



Key partner in Design Process Innovation

Introduction to HPDC process & Light alloys

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Casting Process Production

Main Known Process Production:

- Sand Casting
- Permanent mold gravity casting
- Low Pressure Die Casting (permanent mold and sand)
- **High Pressure Die Casting**

Materials and alloys

Melting and treatment of alloy

Pouring

Filling of the cavity

Solidification of the casting

Cooling & (heat treat.)

1

Inclusion and undesired phases

2

Filling defects

3

Gas entrapment/development

4

Metal die interaction

5

shrinkage

6

Cracks and deformation

A

Sand Gravity casting

Parameters, process design, defects, mech. properties

B

Permanent mold Gravity casting

Parameters, process design, defects, mech. properties

C

Low pressure die casting

Parameters, process design, defects, mech. properties

D

High pressure die casting

Parameters, process design, defects, mech. properties

Monitoring Melting

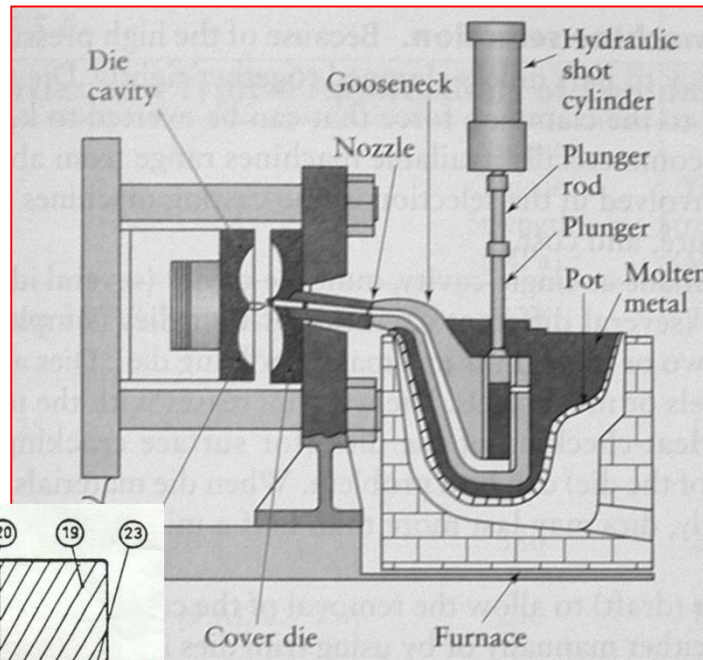
Monitoring Pouring

Monitoring Filling

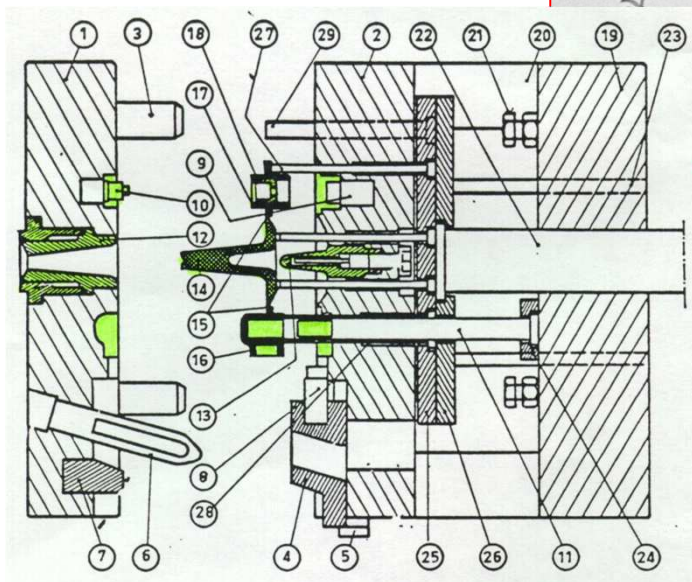
Monitoring Solidification

Monitoring Cooling

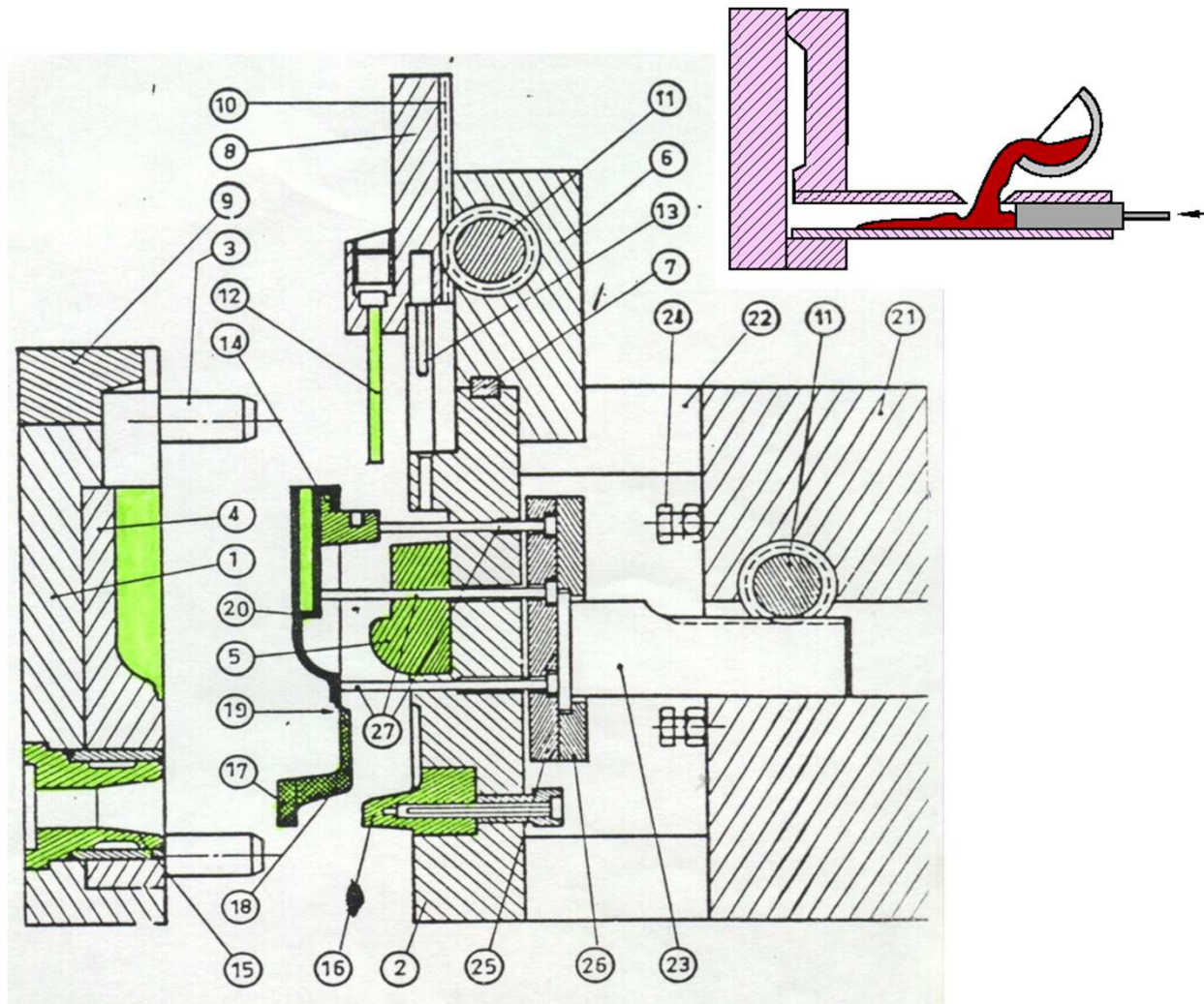
HPDC Process: Hot chamber



1. Fix Die Holder
2. Mobile Die Holder
3. Column mold guide
4. Slider glide
5. Starting point location of the slider
6. Tilted column
7. Shoulder plate
8. Slider tap
9. Insert
10. Plung door slider
11. Pin
12. Cooled part
13. Cooled pin
14. Carrot
15. Gate
16. Cast
17. Cast
18. Insert
19. Plate
20. Spacer brick
21. Ejection pillar
22. Ejection plung
23. Ejection plung
24. Plate for plung pointing
25. Front ejection plate
26. Back ejection plate
27. Ejector
28. Ejector

