The Influence of Wax Properties on Thermal Hysteresis

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Agenda

- Wax thermal hysteresis (wax memory)
- Previous research
- Fundamentals of wax memory
- Latest research into the effects of injection and reforming variables
- The effect of wax type
- Conclusion

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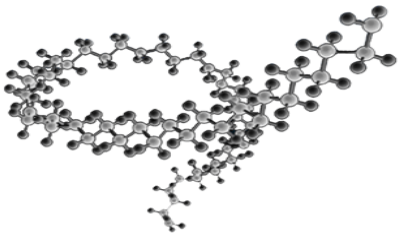
Wax Thermal Hysteresis



- Wax is polymeric in nature
- It is thought to release internal stress over time
- This mechanism is referred to as **wax thermal hysteresis**
- The outcome of this property is process dimensional variability
- The main problem is that the variability is inconsistent
- Various techniques have been adopted to try and control this phenomenon
  - Reformers
  - Thermal treatment
  - Modifying the die

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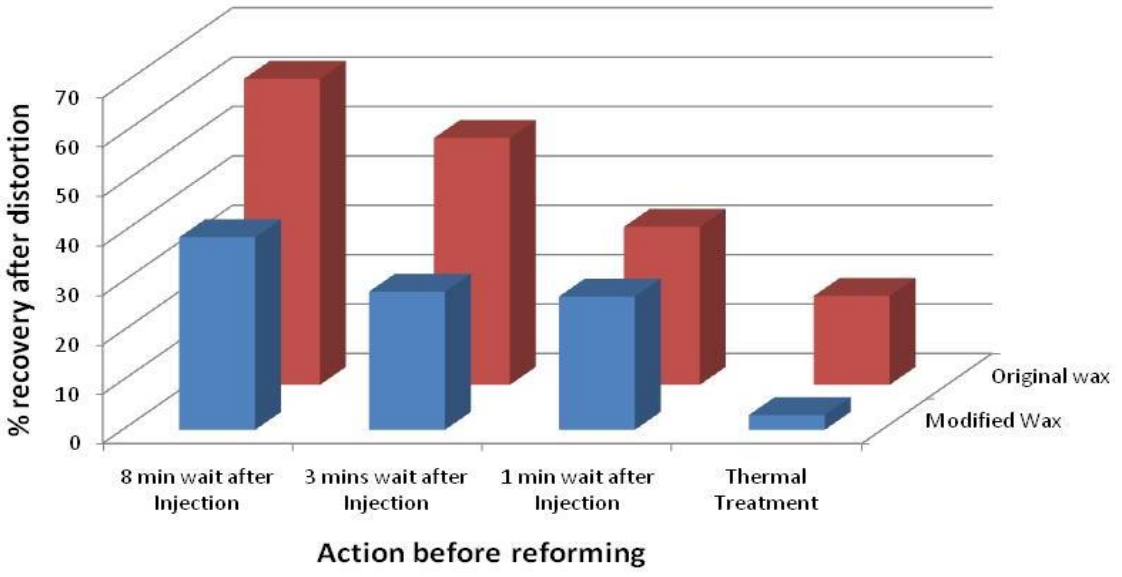
Previous Research

- A standard test pattern was either
  - Reformed immediately after removal from the die
  - Thermally treated and reformed
- The test pattern was allowed to stand for 24 hours
- Then the percentage recovery calculated
- A critical variable was the transfer time to reformer



