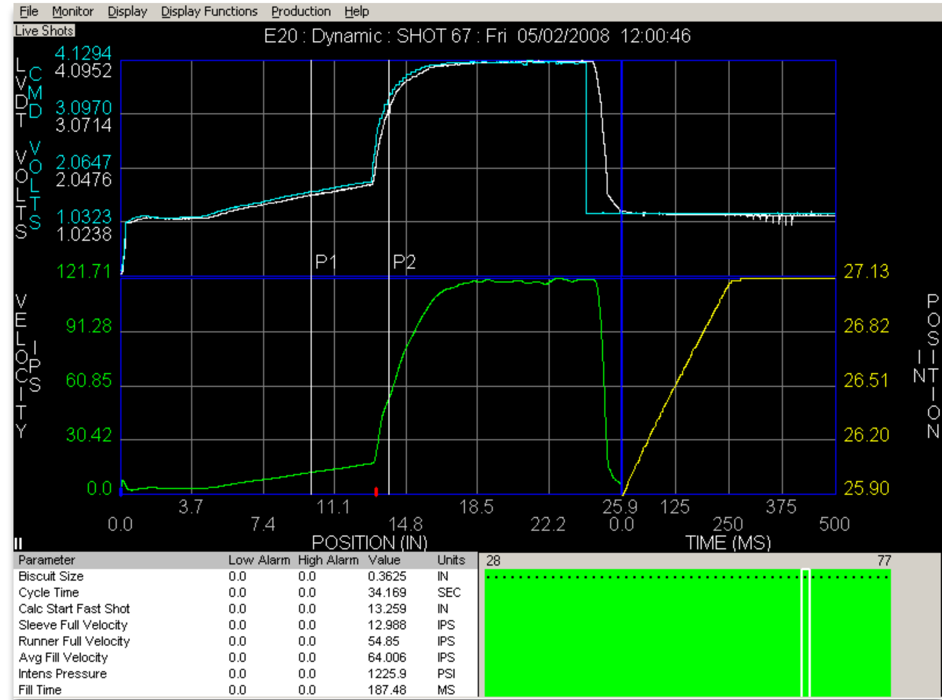
Thermal isolation plates are used to improve warm-up time

Multiple short hot oil zones are utilized to control die temperature

Shot monitoring and control

Visi-Trak Sure-Trak2 real time shot control system

- Real time control of shot velocity.
- Monitor key variables
- Derive key process parameters
- Casting characteristics are calculated and reported.



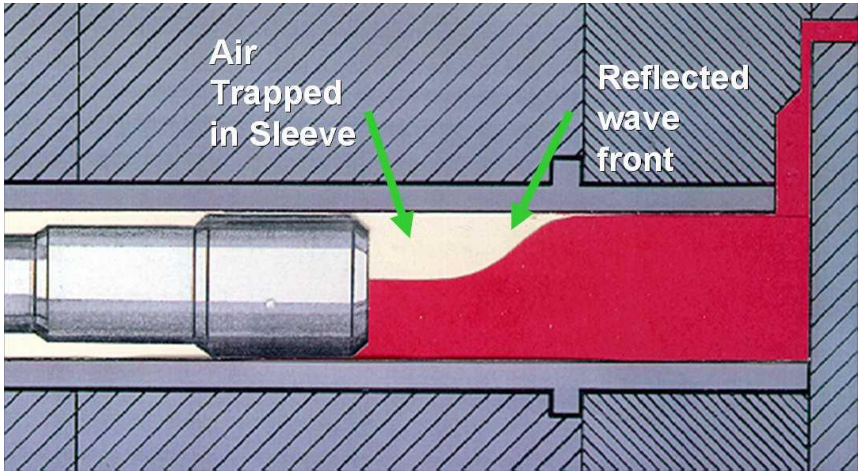
Produce Precise and Repeatable Injection Control

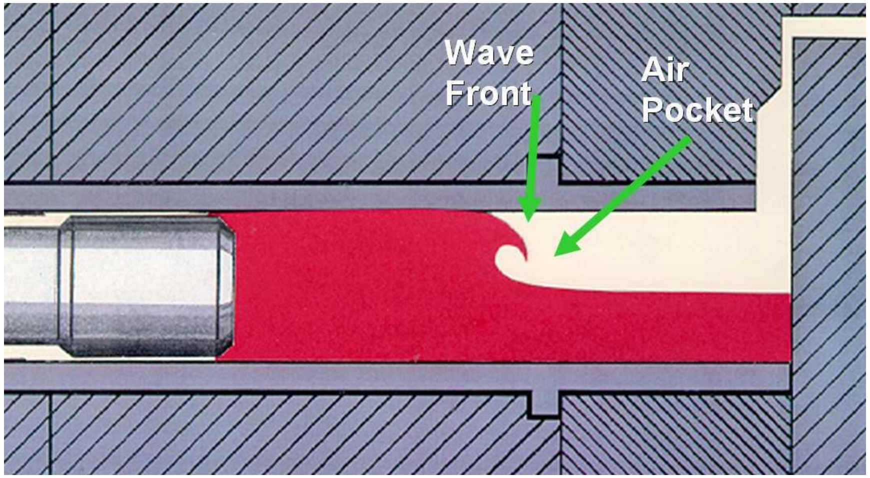
- Design experiments to understand relationships and causes of variation
- Accrue production information including scrap and downtime data

Courtesy of Visi-Trak Worldwide, LLC

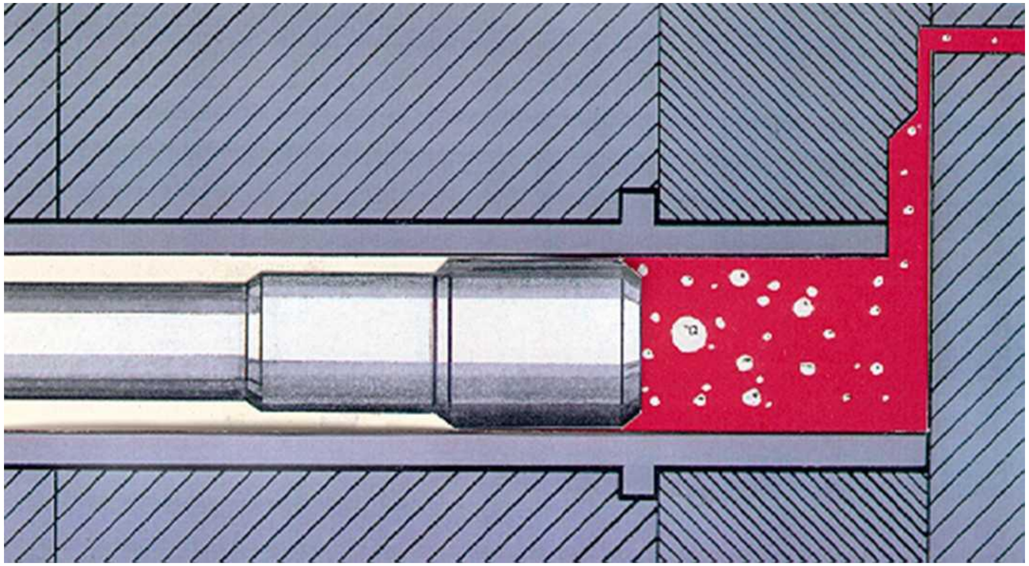
http://www.visi-trak.com/Media/Vann_Proof_withAd.pdf

