Advanced Wax Testing and Subsequent Wax Developments

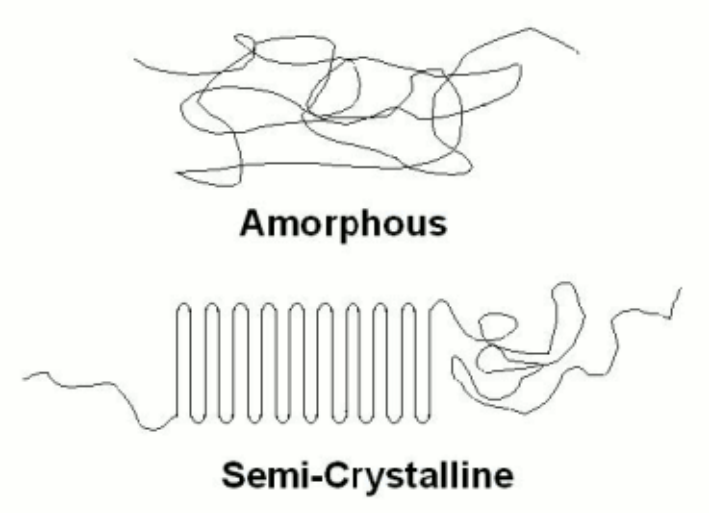
David Bond
Phil Hancock
The Blayson Group Ltd

13th World Conference on Investment Casting
Kyoto, Japan
April 2012

Introduction

- Background to wax properties
- Factors that influence wax pattern shape
- Development of process related testing
- Advanced wax developments
- Understanding Wax Thermal Hysteresis (wax memory)
- Conclusion

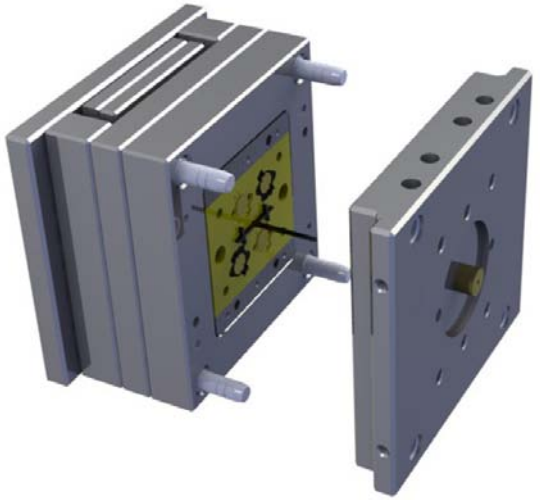
Wax Structure



- Wax is an amorphous structure
- Wax is a blend of various compounds each with its own complex thermal behaviour

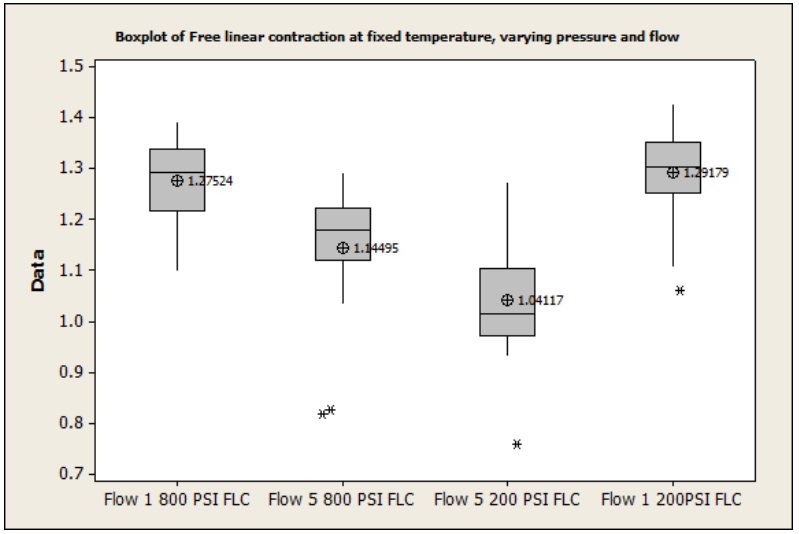
- Each blend of materials gives unique thermo mechanical and elastic properties
- Effect of thermal history on properties and net shape is often misunderstood