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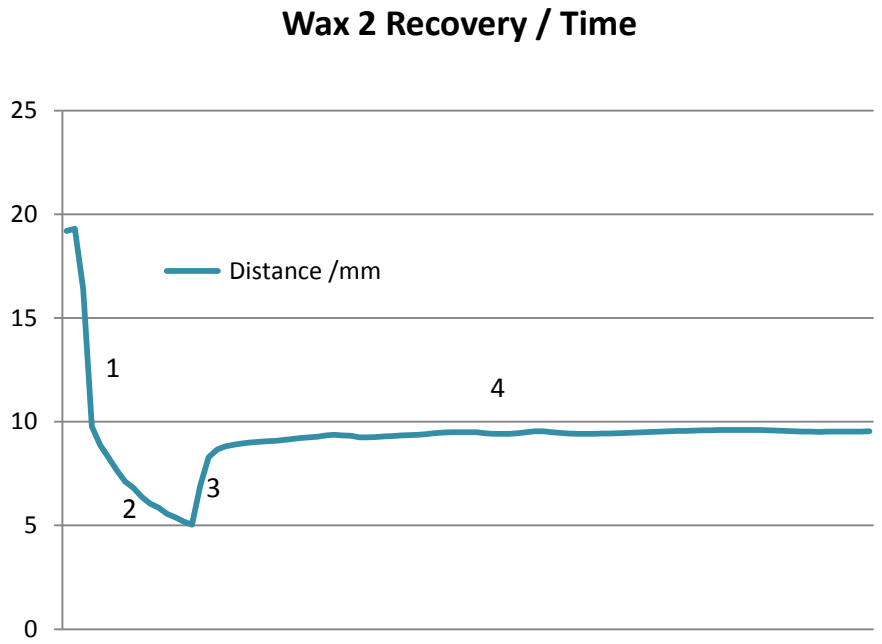
Previous Research Results

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

The Process of Wax Memory

To model recovery a wax was distorted immediately after injection using its own weight

- Stage 1 – Initial deflection
- Stage 2 – Wax “green” strength develops
- Stage 3 – Wax turned 90 degrees immediate elastic behaviour is seen
- Stage 4 – Gradual recovery



In this case “green” strength develops between 35 and 32°C

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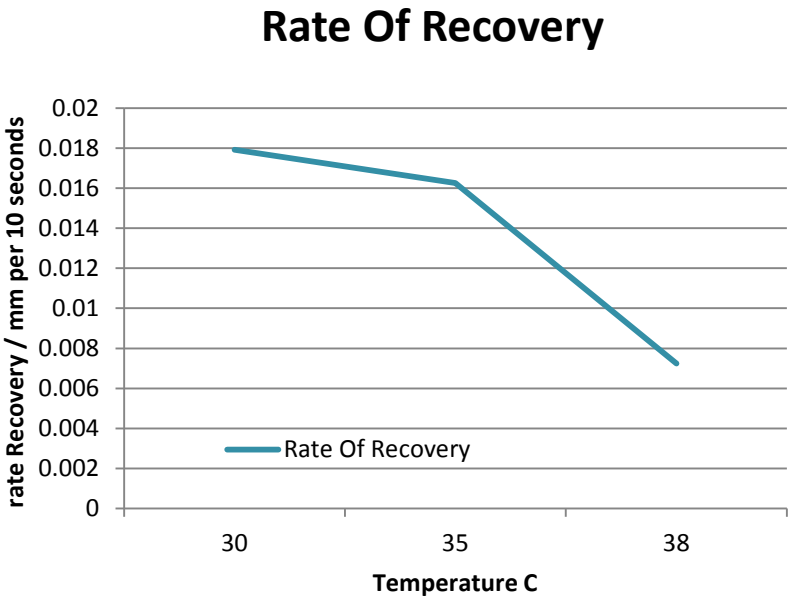
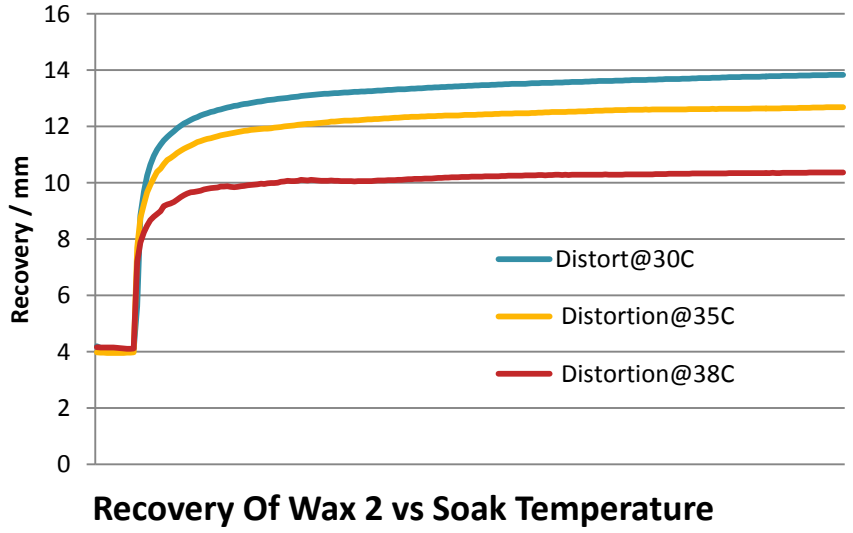
The Process of Wax Memory