Example: The slow shot



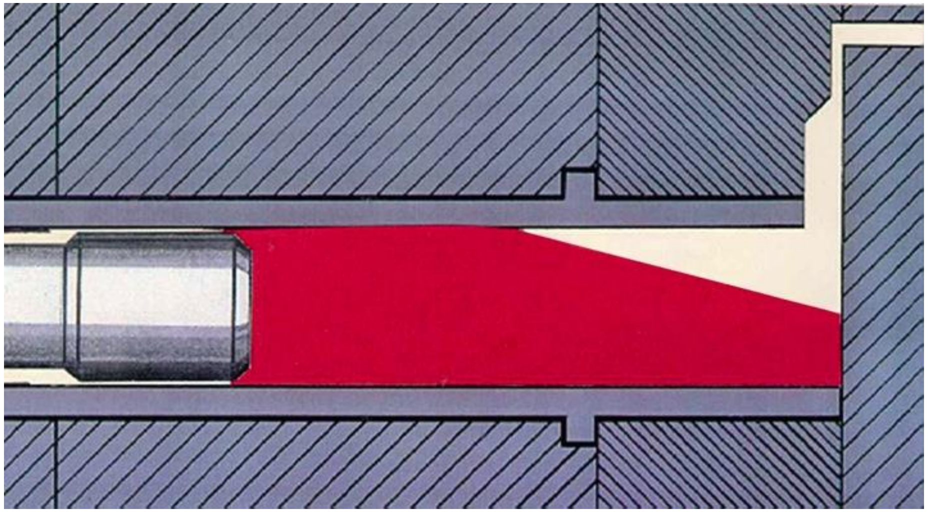


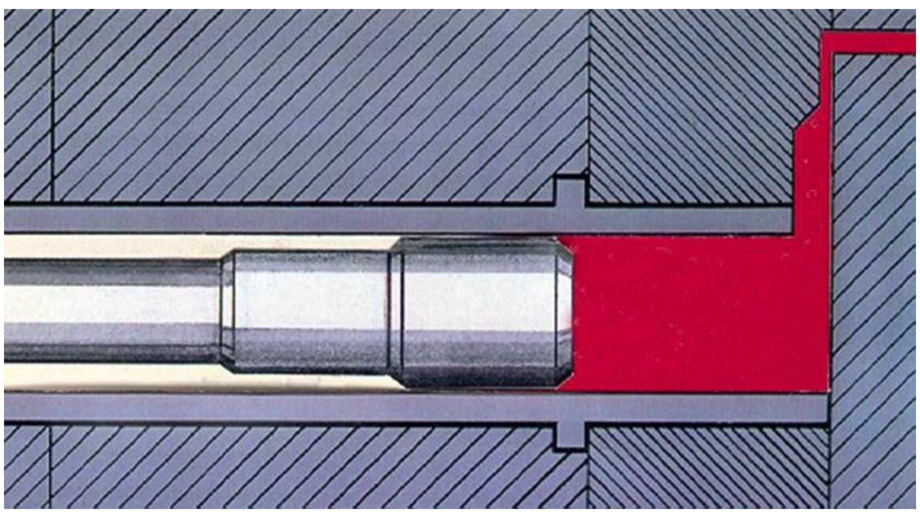
Too Slow?

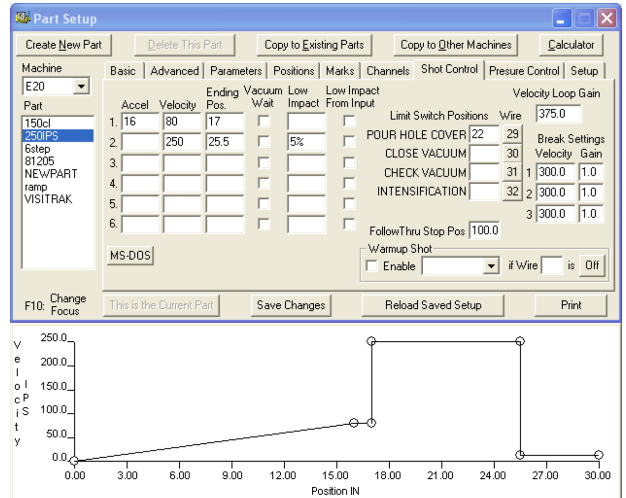


Too Fast?

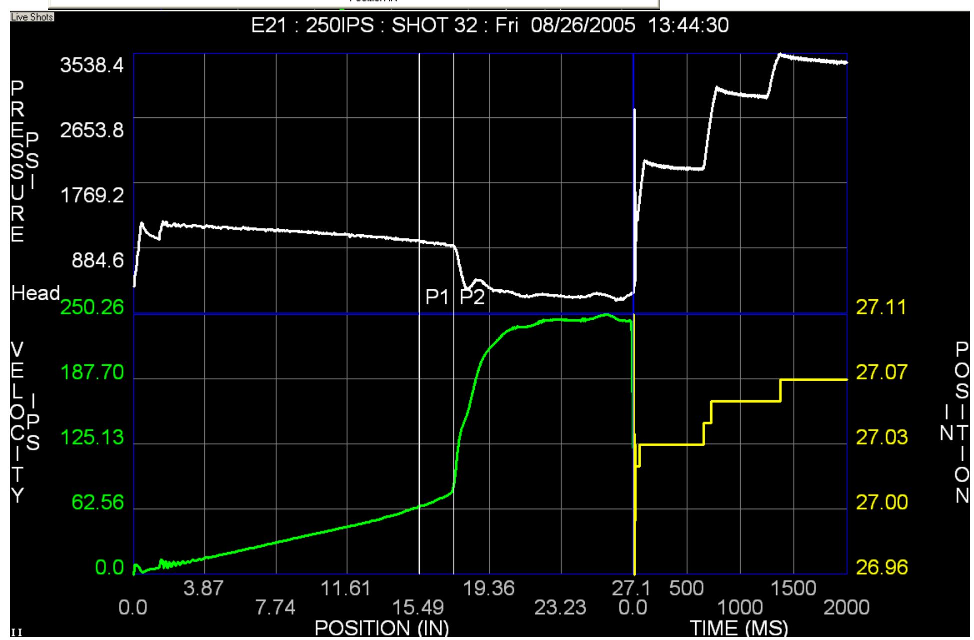
Example: The slow shot







Constant acceleration



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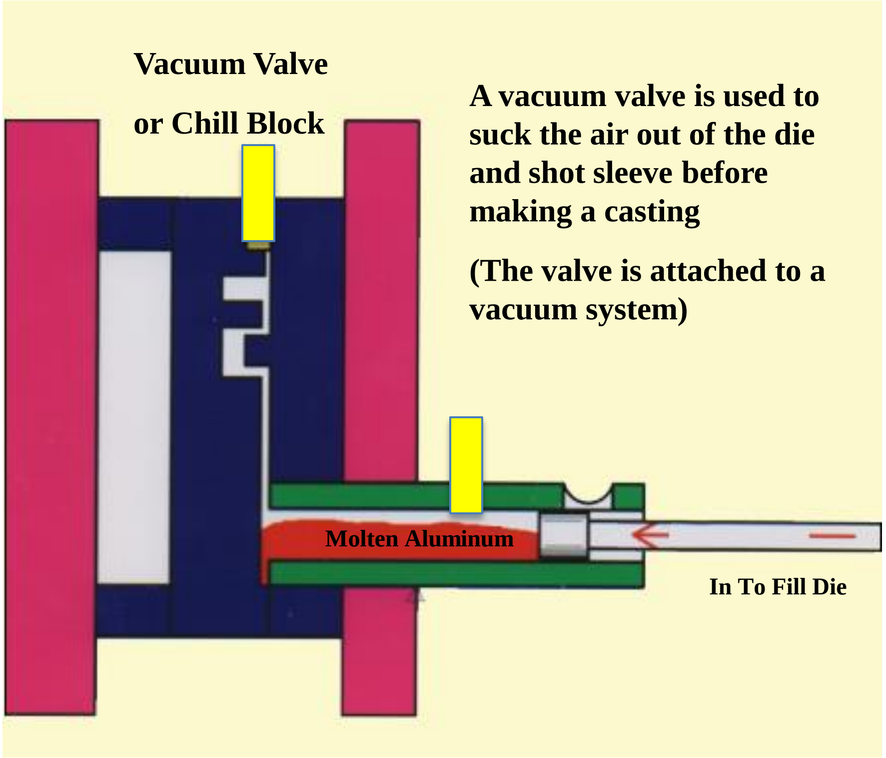
High vacuum die casting

Why vacuum diecasting:

