Wax Fundamentals and Use with Ceramic Cores

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Aims of Presentation

- To give an understanding of the make up and use of wax.
- To help the participant to be able to visualise wax injection and how this can affect possible defects.
- To give an insight of the use of wax with ceramic cores.

Agenda

- Wax Manufacture and testing.
- Surface Defects and Flow Conditions
- Wax Dimensional aspects
- The Use Of Fillers In wax
- Theoretical and Practical considerations when using cores at injection.
- The effect on mechanical strength of wax injection parameters.
- The make up of Ash in wax
- Glossary of Defects.

Historical Use Of Investment Casting Wax


Ancient Egyptian investment castings from the tomb of Tut-Ankh-Amun.

- Investment casting or “The lost wax process”, has been used for thousands of years.
- Our forefathers did remarkable things with basic wax made from such components as “Bee’s wax”.
- However modern wax must be capable of fulfilling many varied and sometimes opposing functions.

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The Uses of Modern Wax

- Wax must be capable of achieving **intricate detail**, as well as **tight tolerances**.
- Must have the **mechanical strength** to withstand the sometimes significant loads associated with the shell systems.
- Must have very low ash contents so as not to affect the mechanical strength of the finished part by means of **inclusion matter**.
- Must be **commercially viable**.
- Must be aesthetically attractive, with colours to aid **defect identification**.
- Must be **capable of reclamation.**
- Must be forgiving enough to **allow injection** under a **variety of conditions** and with a variety of machines.

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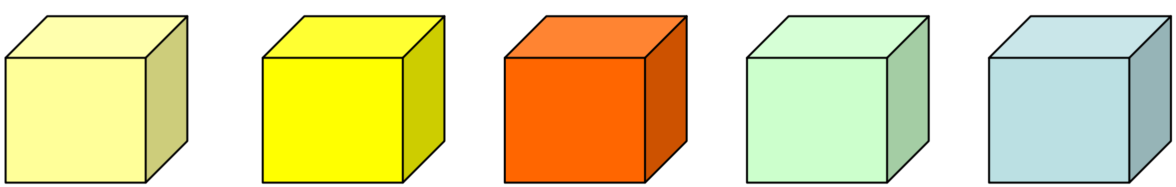
Composition of Investment Casting Wax

There can be from as little of 3 or 4 to as many as around 15 different components to each wax, giving each material its own unique properties and fingerprint.

With wax, small percentages of materials can make very big differences.

Today's investment casting wax are very complex materials.

Paraffin wax | **Microcrystalline wax** | **Resins** | **Plasticisers** | **Fillers ?**



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Testing

- A product is tested to establish whether it meets its specification.
- The specification is determined during the development stage, and is a reflection of the capability of the process when manufacturing the wax.
- This variability is due to raw materials, equipment and operator capability and small variations in the manufacturing process.

Test Methods

Blayson currently uses a number of tests which are industry standard, and are proven over a number of years in investment casting foundries

- Congealing Point reflects the point at which the liquid wax starts turning into a solid, this is important since it gives the injector a guideline at which to begin injecting. (For liquid we normally recommend Cp plus 4 degrees, for paste Cp minus 4C)
- Drop Melting Point indicates the point at which the wax turns to liquid. This is important when considering dewaxing
- Penetration gives an idea of how hard the wax is, can be very important when considering thin sections such as turbine blades which can be damaged easily. Also too soft a wax may distort easily.

Test Methods

- Viscosity is an indication of how a wax flows at different temperatures, (This test in conjunction with the CP test is the most important for injection since together they give an idea of the parameters that should be used.) It is important to not to consider these results in isolation, but keep records of parameters required with each viscosity etc.
- Ash gives an idea of the cleanliness of the wax. The importance of this is very much process dependent.
- Filler test gives an idea of the level of filler within the wax, filler level can effect viscosity as well as shrinkage of the wax.

Surface Defects

The Effect of Injection Parameters

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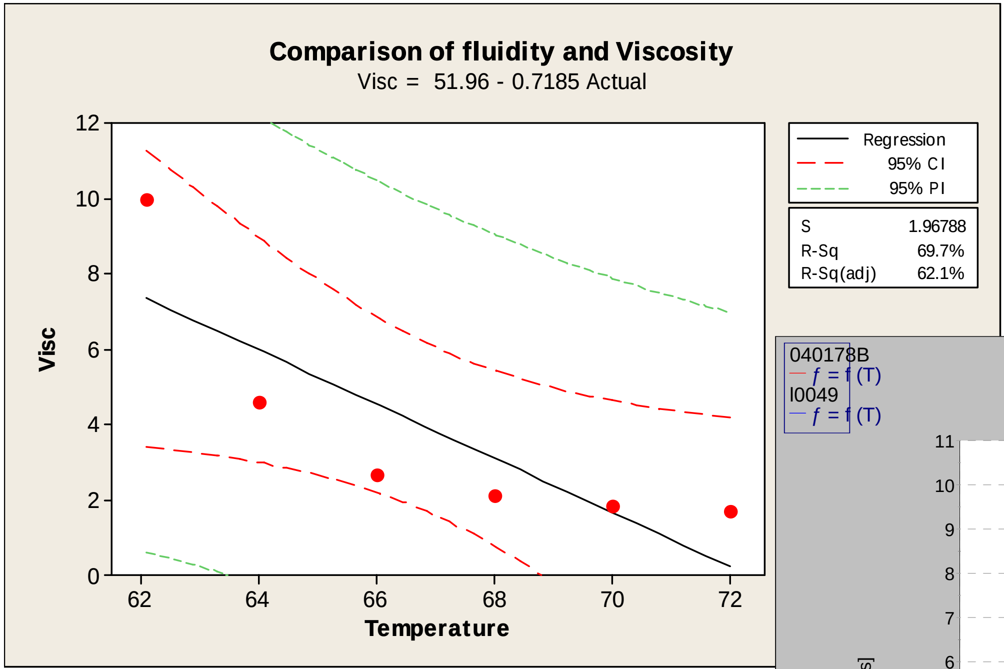
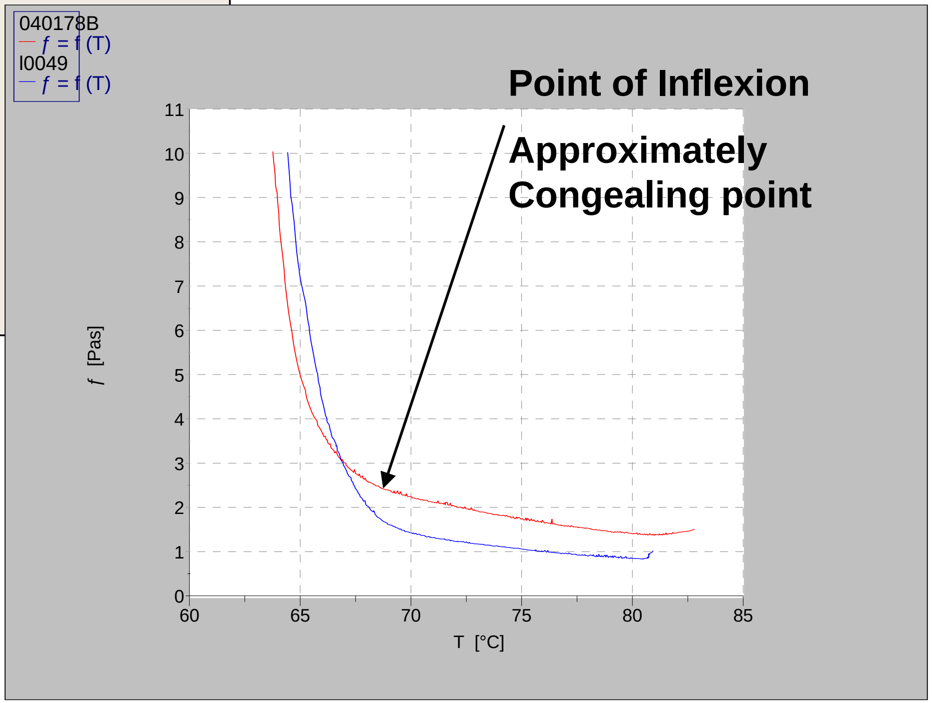
Relationship between Temperature and Viscosity.



A relationship does exist between temperature and Viscosity, which is linear up to a point.

At and below Congealing point it is non linear



Minor variations that take place within specification, in particular parameters such as Congealing point need to be taken into account when injecting.

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How Injection Parameters Affect Surface Defects.

- The results shown in this section are based on an experiment conducted using supplied tooling (A Blade die)
- The aim of this experiment was to improve surface defects, in particular; **flow lines, surface pitting or "orange peel" and surface cavitation or "sinking**".
- This experiment took the form of a designed experiment, with the variables being Temperature **(72ºC & 76ºC**), Pressure (**200 & 600 PSI**), Flow (**20% and 100%**)
- The scoring was a visual analysis, from 1 to 5.

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Results of Trials

- To understand Fluidity relationship, a “Spiral” was injected at the same time as the patterns.

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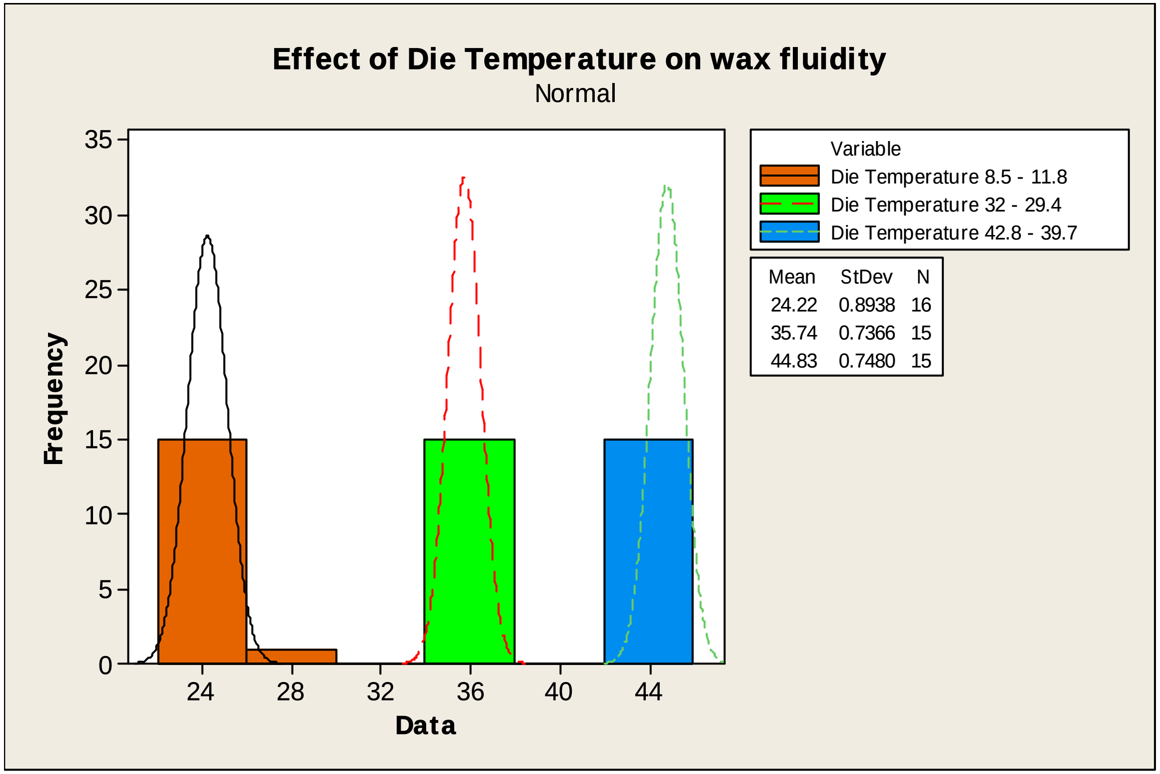
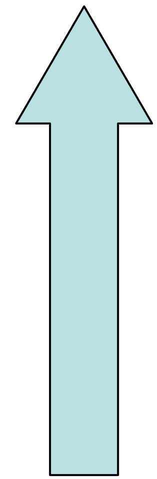
Effect of Die Temperature on Fluidity.