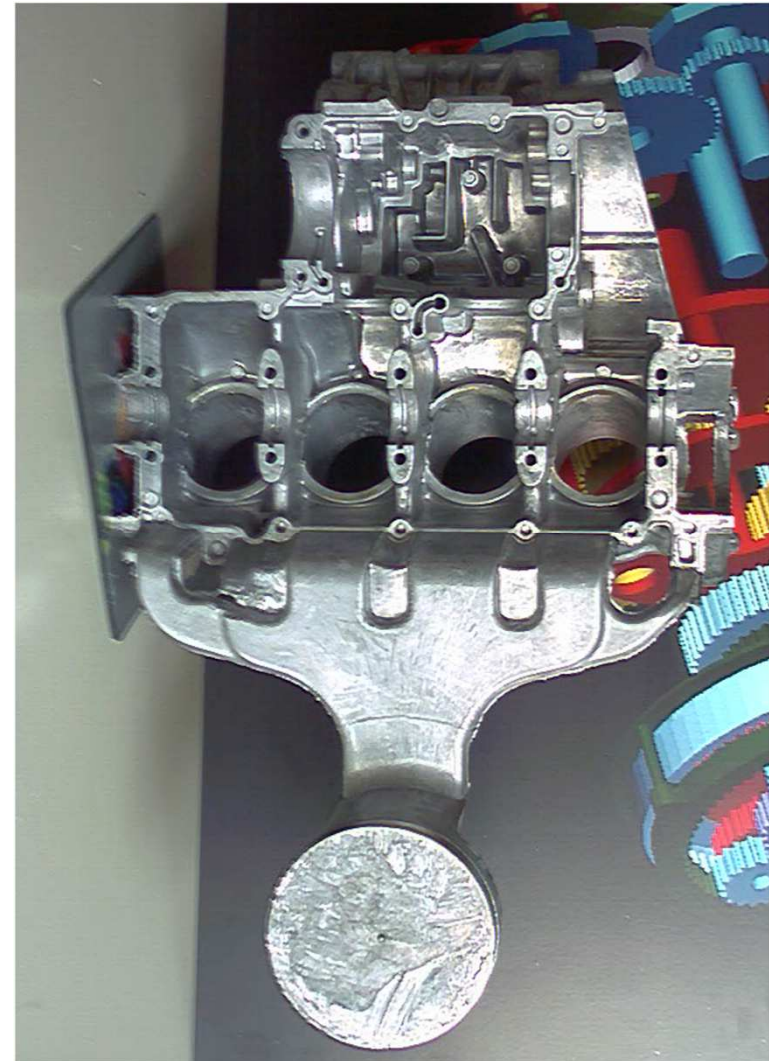


HPDC Process: Cold chamber

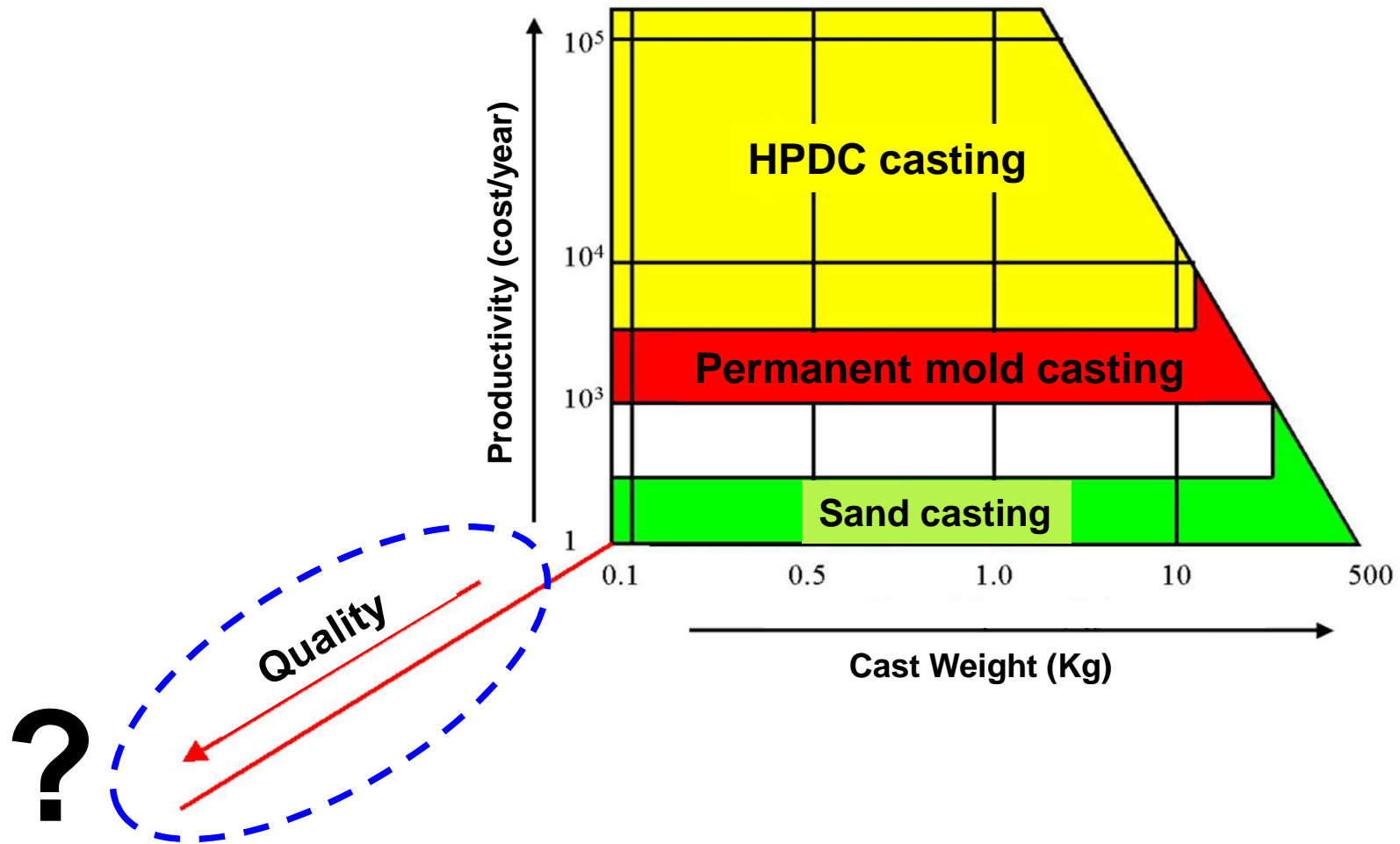


1. Fix Die Holder
2. Mobile Die Holder
3. Pins
4. Dies
5. insert
6. Spacer
7. Adjustable plate
8. Slider
9. Shoulder
10. Rack
11. Pinion
12. Pin
13. Lock pin
14. Cast
15. Cooled shot chamber
16. Cooling pin
17. Biscuit
18. Runner
19. Gate
20. Cast
21. Abutment
22. Rack rail
23. Ejection plung
24. Plate for plung pointing
25. Front ejection plate
26. Back ejection plate
27. Ejector

HPDC Process: Cold chamber (examples)

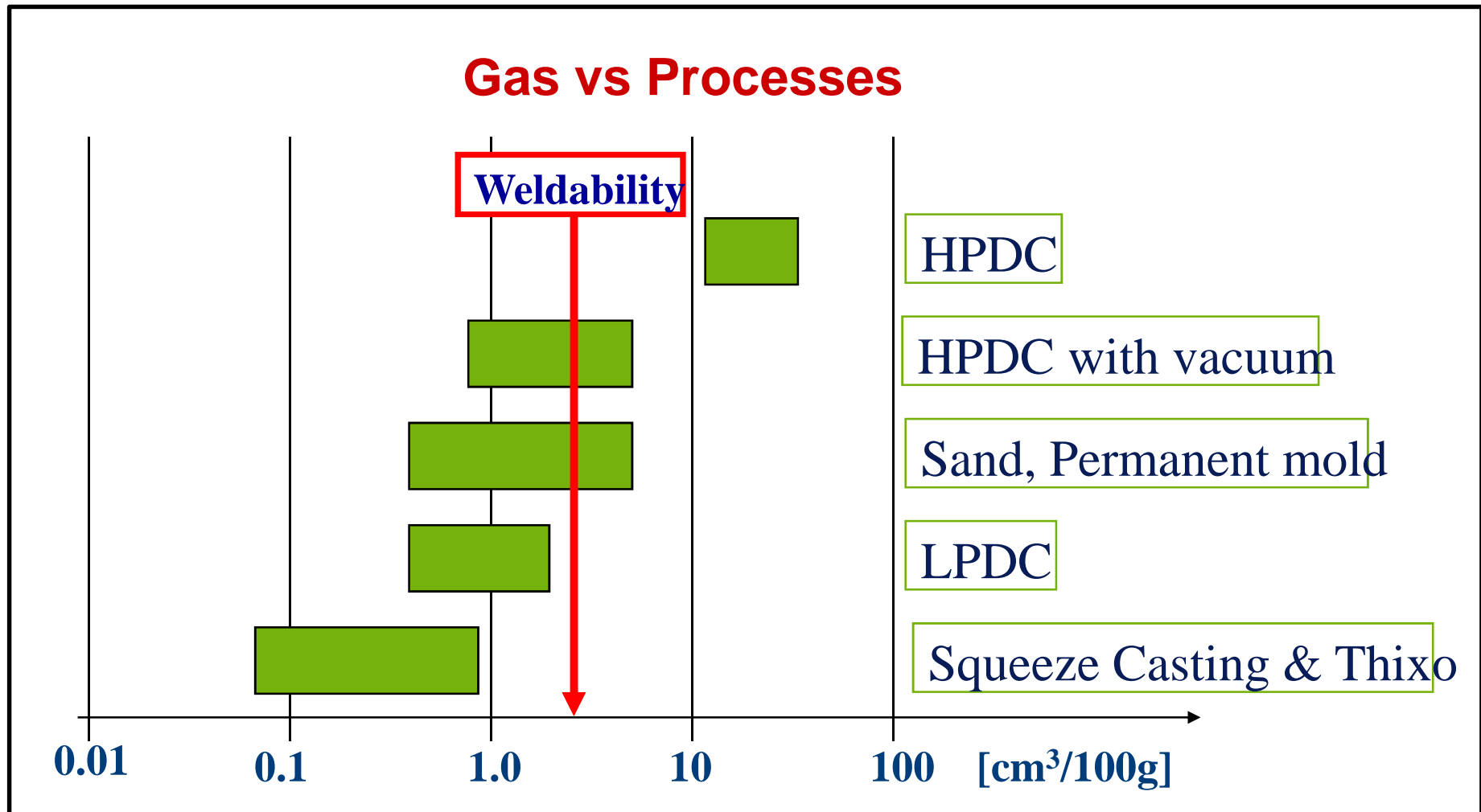


Introduction

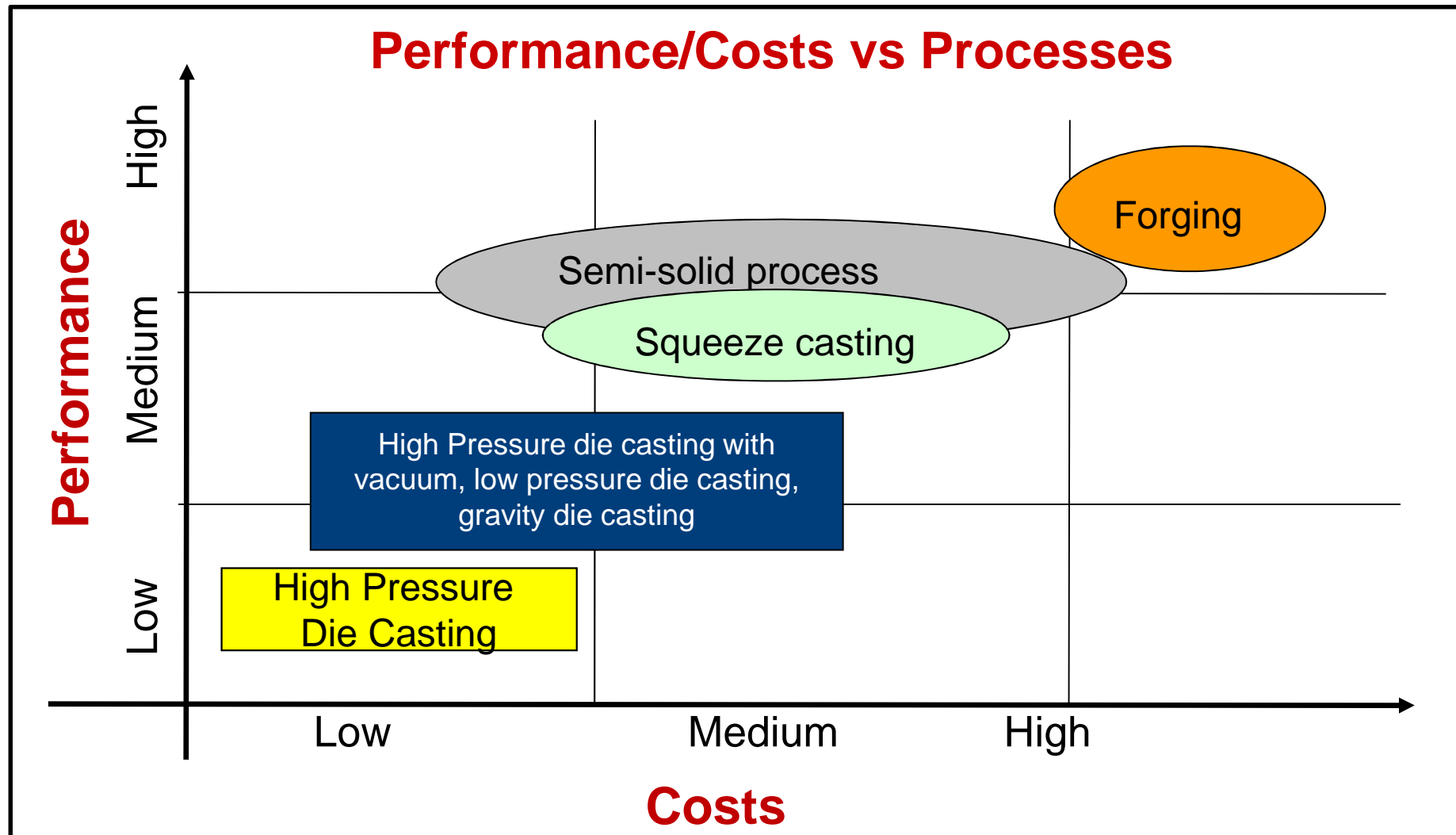


Introduction

Gas entrapment due to: hydrogen, air, gas from lubrication, etc, in function of the process