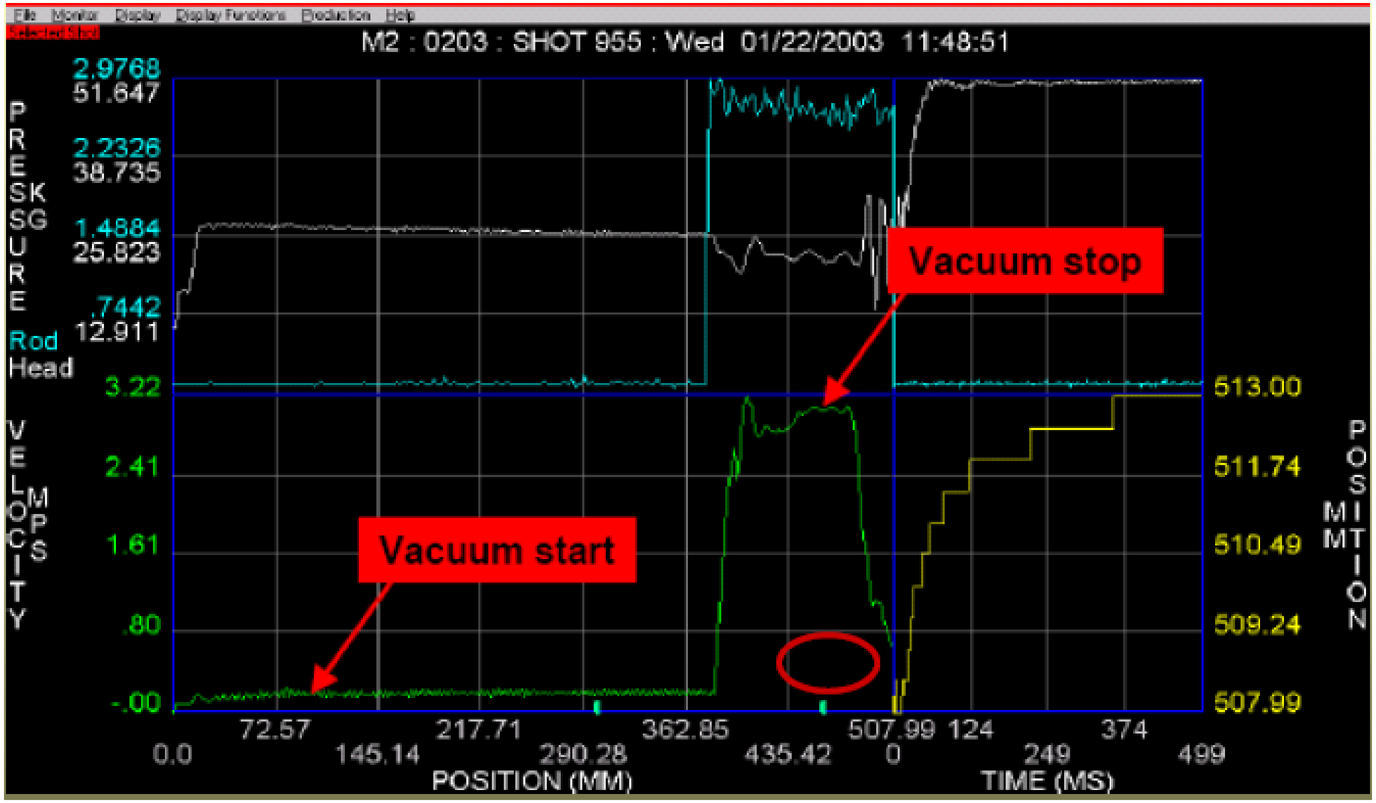


- Vacuum levels in the die cavity and shot sleeve below 50 millibar (ideally 2 stage vacuum system)
- Reduced cavity gases from the shot sleeve and die.
- Reduced porosity levels
- Reduced wall-thickness
- Ability to produce otherwise unsuitable parts in aluminium die casting

Main differences in equipment/processes are in: Vacuum valve type, vacuum control system, and vacuum monitoring approach

High vacuum die casting

Advanced monitoring techniques used to ensure proper vacuum level during the casting process, proper vacuum response & vacuum evacuation time and to detect vacuum leaks, vacuum blockages as well as excessive moisture



Courtesy of Visi-Trak Worldwide, LLC

High vacuum die casting – valve types

Mechanical Valves

Pros

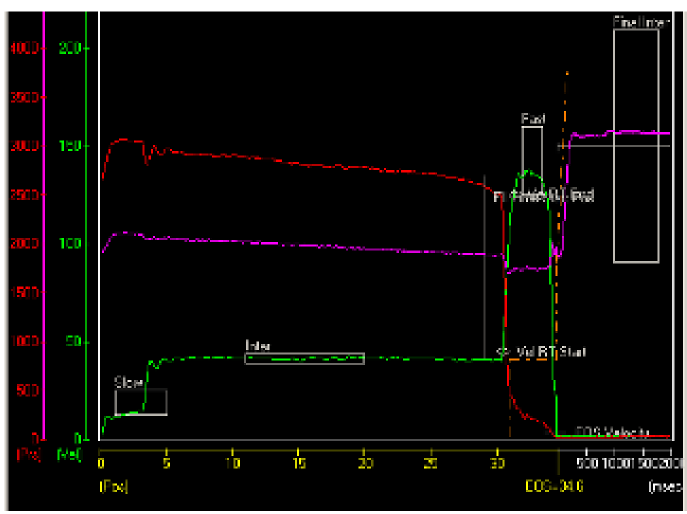
- Vacuum pulled through entire shot
- Does not require expensive controller
- Easy to remove and clean
- Biscuit size variation is not an issue

Cons

- Smaller valve cross sectional area – less vacuum
- Potential for metal to fill evacuation line if metal does not completely fill
- Valves are expensive

Suppliers

- Castool
- Provac/VDS
- Fondarex
- …



High vacuum die casting – valve types

Hydraulic/ Pneumatic vacuum valves

Pros

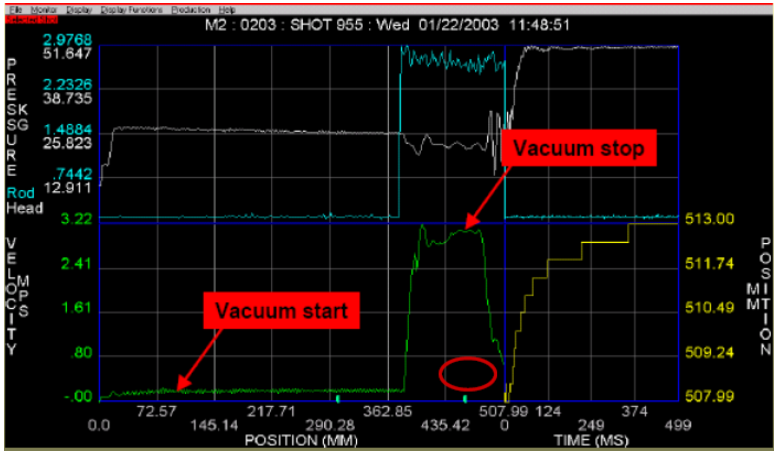
- Allows for larger valve (cross sectional area up to 400 square mm)
- Does not rely on metal to close valve (no issues with startup)
- Usually less down time (no metal shot into valve)

Cons

- Requires better control system
- drawing vacuum through entire shot is more difficult
- Does not account for biscuit variation (requires very stable process)
- Requires hydraulic cylinders within tool

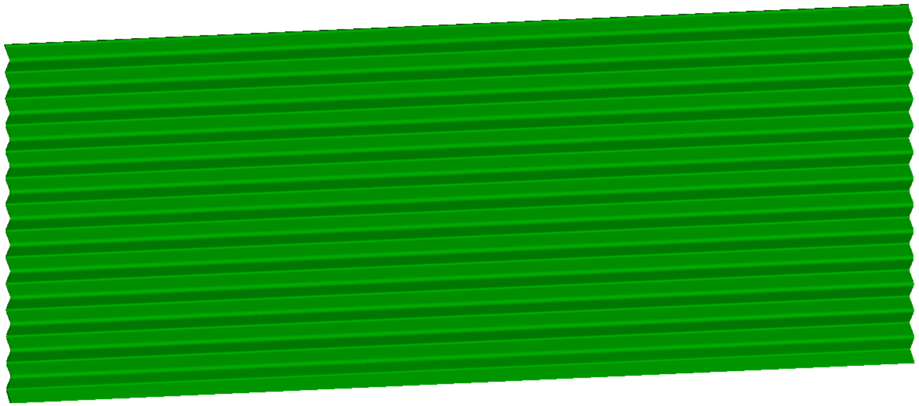
Suppliers

- MFT
- Buhler/ Prince
- …



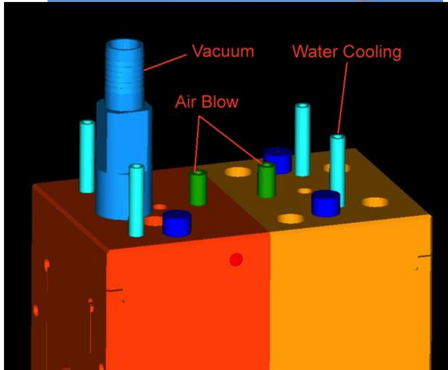
High vacuum die casting – valve types

New chill vent/valve approach CASTvac



Chill face: 100mm x 100mm
requires 80tonne locking force;
Increased by 4 times: 400mmx100mm
requires 320tonne locking force