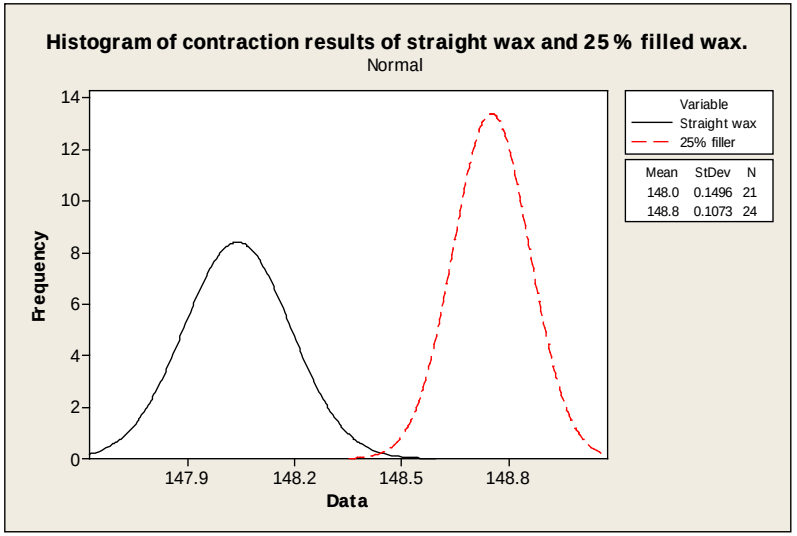
Net Shape



- There are certain features that determine net shape
- **Contraction** is the difference between the dimensions of the die and those of the final pattern
- **Temperature of injection** significantly affects contraction rates
  - as a rule the higher the temperature the greater the contraction

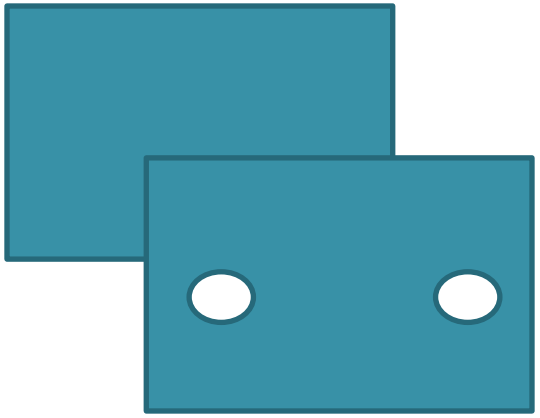
Net Shape

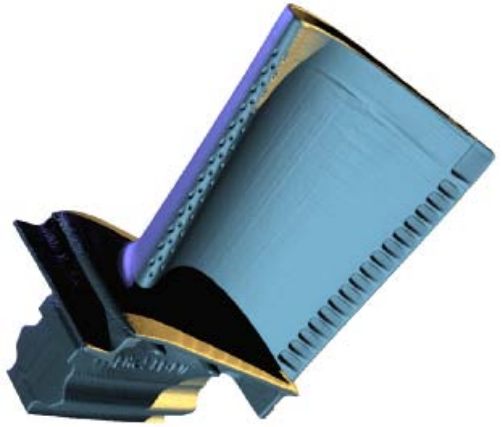




- Die temperature is important but less influential than wax temperature
- Time and pressurisation at injection is another important consideration
- Filled waxed generally exhibits less contraction and less cavitation
- The solidification rate of the wax has an influence
- The shape of the pattern is influenced by wax contraction and Wax Thermal Hysteresis
- **The understanding of these phenomena is critical to dimensional control**

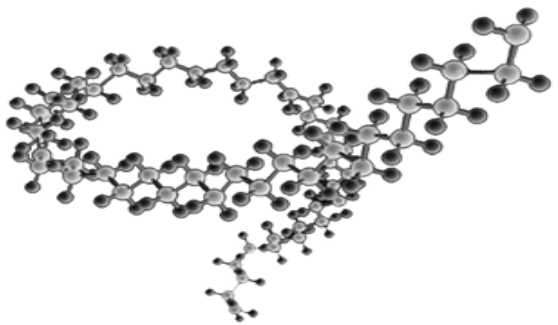
Types of Contraction





- Free linear contraction occurs when a pattern is free to contract in any direction
- Restricted contraction occurs when a pattern is held rigid by the die in a number of areas
- Shrinkage or cavitation is often a result of poor injection technique or poor die design
- Wax Thermal Hysteresis is a cause of distortion rather than contraction and can be shape related
- Understanding and overcoming Wax Thermal Hysteresis is critical to the production of net shape patterns