Introduction



Alloy definition

Equilibrium between: Technical Efficiency and Cost

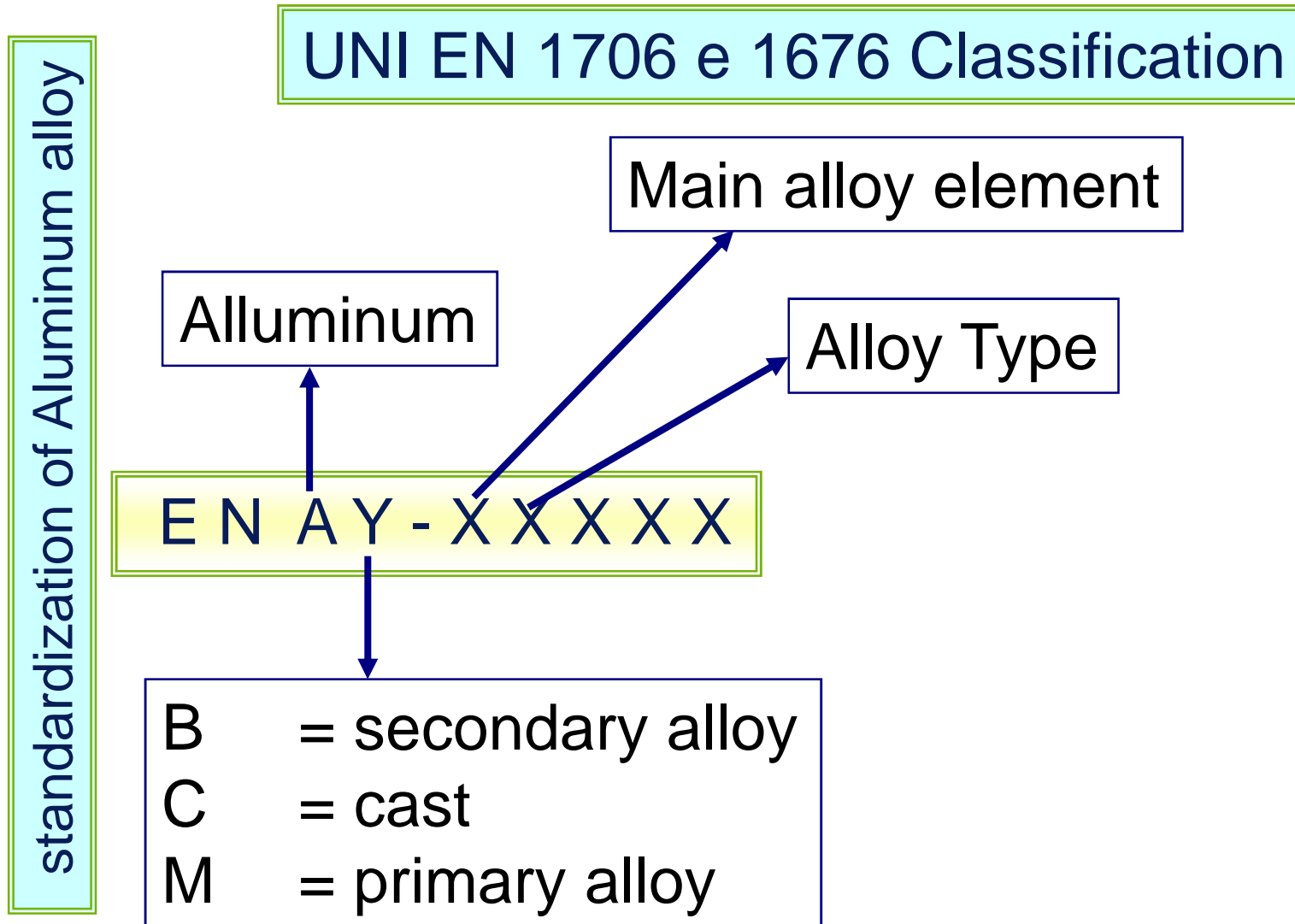
Defined the field of application of the configured component, the designer may be faced with different types of materials equally applicable

The choice is made on the basis of cost and availability.

The light alloy are divided into 4 categories:

- General purpose alloy
- Corrosion resistant alloy
- Hot resistant alloy
- Special purpose alloy

Classifications



Classifications

UNI EN 1706 e 1676 Classification

standardization of Aluminum alloy

ENAC - XXXXX

Main alloy element
 2XXXX = copper
 4XXXX = silicon
 5XXXX = magnesium
 7XXXX = zinc

Alloy Type

21XXX = Al Cu	46XXX = Al Si9Cu
41XXX = Al SiMgTi	47XXX = Al Si(Cu)
42XXX = Al Si7Mg	48XXX = Al SiCuNiMg
43XXX = Al Si10Mg	51XXX = Al Mg
44XXX = Al Si	71XXX = Al ZnMg
45XXX = Al Si5Cu	

Alloy for HPDC process

Norma EN-AB	43100	43400	44100	44300	46000	46100	46400	47100
UNI	AlSi10Mg	AlSi10Mg(Fe)	AlSi12	AlSi12(Fe)	AlSi9Cu3(Fe)	AlSi11Cu2(Fe)	AlSi9Cu3Mg	AlSi12Cu1(Fe)
Si	9,0-11,0	9,0-11,0	10,5-13,5	10,5-13,5	8,0-11,0	10,0-12,0	8,3-9,7	10,5-13,5
Fe	0,45 (0,55)	0,45-0,9 (1,0)	0,55 (0,65)	0,45-0,9 (1,0)	0,6-1,1 (1,3)	0,45-1,0 (1,1)	0,7 (0,8)	0,6-1,1 (1,3)
Cu	0,08 (0,10)	0,08 (0,10)	0,10 (0,15)	0,08 (0,10)	2,0-4,0	1,5-2,5	0,8-1,3	0,7-1,2
Mn	0,45	0,55	0,55	0,55	0,55	0,55	0,15-0,55	0,55
Mg	0,30-0,45 (0,25-0,45)	0,25-0,50 (0,20-0,50)	0,1		0,15-0,55 (0,05-0,55)	0,3	0,30-0,65 (0,25-0,65)	0,35
Cr					0,15	0,15		0,1
Ni	0,05	0,15	0,1		0,55	0,45	0,2	0,3
Zn	0,10	0,15	0,15	0,15	1,2	1,7	0,8	0,55
Pb	0,05	0,05	0,1		0,35	0,25	0,1	0,2
Sn	0,05				0,25	0,25	0,1	0,1
Ti	0,15	0,15 (0,20)	0,15 (0,20)	0,15	0,20 (0,25)	0,20 (0,25)	0,10-0,18 (0,10-0,20)	0,15 (0,20)
Altri casc.	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Altri Totale	0,15	0,15	0,15	0,15	0,25	0,25	0,25	0,25

UNI EN 1706 Foundry Alloy requirements

- Filling and Solid properties
 - Fluidity
 - Feeding properties
 - Hot tears generation
- Machining
 - As cast
 - after HT
- Corrosion resistance
- Anodizing
- Weldability
- Polishing

**C
O
M
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- A → Excellent
- B → Good
- C → Sufficient
- D → Insufficient
- E → Not recommended
- F → Totally unfitting

UNI EN 1706 Foundry Alloy requirements

- Thermal expansion coefficient
- Electrical conductivity
- Thermal conductivity
- Ambient temperature strength
- 200°C temperature strength
- Ductility
- Fatigue strength

**C
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UNI EN 1706 Foundry Alloy requirements

Mechanical properties

Fluidity

Shrinkage porosity

Hot tears reduction

Easy mold ejection

Costs

.....



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Properties of the elements

	Cu	Mn	Si	Mg	Zn
Mechanical properties	↗ ↗	↗	↗	↗	↗ ↗
Corrosion resistance	↘	↗	↔	↗	↔
Electrical conductivity	↗	↘ ↘	↘	↘	↔
Weldability	↗ ↘	↗	↔	↗	↘
Cold displacement	↘	↗	↘	↘	↘
Paintability	↘	↘	↘	↗	↔

Elements effect (positive)

	Norma EN-AB	46000	46100	47100
	UNI	AlSi9Cu3(Fe)	AlSi11Cu2(Fe)	AlSi12Cu1(Fe)
Castability, Low shrinkage	Si	8,0-11,0	10,0-12,0	10,5-13,5
Cast ejection	Fe	0,6-1,1 (1,3)	0,45-1,0 (1,1)	0,6-1,1 (1,3)
Mechanical strength	Cu	2,0-4,0	1,5-2,5	0,7-1,2
Reaction with Fe, Cast ejection	Mn	0,55	0,55	0,55
	Mg	0,15-0,55 (0,05-0,55)	0,3	0,35
Corrosion resistance, Anodizing	Cr	0,15	0,15	0,1
	Ni	0,55	0,45	0,3
Mechanical strength	Zn	1,2	1,7	0,55
	Pb	0,35	0,25	0,2
Mechanical strength	Sn	0,25	0,25	0,1
	Ti	0,20 (0,25)	0,20 (0,25)	0,15 (0,20)
Machining	Altri cisc.	0,05	0,05	0,05
Grain refining	Altri Totale	0,25	0,25	0,25

Elements effect (negative)

	Norma EN-AB	46000	46100	47100
	UNI	AlSi9Cu3(Fe)	AlSi11Cu2(Fe)	AlSi12Cu1(Fe)
Fragility, low paintability	Si	8,0-11,0	10,0-12,0	10,5-13,5
Fragility, low castability	Fe	0,6-1,1 (1,3)	0,45-1,0 (1,1)	0,6-1,1 (1,3)
Corrosion	Cu	2,0-4,0	1,5-2,5	0,7-1,2
Low paintability	Mn	0,55	0,55	0,55
Low castability, oxide	Mg	0,15-0,55 (0,05-0,55)	0,3	0,35
	Cr	0,15	0,15	0,1
	Ni	0,55	0,45	0,3
Low castability, low weldability, low paintability	Zn	1,2	1,7	0,55
	Pb	0,35	0,25	0,2
	Sn	0,25	0,25	0,1
Low properties at high temperature	Ti	0,20 (0,25)	0,20 (0,25)	0,15 (0,20)
	Altri cisc.	0,05	0,05	0,05
	Altri Totale	0,25	0,25	0,25