3D (CASTvac)
4 times of chill face but
only 80tonne force



In production in Nissan Australia for 6 years

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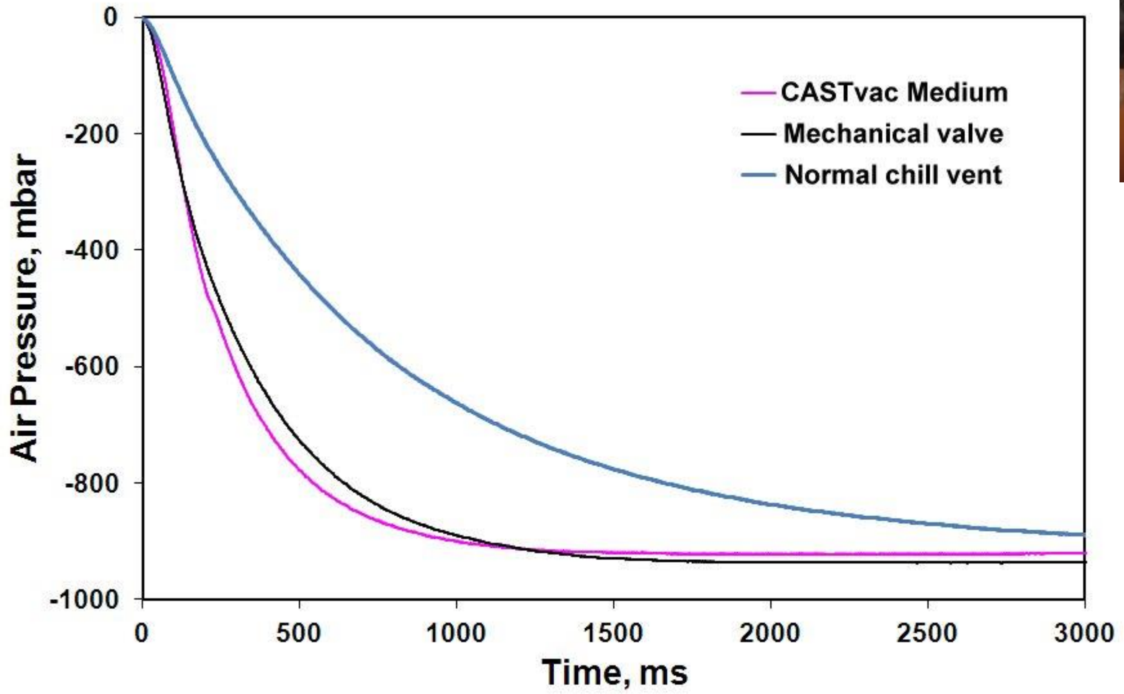
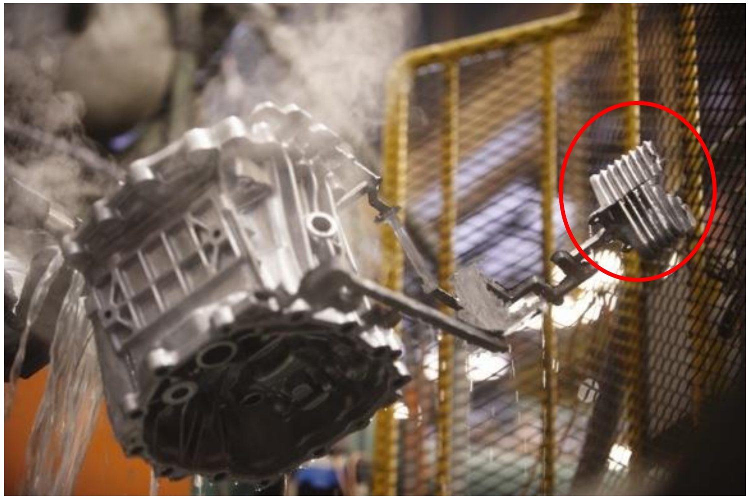
High vacuum die casting – valve types

Efficiency comparison with bench test





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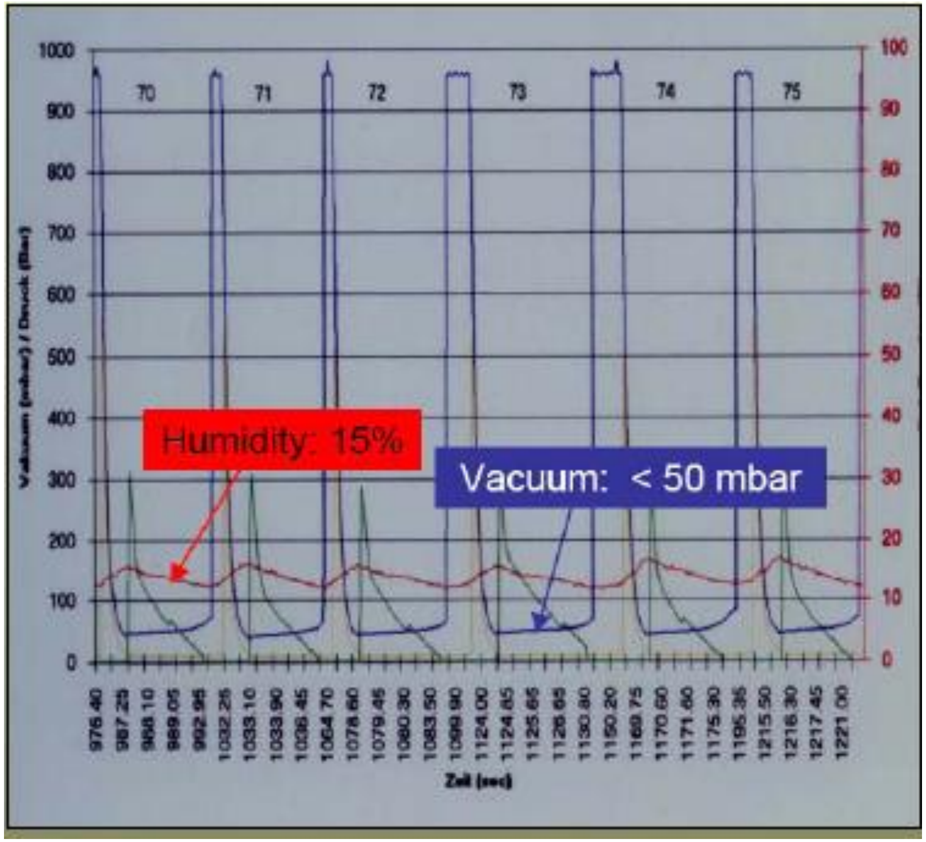
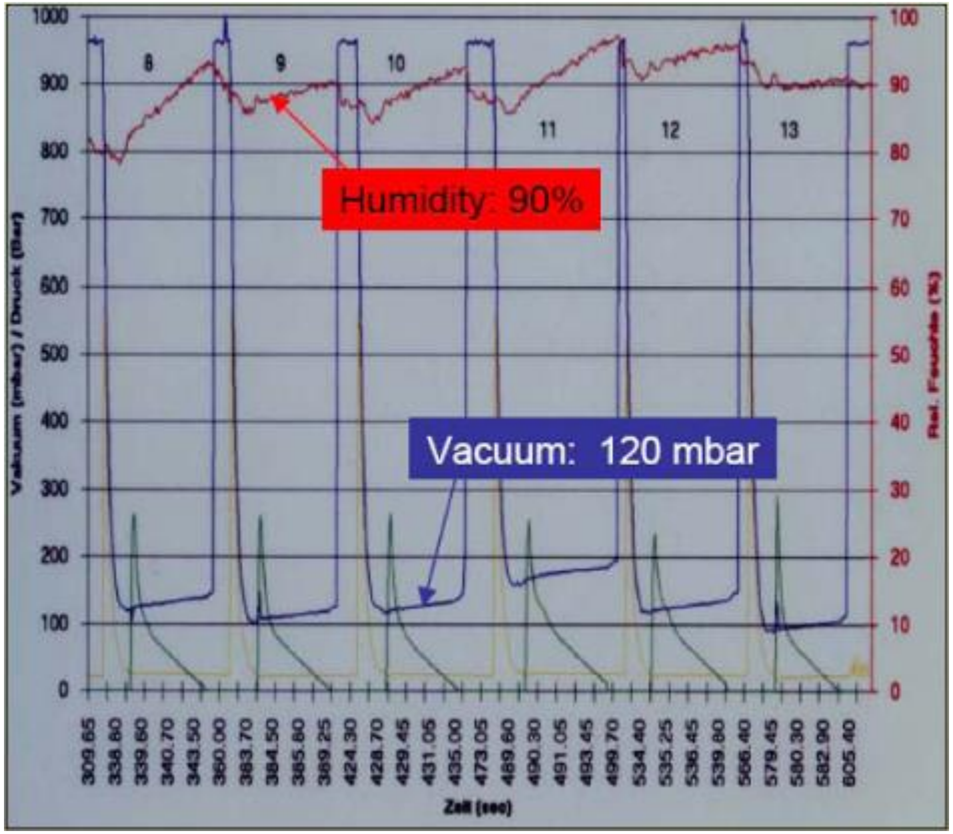
Vacuum and moisture are not compatible!