Increased Die temperature

Increased Flow

The injection work carried out using the Fluidity spiral clearly demonstrates that wax fluidity <u>increases with Die Temperature.</u>

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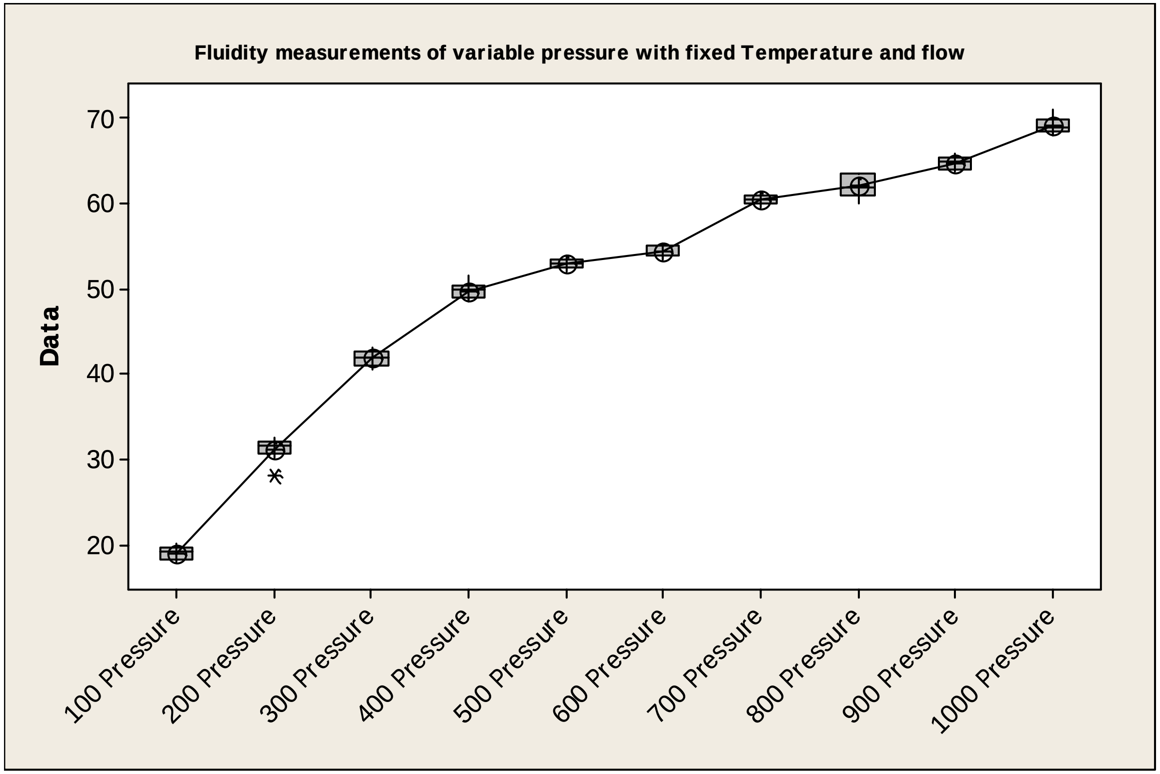
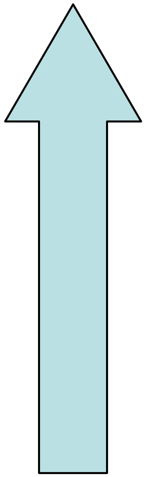
All work took place with a filled wax.

Relationship Between Injection Pressure and Fluidity.





Increased Pressure.

Increased Flow

<u>As injection pressure increases, for fixed flow and temperature, there is a significant increase in the fluidity of the wax</u>.

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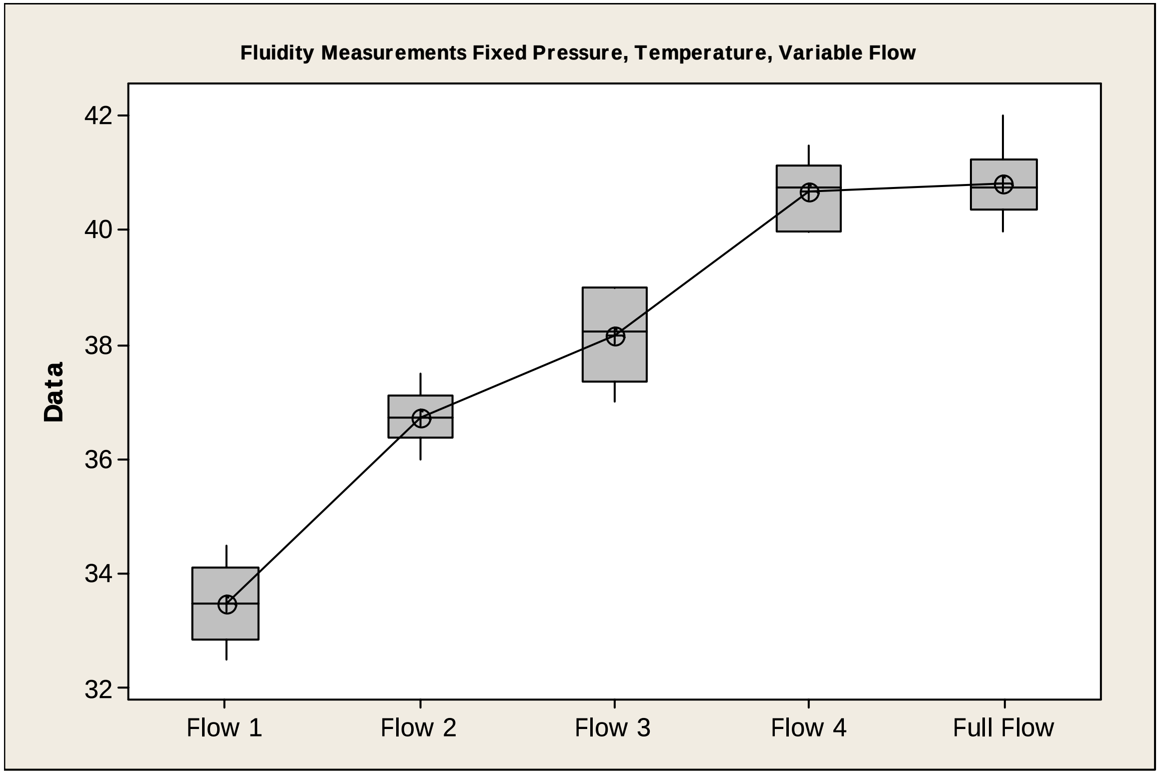
Relationship between Flow and Fluidity.



Increased Injection Flow

Increased Fluidity

Similarly the Fluidity of the wax will increase with increased injection flow, however the effect is much less.

33 – 41mm with change of Flow

20 – 70mm with change in Pressure.

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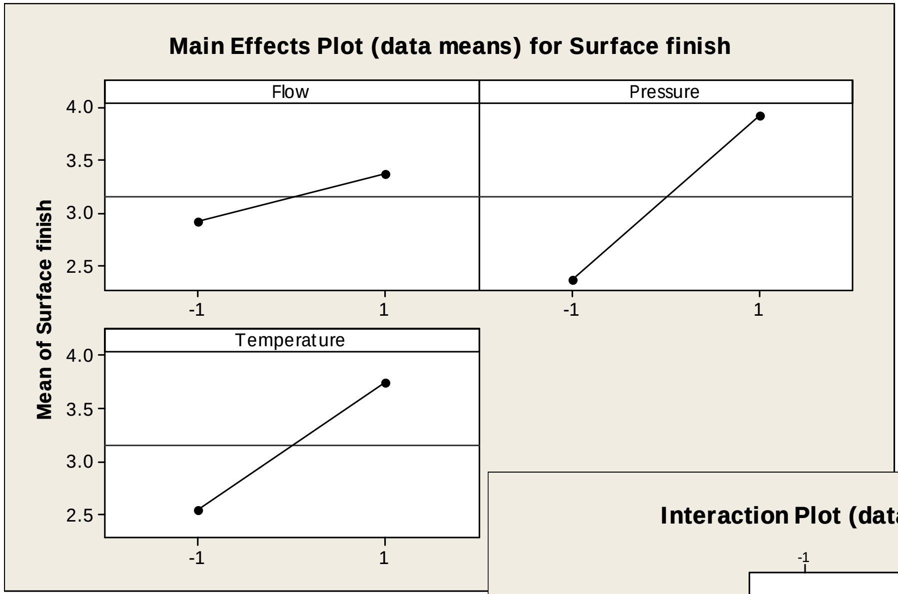
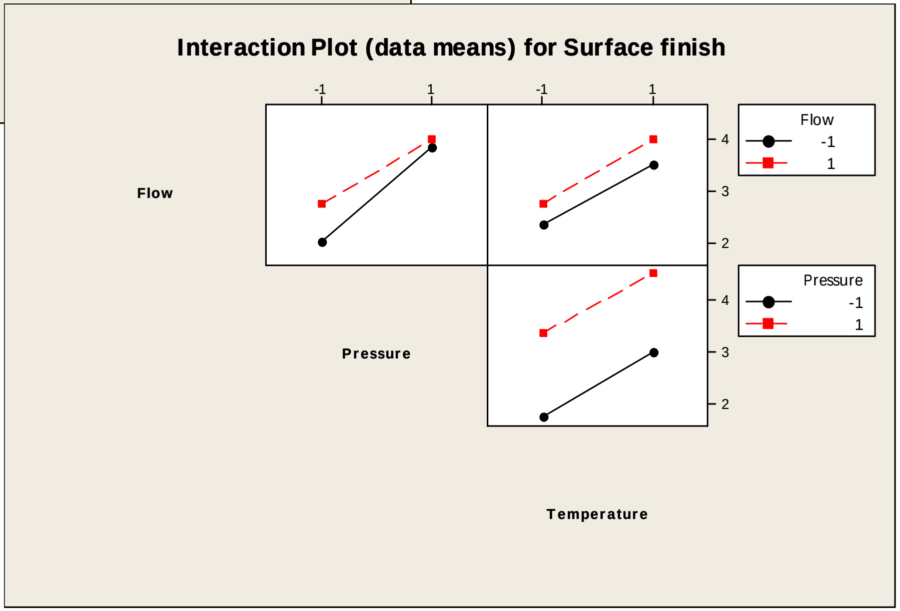
The Causes Of Surface Pitting.



The results of the experiments clearly demonstrated that Surface pitting can be reduced by increasing <u>Temperature or Pressure</u>

It also showed that increasing all three parameters will also reduce this defect.

This suggests that Surface pitting can be reduced by increasing the wax Fluidity.



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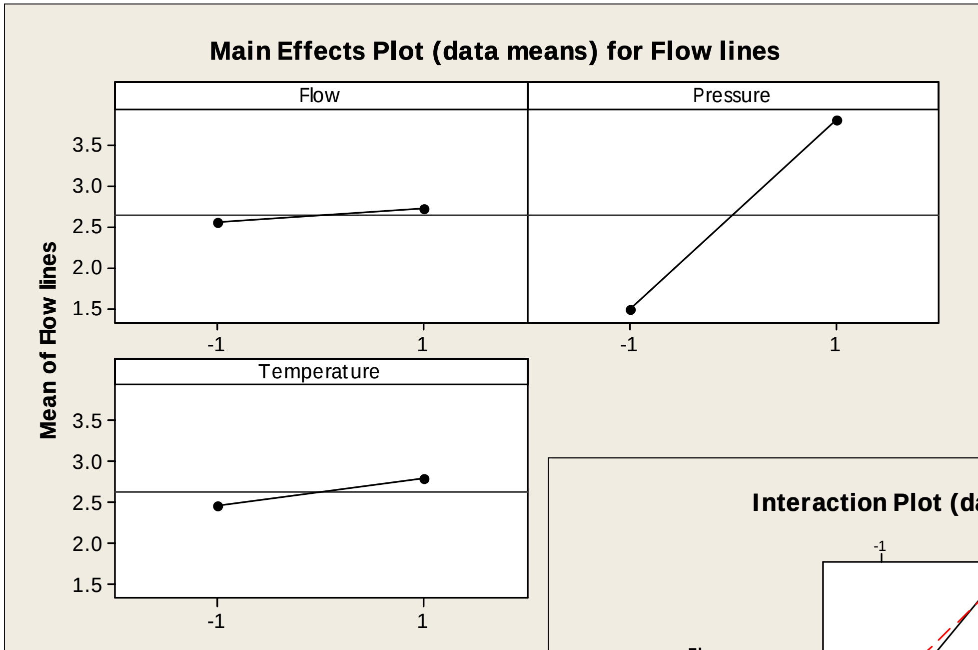
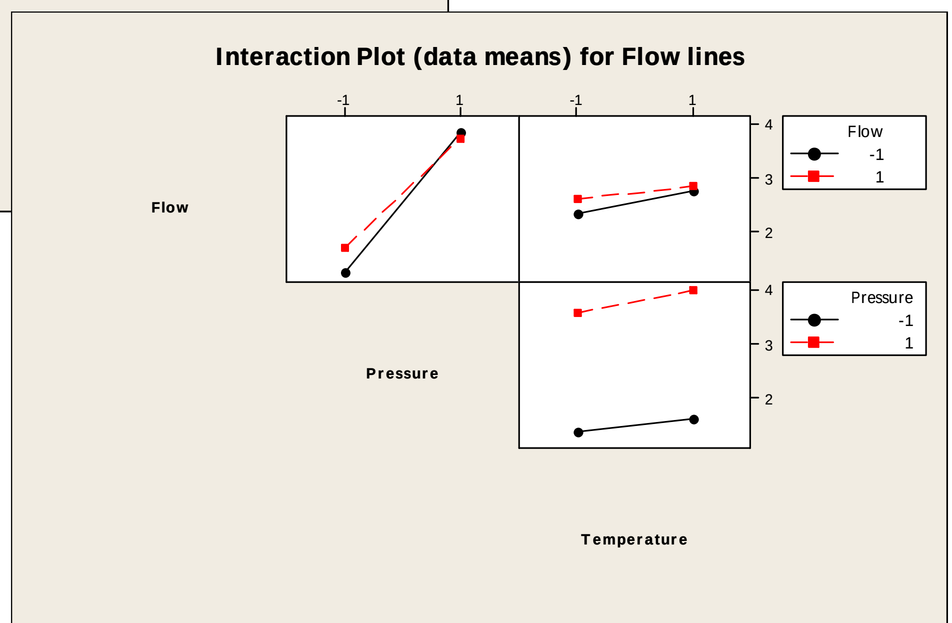
Causes of Flow Lines



The trials results suggest that Injection Pressure is the only parameter that will affect Flow Lines.