Castability

	46000	46100	47100
• Castability			
- Fluidity →	B	A	A
- Low Hot Tears →	B	B	A
- Pressure strength →	C	C	C
• Machining			
- As cast →	B	C	C
- After HT →	--	--	--
• Corrosion resistance →	D	D	C
• Anodizing →	E	E	E
• Weldability →	F	F	F
• Polishing →	C	C	C

- A → Excellent
- B → Good
- C → Sufficient
- D → Insufficient
- E → Not recommended
- F → Totally unfitting

Alloy price



Price

1.40 Euro/kg

6.50 Euro/kg

1.30 Euro/kg

1.80 Euro/kg

38.70 Euro/kg

2.80 Euro/kg

48.00 Euro/kg

Norma EN-AB	46000	46100	47100
UNI	AlSi9Cu3(Fe)	AlSi11Cu2(Fe)	AlSi12Cu1(Fe)
Si	8,0-11,0	10,0-12,0	10,5-13,5
Fe	0,6-1,1 (1,3)	0,45-1,0 (1,1)	0,6-1,1 (1,3)
Cu	2,0-4,0	1,5-2,5	0,7-1,2
Mn	0,55	0,55	0,55
Mg	0,15-0,55 (0,05-0,55)	0,3	0,35
Cr	0,15	0,15	0,1
Ni	0,55	0,45	0,3
Zn	1,2	1,7	0,55
Pb	0,35	0,25	0,2
Sn	0,25	0,25	0,1
Ti	0,20 (0,25)	0,20 (0,25)	0,15 (0,20)
Altri ciasc.	0,05	0,05	0,05
Altri Totale	0,25	0,25	0,25

~ 2.00
Euro/kg

~ 2.00
Euro/kg

~ 2.07
Euro/kg



Alluminum scrap

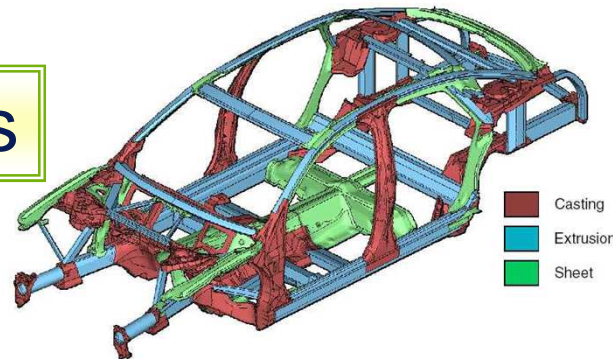
EN 13920/7

1.420
Euro/kg

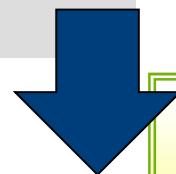


Conclusions

Growing requirements



Reliability – Elongation, toughness
 Crash Resistance – Fatigue strength
 High Yield stress
 Corrosion resistance – Castability
 COSTS

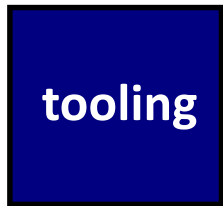


**Alloy
 +
 Design process**

High Pressure Die Casting (HPDC)



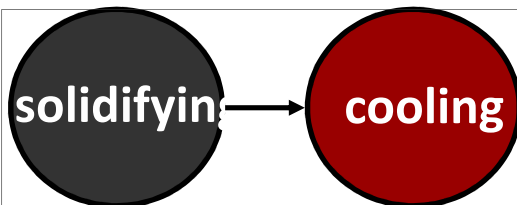
- Pouring in the die/mould
- Pouring in a pre-chamber
- Gravity pouring
- Pouring under pressure (i.e. injecting)



- Sand mould
- Ceramic mould
- Patterns
- Steel mould (i.e. die), permanent
- Sand cores
- Ceramic cores/Salt cores
- Metallic cores (i.e. inserts)

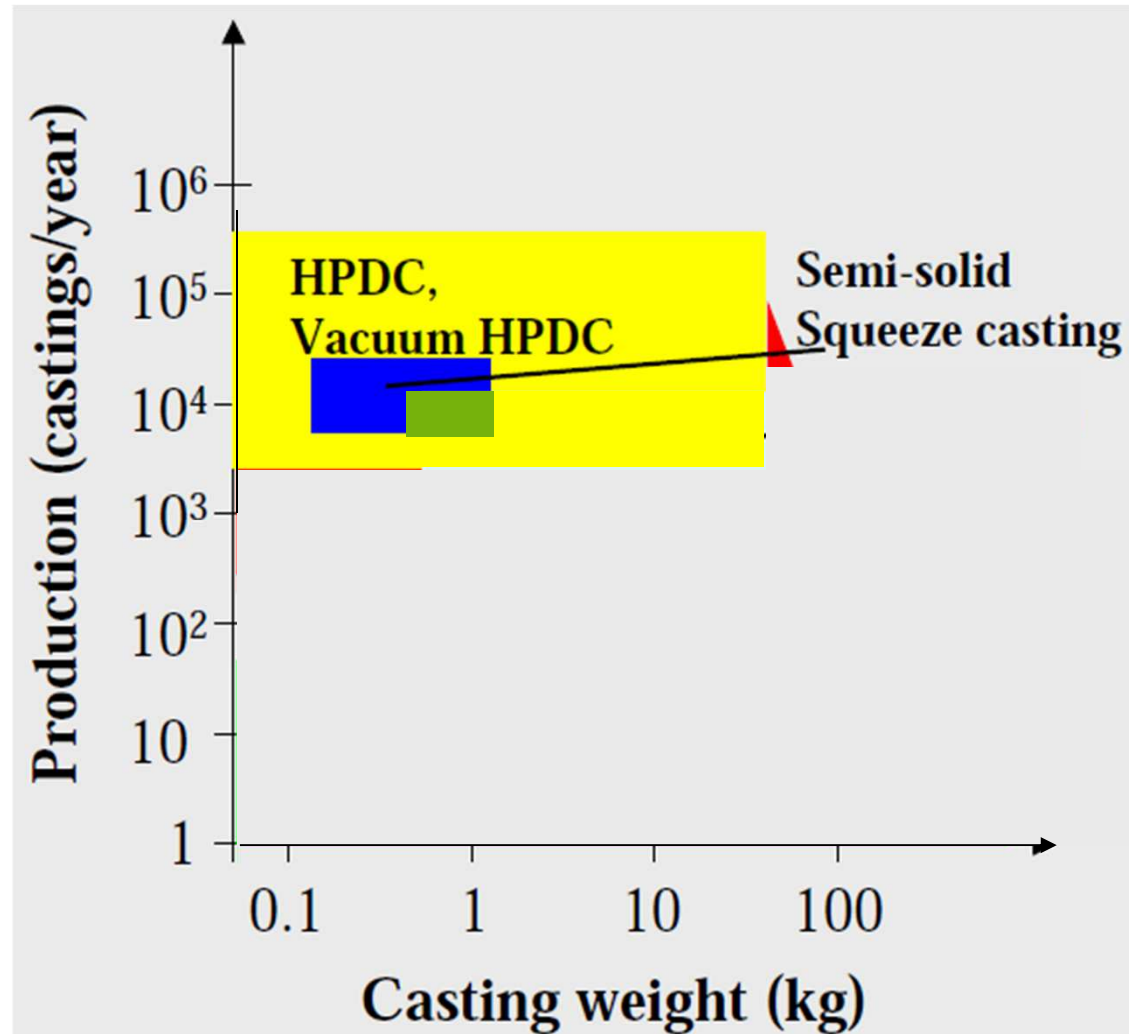


- Without air evacuation
- With air evacuation
- By gravity
- Under moderate (i.e. low) pressure
- Under high pressure



- Spontaneous heat transfer from alloy to mould/die
- Enhanced (cooling channels + air/gases) heat transfer
- Enhanced (cooling channels + water/oil) heat transfer

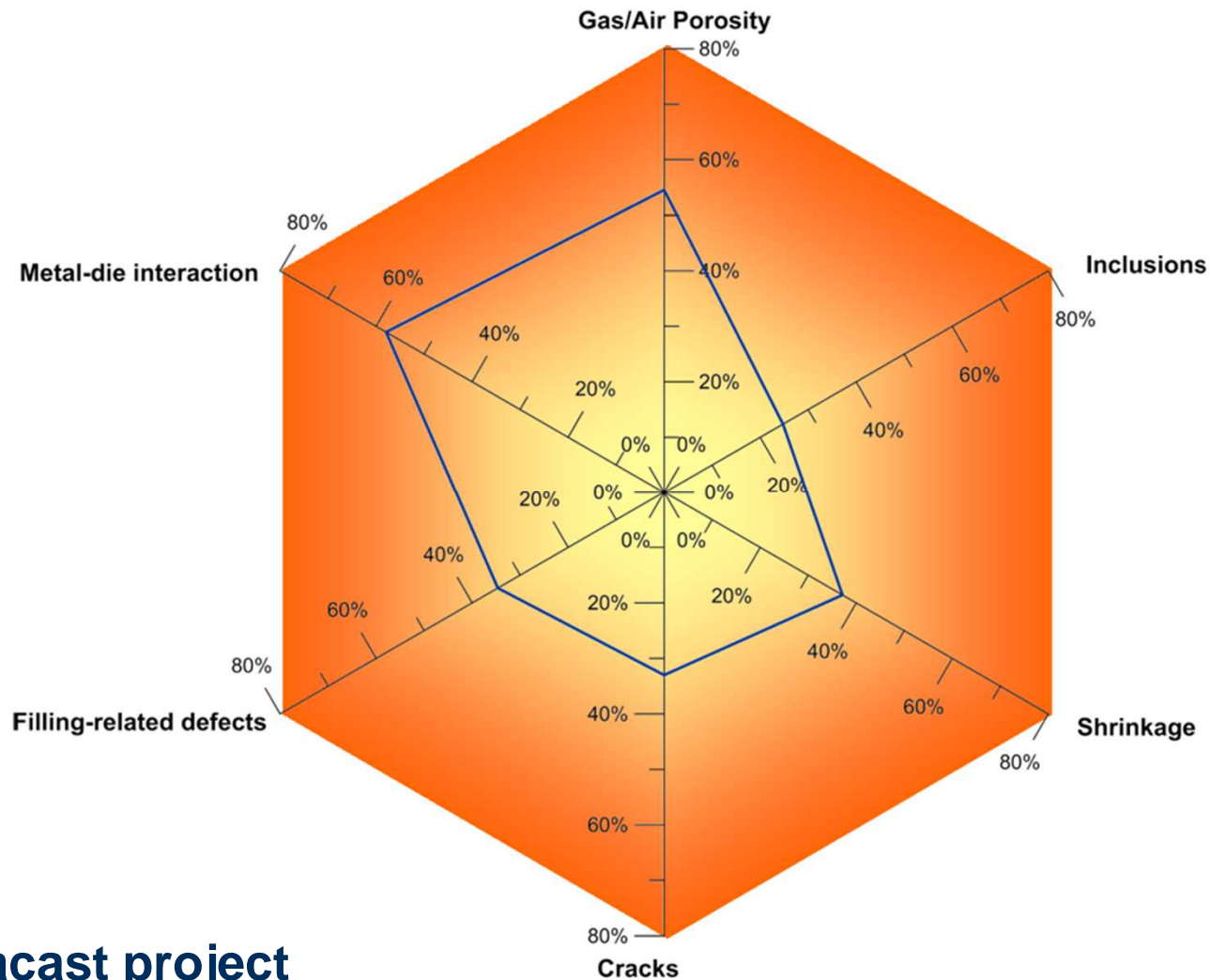
Productivity Range



Characteristics of High Pressure Die Castings

Weight	→ from few grams to 30 kg
Minimum Thickness	→ 1.0-1.2 mm
Maximum Thickness	→ < 15 mm
Minimum diameter of holes (achieved with cores)	→ 3 mm
Degree of complexity	
- internal	→ limitations (cores, inserts)
- external	→ limitations (die opening)
Tolerances	→ ± 0.05 on 25