In the second model, to remove post injection variability, samples were conditioned in a water bath and allowed to distort to a fixed point prior to recovery

1. The rate of recovery is affected by temperature, and in this case significantly increases below 35°C
2. The total amount of recovery is affected by the temperature at which the part is reformed





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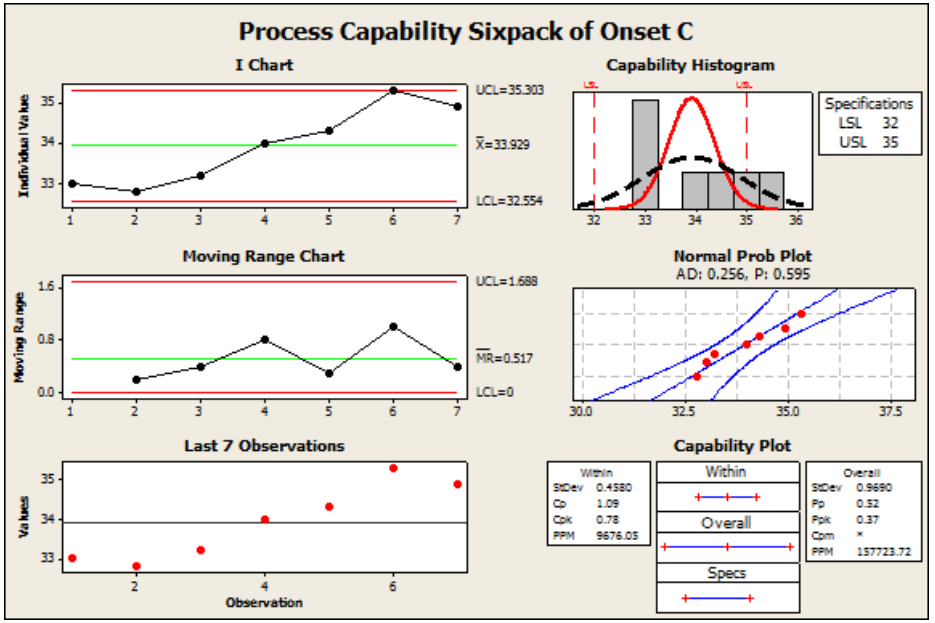
Relationship to DSC

- To further understand which characteristics of the wax may affect recovery we compared the previously identified “green” strength temperature with the DSC curves for a number of batches of the wax
- A possible correlation was found with the **Onset,** the point at which “wax softening begins”



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Latest Research

- Further research into the key areas was undertaken
  - The effect of injection properties
  - Reforming techniques
  - The characteristics of the wax
- Previous research had shown that results could be affected by force applied and contact probes
- This research used laser measurement and gravity as the constant force

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The Effect of Injection Parameters

Injection Parameter	Summary of Research
Injection of liquid wax (68°C) vs paste (60°C)	• Overall memory in liquid phase was greater • Variability of memory was similar
Varying die temperature between 21 and 30°C	• No significant difference in either average memory of variability was noted
Injection at high pressure (75 bar vs low pressure 30 bar)	• A significant difference in variability of memory was seen at High pressure injection
Injection times under pressure were varied from 20 to 130 seconds	• The low injection time gave both a significant increase in both mean and variability of memory • With this test piece above 60 seconds no real difference was noted

The Effect of Reforming

Injection Parameter	Summary of Research
Test piece reformed for different time periods and under different loads	• The overall memory and variability were both affected by increased load
The following parameters were modelled against each other • **Time in the die** • **Time in the reformer**	• Increased time in the die significantly reduced variability • Increased time in the reformer significantly reduced the overall memory