No combination of parameters had the same effect.



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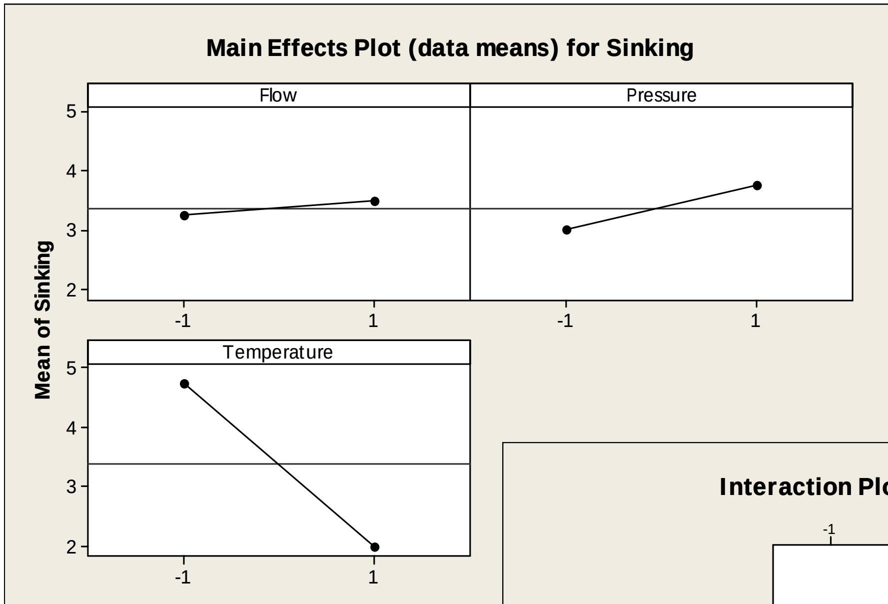
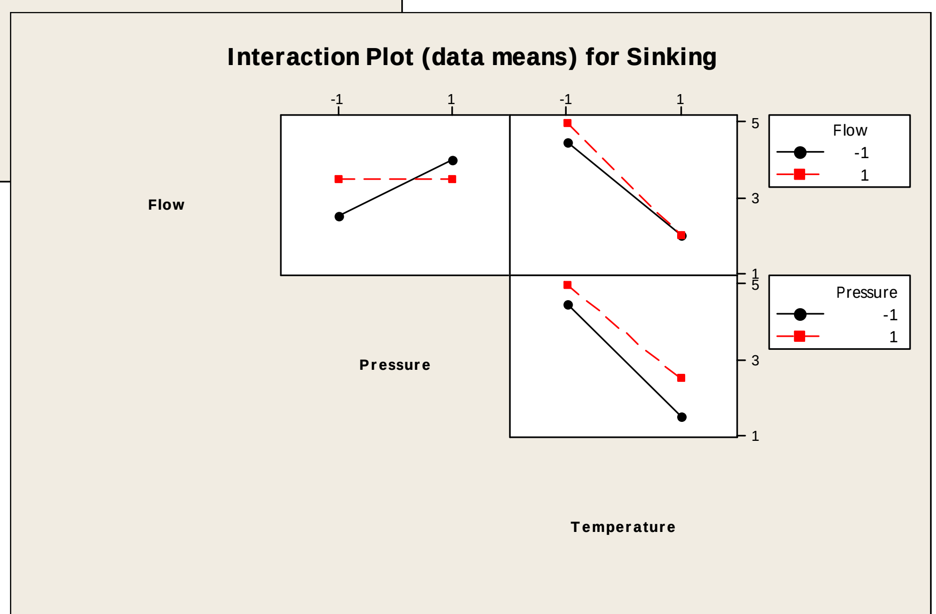
The Cause of Cavitation





Trials results show that cavitation is purely a function of Temperature.

The higher the temperature, the worse the effect.

(It suggests a lack of feed material, the same principle as poor sprue design.)

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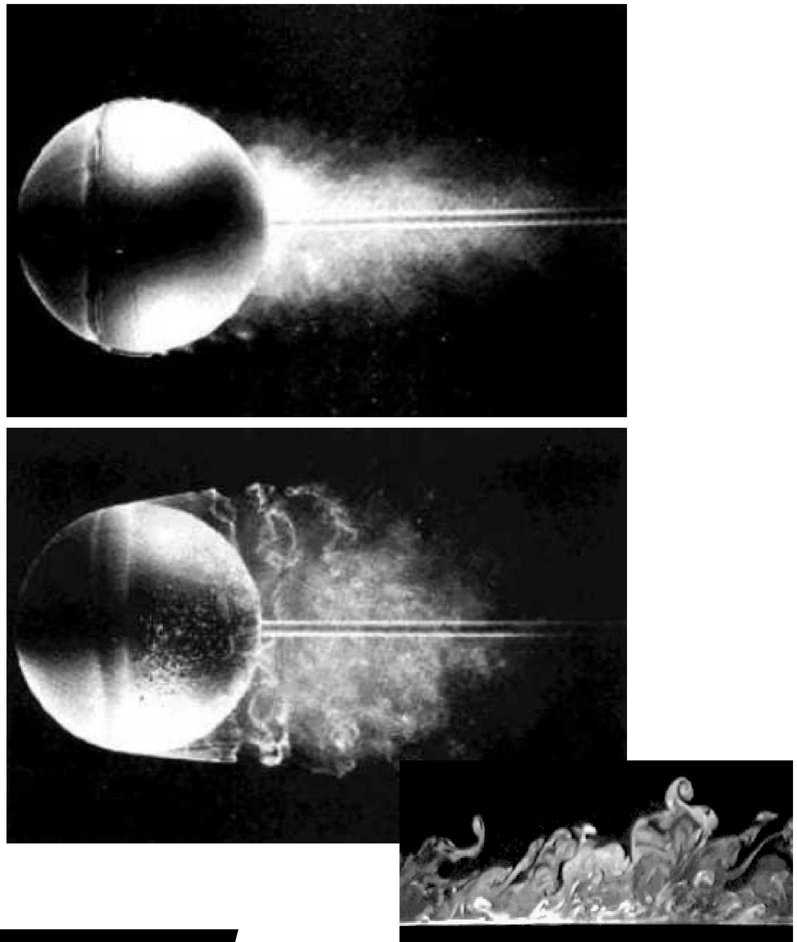
Flow Conditions



- Lamellar flow is the name given to a flow of fluid which is in steady state, that is to say “calm”
- Turbulent flow is when the condition becomes violent, leading to a break down of the steady state conditions.

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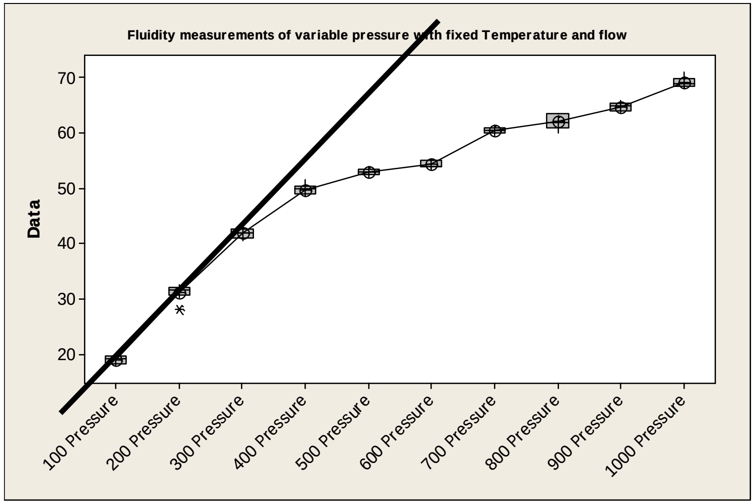
Why is Turbulence a Problem ?

- Turbulence within the flow of any liquid will reduce the amount of energy available, and thus the fluidity of that liquid.
- In the opposite example, the flow of the wax should be linear, but due to loss of energy as a result of turbulence, it becomes non linear.
- Turbulence can be a major cause of defects such as air entrapment and flow lines.



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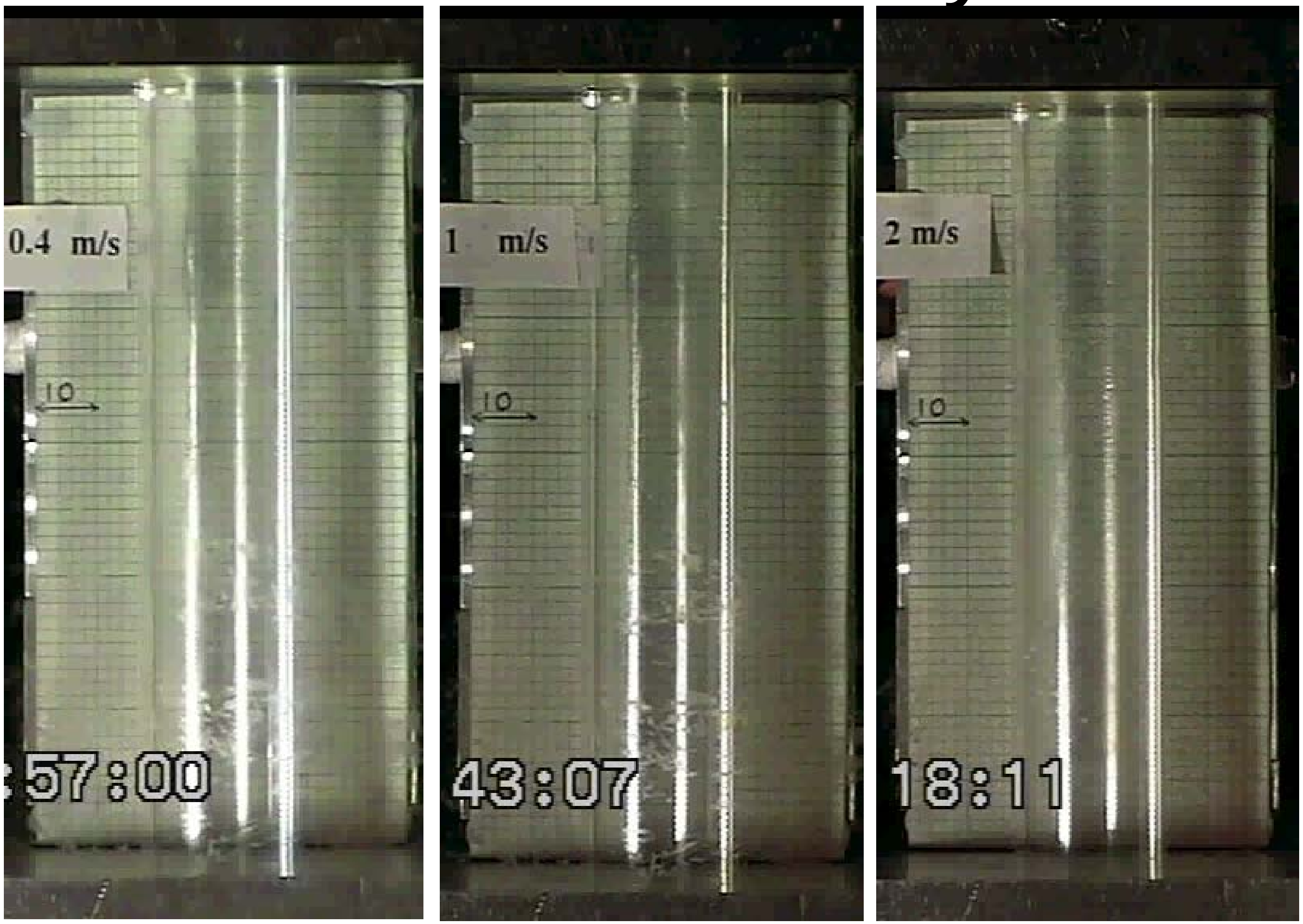
Change Of Flow Conditions With Fluid Velocity



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Focast Models

- The Focast models demonstrate the followi…
1. Even a… behave… models…
2. Thin li… (the hi… the wa…
3. The di… the air, leading to situations of non-…

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Summary.. Fluidity

- Viscosity indicates the Fluidity of a wax.
- The Fluidity of a wax increases with wax temperature and die temperature.
- The Fluidity of the wax can be improved with increased flow and in particular increased injection pressure.
- Wax Fluidity is a key contributor to injection defects due to changes in flow conditions, it can be improved by changing injection pressure, Flow, Temperature or the Viscosity of the wax at the preferred injection temperature.