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Complete process control and visualization

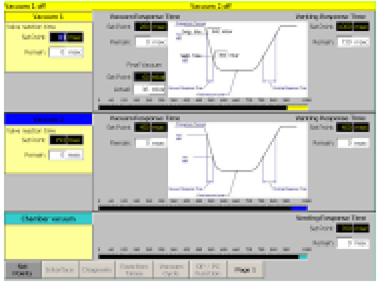
Example: Total-Trak HMI

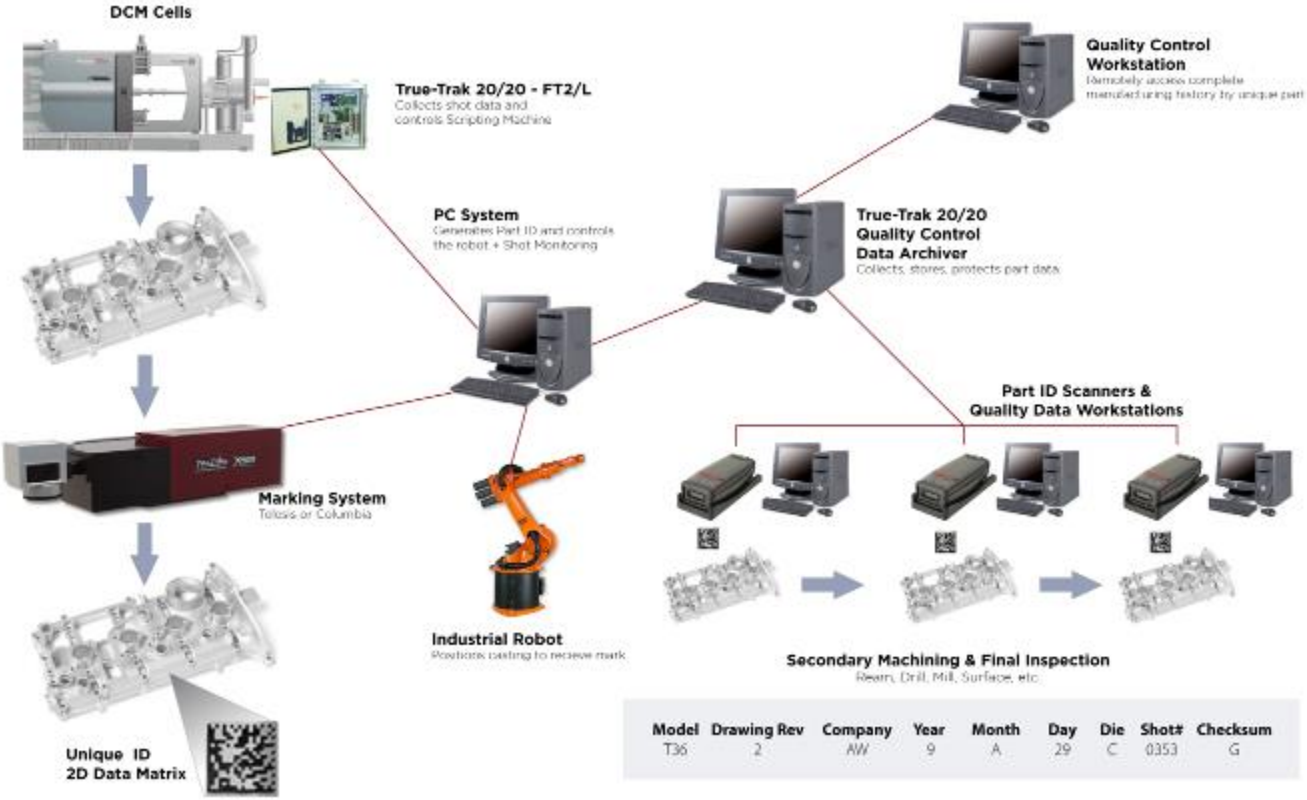
- **Monitor & control** the entire automated machine cell & periphery
- **Easy set-up** - restore saved jobs in seconds.
- **Complete I/O Diagnostics** for a comprehensive view.
- **Integrated shot control** with the True-Trak20/20™ or Sure-Trak2™.
- **Ladder logic display** options available.

Courtesy of Visi-Trak Worldwide, LLC

Part traceability

- Proper identification of each part for customer and quality improvement
- Collect, store, archive, recall and download all process information





Courtesy of Visi-Trak Worldwide, LLC

Part traceability

- Automatically **collect and archive valuable process data** for each part (automatic back-up, compress and store data)
- **Uniquely identify each part**
- Capture and **link important secondary process (heat treatment, machining, etc.) and test data**.
- Analyze your data to
  - **Determine cause of variation**

tomer

Alloys for high integrity diecastings

Low Fe (<0.25%), Mn to beat die soldering; low Cu; Sr

Al-Si alloy family: Al + 4-12%Si +0-0.6%Mg, Mn, Fe

- Silafont®-36 (365), Aural®-2/-3 (A365) and -5S, Mercalloy® (362, 367, 368), Castasil®-37, W3, etc.
- Excellent castability, heat treatable, most commonly used and wide variety of alloys commercially available

Al-Mg-Si family: Al + 2-5.5%Mg + 1.5-3%Si

- Magsimal®-59, C446, Aural®-11, Calypso 53 & 54SM, etc.
- Excellent properties as cast and in T5 temper
- Difficult to cast, properties extremely wall thickness dependent, require Be, hot tear and SCC susceptible

See May 2013 edition of Diecasting Engineer
http://www.diecasting.org/dce/issues/0513/51340.pdf

Alloys for high integrity diecastings

The key role of each element:

Si $\Rightarrow$ higher silicon content alloy promotes fluidity & castability

Mg $\Rightarrow$ imparts strength

Fe $\Rightarrow$ helps reduce solder but impacts negatively ductility

Mn $\Rightarrow$ higher manganese content helps minimize solder and corrects Fe phase