Wax Thermal Hysteresis



- Wax is polymeric in nature
- It releases internal stress over a period of time
- This mechanism is referred to as **Wax Thermal Hysteresis** (or wax memory)
- This effect of thermal hysteresis is well known but not fully understood
- Various techniques have been adopted to try and control this phenomenon
  - Setters or formers
  - Thermal treatment
  - Modifying the die
- Main problem is that the movement is not consistent

Process Based Testing

To understand dimensional shift and wax pattern distortion

Current Testing and Reasons To Change!

- Wax testing for years has been based around the Petrochemical industry, with tests such as
  - Congealing Point/ Melting Point
  - Viscosity
  - Penetration
  - Percentage Ash
- Although a place remains for such tests, complexity of design and performance demands necessitates a change in thinking!

Process Based Testing

Temperature	Fluidity	Dimensional Aspects
• Wax temperature fixed • Die temperature fixed	• Die temperature fixed • No release agent used	• Larger and smaller test pieces used • Pieces conditioned for 24hrs at fixed temperature

Data Collection

- Wax specific data was collected
- Analysis of data allowed capabilities to be generated

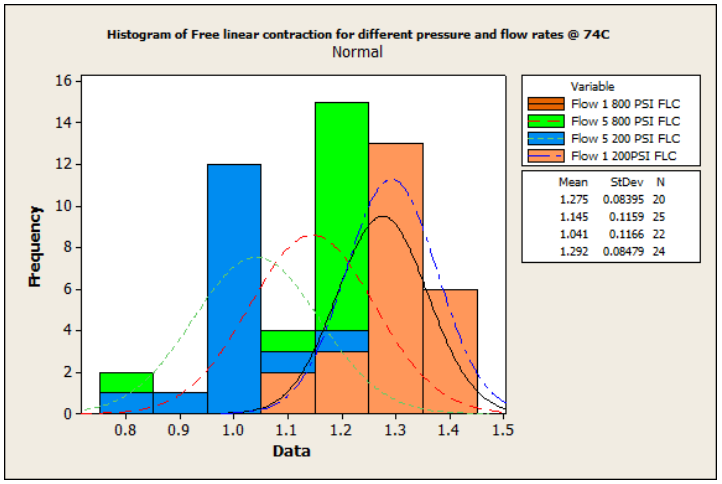
Advance Wax Development

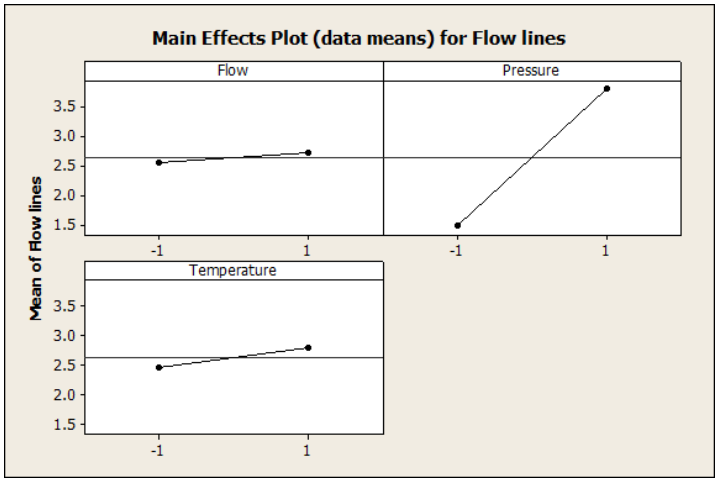
- Inherent variability on smaller test piece
- New process undertaken to understand thermal hysteresis thought to be the cause

The areas investigated were

- Temperature
- Flow
- Free linear contraction
- Data collection both within the die and via the injection unit
- Advanced wax developments