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How To Control Wax Temperature

1. Wax has a very poor thermal conductivity, any temperature changes will take hours to achieve.
2. It is important when using automatic wax filling, that the liquid level in the holding tank does not get too low since the wax coming from the melters will generally be much hotter leading to a rise in the temperature in the holding tank.
3. Temperature gauges give an indicative reading only, this is due to the sensors being located around the outside of the tanks and do not reflect the temperature in the centre.
4. Keep in mind that the die temperature will change with use, and this may give rise to changes in injection characteristics.
5. Remember that the Congealing point of the wax may change from batch to batch, and this needs to be taken account of when setting injection temperatures.

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Dimensional Aspects

Control of Wax Dimensions at Injection.

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Parameters Affecting Free Linear Contraction

- Three sets of experiments were conducted

1. A designed experiment involving wax Temperature, Injection pressure and Dwell time
2. A measurement of the Free linear contraction on a very cold die, and also a very hot die.
3. A measurement of the contraction with different filler loadings in the wax.

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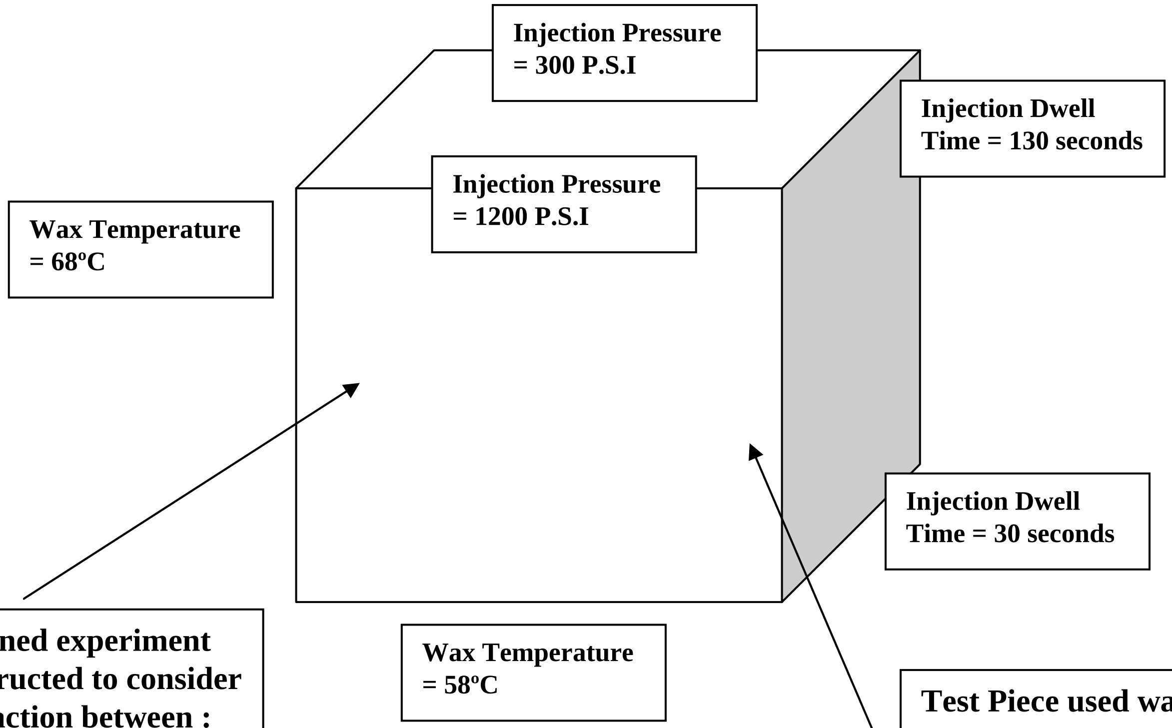
Design of the Experiment



Designed experiment constructed to consider interaction between : Wax temperature, Injection pressure and Dwell time.

Test Piece used was ;
150 * 16 * 10mm. (Total 144 pieces)
Wax used was a filled, Virgin wax.
Test machine M.P.I.
Temperature conditioned for 24 hours.

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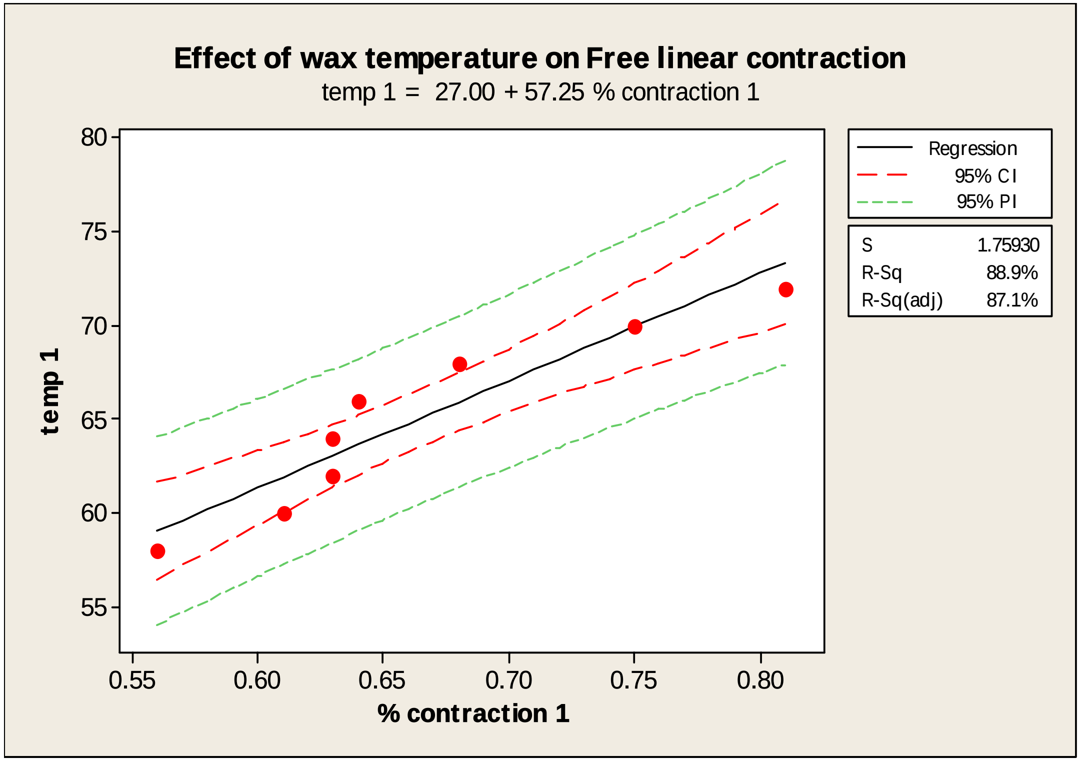
Affect of Wax Temperature on Free Linear Contraction.



Wax temperature has a significant effect on the Contraction.

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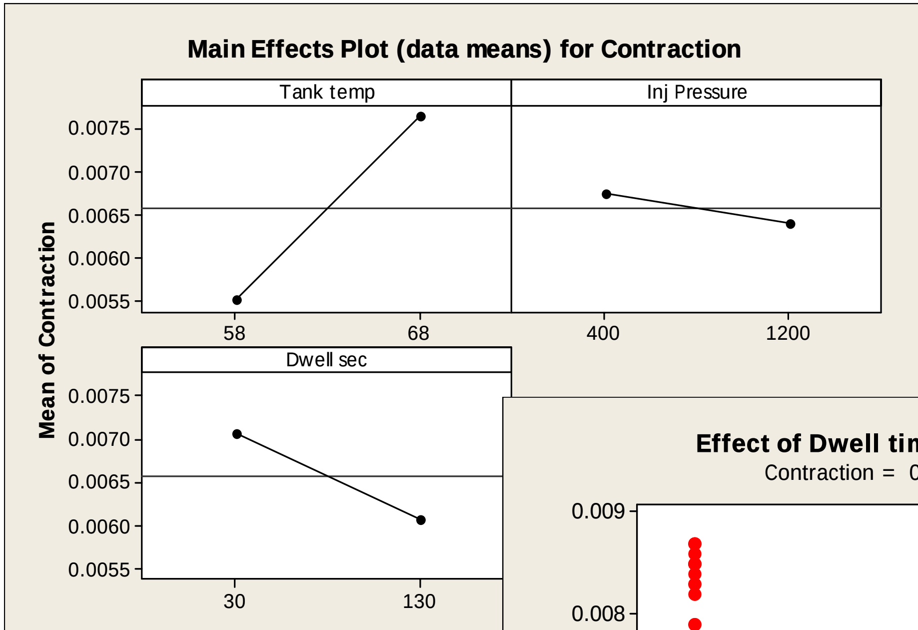
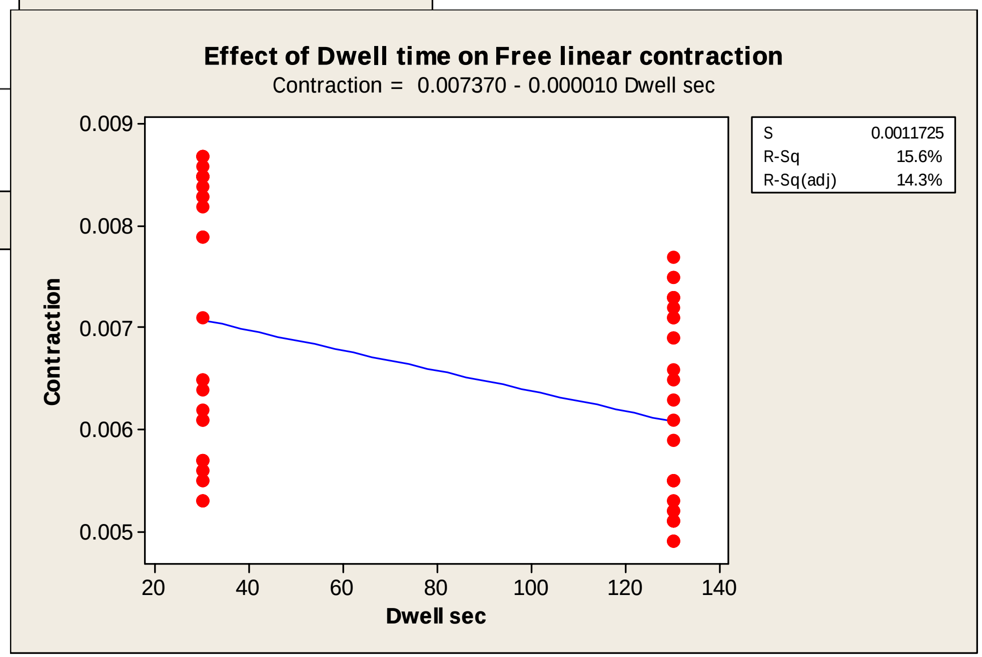
Affect of Dwell Time and Injection Pressure on Free Linear Contraction.



The Dwell Time and Injection Pressure seem to have little effect on contraction.



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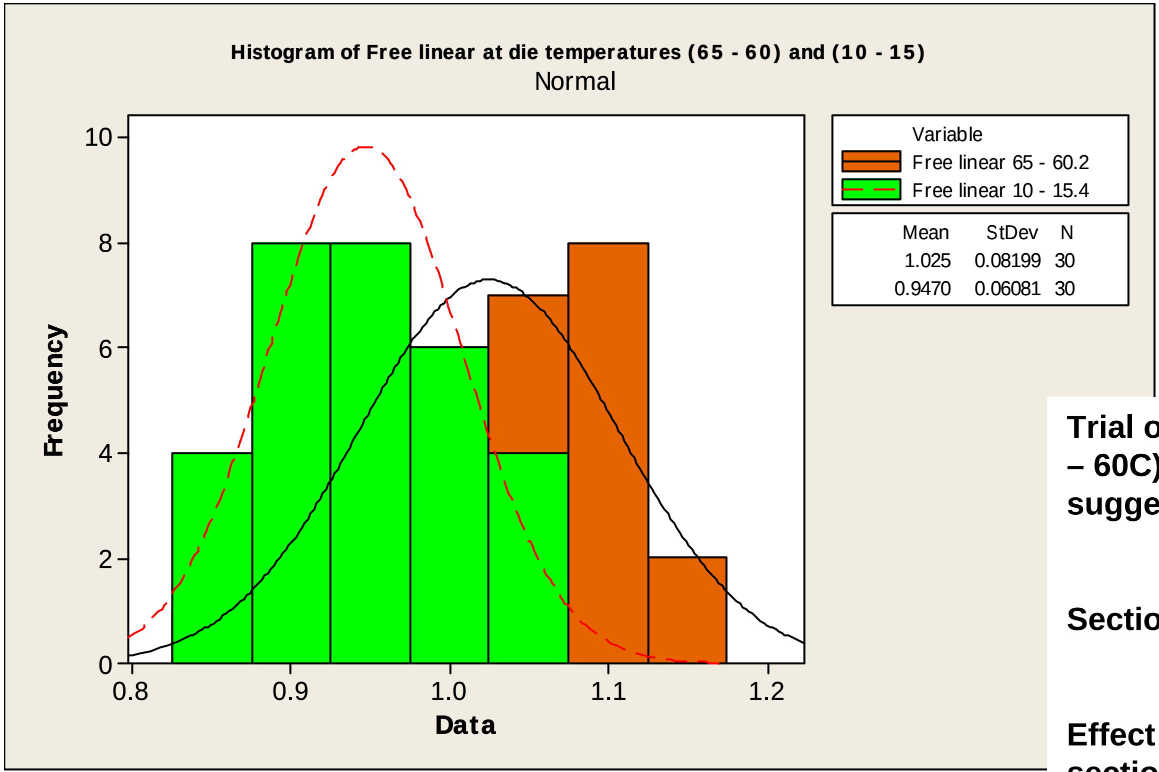
Affect of Die Temperature on Free Linear Contraction



Trial of die temperatures at high value; (65C – 60C) and low values (15C – 10C), suggests only a small effect exists, if any.

