Aspects of the Use of Investment Casting Wax with Ceramic Cores

Blayson Conference Centre

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Dave Bond – Technical Director

Phil Hancock – Technical Manager

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Agenda

- Section 1
  - Composition, Control and Testing of Wax
- Section 2
  - Relationship between Wax and Injection Characteristics
- Section 3
  - Use of Wax with Ceramic Cores, Theoretical and Practical Considerations

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SECTION 1

Composition, Control and Testing of Wax

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Composition of Investment Casting Wax

- Investment casting waxes are complex formulations containing many components :
  - Paraffin wax
  - Microcrystalline wax
  - Resins - strong, viscous, brittle
  - Polymers - ductile
  - Fillers - reduce contraction, improve mechanical strength
- The % addition and control of these additives is critical in determining the properties of the wax, they make each wax unique
- Blayson's strength is understanding these properties and their interaction, allowing adjustments to be made to maintain key process parameters

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Manufacturing

Close control is achieved by :

- Automatic temperature control of the melting process
- Data monitoring of both temperature of the melt and pressure used on the filtration unit
- Extensive testing
- Statistical Process Control of both raw materials and finished products

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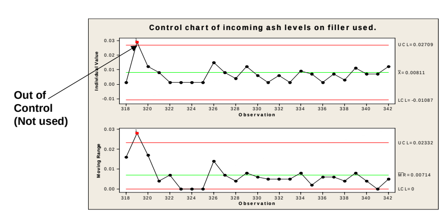
Statistical Process Control



Both incoming test results and in-house test results on raw materials are fed into a control chart, and use based on the results determined.

The use of SPC also allows tracking of trends in suppliers processes, and allowing pre-emptive corrective action.

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Test Methods

A number of industry recognised physical tests are used :

- Congealing Point
- Drop Melt Point
- Viscosity
- Penetration
- Ash
- Filler content
- Mechanical strength
- New Tests – DSC, Oscillation, Volumetric Expansion

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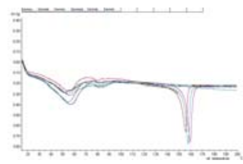
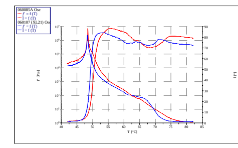
DSC

Differential Scanning Calorimetry



DSC analysis gives an indication of the melting phases of different compounds.

Oscillation



Oscillation curves give an indication of the shear properties of wax at different temperatures. Gives a good indication of the setting properties of a wax.

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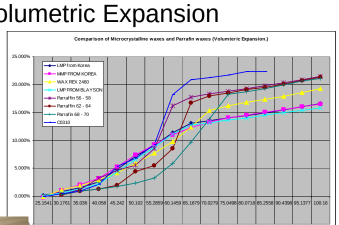
Volumetric Expansion



Blayson Japan has developed a volumetric expansion test to dewax temperatures.

A unique feature is that data capture is automatic and not dependent on operator measurements.

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SECTION 2

Relationship between Wax and Injection Characteristics

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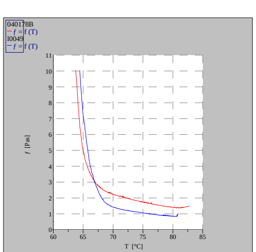
Wax Fluidity



- Wax fluidity is key to control of many problems
  - flow lines.
  - surface finish
  - non fill and air entrapment
- A relationship exists between wax temperature and fluidity. Important when operating near the congealing point
- Effect of die temperature should not be underestimated

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Fluidity Measurement

- Wax Fluidity can be measured using the 'Fluidity Spiral'
- Injected at :
  - fixed wax temperature
  - fixed die temperature
  - fixed injection pressure
  - fixed flow rate
- Recommended for use by foundries to ensure individual machine settings optimised for every batch

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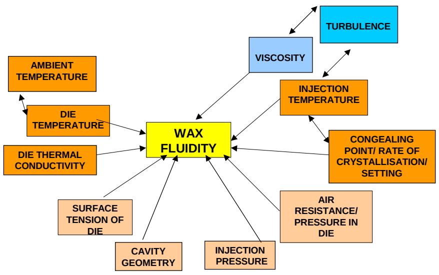
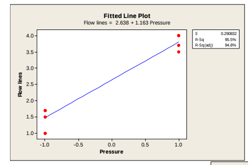
Factors Affecting Fluidity



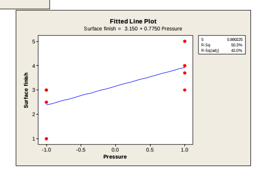
Relationships with Injection Pressure



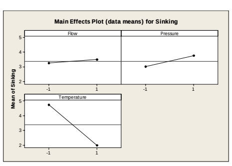
Recent trials suggest a relationship between flow lines and pressure, higher pressures minimise flow lines.