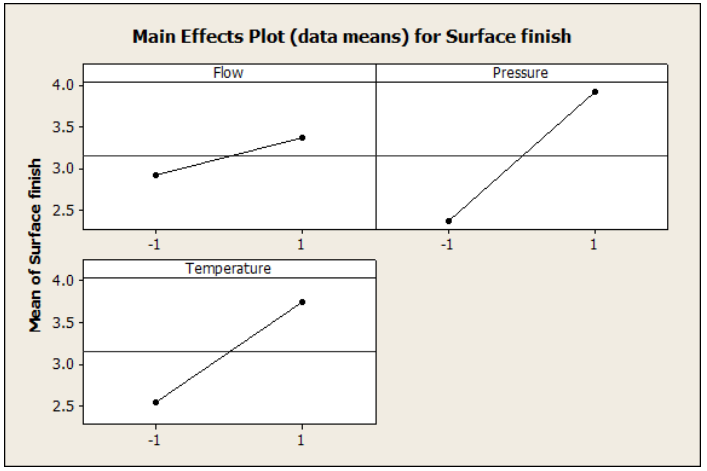
Process Based Testing

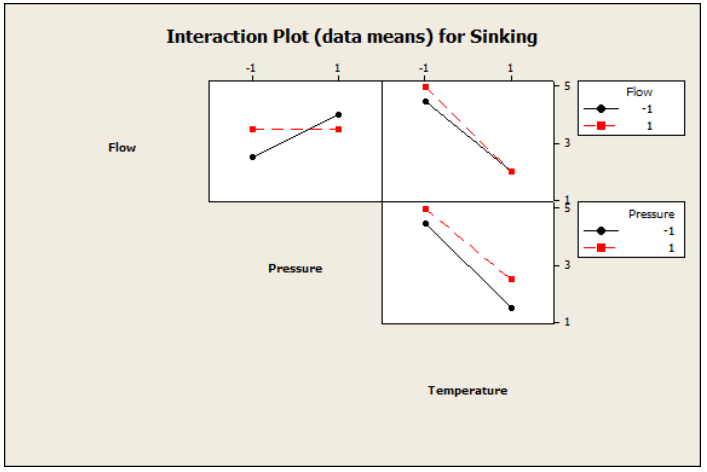




- Using state of the art wax injection equipment it is possible to understand more about the nature and cause of injection defects
- The following charts demonstrate that
  - The mean free linear contraction of a material could be affected by the flow of the wax
  - There is a relationship between flow lines and injection pressure

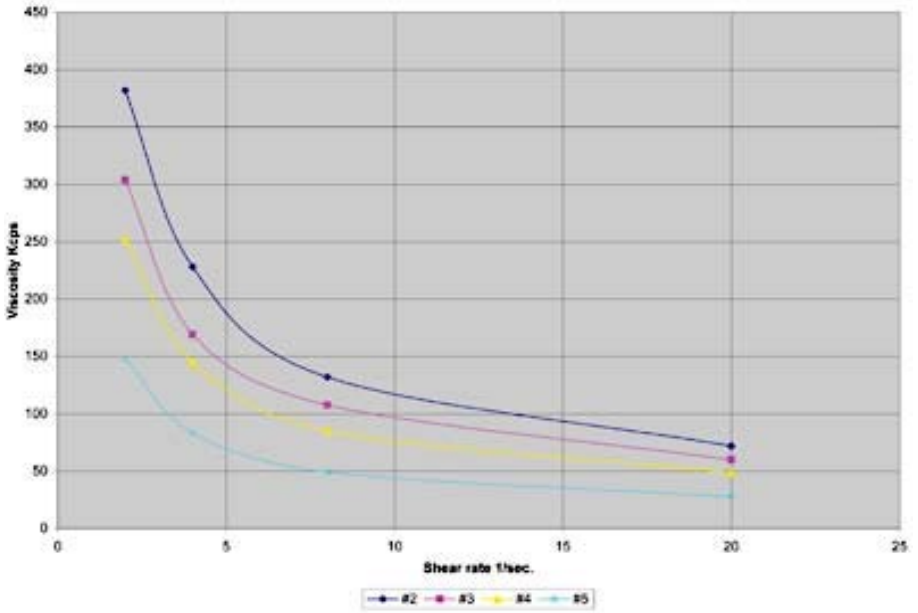
Process Based Testing





- Previous work demonstrated that both temperature and pressure can affect surface finish
- There is a possible relationship with the combination of temperature, flow and pressure on wax cavitation
- As a conclusion we identified a need to characterise wax effects under injection conditions