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The Effect of Reforming

Injection Parameter	Summary of Research
Waxes were reformed using different thermal techniques • **High temperature reforming** • **Low temperature reforming**	• Low temperature reforming was the most consistent • Type of wax was found to be important

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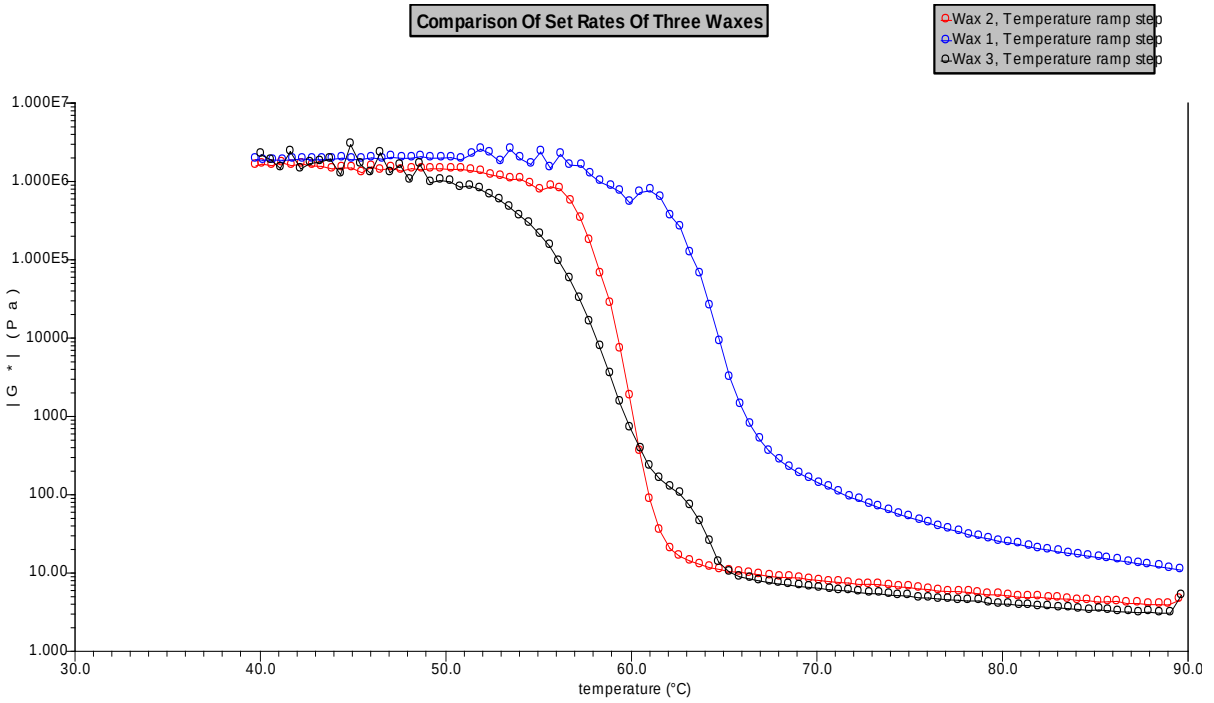
The Effect of Wax Characteristics

- In order to characterise the effect three waxes were tested
  - Wax type 1 - Hard fast setting
  - Wax type 2 - Standard polymeric
  - Wax type 3 - Longer set reduced memory