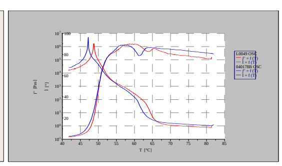
Evidence exists for a similar relationship between pressure and surface finish (orange peel).

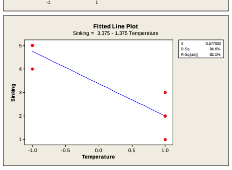
Obviously care must be taken when using cored parts (core breakage)



Temperature and Cavitation







Injection trials suggest a strong link between wax temperature and cavitation.

Indications are that the cause is the time that the wax is liquid/semi liquid, increasing the temperature increases the time.

This explains why sprue size and location affects sinking, and also that sinking is probably related to the setting rate of the wax.

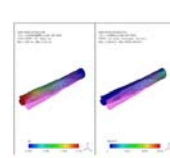
Filler reduces liquid by around a third and imparts a nucleant, also reduces contraction.

Questions ?

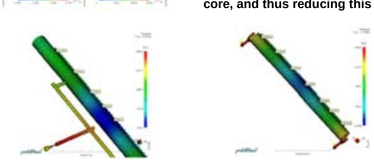
SECTION 3

Use of Wax with Ceramic Cores, Theoretical and Practical Considerations

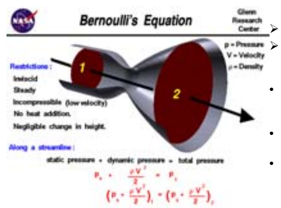
Sprue Location



- Work carried out by G T Mars on plastic injection demonstrates that cores are deflected during injection.
- The results suggest that this is flow related, (due to change in pressure gradient across the core) and that sprue position is critical.
- The conclusion was to move the sprue from the side to the end of the piece, thus changing the direction of flow onto the core, and thus reducing this gradient



Pressure Exerted by the Wax



- Thermo fluid mechanical theory suggests that the total pressure exerted within the fluid comes from the sum of:
  - Static pressure - fixed
  - Dynamic pressure - as the density is fixed at a particular temperature is dependant upon velocity.
- Increasing either wax temperature, flow or pressure, will increase the overall pressure within the wax.
- From this it can be seen why sprue position is important
- By locating the sprue at 90° to the core, the flow of the wax would be concentrated onto the core where little support exists.

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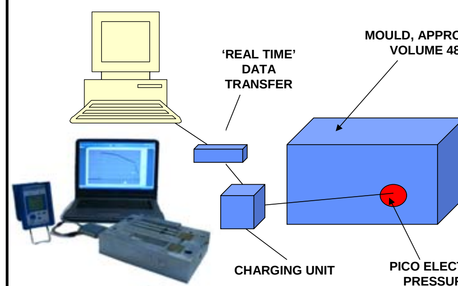
Injection Pressure Measurement Schematic



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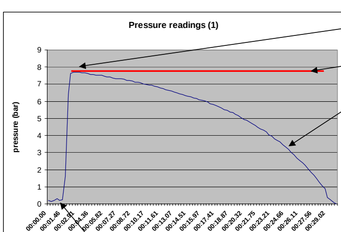
Die Pressure Results 1



INITIAL PRESSURE.. AROUND 8 BAR.

APPLIED PRESSURE

RECORDED PRESSURE

Q - WHY DOES RECORDED PRESSURE NOT MATCH APPLIED PRESSURE ?

A - PROBABLY A RESULT OF CRYSTALLISATION (SETTING) OF THE WAX.

TIME TAKEN TILL PRESSURE CAN BE REMOVED IS AROUND 30 SECONDS.

AIR EVACUATION 1.46 SECS

APPROXIMATES TO 33CM³ PER SECOND @ 8 BAR PRESSURE.

AIR PRESSURE RECORDED 0.25 BAR (4 psi)

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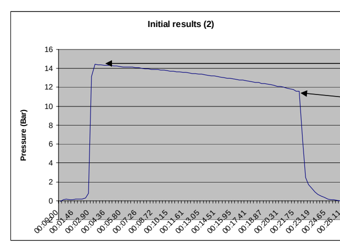
Die Pressure Results 2



HIGHER INITIAL PRESSURE 14 BAR.

INJECTION PRESSURE CEASED TOO QUICKLY, POSSIBILITY OF CAVITATION.