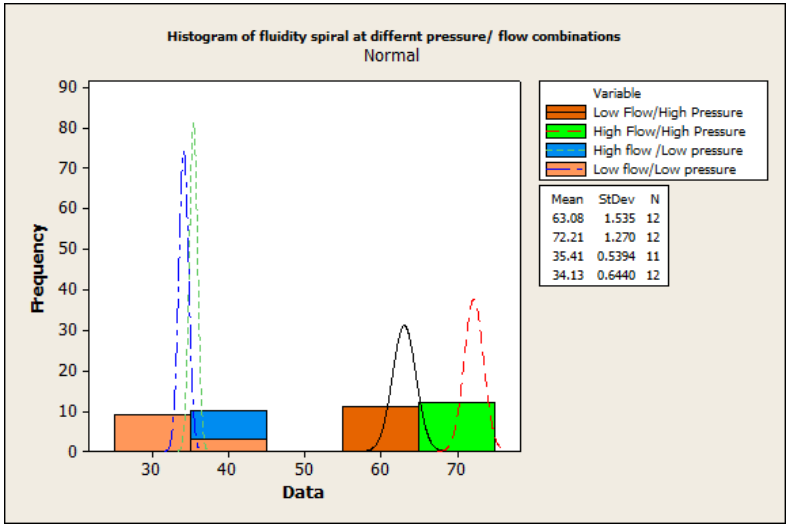
Fluidity Testing



- Viscosity is a representation of the fluid properties of a wax across a range of temperatures
- However there is a difference between viscosity and injected wax fluidity
- A fluidity test has been devised to provide relevant data which can be used to improve process control

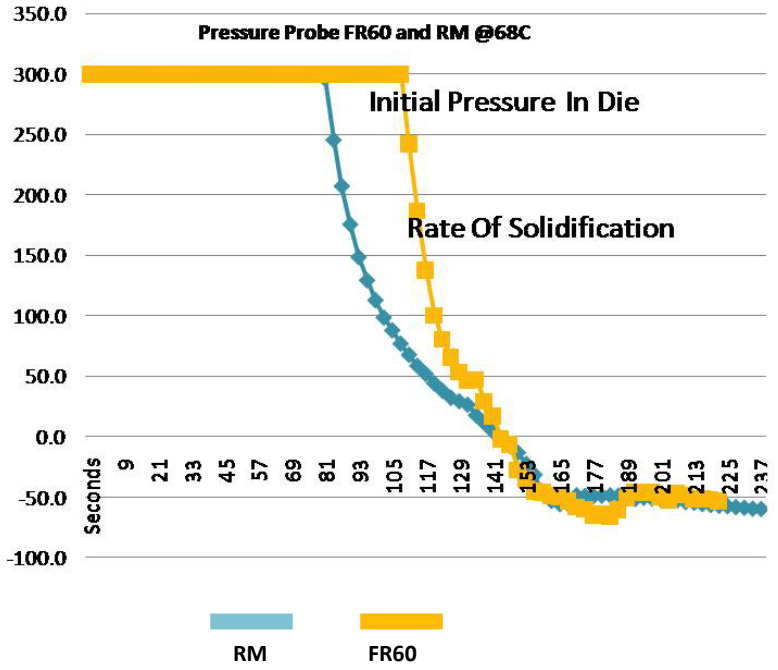
Fluidity Testing

- Test pieces are injected with controlled wax & die temperatures, flow and pressures
- The spiral test measures fluidity of the wax
- This provides advanced information on the fluidity behaviour of the wax at injection