Defects & Imperfections of High Pressure Die Castings

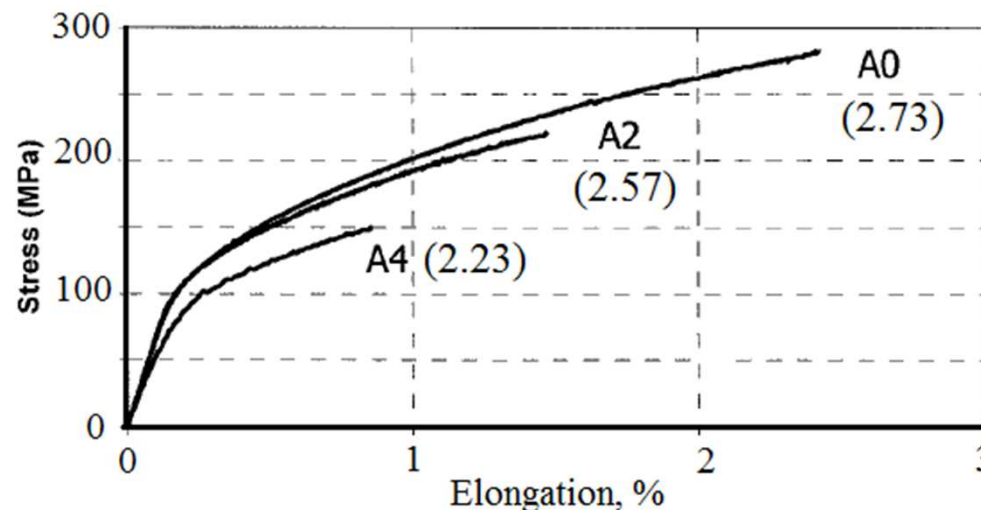


Stacast project

Mechanical Properties vs Defects & Imperfections of High Pressure Die Castings

The quality or soundness of castings govern the strength of a cast material. This implies that higher strength values could be obtained from a material by controlling the casting parameters.

Defects arising from the foundry process will determine the final quality of castings. Generally, casting defects are very difficult to be completely eliminated, i.e. zero-defect casting

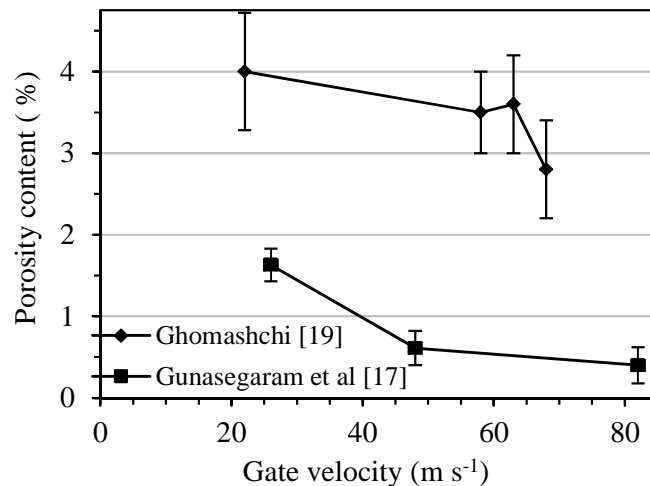


Tensile stress-strain curves of three different AlSi9Cu3(Fe) castings with density values indicated within the parentheses (g cm⁻³). Lower density castings show reduced strength properties owing to higher casting defects

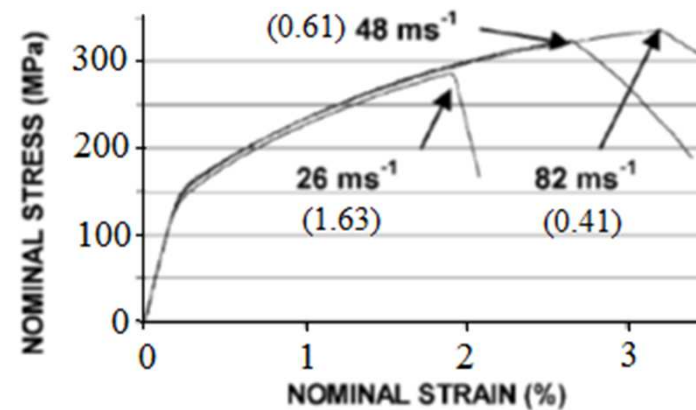
Mechanical Properties vs Defects & Imperfections of High Pressure Die Castings

The size of the porosity decreases with the increase in the gate velocity to a certain value (~ 55 m/s – Alloy A380).

The porosity content was minimum near the gates and maximum near the overflows. The authors attribute it to the increase in density and reduction in porosity. Further, it is shown that the scatter in the strength values decreases with increasing the melt velocity, therefore suggesting higher repeatability in HPDC process.



Change of porosity content with different gate velocity in HPDC

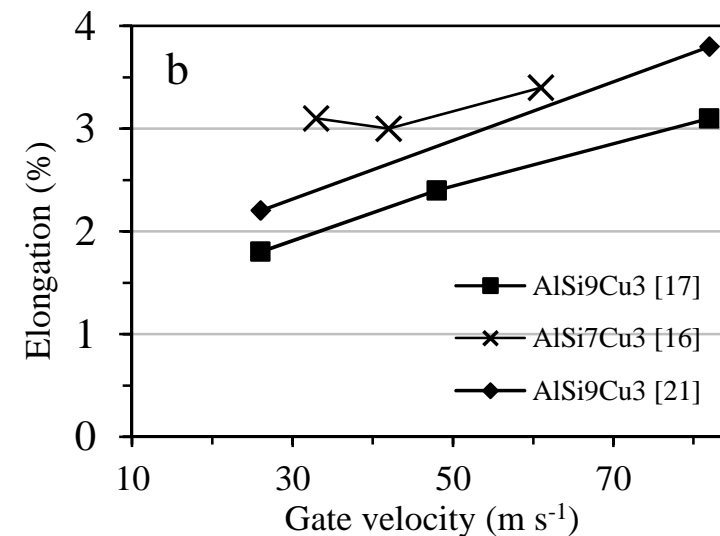
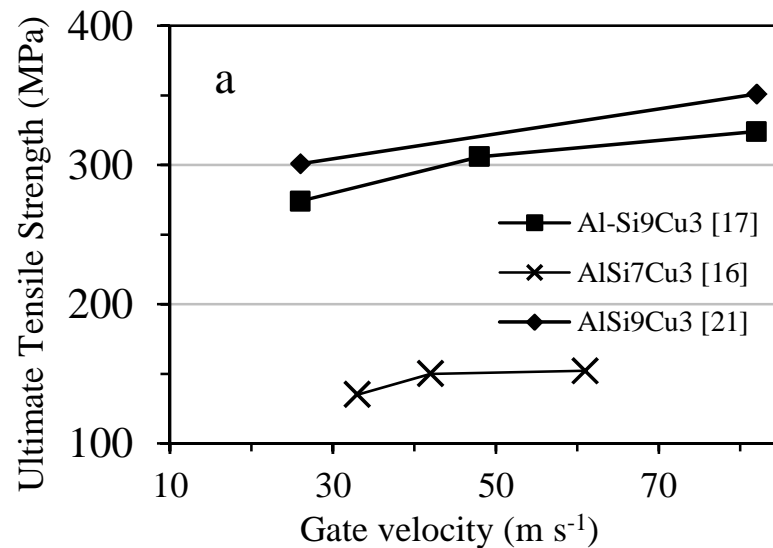


Tensile test curves of specimens cast with three different gate velocities: porosity content (%) are also indicated in the brackets

Mechanical Properties vs Defects & Imperfections of High Pressure Die Castings

Lumley et al. also reported improvement in tensile strength properties with an increase in gate velocity.

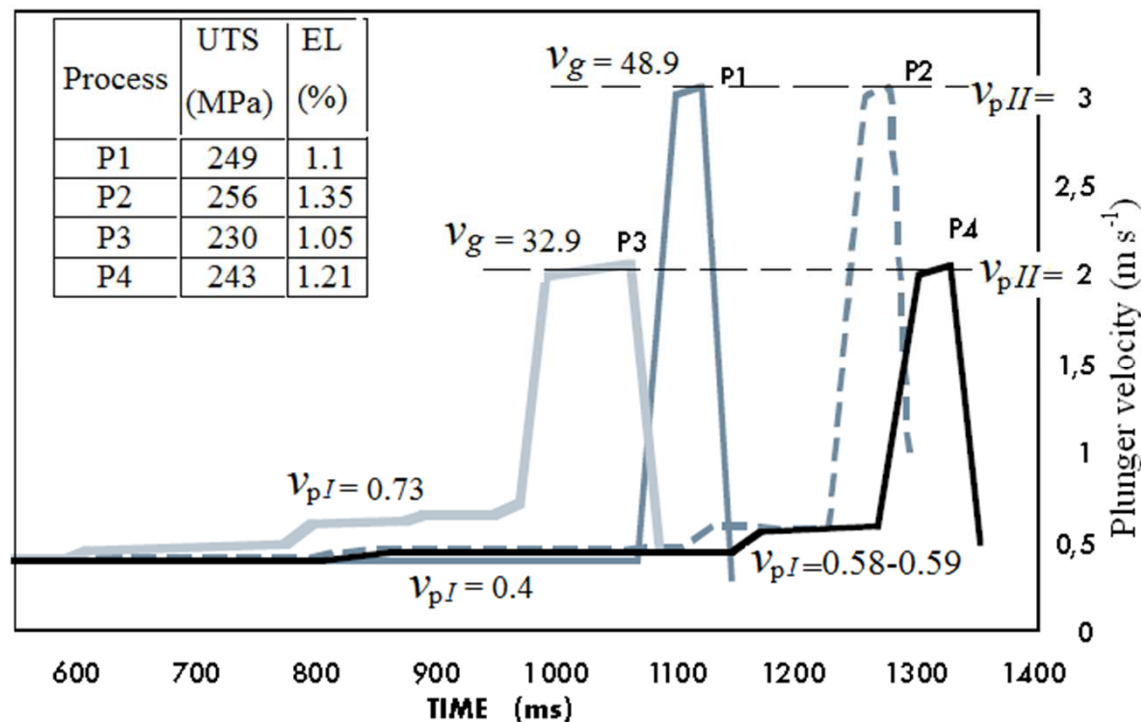
The influence of gate velocity on the tensile properties from different works