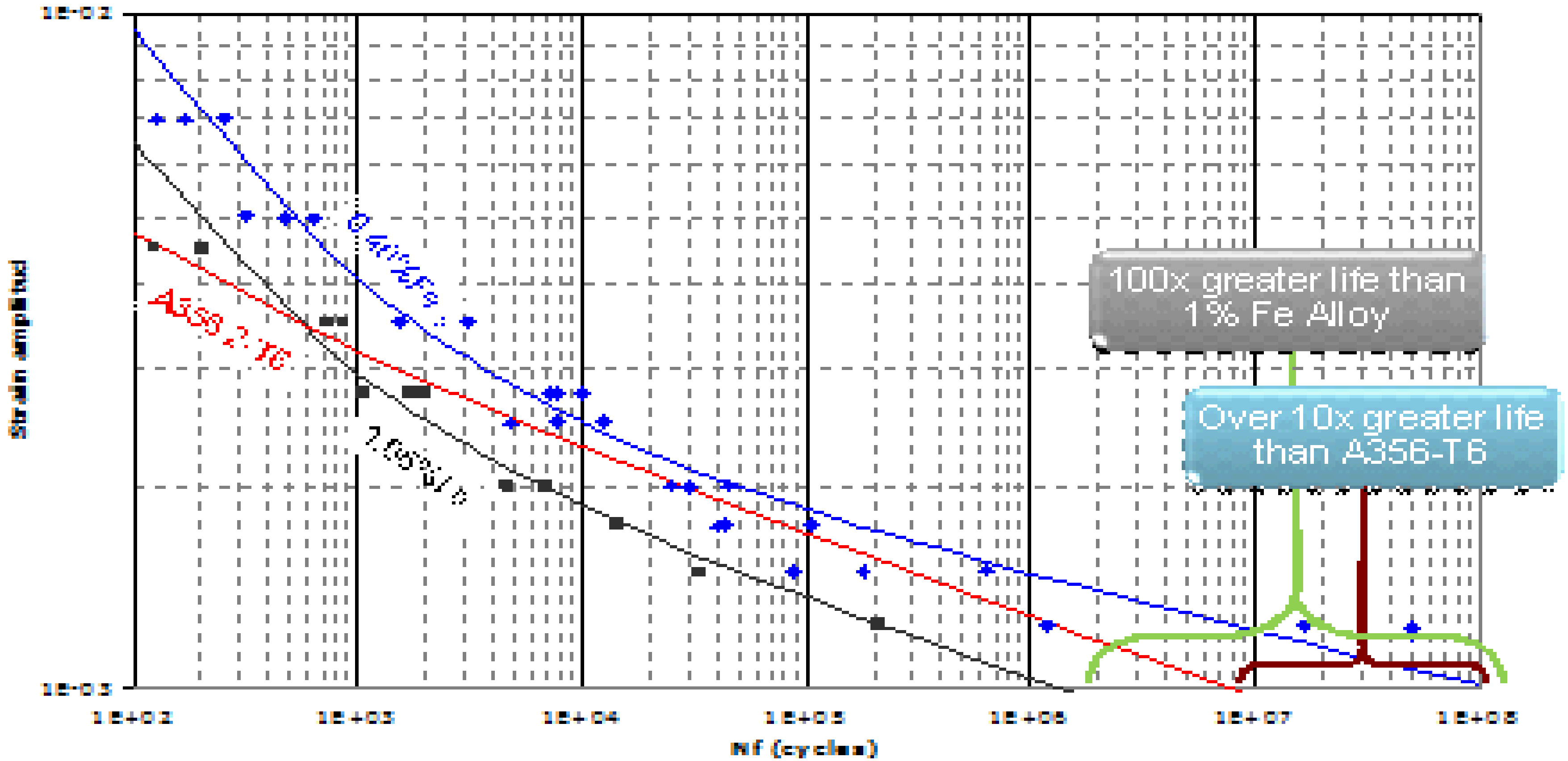
Ti $\Rightarrow$ used as a grain refiner

Cu $\Rightarrow$ lower copper content of the alloy imparts higher corrosion resistance (usually strengthening element)

Sr $\Rightarrow$ helps modify the eutectic silicon, thereby improving ductility of the alloy – also helps beat die soldering

Alloys for high integrity diecastings

Effect of Iron on Fatigue Curve for XK360 [100X life @0.001 strain]

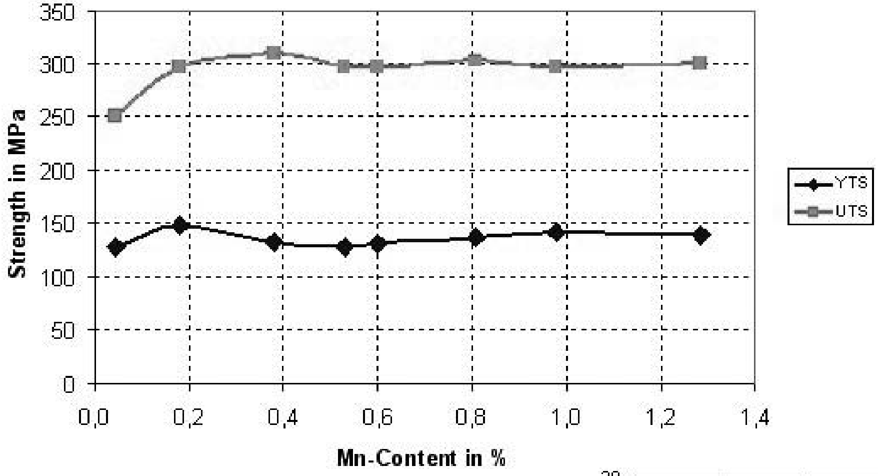


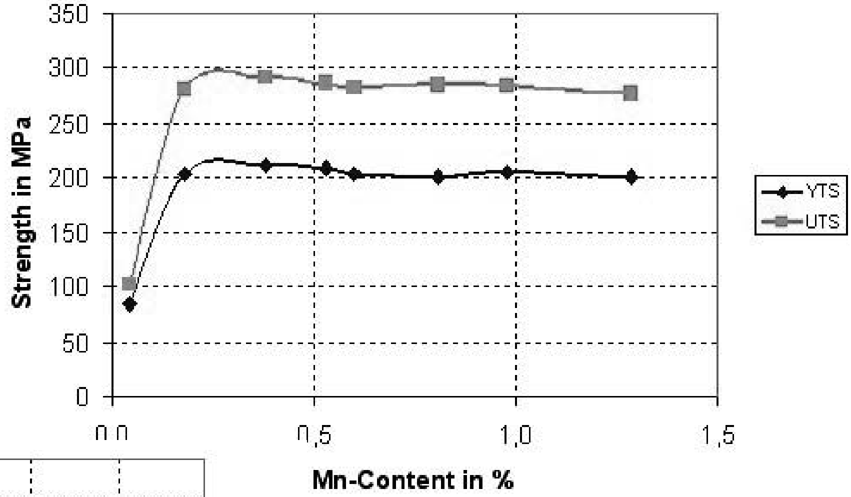
Curve fits generated using ASTM E 739-91 practices

Courtesy of Mercury Marine

Alloys for high integrity diecastings

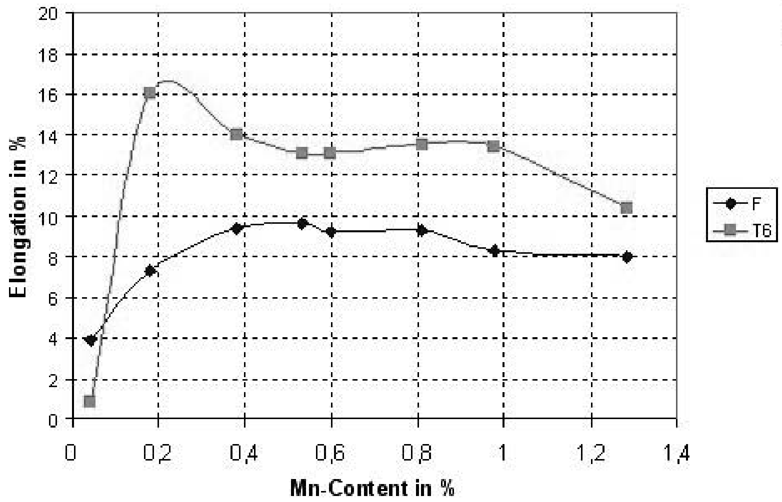
The influence of Mn (replacing Fe) mechanical properties
(example of Silafont® 36)