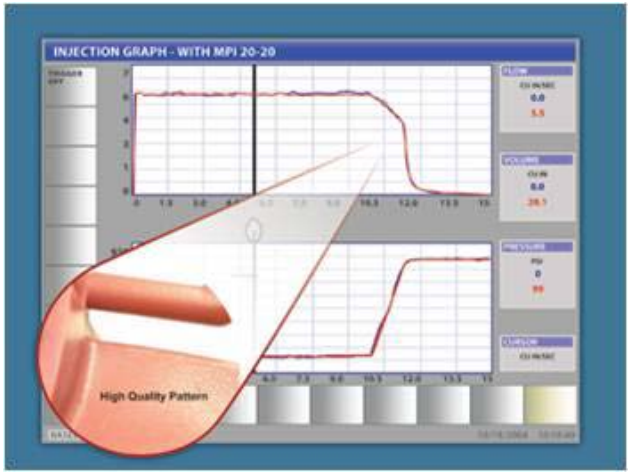


Monitoring Internal Pressure and Solidification

- Internal die pressure is measured using a piezoelectric probe
- This also demonstrates the process of wax solidification in a die
- The graph shows two different wax formulations

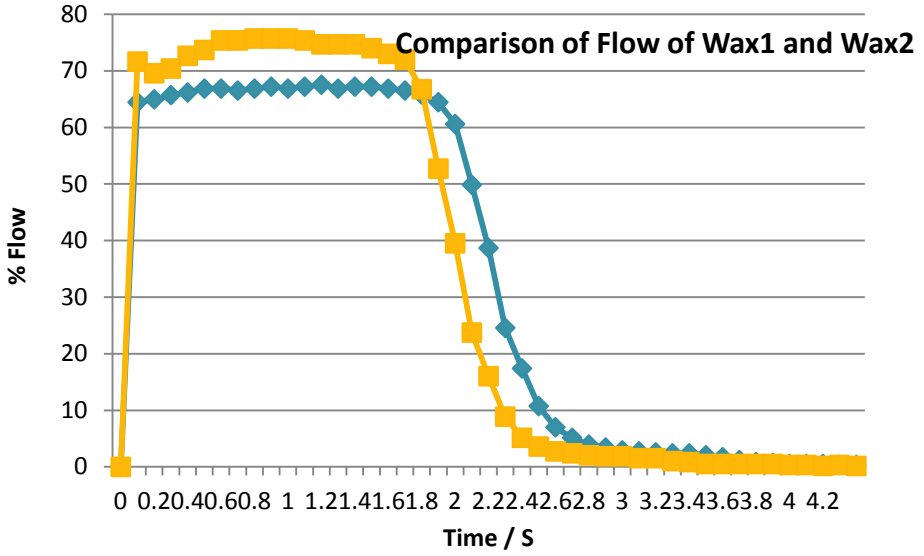


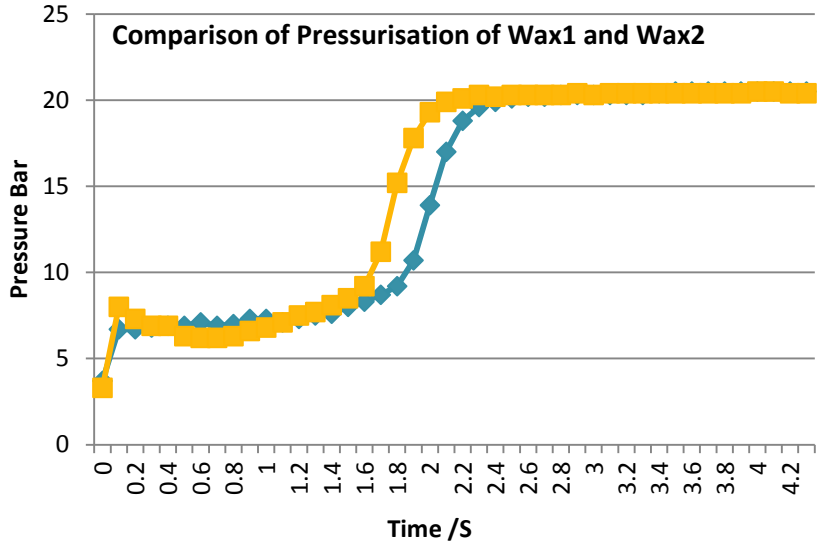
Data Collection and Analysis



- Using a data collection tool real time injection information can be recorded
  - Cycle time
  - Pressure
  - Flow
  - Wax temperature at the injection nozzle