Effect of gate velocity on the tensile properties of die cast Al-Si alloys

Mechanical Properties vs Process Parameters in HPDC

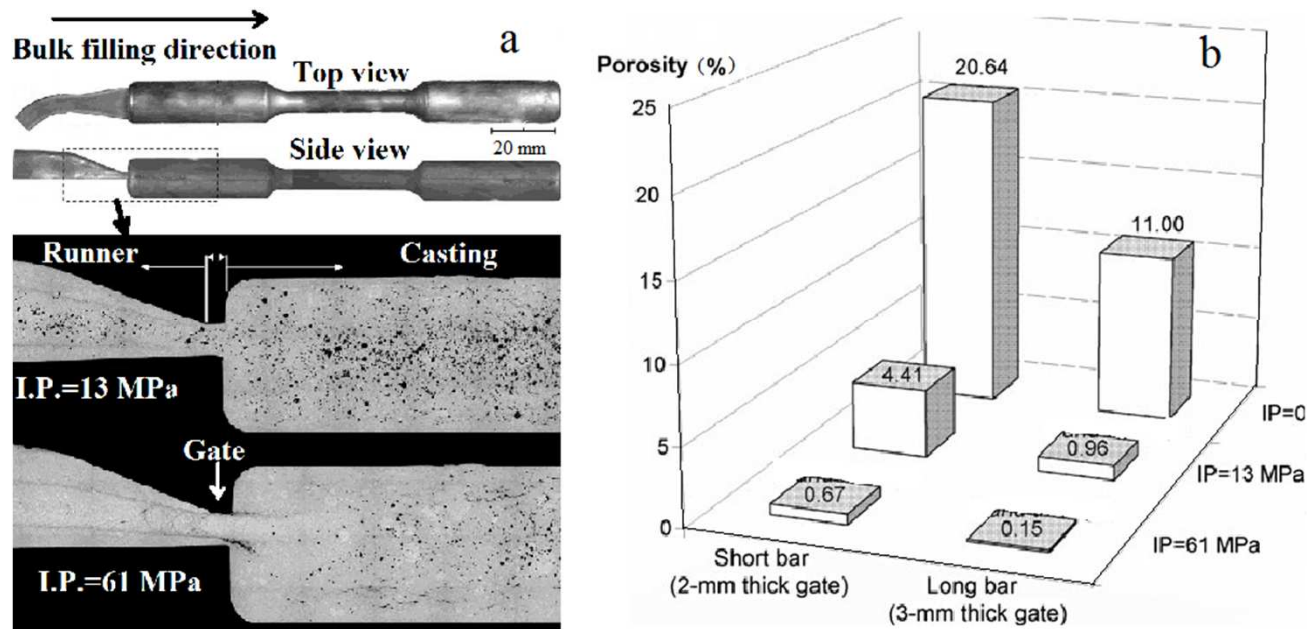
Changing plunger velocities and maintaining the intensification pressure (IP) constant, higher gate velocity yielded better tensile properties



Plot depicting the effect of varying plunger velocity on the tensile properties of Al-9Si alloy equivalent to US A380 aluminum alloy

Mechanical Properties vs Process Parameters in HPDC

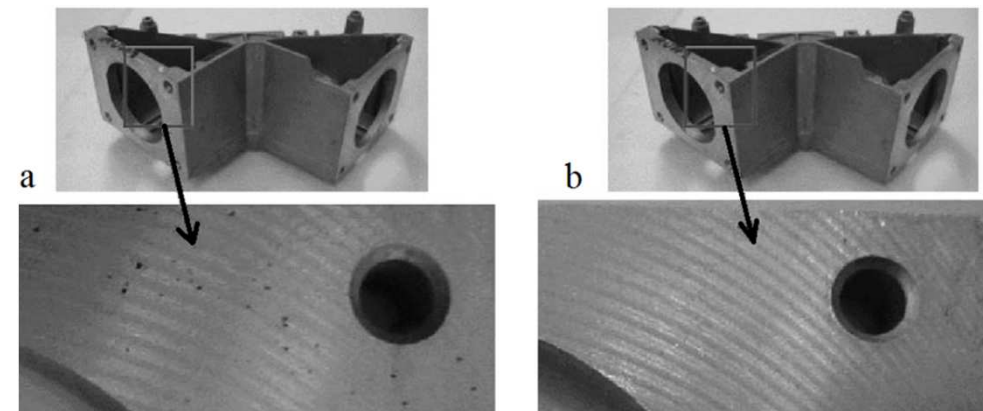
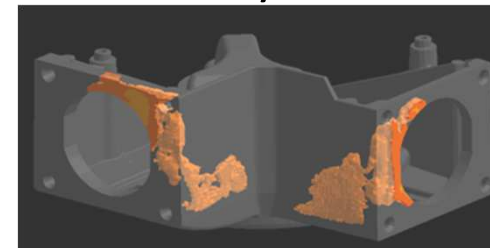
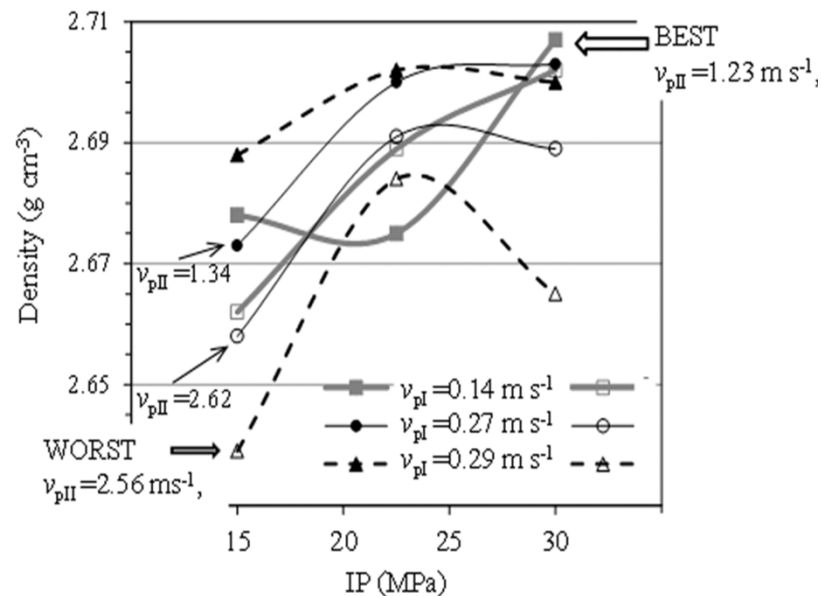
Intensification pressure is applied once the die cavity is completely filled to limit the formation of porosity due to solidification shrinkage, gas evolution and the expansion of entrapped air, improving the strength properties of the casting.



Effect of different IP on the (a) microstructure of the die castings and (b) percentage porosity (AlSi3MgMn)

Defects vs Process Parameters in HPDC

Verran et al. tried with different values of melt velocity and IP, using the design of experiments (DOE) methodology, to cast a double cylinder cover of AlSi12Cu1.3 alloy with the 'Best' density value

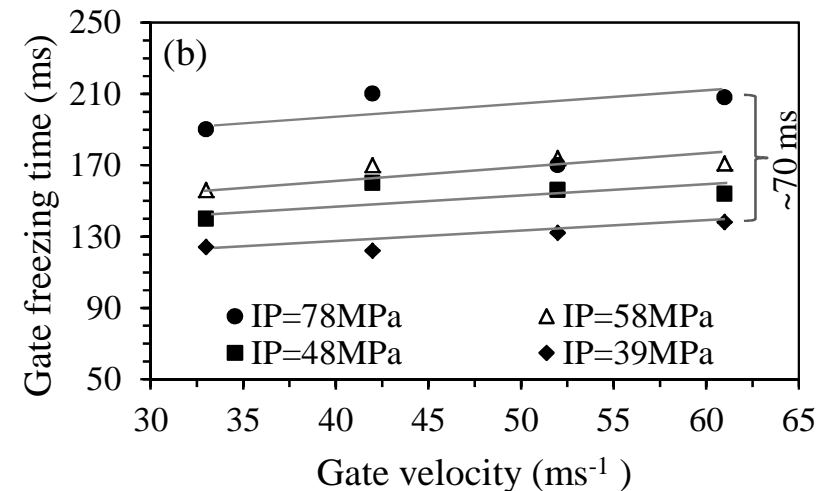
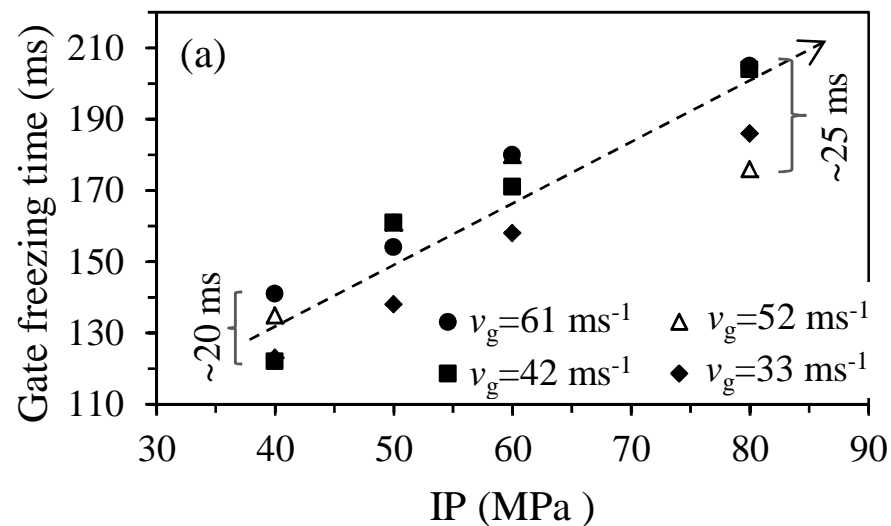


Density as a function of different IP levels: the curves refer to different injection plunger velocities.

Photographs showing the double cylinder cover casting under Worst and (b) Best density values.