Section size was again 150 * 16 * 10mm

Effect could be more pronounced on large sections or those with restricted contraction.

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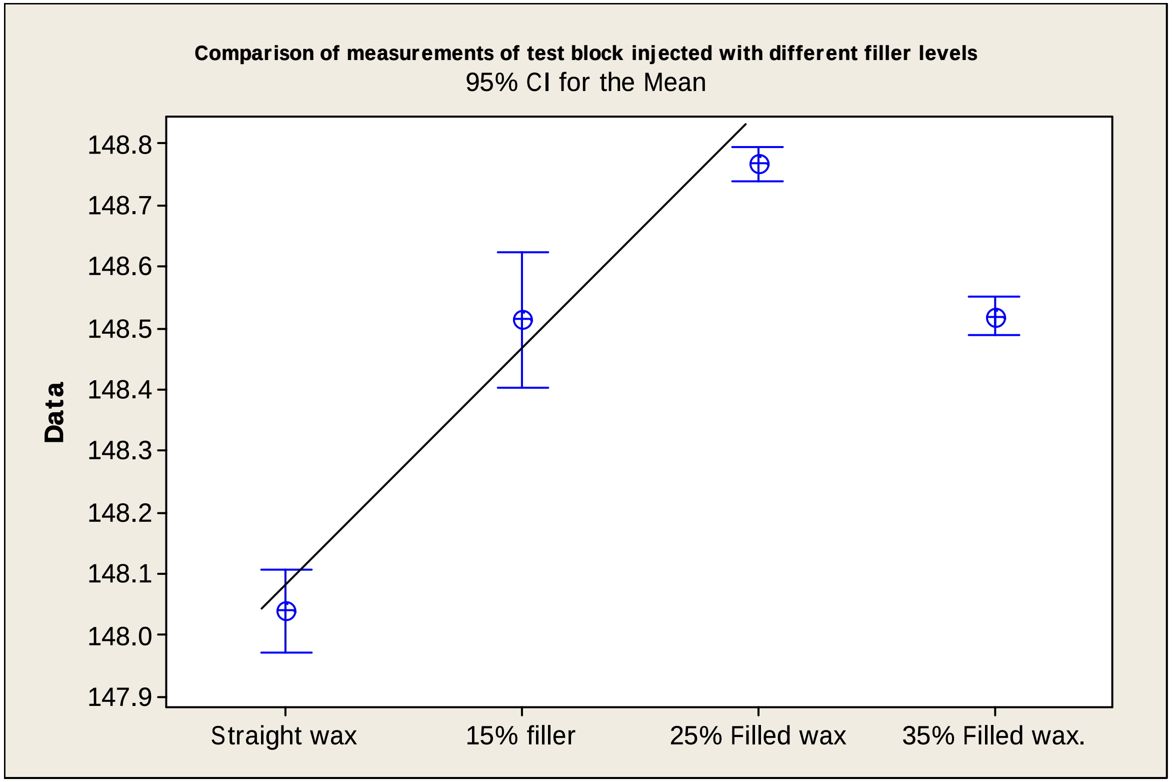
Affect of Filler Content on Free Linear Contraction.



Analysis of data from injected test blocks at different filler levels, demonstrates the following;

1. **That filler level does have an effect on the contraction of the wax. (Important if wax is unstirred or left over periods of time)**
2. **That other factors affect the contraction (25% result is greater than 35% result.)**

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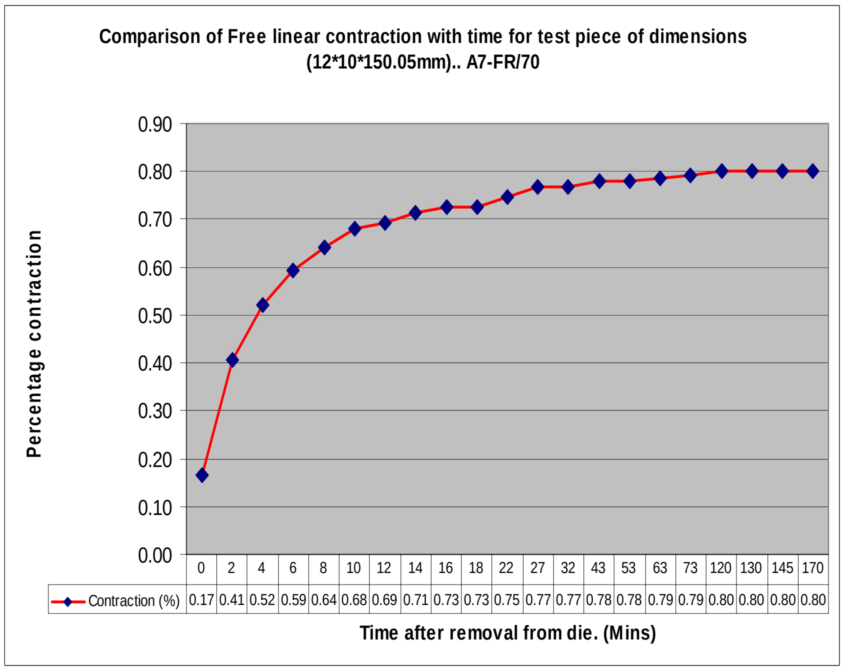
Dimensional Change of Wax After Injection.



- The chart opposite demonstrates the dimensional change of a small test piece immediately after injection.
- It can be seen that it takes in excess of two hours for this piece to stabilise dimensionally.
- It can be seen from this that during this time it is critical for the parts to be held in “setters” to control this dimensional movement.

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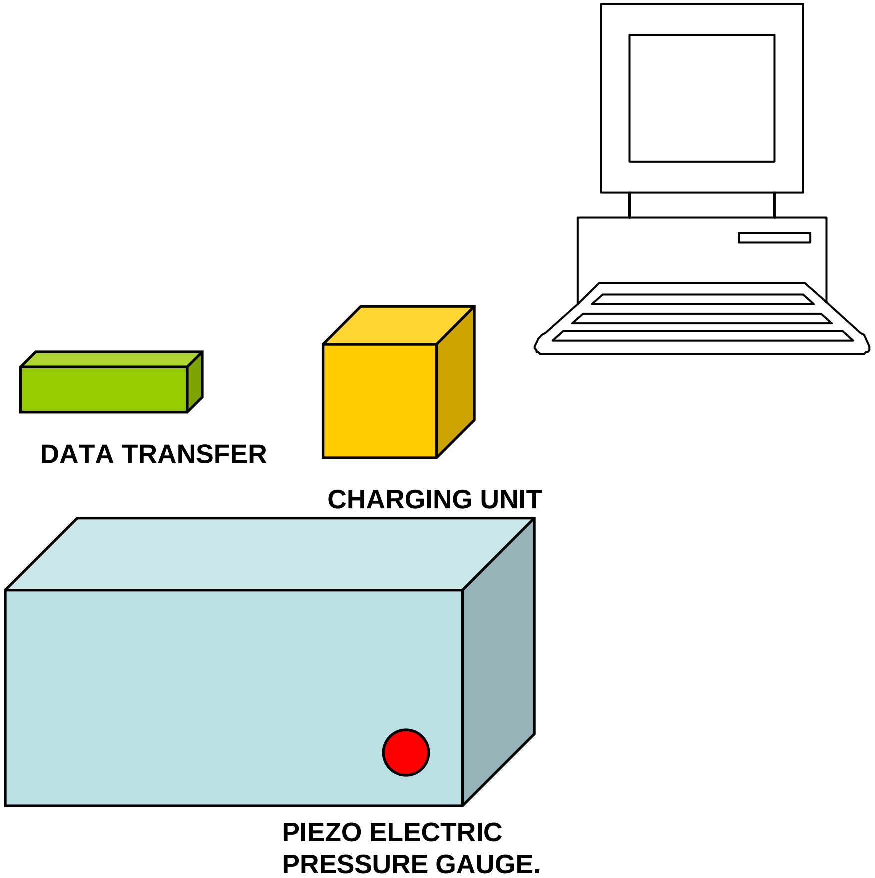
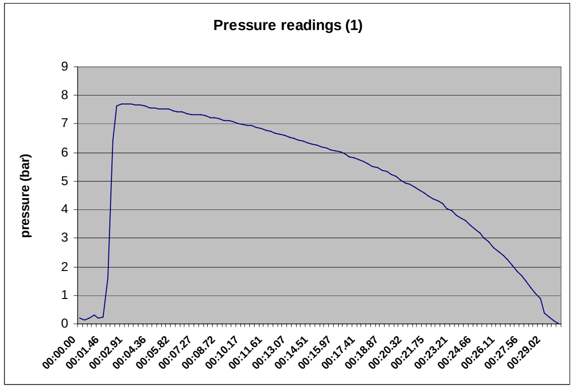
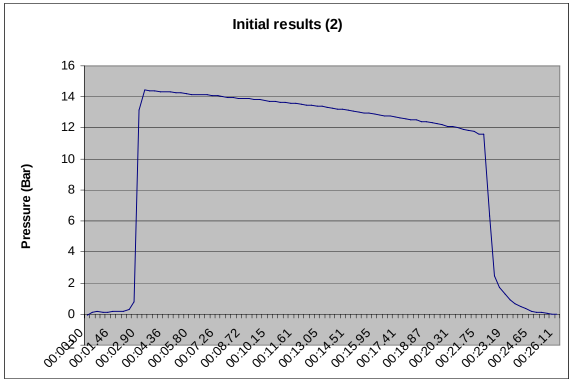
Testing Pressure in the Die

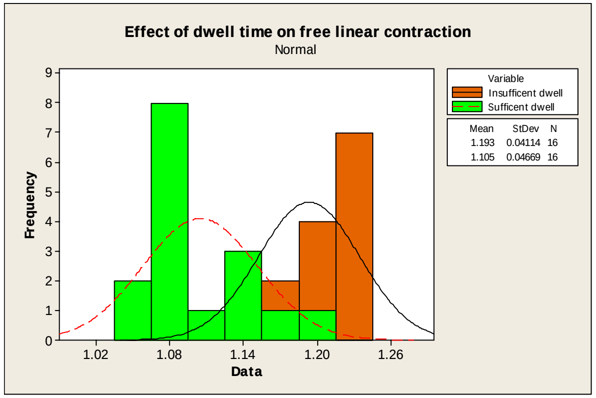


- Blayson has developed a system capable of measuring the pressure within the die rather than at the nozzle.
- It allows us to monitor things such as;
- True injection pressure.
- Wax Set times.
- Transfer of pressure to the wax system from the platten
- The evacuation of air from the system.

The Importance of Correct Injection Times.







1. **The first trace shows the pressure analysis of a part with sufficient injection time.**
2. **The second trace shows insufficient injection time.**
3. **The chart demonstrates the recorded change in dimensions.**

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Summary – Dimensional Aspects

- The contraction of the wax is very much dependant upon Temperature.
- Dwell time and Injection pressure do not appear to have a significant effect, but insufficent injection time can have an effect.
- Die Temperature appears to have an effect on Free Linear Contraction, this may be magnified with piece size.
- Filler Content does have a significant effect on wax contraction.
- It is important to control the dimensions of pieces after injection by means of “setters” etc.

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Fillers.

The Benefits of Fillers in Wax

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What are Fillers ?

- Fillers are mediums designed to bulk out wax.
- There are four general types;
- Cross linked polystyrene (most common type, very stable up to high temperatures)
- Linear polystyrene (similar to cross linked, but will settle out of solution above 95©), used if there is a wish to recycle the wax on site.

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Types of fillers

- Acid filled (gives very good surface finish, but very dense and requires good agitation to keep in suspension)
- Emulsified or Water filled (environmentally friendly, however need careful control to avoid boiling off retained water)

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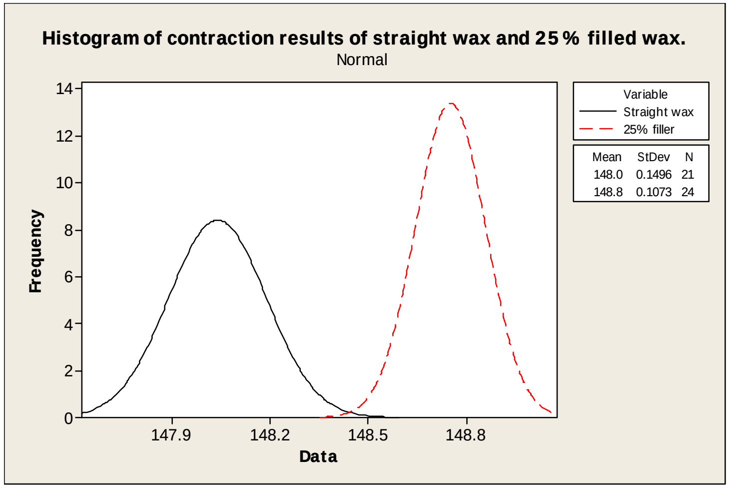
The affect of Filler



- Fillers are added into the wax for a number of reasons;
- Improved surface finish, less cavitation and flow lines.
- Better dimensional controls (less contraction and more uniform).
- Improved mechanical strength.
- Increase the wax viscosity which may help to reduce turbulence defects.