Data Collection and Analysis





The system is used in two ways

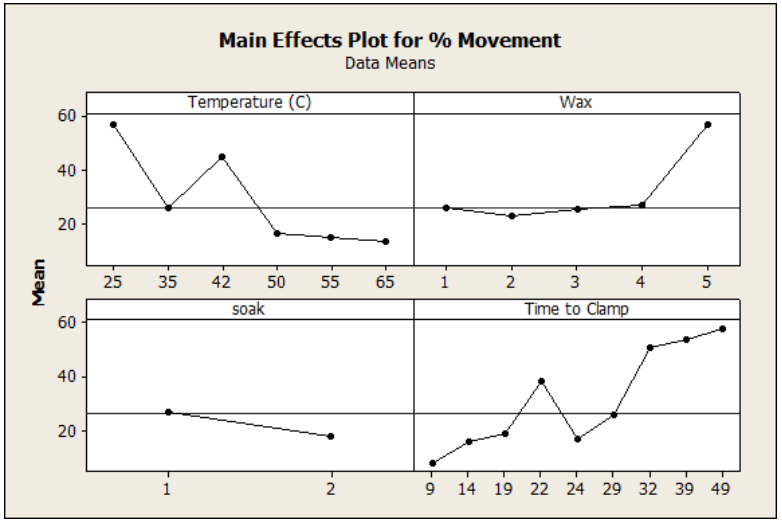
1. As a quality control tool the injection profile is overlayed against the corresponding control template
2. Recording data during R&D trials

- The graphs show the difference between two injected waxes

Advanced Wax Developments

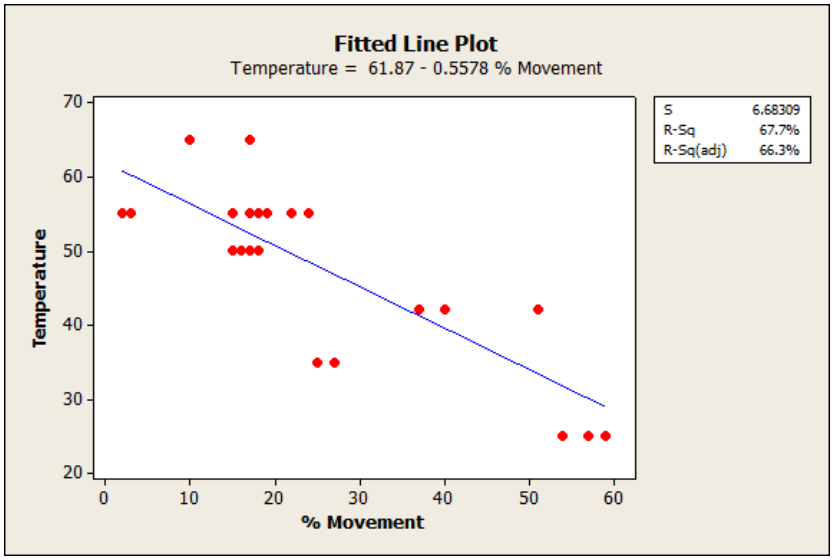
- The process related testing led to a better understanding of wax performance under injection conditions
- One of the major points highlighted was the critical effect of Wax Thermal Hysteresis (wax memory) on dimensional variability
- As a result extensive research into advanced wax materials has led to a development programme for controlling Wax Thermal Hysteresis