Defects vs Process Parameters in HPDC

Verran et al. tried with different values of melt velocity and IP, using the design of experiments (DOE) methodology, to cast a double cylinder cover of AlSi12Cu1.3 alloy with the 'Best' density value



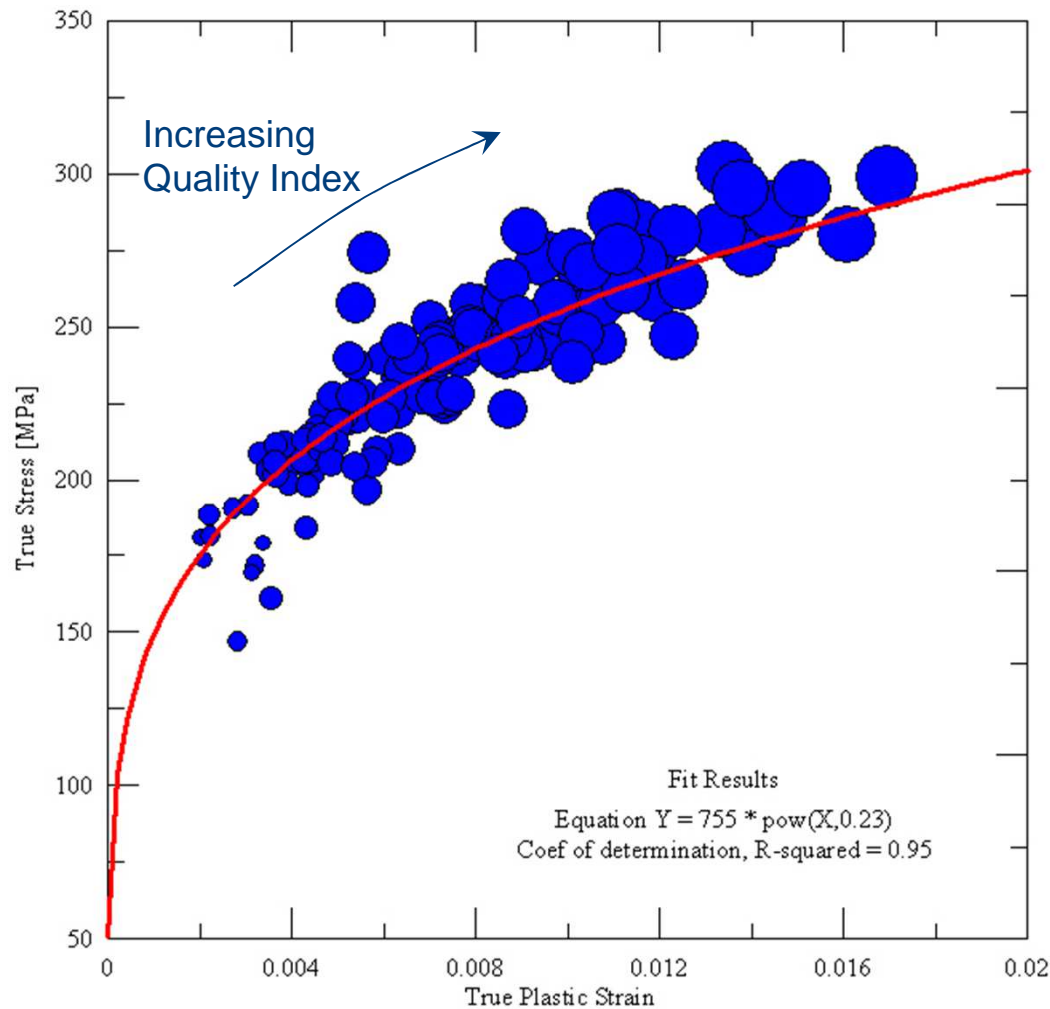
Effect of (a) intensification pressure and (b) gate velocity, on the gate freezing time

High Pressure Die Castings: Mechanical Properties

HPDC Al alloys – EN 1706:2010 Standard

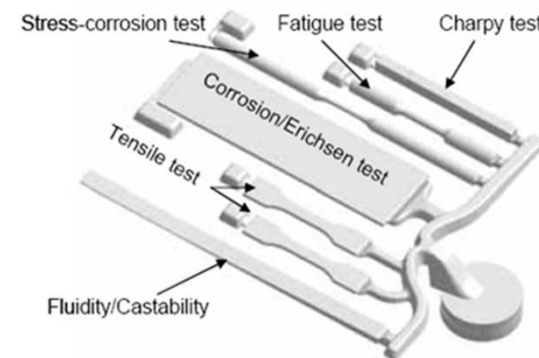
Group	Number	R_m min [MPa]	$R_{p0,2}$ min [MPa]	HB
AlSi10Mg	EN AC-43400	240	140	70
AlSi	EN AC-44300	240	130	60
	EN AC-44400	220	120	55
AlSi9Cu	EN AC-46000	240	140	80
	EN AC-46100	240	140	80
	EN AC-46200	240	140	80
	EN AC-46500	240	140	80
AlSi(Cu)	EN AC-47100	240	140	70
AlMg	EN AC-51200	200	130	70

High Pressure Die Castings: Mechanical Properties



The dimension of the porosity reduces the quality, so the mechanical properties (UTS).

Yield Strength (YS) depends on microstructure – constant for HPDC components



a)

High Pressure Die Castings: Mechanical Properties

Process	1 st phase Velocity [m/s]	2 st phase Velocity [m/s]	Switch Point [mm]	3 st phase Upset Pressure [MPa]	Metal velocity at ingates [m/s]	Filling Time [ms]
P1	0.26	2.60	220	40.0	47	10.7
P2	0.26	2.33	220	40.0	42	12.0
P3	0.29	2.40	220	40.0	43	11.6
P4	0.29	2.29	220	39.8	41	12.2
P5	0.19	2.86	210	39.4	51	9.7
P6	0.27	2.41	220	40.2	43	11.6

The multispecimen die was used to produce 150 castings.

About every 25 items the process parameters were changed, as reported in the Table

High Pressure Die Castings: Mechanical Properties

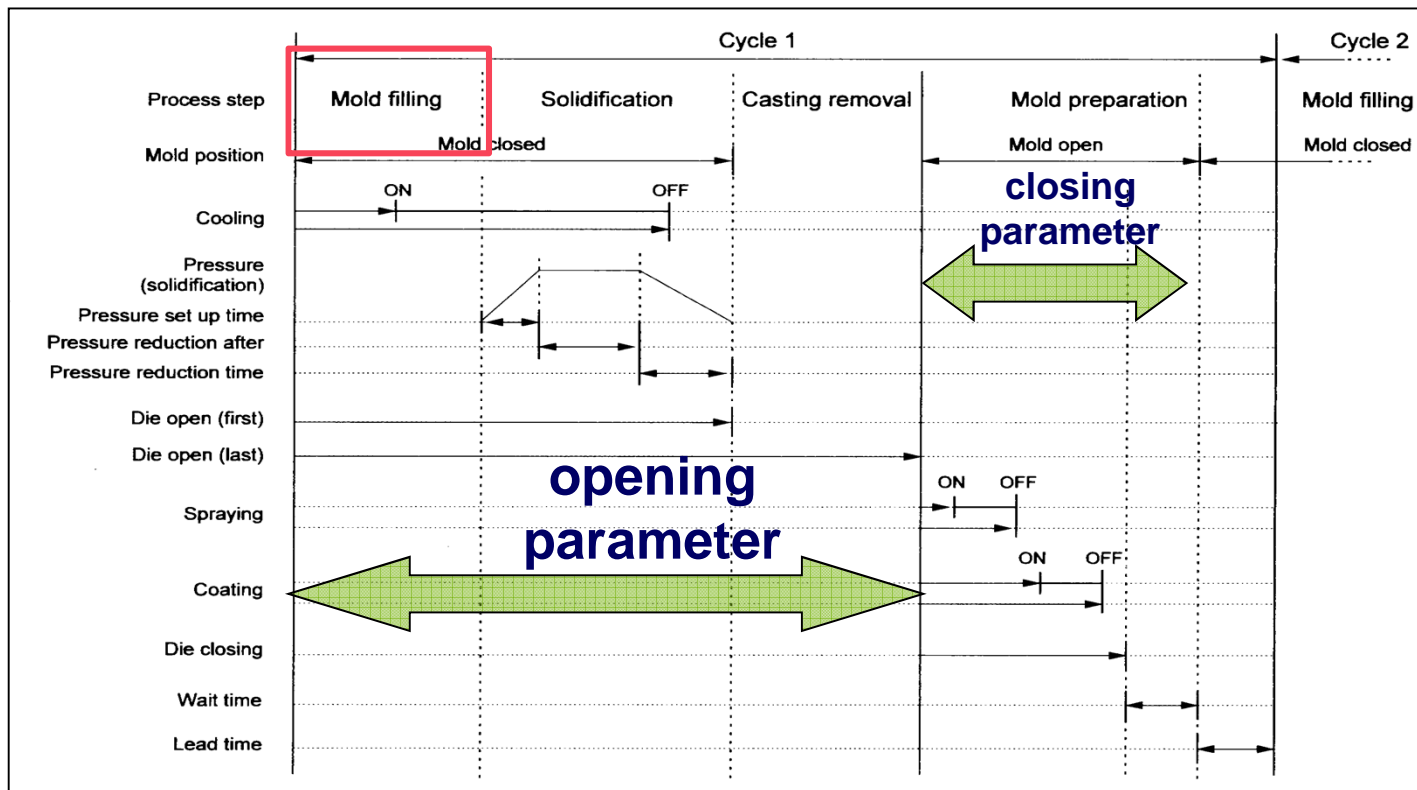
UNI EN AB 46000



	YS (MPa)	UTS (MPa)	e (%)
P1	160,5 ± 0,7	265,7 ± 7,6	2,12 ± 0,22
P2	161,0 ± 1,0	275,7 ± 6,8	2,29 ± 0,20
P3	162,6 ± 0,6	304,4 ± 6,5	3,53 ± 0,32
P4	164,9 ± 1,3	292,2 ± 12,8	2,85 ± 0,50
P5	163,0 ± 0,9	308,6 ± 6,2	3,58 ± 0,33
P6	163,0 ± 3,3	302,2 ± 9,4	3,28 ± 0,41
P7	161,5 ± 1,6	301,6 ± 12,0	3,26 ± 0,52