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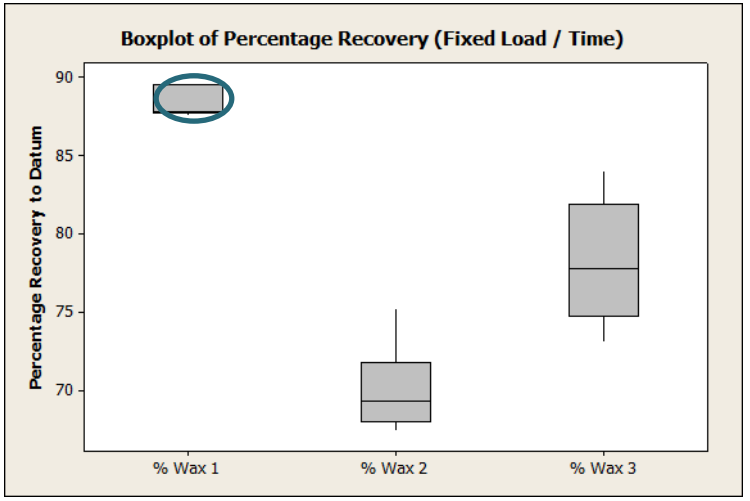
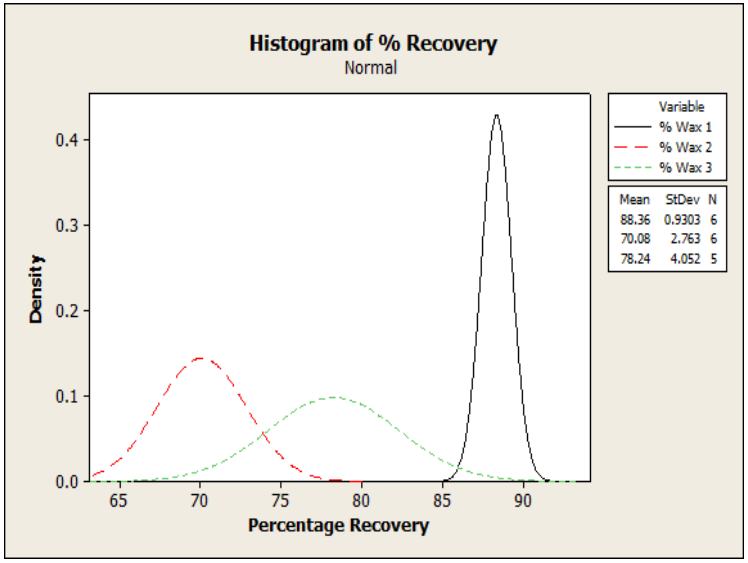
The Effect of Wax Characteristics

The three waxes were distorted under their own weight for a fixed time prior to turning through 90 degrees and allowing to recover for 24 hours

1. Wax 1 shows a significant reduction in both mean and variability of wax memory
2. This demonstrates that this type of wax would give a repeatable product of the die





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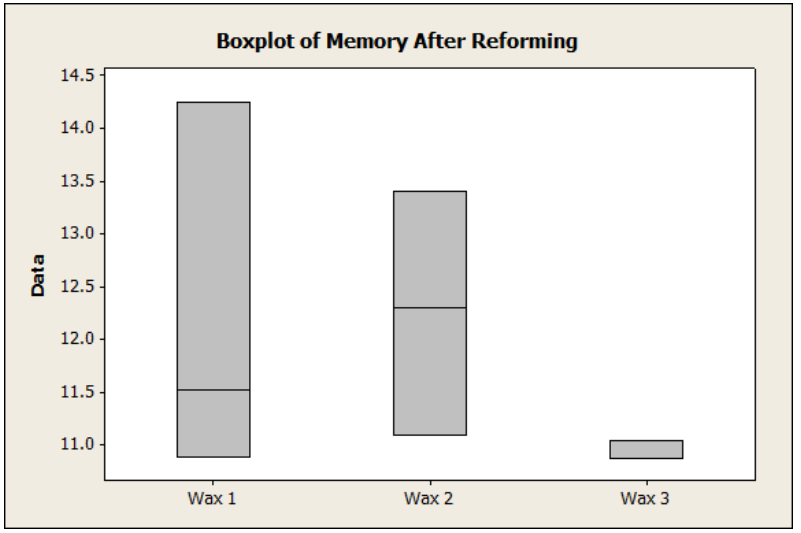
The Effect of Wax Characteristics

The three waxes were reformed on removal from die to a datum of 4mm for 2 minutes and allowed to recover for 24 hours

- Wax 3 was by far the most consistent of all three waxes
- This demonstrates that this type of wax would give repeatable a product of the reformer



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Conclusion

- The research highlighted Wax Thermal Hysteresis to be a significant cause of process dimensional variation
- In order to control this phenomenon the following options are available
  - Control both Injection and Reforming Parameters closely
  - Use a wax designed specifically to minimise the effect
  - Wax type 1 to give repeatable product of die
  - Wax type 3 to give repeatable product of reformer

Thank You

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