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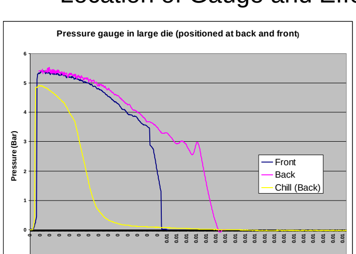
Location of Gauge and Effect of Chill



- When the pressure gauge is relocated, the trace is different, even under the same injection conditions.
- This may demonstrate different solidification conditions within the die and a possible pressure gradient within the die.
- The effect of a chill can also be seen. This allows a reduction in injection time. However the long "tail off" time was not predicted, and may suggest a softening of the chill wax.

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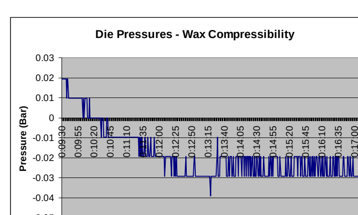
Wax Compressibility



- An unforeseen result of the tests, was the demonstration of a negative pressure result.
- As predicted by the Focast models it shows that wax is compressible to a degree.
- This has implications where core injection is concerned, as it suggests a store of energy remains within the wax which could be transferred to the core.

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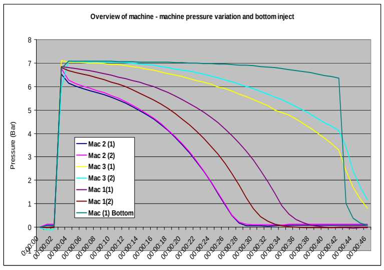
Machine Tests



Calibration showed significant variations between injection machines.

Up to 7% variation between the pressure indicated by the gauge and the pressure recorded by the probe.

The probe also highlighted a considerable variation between side and bottom injection on the same machine.

This may be a result of sprue position.

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Die Pressure - Initial Assessment

- Evacuation of air from the die can be observed
- Transfer of pressure to the die can be observed
- Probable effect of crystallisation on pressure observed
- Effect of premature cessation of injection pressure observed
- A pressure gradient may exist in the die during injection
- Chill wax may soften during injection
- Wax is compressible to a certain extent
- Injection machines vary considerably
- On-going work
  - effect of sprue position
  - effect of wax
  - effect of temperature
  - effect of volume

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Use of Ceramic Cores

- When a die is closed, the pressure will be transferred from the die to the core
- With an unsupported core there is a risk of cracking
- Holding a core too rigidly by use of chaplets may also contribute, support position is critical
  - ensure it is not held too firmly, allow one end to "float", move freely, by use of a 'Slip Joint'
- Important to consider sprue position
  - combination of poor sprue position and a rigid core may give rise to increased deflection and risk core breakage

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Core Print

- The out of cast area used to locate and hold the core in position in the die and in relation to the wax
- A core print does three jobs, it is essential to keep all three aspects in mind :
  1. Holds the core in position during injection
  2. Gives a surface for the shell to adhere to
     - build a feature into the core print which allows the shell to grip it, often accomplished by use of notches 'Shell Lock'
  3. Allows access to the core leach solution in the casting
     - make the print of sufficient length to penetrate the finished casting in a non critical area
     - important to make its surface area sufficient for this process to take place

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Core Inspection

- Dimensions must be checked, with complex cores best accomplished by use of a co-ordinate measuring machine (CMM)
- Check the core surface for any negatives, these give a positive defect on the finished casting
- Visually inspect for cracks, also by X-ray if required. The X-ray direction in relation to the possible crack must be taken into account. Other methods may involve the use of resonant frequency/ring testing
- Check if the cores have been impregnated
- Inspect for flash lines on the cores, these will leave negatives in the casting. Also flash on the core print may be a stress propagator leading to shell cracking

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Core Preparation

- For correct support during injection
  - Wrapping the core in supporting wax, prevents localised sinkage/cavitation
  - Fill weak areas with glue. NB - may hold it too rigid
  - Injecting a wax support to fit onto the core
  - Checking the pin adhesion if applicable, often a source of cracking.
  - Impregnating the core if necessary, may involve the use of silica or wax, best done by core supplier
  - Preheating the core. May help to reduce cracking, no fixed temperature or time, liase with core supplier
  - Boundary layer conditions a contributor to cracking ?

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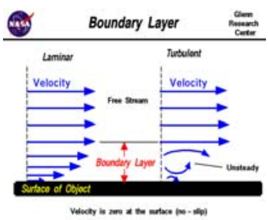
Boundary Layer Conditions



- Boundary layer theory states that at the point of interaction between the wax and an object such as a core or die, that the velocity of the wax will be the same as that object, ie nil and there will be a velocity gradient between this and the "free stream velocity"
- Logic suggests that the core temperature will affect the velocity of the wax adjacent to the surface and the resultant pressure gradient
- Another aspect is that if the velocity gradient is large enough, it may give rise to turbulent conditions

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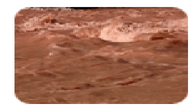
Turbulent Flow

Turbulence is created when smooth, laminar flow conditions break down.