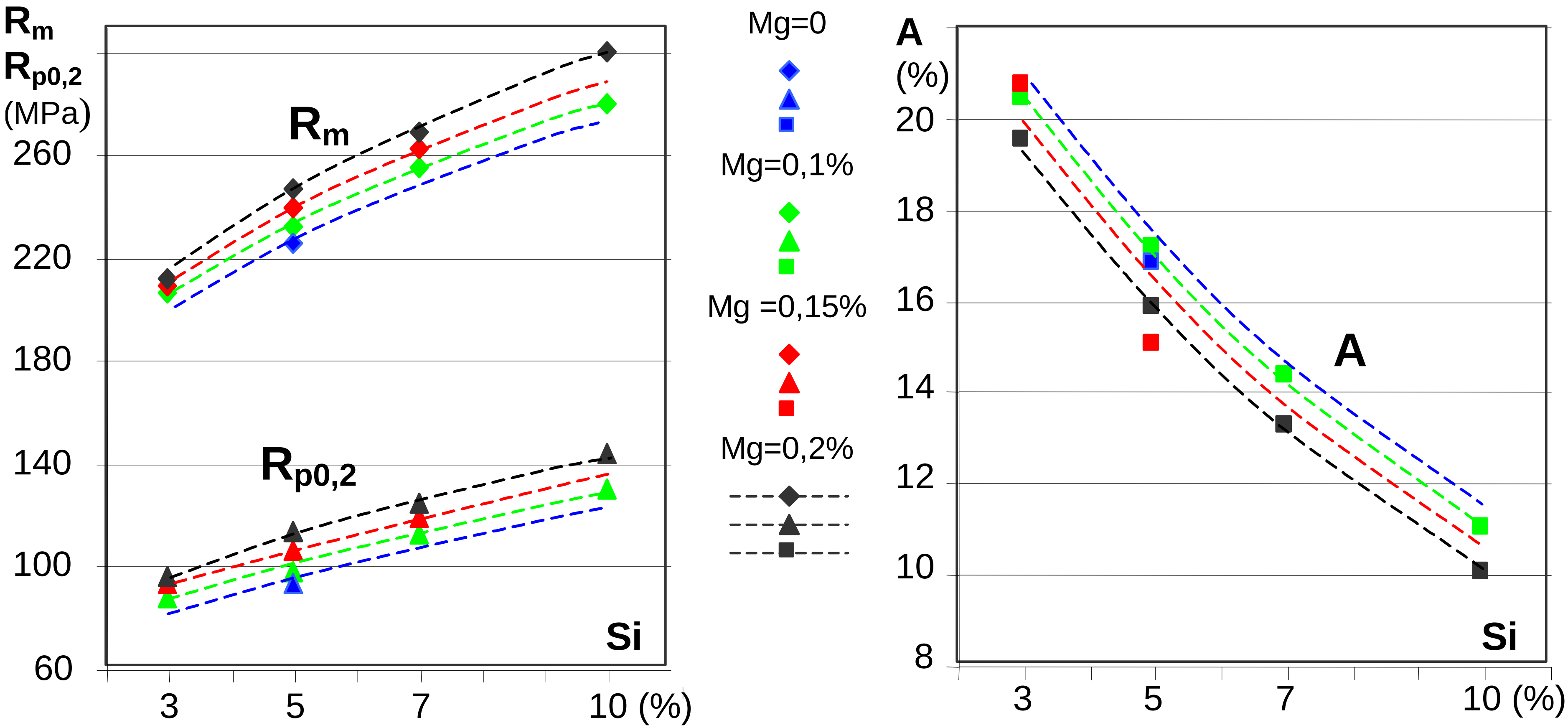
F temper

T6



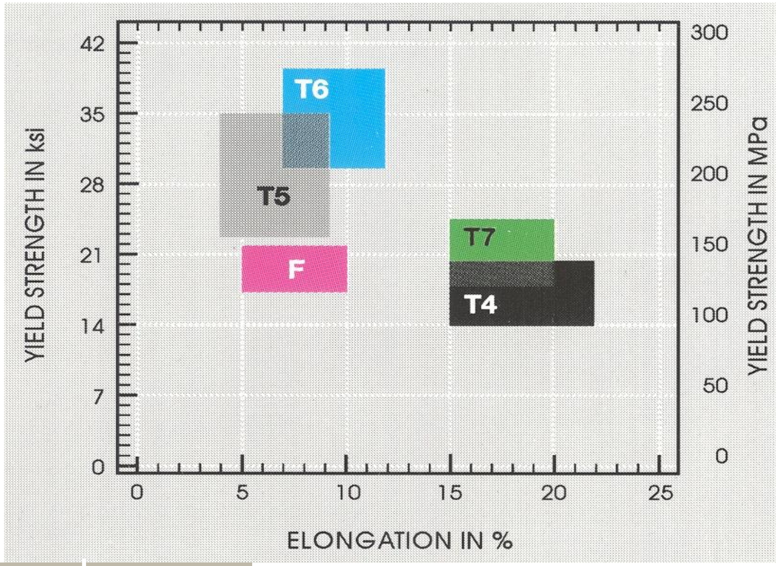
Alloys for high integrity diecastings

The influence of Si and Mg on mechanical properties in the F temper



Alloys for high integrity diecastings

AA 365 - Silafont 36 (Rheinfelden)



Alloy denomination

Chemical denomination: AlSi9MgMn Numerical denomination: 43 500

Composition [% of mass]

Si	Fe	Cu	**Mn**	**Mg**	Zn	Ti	**other**
9.5–11.5	0.15	0.03	**0.5–0.8**	**0.1–0.5**	0.07	0.15	**Sr**

Mechanical properties

Casting method	**Treatment state**	**Yield tensile strength** $R_{p0.2}$ [N/mm²]	**Ultimate tensile strength** R_m [N/mm²]	**Elongation** A [%]	**Brinell hardness** HBW
High press. die casting	F	120–150	250–290	5–11	75–95
High press. die casting	T5	155–245	275–340	4–9	80–110
High press. die casting	T4	95–140	210–260	15–22	60–75
High press. die casting	T6	210–280	290–340	7–12	90–110
High press. die casting	T7	120–170	200–240	15–20	60–75

Alloys for high integrity diecastings

AA A365 – Aural-2 & 3 (Magna-Cosma)

	Mg %	Si %	Fe %	Mn %	Ti %	Cu %	Sr (PPM)	Others %
Aural 2	0.27 – 0.33	9.5 – 11.5	0.15 – 0.22	0.45 – 0.55	max 0.08	max 0.03	100–160	each 0.03 total 0.1
Aural 3	0.4 – 0.6	9.5 – 11.5	0.15 – 0.22	0.45 – 0,55	max 0.08	max 0.03	100–160	each 0.03 total 0.1
Aural 4	0.40-0.50	4.0-4.5	0.15-0.20	0.45 - 0.80	max 0.08	max 0.03	40-70	each 0.03 total 0.1
"A-Alloy"	0.15-0.40	7.5-8.5	0.15-0.20	0.45 – 0,55	Max 0.08	max 0.03	50-100	each 0.03 total 0.1

Mechanical Properties of Aural alloys

	R_m [Mpa]	$RP_{0,2}$ [Mpa]	A_5 [%]	Condition
Aural 2	250 – 310	120 - 150	5 -10	F
	270-300	150-190	6.5 - 9	T5
	200 – 220	120 – 140	14 – 18	Auraltherm – 2
Aural 3	250 – 310	130 – 160	4 – 8	F
	300-340	190-240	4 - 6.5	T5
	210 – 280	140 – 220	6 – 14	Auraltherm – 3
Aural 4† †SSF Properties	219	103	17	F
	221	112	16	T5
	260-300	170-235	9-17	T6
"A-Alloy"	250-270	110-150	8-12	F
	270-300	150-190	5-8	T5

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Alloys for high integrity diecastings
Mercalloy 367

Alloy 367.0											
Alloy 367.0–Chemical Composition Limits											
Si	**Fe**	Cu	**Mn**	**Mg**	Cr	Ni	Zn	Ti	**Sr**	Other Elements	
										Each	Total
8.5-9.5	**0.25**	0.25	**0.25-0.35**	**0.30-0.50**	--	--	0.10	0.20	**0.05-0.07**	0.05	0.15

Typical Tensile Properties at 0.40% Mg				
Casting Process and Temper	**Aging Time and Temperature**	**Ultimate Strength ksi (MPa)**	**Yield Strength ksi (MPa)**	**Elongation (%)**
Die Cast 367.0—F	as cast	39.3 (270)	16.6 (115)	8.1
Die Cast 367.0—T5	2 hour at 170C	42.8 (295)	24.5 (170)	5.0
Die Cast 367.0—T5	4 hour at 170C	43.9 (300)	27.8 (190)	6.7
Die Cast 367.0—T5	6 hour at 170C	45 (310)	29 (200)	8.2
Die Cast 367.0—T5	8 hour at 170C	45 (310)	30 (205)	9.0
Die Cast 367.0—T4	3 hr at 490C + water quench	35.6 (245)	21.6 (150)	15
Die Cast 367.0—T6	2 hour at 170C	43 (295)	33.2 (230)	10.3
Die Cast 367.0—T6	4 hour at 170C	45 (310)	35 (240)	8
Die Cast 367.0—T6	6 hour at 170C	43.4 (300)	35.3 (245)	7.8
Die Cast 367.0—T6	8 hour at 170C	41.4 (285)	33.4 (230)	9.5

Alloys for high integrity diecastings

Mercalloy 368 & 362

Alloy 368.0

Alloy 368.0–Chemical Composition Limits

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Sr	Other Elements	
										Each	Total
8.5-9.5	**0.25**	0.25	**0.25-0.35**	**0.10-0.30**	--	--	0.10	0.20	**0.05-0.07**	0.05	0.15