key aspects of HPDC process: *cycle time*

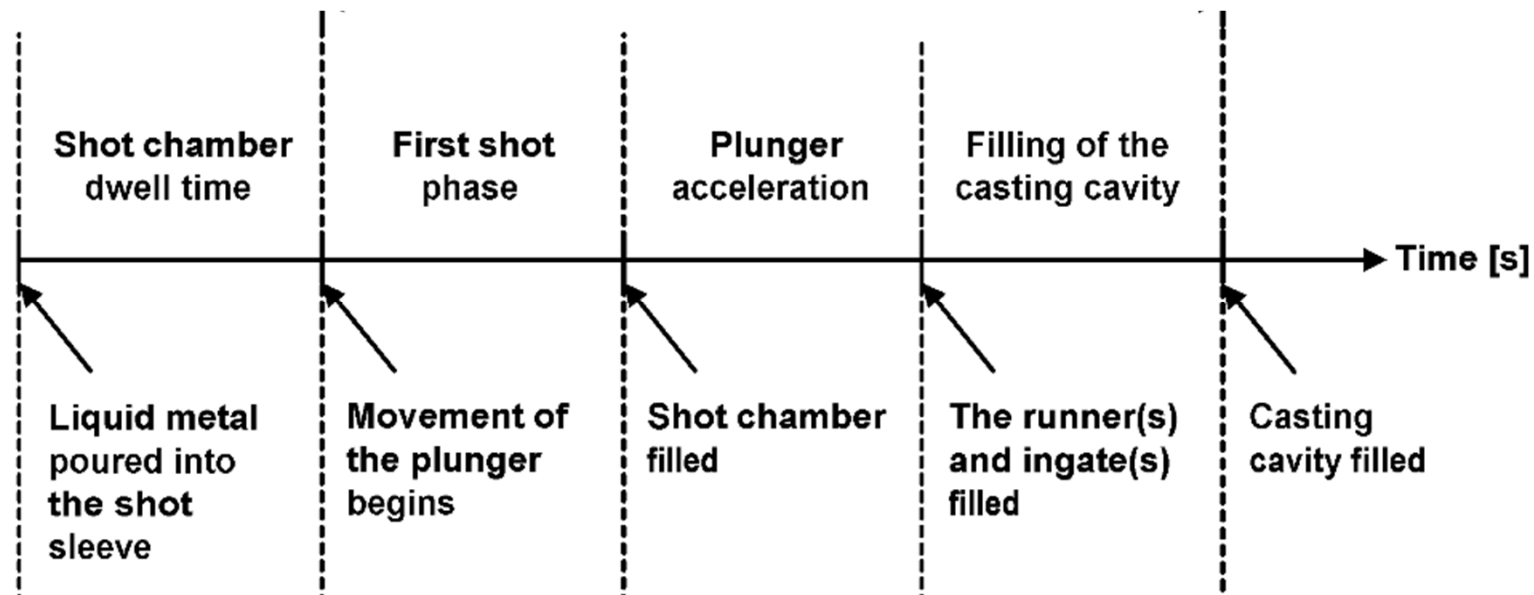
The cycle of the HPDC process consists of mold filling, solidification, casting removal and mold preparation.



key aspects of HPDC process: *shot profile*

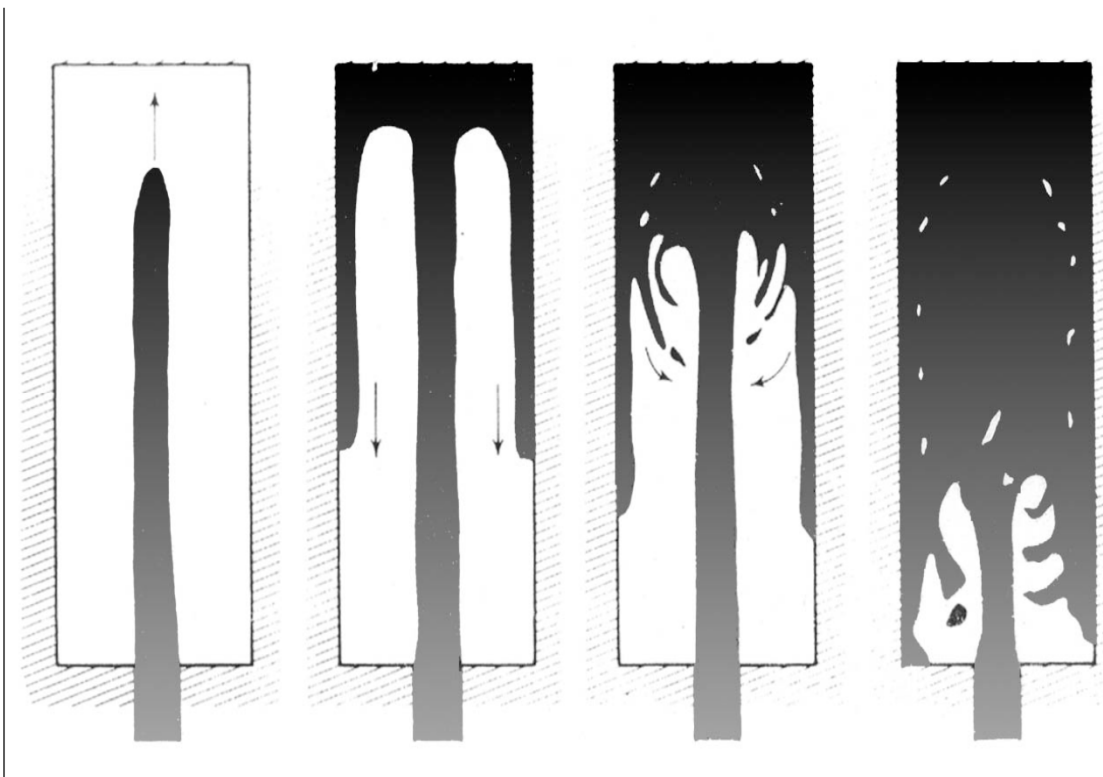
The mold filling is further divided into four separate time periods:

- The initial filling of the shot chamber
 - The slow piston movement until the shot chamber is 100% filled
 - The acceleration plunger at the filling the running and gating system
- The filling of the die cavity
The flow flux can be calculated automatically through the software calculator or by one self



key aspects of HPDC process: *conventional flow*

Conventional HPDC Flow



Melt *sprays* into cavity

@ velocity typically > 30 m/s

– **ultra-*turbulent* cavity fill**

- **entraps cavity gasses**

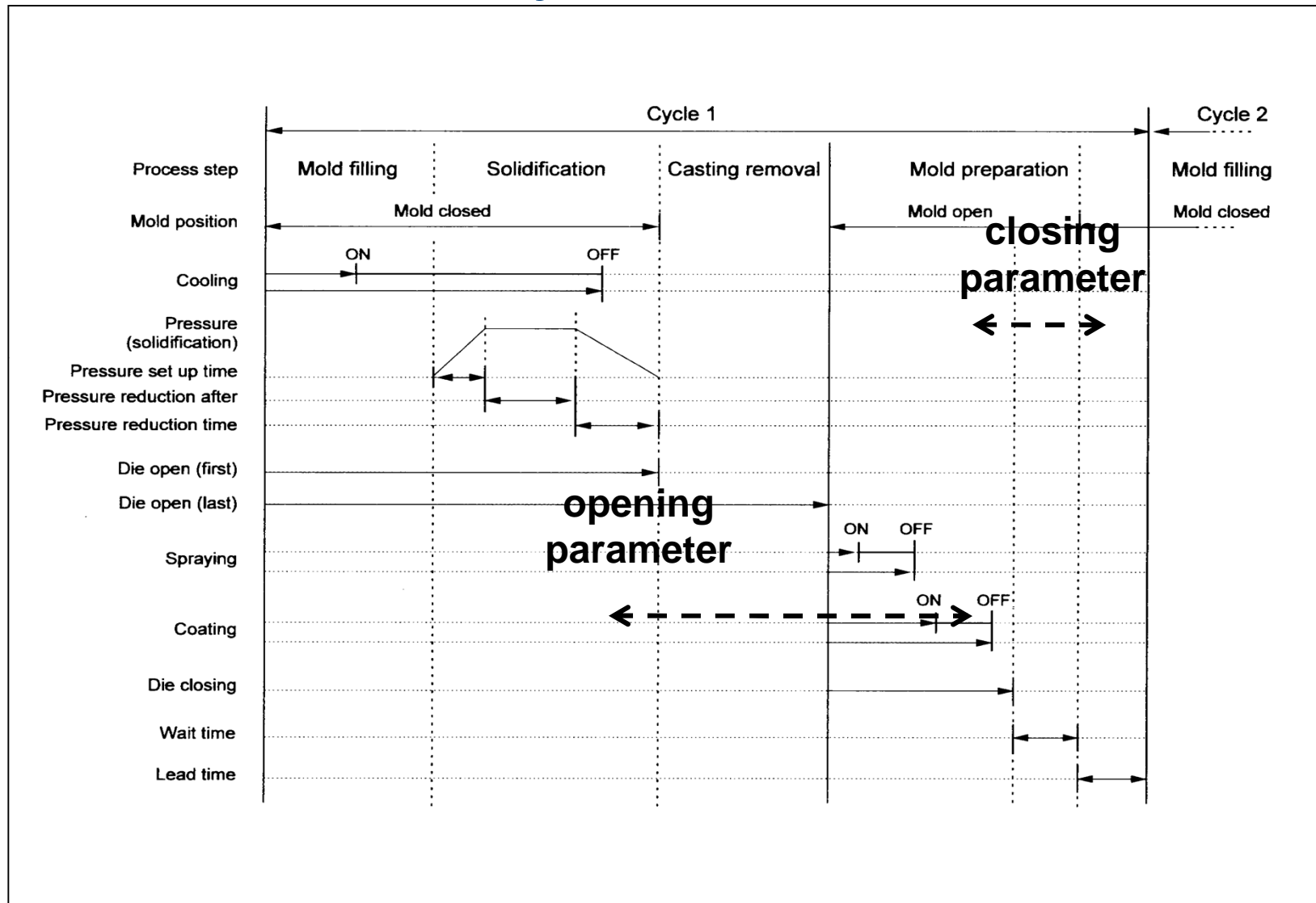
- **entraps lubes**

– **Causes high terminal pressure spike that must be contained by locking force of casting machine and by well-locked and sealed tooling**

GOAL: the best shot profile to injecting the melt



GOAL: the best HPDC Cycle



AGENDA



Key partner in Design Process Innovation

HPDC workshop at SAPCO – 16th November 2016

- 1 Introduction to HPDC process [EnginSoft] - 60 min
 - 1.1 *Materials for High Pressure Die Casting: castability and general mechanical properties*
 - 1.2 *Defect classification and correlation with casting process phases*

- 2 HPDC Machine and the Injection system [IDRA] – 60 min
 - 2.1 *The HPDC Machine and innovation for the injection process*

- 3 Die design [EnginSoft]- 60 min
 - 3.1 *Design of the gating and venting system*
 - 3.2 *Optimization of high pressure die casting process parameters*

Lunch break

AGENDA

4 Solidification of the casting – 180 min

4.1 *Introduction to the thermal steady state of the die [EnginSoft] – 30 min*

4.1.1 Analysis of the factors contributing to the heat balance of an high pressure die-casting mould

4.2 *The role of lubricant and lubrication [MotulTech_Baraldi] – 90 min*

4.2.1 Lubricant materials

4.2.2 Thermocamera to measure the die surface temperature by TTV system

4.3 *The role of thermoregulation unit [IECI] – 60 min*

4.3.1 Thermoregulation of the die

4.3.2 Thermoregulation of the shot chamber

Coffe break

5 Conclusions of HPDC workshop [EnginSoft] – 60 min

5.1 *Integrated product-process design improving the mechanical performance of light alloy automotive components*

5.2 *Thermo-mechanical behavior of HPDC equipment*

5.3 *The real-time Control of the HPDC process predicting the Quality at any shot*

6 Questions & Answers [All] – 30 min

CONTACTS

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