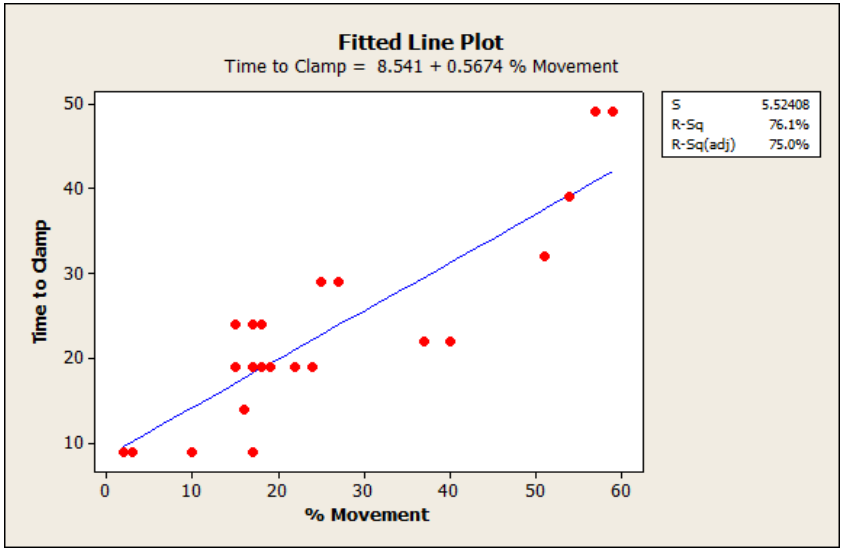
Understanding Wax Thermal Hysteresis



- To understand the nature of WTH, a standard test pattern was used which was
  1. Distorted on a “rig” immediately after removal from the die **or**
  2. Thermally treated and distorted
- The test pattern was allowed to stand for 24 hours
- On measurement the percentage distortion was calculated
- The test was repeated using various injection times

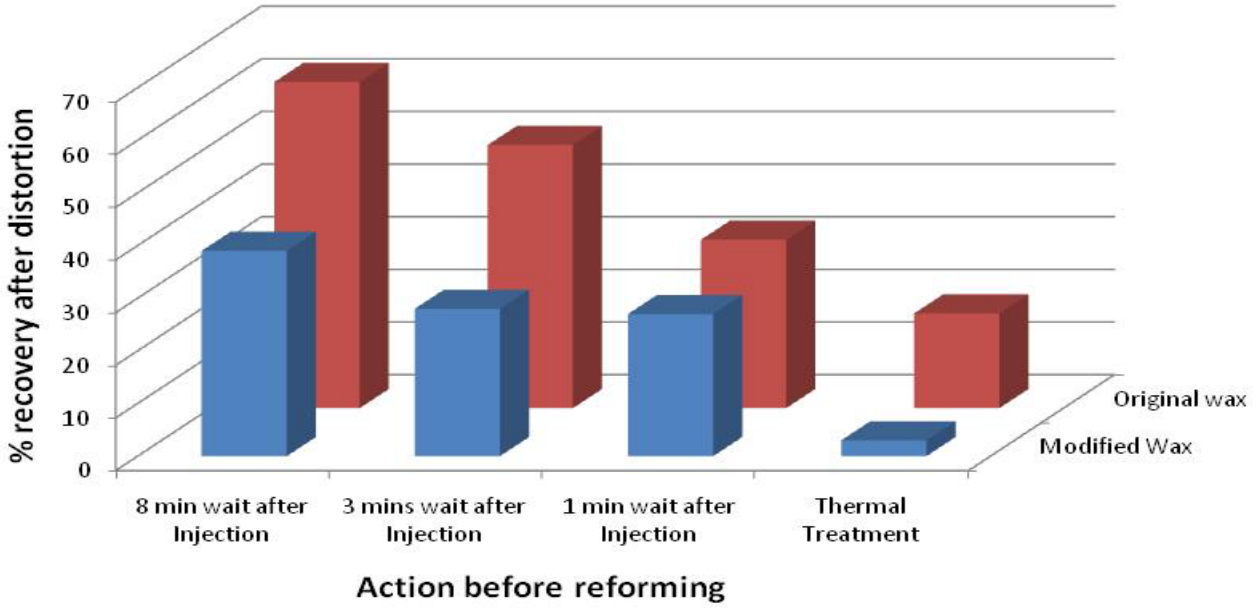
Wax Thermal Hysteresis Research





- Critical variables
  - Pattern temperature
  - Transfer time to setter or former
- Possible solutions
  - Modify process condition
  - Post injection treatment
  - Design a wax to minimise this effect

Overview of Results



- A combination of thermal treatment and the modified wax gave the optimum results
- Another unexpected result of the wax modifications was significantly improved wax fluidity
- Modified wax has no significant change on process times
- Solidification ranges of the wax were effectively unchanged

Conclusion

- Final wax dimensions are affected by
  - Wax contraction
  - Cavitation
  - Wax Thermal Hysteresis
- Control of the injection parameters is critical to the final dimensional capability
- Wax Thermal Hysteresis is a function of wax injection process conditions
- The ideal solution would be to adopt an advanced wax formulation with a significantly reduced wax memory