A good example of this is watching a river in deep water when its flow is smooth, and then in the shallows over rocks when it is rough and turbulent. (white water)

Turbulent flow gives rise to a number of problems:

- Loss of energy and its effect on flow characteristics
- Gives rise to defects such as non fill and flow lines
- Possible air pick up
- Poor surface finish



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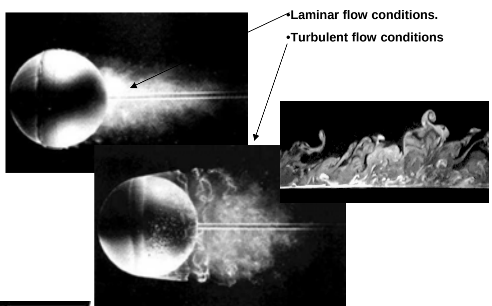
Examples of Flow Conditions



•Laminar flow conditions.

•Turbulent flow conditions

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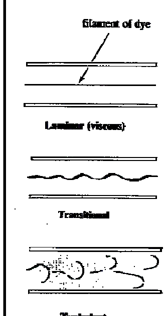
Turbulent Flow



The general accepted relationship for turbulent conditions is the Reynolds number:

Reynolds number = (Density * Mean velocity * Section diameter) / viscosity

Generally the following applies :

<2000 Laminar conditions

2000 – 4000 Transitional

Above 4000 Turbulent conditions

For core injection, the biggest effect would be the change of section diameter caused by the introduction of the core.

Another parameter is core temperature, the core will take temperature away from the wax, may be minimal due to contact time but will affect the viscosity

This creates a paradox, to improve the wax surface (flow lines and orange peel) requires higher fluidity – can be achieved by increasing pressure and/or temperature. However increasing both of these may introduce turbulent flow conditions thus reducing some of this extra energy input and increasing the risk of core breakage.

There is no clear solution to this problem, and a compromise must be reached.

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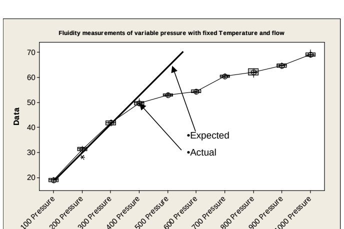
Effects of Turbulence on Wax Fluidity



The effects of turbulent flow are shown on the chart.

It would be expected that as pressure is increased, the measured fluidity should follow the linear relationship. However, a non linear relationship exists, showing that not all the extra energy input is affecting the wax fluidity.

This condition can also be seen if the wax flow is increased.

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Real Time Flow (Focast)

- Bottom filling at 0.4, 1.0 and 2.0 m/s
- Demonstrates increase in turbulent behaviour with velocity
- Also demonstrates how properties such as air pick up and fluidity will have a relationship with the wax viscosity

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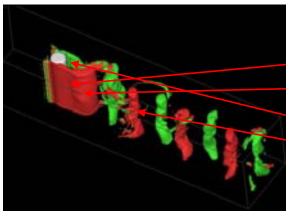
Courtesy of Birmingham University

Passage of a Fluid Medium past a Static Object e.g. a Core



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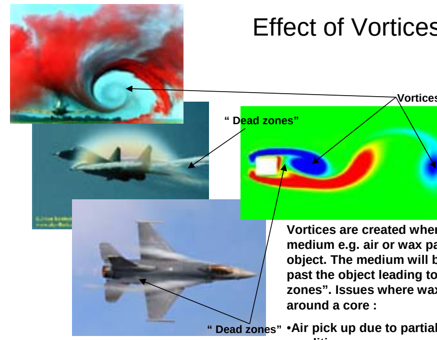
Effect of Vortices



Vortices are created when a fluid medium e.g. air or wax passes an object. The medium will be "thrown" past the object leading to "dead zones". Issues where wax is injected around a core :

- Air pick up due to partial pressure conditions.
- Surface defects caused by reduction in fluidity.

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Summary -Injection Around Ceramic Cores

- Accepted wisdom is that high injection pressures increase the chances of core breakage
- Injection machines usually have variable flow controls allowing wax to be injected in a more controlled manner reducing pressure on the cores
- Sprue position and size is critical
- Use a "dry" run to ensure that "crunching" of the core does not take place on closure
  - paint with thin red dye to show any cracks
- Build the die in such a way that the pattern can be easily removed
- Supporting patterns after injection is critical, failure to do this correctly may lead to distortion and/or core failure
  - time is dependant upon piece size
- Check for core breakage after injection by use of X-ray inspection

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Questions ?

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