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Why use Fillers ?

- The only means of achieving dimensional control with an unfilled wax is to inject at low temperatures eg 56ºC.
  - This is not possible with cored parts due to the high pressures required.
- Improved mechanical strength when compared with unfilled wax
- Helps to reduce turbulence and its effects such as flow lines and air entrapment.
- Reduces cavitation.

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How to use Filled wax.

1. Always keep agitated, if the Filler is allowed to settle out it is very difficult to get back into solution. (Density Cross linked 1.03g/cm3, Acid 1.07g/cm3)
2. Do not keep at too high a temperature, the thinner the wax, the more it will be prone to settlement.
3. When not in use, between shifts, weekends and holidays, purge the wax from the injection units etc.
4. Used fillers can increase ash levels in reclaim wax, for virgin quality reclaims, the filler would have to be replaced. The decision must be both commercial and process driven.

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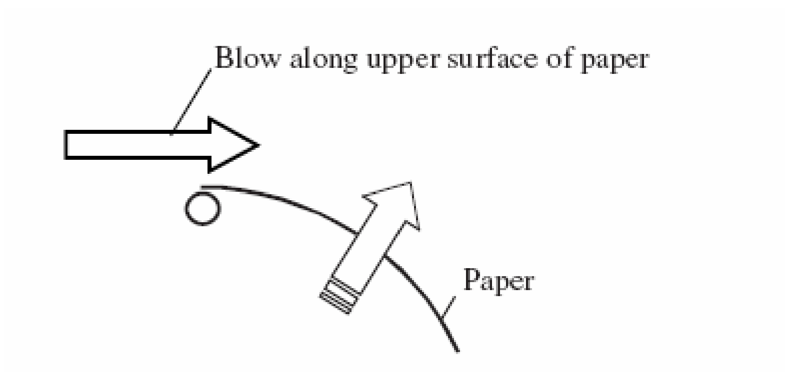
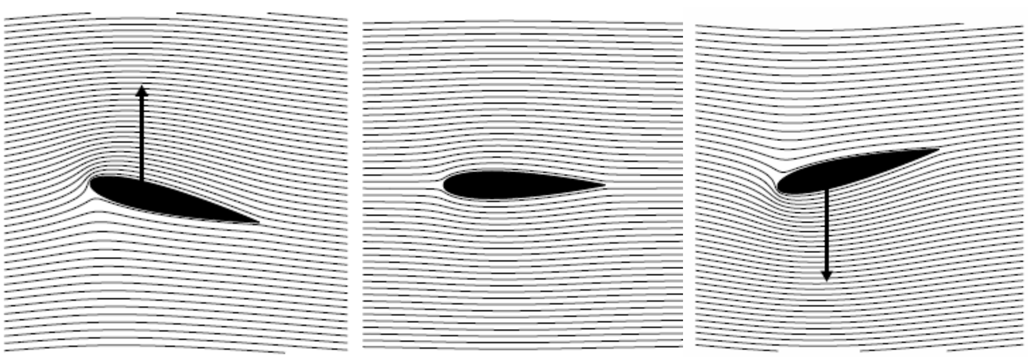
Use of Wax with Ceramic Cores.

Theoretical and Practical Considerations

The Force Exerted on the Core by the Wax.. The Idea of Lift



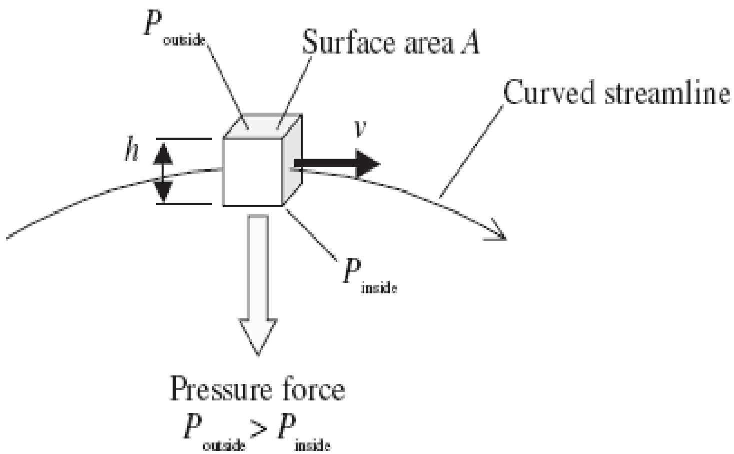


Resultant upward force | **No resultant force** | **Resultant downward force**

- The simple experiment of blowing across a piece of paper will demonstrate what is meant by the term lift. Although, the air flow is across the top of the paper, the force is from below.

  This the same effect that will be exerted on aircraft wings during flight, and also on ceramic cores during injection.

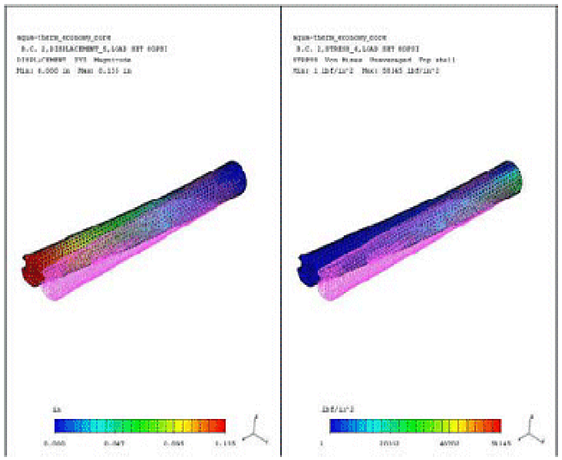
Factors Affecting the Force Exerted on the Core



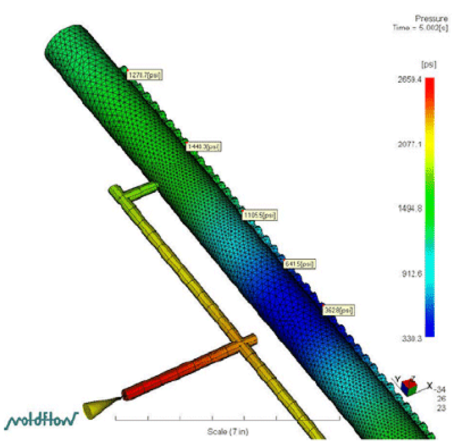
$$F = A\,\mathrm{d}p = Ah\frac{\mathrm{d}p}{\mathrm{d}n} = \rho Ah\frac{v^2}{R}$$

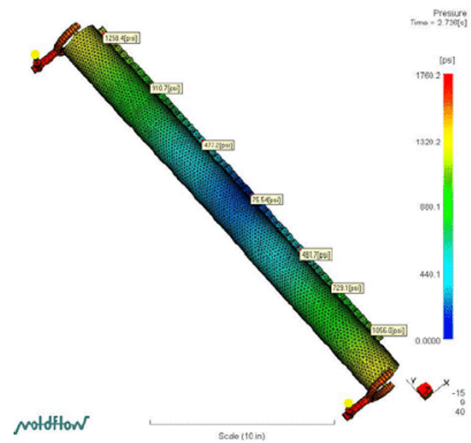
- If the wax were to be considered as a single element similar to the square block opposite, then the force exerted on the core would be dependant upon;
- Density
- Surface area
- Height
- Velocity or Flow
- Radius of curvature of the core.
- This is clearly a complex model, but it does demonstrate that factors such Temperature, Injection Pressure and Change in section will influence the result.

The Effect Of Sprue Location

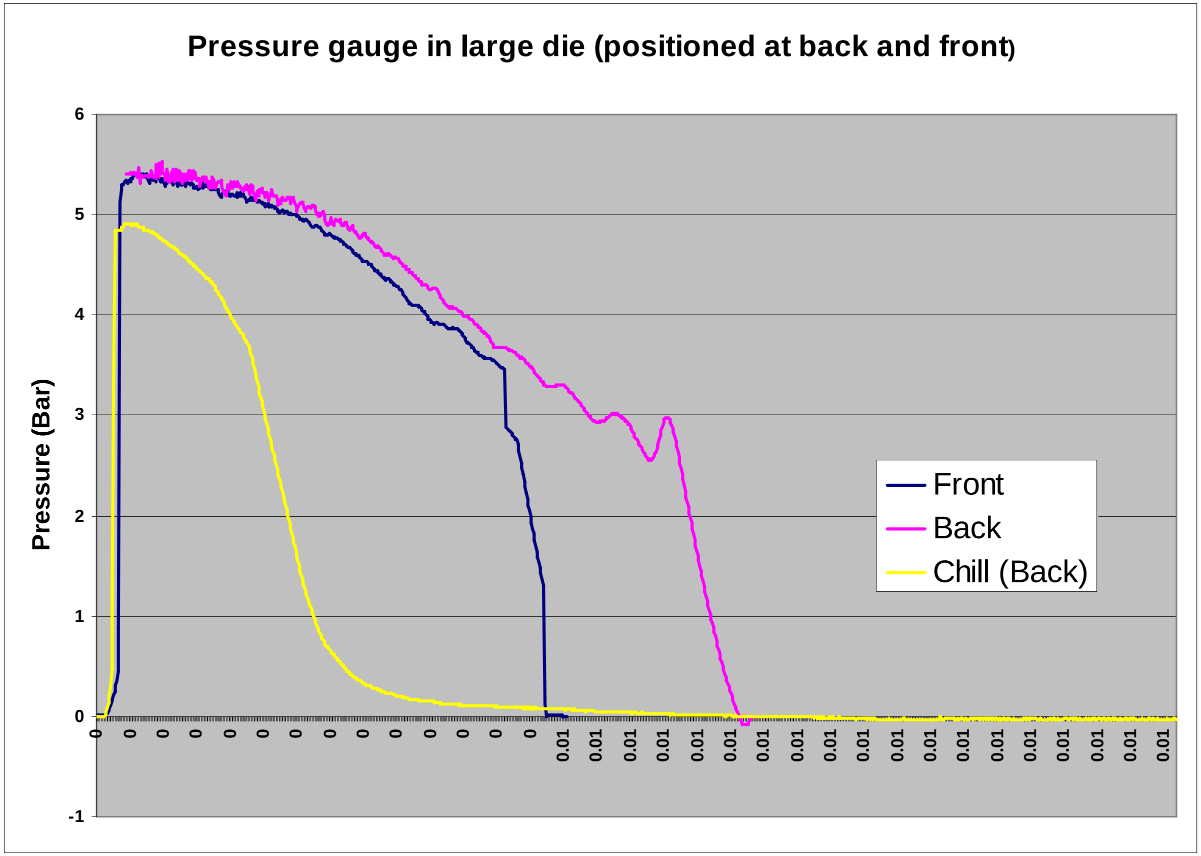


- **Work carried out on plastics injection clearly demonstrated that deflection could take place during injection, and that the location of the injection point could affect it.**
- **Gating perpendicular to the core was found to have the biggest influence**
- **Gating in line with the core gave the best result.**



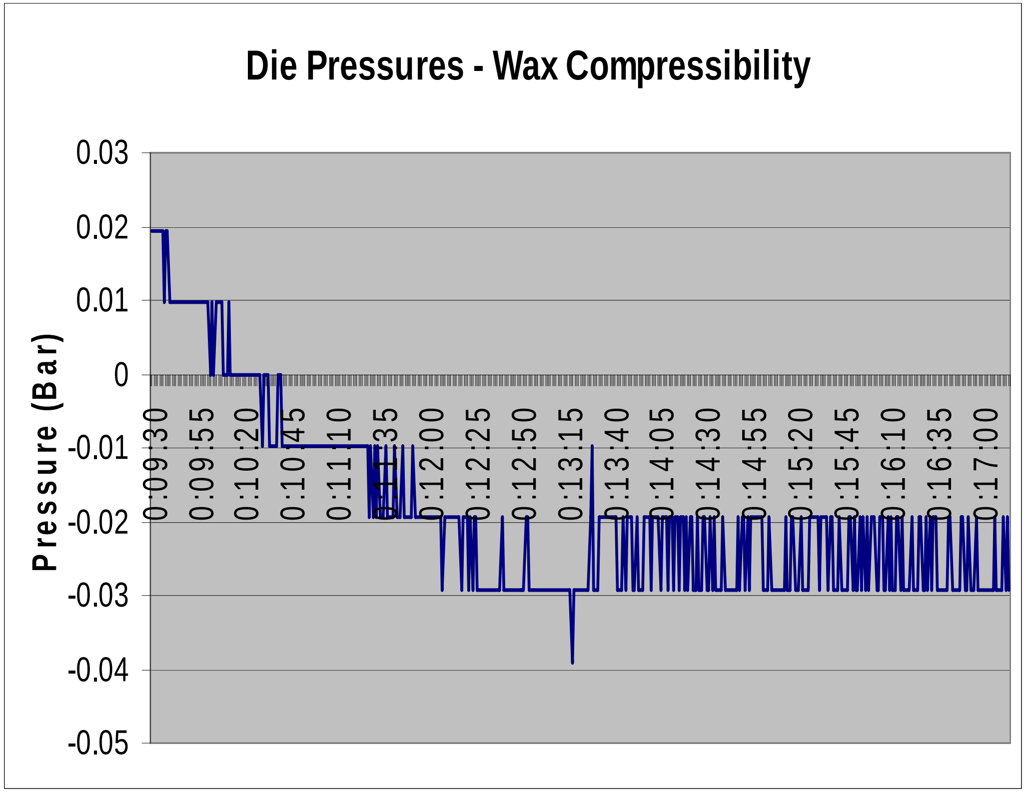


Effect on Pressure of Gate Position and Chill



- 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.