Typical Mechanical Properties at 0.20% Mg*

Casting Process and Temper	Aging Time and Temperature	Tension			Endurance Limit Ksi (Mpa)
		Ultimate Strength ksi (MPa)	Yield Strength ksi (MPa)	Elongation (%)	
Die Cast 368.0--F	as cast	38-40 (260-275)	18-20 (125-140)	10-12	21 (145)
Die Cast 368.0--T6	6 hr at 320 F	41-43 (280-295)	27-29 (185-200)	14-16	20 (140)

Alloy 362.0

Alloy 362.0–Chemical Composition Limits

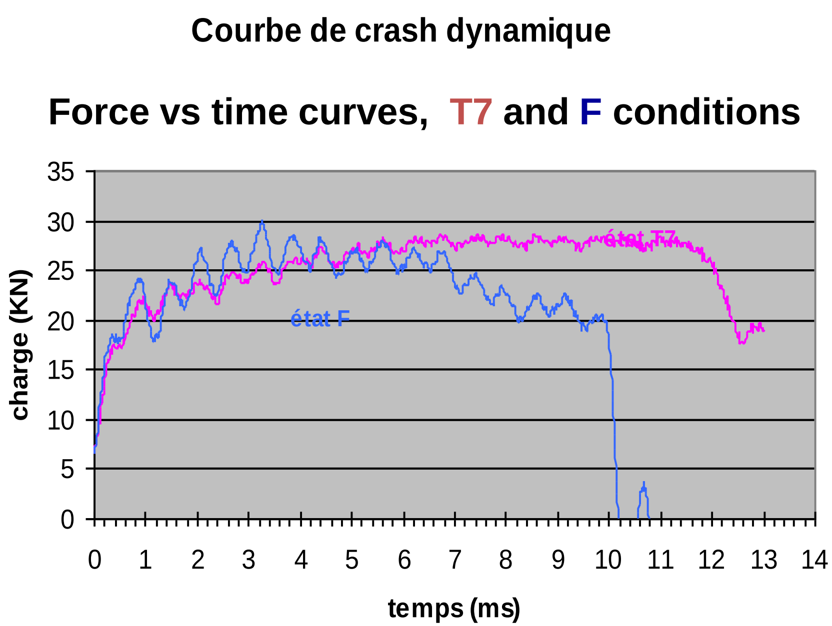
Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Sr	Other Elements	
										Each	Total
10.5-11.5	**0.25**	0.20	**0.25-0.35**	**0.50-0.7**	--	0.10	0.10	0.20	**0.05-0.07**	0.05	0.15

Typical Mechanical Properties at 0.60% Mg*

Casting Process and Temper	Aging Time and Temperature	Tension			Endurance Limit Ksi (Mpa)
		Ultimate Strength ksi (MPa)	Yield Strength ksi (MPa)	Elongation (%)	
Die Cast 362.0--F	as cast	38-40 (260-275)	18-20 (125-140)	9-11	21 (145)
Die Cast 362.0--T6	6 hr at 320 F	43-46 (295-315)	33-36 (230-250)	14-16	20 (140)

Alloys for high integrity diecastings

Example: CALYPSO 61D (Al Si10MgMnFe) : Difference between crash behaviours in T7 and F



Condition	YS	UTS	Elongation %
F	120 ~ 140	270 ~ 290	10 ~ 12
T7	155 ~ 165	215 ~ 225	14 ~ 18

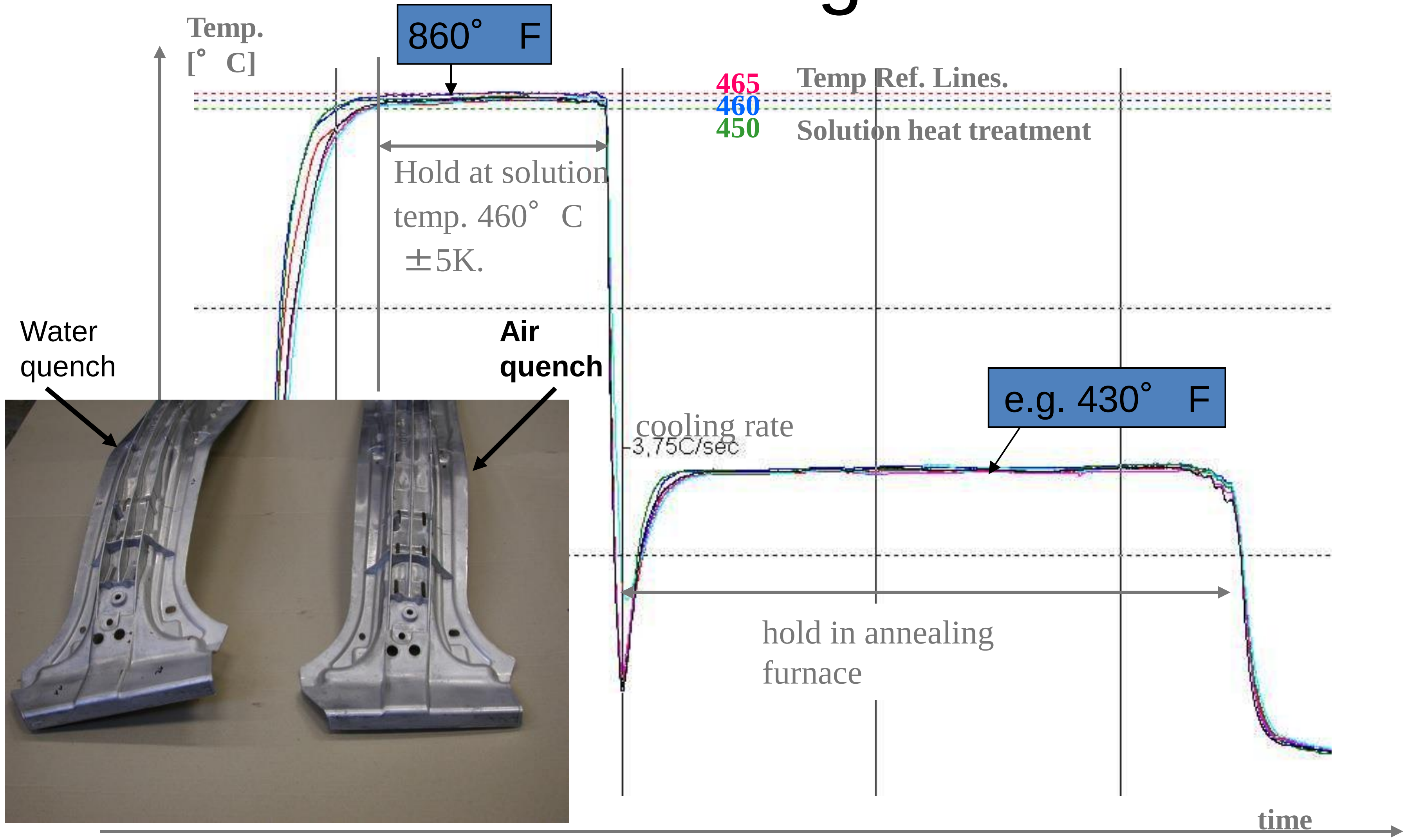
Alloys for high integrity diecastings

Example: CALYPSO 61D (Al Si10MgMnFe) : Difference between crash behaviours in T7 and F

T 7

F

Heat treatment of high integrity die castings



Where could I do R&D in this field?

Examples: Delaware Dynamics, Muncie, IN
Diecasting R&D center with 1600t, 2000t and 3500t HPDC machines

Canmet MATERIALS
A national laboratory of Natural Resources Canada, Hamilton, ON
1200t HPDC machine

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Summary

- Traditional diecasting processes had difficulty in achieving high integrity (low porosity) castings and were therefore unusable for structural applications
- Traditional diecasting has relied upon high levels of Fe in Al to reduce die soldering. As known, Fe also destroys mechanical properties (especially elongation)
- New diecasting processes applying process control, high vacuum, proper die design, etc. and new alloys allow production of diecastings with high quality / mechanical properties (heat treatable, weldable, crash worthy, high fatigue life, etc.)
- The inherent advantages of diecasting (high freezing rate, thin walls, high precision, etc.) can now be used to produce high quality structural castings at competitive costs.

VIAMI INTERNATIONAL INC.

Questions?

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