Wax Compressibility



Two other factors to consider regarding the injection of wax around a core.

•Our Pressure modelling clearly demonstrates that during solidification, the wax exhibits a small "spring like" behaviour

•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.

•The model also demonstrated that on closure, there is a transfer of energy from the platten to the wax.

Practical Considerations when Injecting Around a Core.

- 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

Use of Core Prints

- 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 <u>three</u> 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

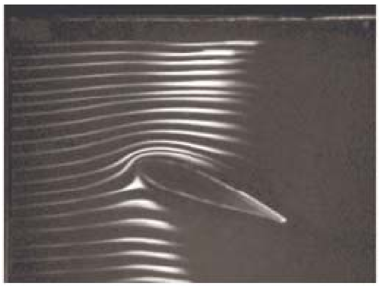
Practical Considerations for Core Inspection.

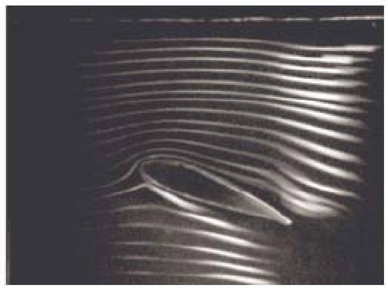
- Dimensions must be checked, with complex cores best accomplished by use of a co-ordinate measuring machine (CMM)
- Check the core surface for any negatives, these give a positive defect on the finished casting
- Visually inspect for cracks, also by X-ray if required. The X-ray direction in relation 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

Essentials of Core Preparation

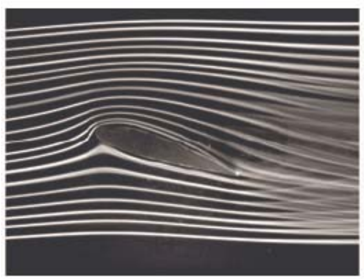
- For correct support during injection
  - Wrapping the core in supporting wax, prevents localised sinkage/cavitation
  - Fill weak areas with glue. NB - may hold it too rigid
  - Injecting a wax support to fit onto the core
  - Checking the pin adhesion if applicable, often a source of cracking.
  - 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

Fluid Flow Around a Core

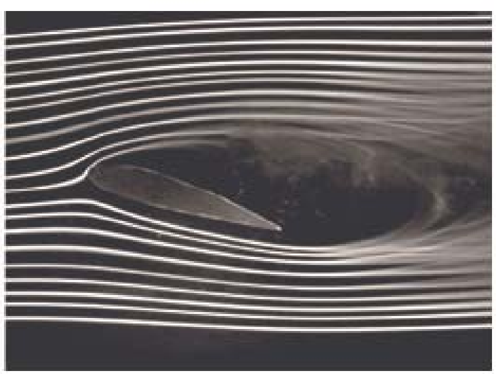




(*a*) low angle of attack



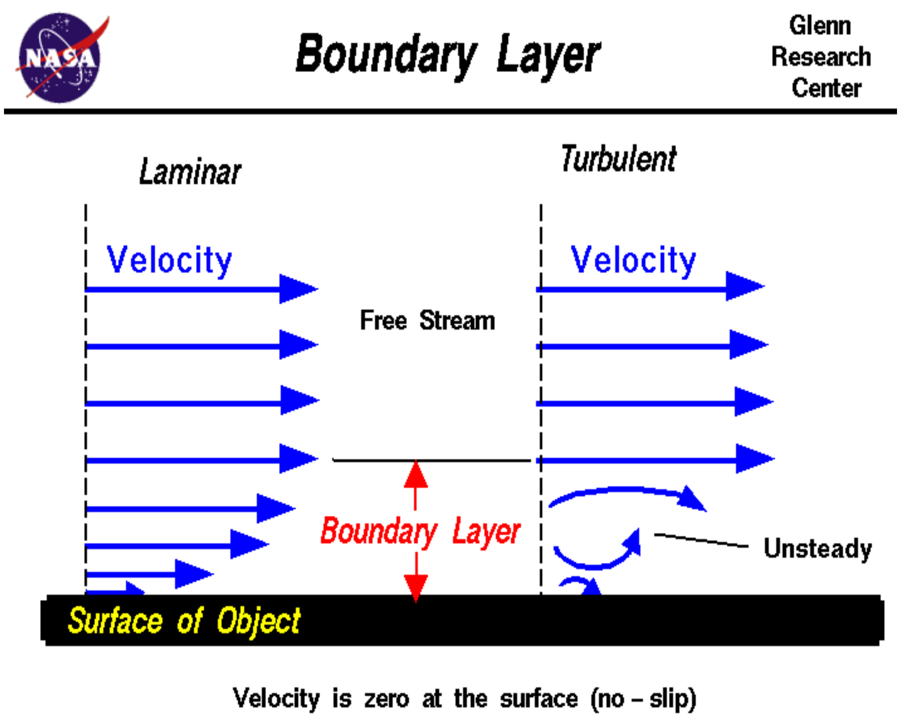
(*b*) high angle of attack



(*c*) stalled flow

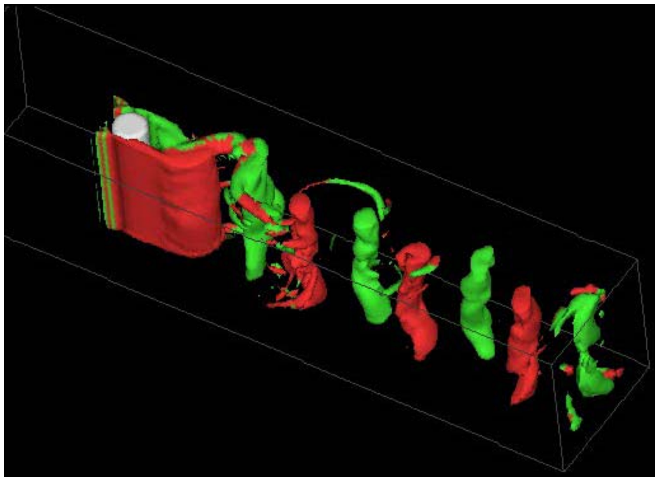
- Fluid Flow Around a core is dependant upon many factors;
- Wax density
- Velocity
- Section Diameter
- Wax Viscosity.
- It can also be seen from above that it is dependant upon shape and “Attack” angle

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”
- This Velocity Gradient if large enough, it may give rise to turbulent conditions

Flow of Wax Past a Core



- Flow of wax past a core may give rise to a numbers of conditions;
- Change of flow characteristics.
- Voids within the flow.
- Extreme turbulence or Vortices (Loss of energy and associated defects)

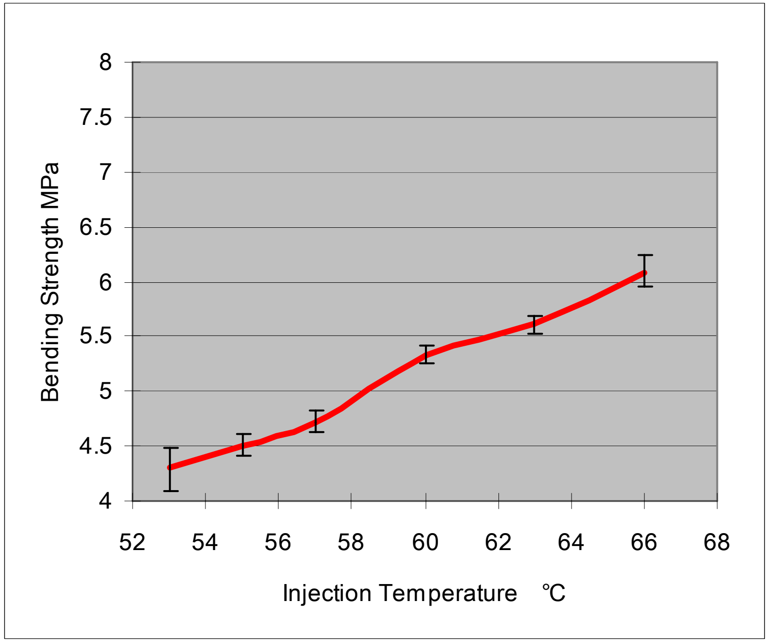
The Effect of Wax Injection Parameters on Wax Strength.

A study carried out by Blayson Japan

Blayson

The Effect of Injection Temperature on Bending Strength

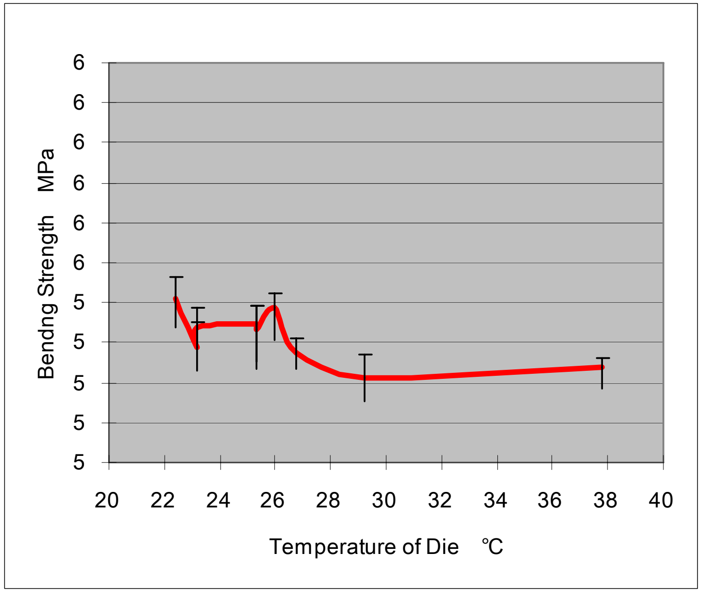
- The legs measured and reported opposite were injected at between 52 © and 68 ©
- Results suggest that the resultant wax strength increases with increased wax temperature between this range



Blayson

The Effect of Die Temperature on Wax Strength

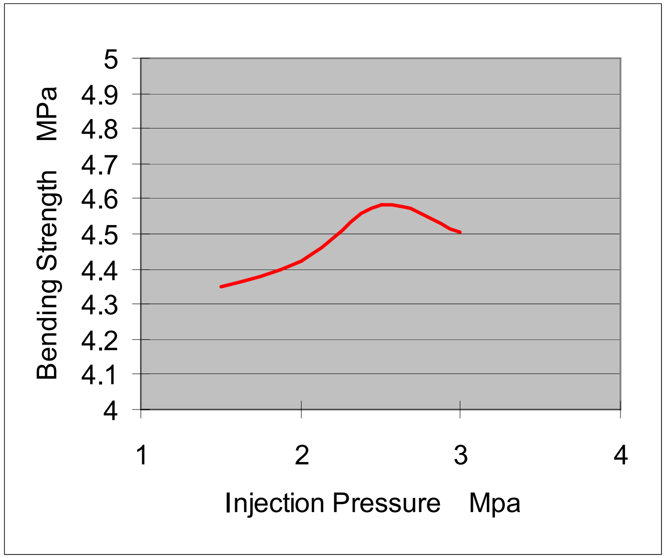
- These parts were injected with die temperatures between 22© and 38 ©
- Contrary to wax temperature, there is a reduction in strength with die temperature.
- Their also appears to be a strange effect taking place at around 26 - 28 © which cannot be explained



Blayson

The Effect of Injection Pressure on Wax Strength

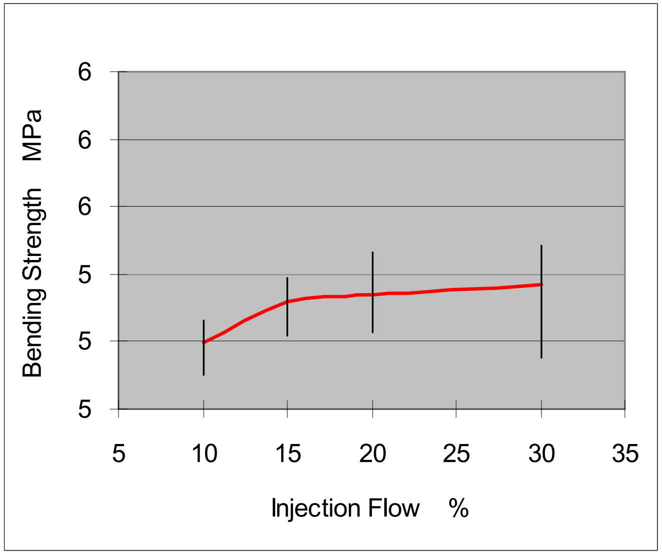
- These parts were injected with pressures between 1.5 and 3 Mpa pressure
- The results seem to suggest an increase in the strength of the wax when injected between 1.5 and 2.5 Mpa
- However there appears to be a small reduction in strength after this point



Blayson

The Effect of Injection Flow on Wax Strength

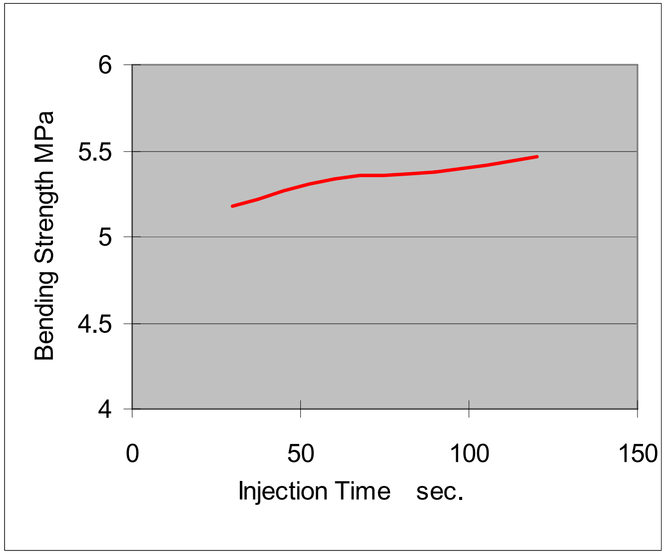
- These parts were injected with flow rates between 10 and 30%
- The results indicate a small increase in strength with flow



Blayson

The Effect of Injection Times on Wax Strength

- These parts were injected with injection times varying between 25 and 125 seconds
- The results indicate a small increase in strength with injection time



Blayson

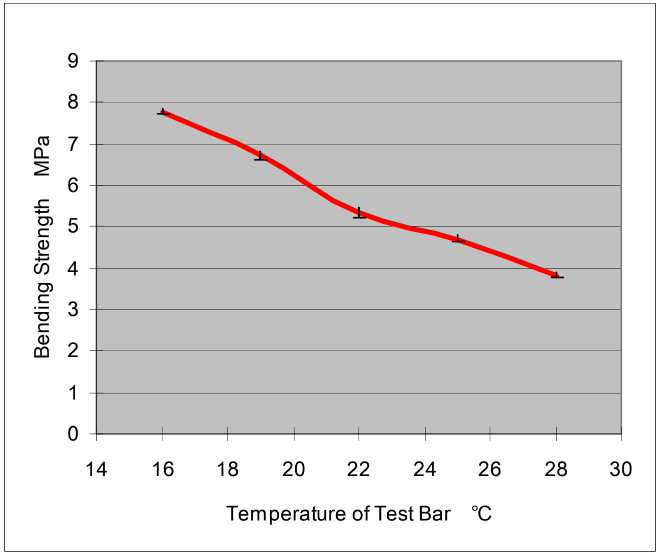
The Effect of Ageing on Wax Strength

- These parts were aged between 1 and 22 days after injection, prior to test.
- The curious results suggest that after an initial weakening, a strength is achieved after approximately 2 days with this dimension.
- However this is followed by another weakening of the wax before its maximum strength is achieved after around 15 days, after this time the wax ages and weakens

Blayson

The Effect of Component Temperature on Wax Strength

- These parts were tested with bath temperatures ranging between 16 and 28°C
- Unsurprisingly, the strength of the wax was found to reduce with temperature, suggesting a wax softening effect



The Contents of Wax Ash.

The components of Ash and possible effect on foundry inclusion matter.

Blayson

Understanding the Make up of Wax Related "Ash".

- The effect of Ash on a foundry process is very much dependant on; types of alloy, mould orientation and N.D.T criteria.
- To understand the make up of the Ash, tests included;
- Elemental analysis of the material removed from the reclamation unit .
- Analysis of the effects of liquid additions to the wax.

Blayson

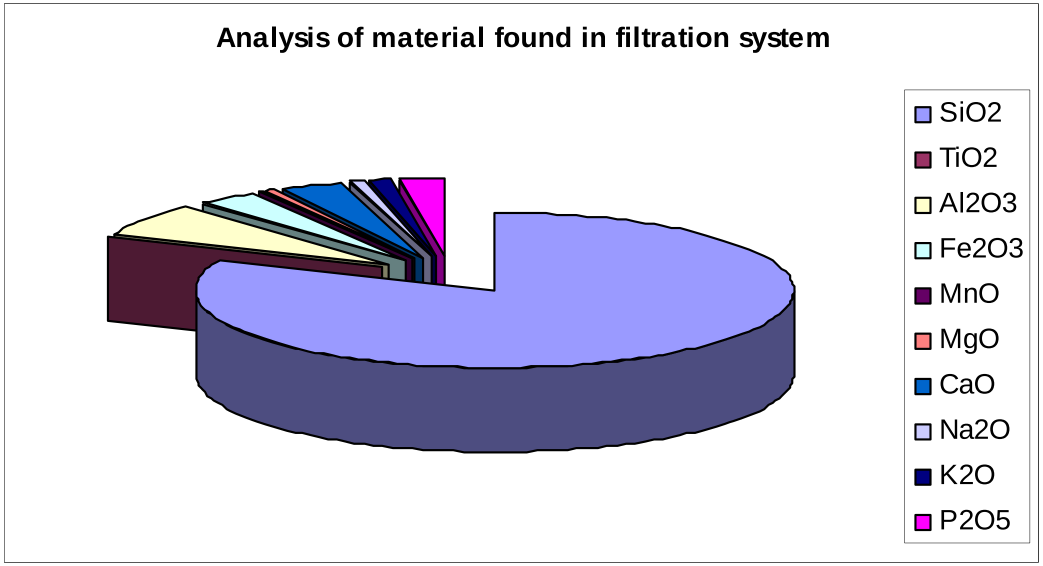
Elemental Analysis

Analysis of material found in our filtration process showed high levels of silica in particular, followed by Alumina. Zirconia was not part of the test.

Suggests that the vast majority of the solids in the waste material are from the shelling process

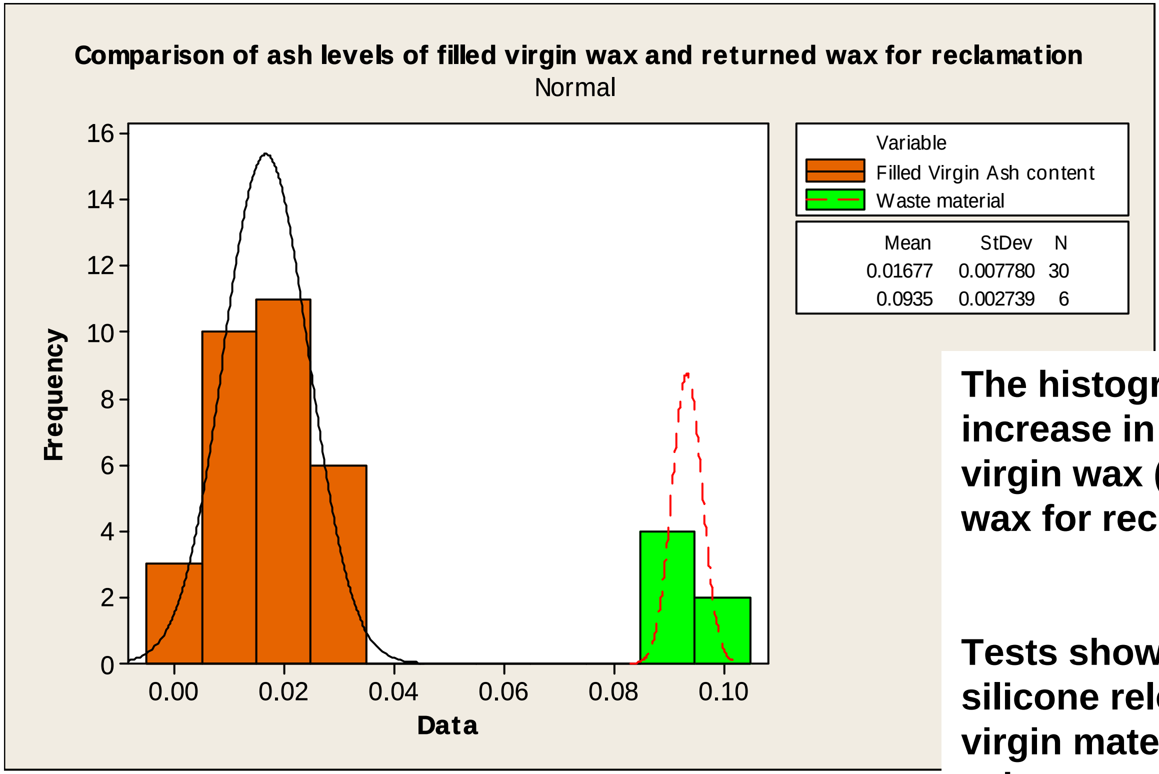
The filtration system removes the vast majority of them, other processes may not be as effective.

Important to discuss the needs of your process with your wax supplier



Blayson

The Effect of Release Agents.



The histogram demonstrates the increase in ash levels from a filled virgin wax (0.17) to the returned wax for reclamation (0.94)

Tests showed than addition of 4% silicone release agent to the filled virgin material would increase this ash content to 0.71%, reclaim specification is generally a maximum of 0.15%. Although this is more than would generally be used, it demonstrates the effect of silicone in the process.

Blayson

Ash Composition.

Shell materials. Make up most of solid content, most removed by good reclamation process

Wax raw materials.. Generally ash within virgin materials is very low.

Water.. Removed at reclamation process, but can be a problem with poor processes.

Solids

Contents of ash within wax.

Liquids

Filler.. Can be a problem with reactive alloys.

Also carbonaceous material can be left within fillers in reclaim materials

The foundry wax needs should be considered as carefully as those of the shelling process.

Before use of new and unfamiliar alloys, it is important to discuss possible implications on process with your wax supplier.

Silicone.. Cannot be removed by reclamation process. (But can be washed off with a pattern wash prior to shell build.)

Certain alloys will react with this since, it will leach into the shell at fire off.

Only real answer if it is a problem, is to dilute with virgin wax.

Ash.. Conclusions

- Ash is but one of many possible sources of inclusion matter, and its effect is process dependant.
- Analysis of materials found in the filtration unit suggest that the solid material is mainly shell debris.
- The use of silicone release agents within a process can significantly contribute to the Ash levels

Blayson

Defect Glossary

The Cause and Possible Solution
to Common Injection Problems.

Blayson

Flow Lines

- Definition; A negative surface indication seen as a line from above.
- Cause; Lack of energy within the wax either as a result of cold wax or turbulence.
- Problem; Can be a source of ceramic inclusions on shelling, weakening of the wax structure.

- Possible solutions;
- Increase the injection pressure.
- Increase the temperature.
- Reduce the turbulence by reducing Pressure and/ or Flow.
- Use Filled wax.
- Use more viscous wax.

Surface “Pitting”

- Definition; A rough surface finish which visually has a “sandpaper” effect.
- Cause; Lack of wax Fluidity.
- Problem; Can be a cause of Ceramic inclusions on shelling

- Possible solutions;
- Increase wax Fluidity by means of increasing the temperature.
- Use a more Fluid wax.

Blayson

Cavitation

- Definition; A surface depression, normally in the form of a bowl like shape.
- Cause; Lack of feed to the area in question.
- Problem; A cause of Dimensional problems.

- Possible solutions;
- Reduce the injection temperature.
- Increase the size of the injection sprue.
- Use a filled wax.
- Use a wax “chill”
- Reduce die temperature.

Blayson

Incorrect Wax Dimensions

- Definition; Final wax dimensions are outside of the required specification.
- Cause; Wax contraction is incorrect.
- Problem; The finished parts are to the wrong size.

- Possible Solutions;
- Change wax temperature.
- Change wax.
- Change die dimensions (Expensive)

Blayson

Air Defects

- Definition; Either surface or just below surface depressions caused by air.
- Cause; The air is unable to escape the wax quickly enough.
- Problems; A possible source of Ceramic inclusions on shelling

- Possible Solutions;
- Reduce wax turbulence.
- Increase wax Viscosity.
- Allow air to escape die more easily.

Blayson

Non Fill or Cold Shut

- Definition; The cavity either does not fill completely or the pattern has rounded edges.
- Cause; Insufficent wax energy.
- Problem; Incorrect dimensions.

- Possible Solution;
- Increase injection Pressure.
- Increase wax temperature.
- Make wax more fluid.
- Improve wax venting
- Reduce turbulence.

Blayson