SUMMARY OF CREDENTIALS FOR SUHAS KULKARNI

1. M.S. Plastics Engineering (UMASS, Lowell)
2. B.S. Polymer Engineering (University of Pune, India)
3. 1993 – 1995: Republic Tool & Mfg (Scotts Corp)
5. 2004 – present: FIMMTECH
6. Author of the book ‘Robust Process Development And Scientific Molding’
7. Author of several research papers and magazine articles on Injection Molding related topics.
SUMMARY OF CREDENTIALS FOR SUHAS KULKARNI

6. Developer of the software ‘NAUTILUS’ used for process analysis, development, validation and documentation.

7. Developer of custom Design of Experiments software module for Injection Molding.


FIMMTECH Partner: SymphonyTech
Part to be molded is Shaft Widget

Critical Dimensions:

Diameter 1

Diameter 2

Diameter 3

Length

Shot 1: Part is short
Shot 2: Part is full but have sink in Dia 1 area
Shot 3: Part of the section of Dia 2 is stuck in the mold
Further Steps: Mold release is used, parts are molded with sink because customer wants parts.

Mold Trial No. 1

Thick Section (needs to be packed)

Thin Section (does not need to be packed)

Underpacked section

Overpacked section

Section sticking in the mold during ejection

Gate

Shot 1: Part is short
Shot 2: Part is full but have sink in Dia 1 area
Shot 3: Part of the section of Dia 2 is stuck in the mold
Further Steps: Mold release is used, parts are molded with sink because customer wants parts.
Mold Trial No. 1

- Thick Section (needs to be packed)
- Thin Section (does not need to be packed)
- Gate
- Underpacked section
- Overpacked section
- Section sticking in the mold during ejection

- Customer provides feedback that the
  - Dia 1 is undersized by 0.010”
  - Dia 2 is oversized by 0.002”
  - Dia 3 is undersized by 0.005”
  - Any Sink is not acceptable
- Moldmaker is given the feedback and he adjusts the mold steel based on the T1 results.

Mold Trial No. 2

- Thick Section (needs to be packed)
- Thin Section (does not need to be packed)
- Gate
- Underpacked section
- Overpacked section
- Section sticking in the mold during ejection

- Molder is trying to mold parts to get rid of the sink but keeps sticking the Dia 2 in the mold.
- The results are discussed with the customer and he agrees to put a generous draft on Dia 2 which will now help the sticking issue.
Mold Trial No. 3

- Molder starts molding, the sink is eliminated, parts eject out beautifully
- Part and sent to the Quality Lab for inspection
- The results are ....OOOOOPPPPPSSSSSS!!

VARIATION

Variation is natural

If you do not have data, you are another person with an opinion.
- William Edwards Deming.

Variation in part quality

- Time it takes to get to work
- Part weights in injection molding

Part quality variation and specifications

CUSTOMER MEASURES THIS PART

INHERENT VARIATION IN PART QUALITY

MOLDER MEASURES THIS PART
SOURCE OF VARIATION IN A MOLDED PART

MACHINE  PERSONNEL  PROCESS

ENVIRONMENT  MATERIALS  MEASUREMENT

The aim should be to understand the source of variation and then minimize it.

It is impossible to eliminate it.

INTRODUCTION TO SCIENTIFIC PROCESSING

Aim Of A Molding Operation

• To mold parts consistently
• To mold parts that meet all the quality requirements
• To run an efficient process
INTRODUCTION TO SCIENTIFIC PROCESSING

The 3 Types of Consistency

- Cavity to Cavity Consistency:
  Parts from each cavity are identical in quality

  Cavity To Cavity Consistency:
  \[ L_{(CAV \ 1)} = L_{(CAV \ 2)} = L_{(CAV \ 3)} = L_{(CAV \ 4)} = \]
  \[ L_{(CAV \ 5)} = L_{(CAV \ 6)} = L_{(CAV \ 7)} = L_{(CAV \ 8)} \]

- Shot to Shot Consistency:
  Every consecutive part that falls out of the mold is identical in quality

  Part Length, \( L_{(n)} = L_{(n+1)} = L_{(n+n)} \)
•Run to Run Consistency:
  During every consecutive run, the molded parts have an identical
  quality as the previous runs

\[ \text{Average length} = \bar{X}_1 = \bar{X}_2, \]
\[ \text{and variation} \sigma_1 = \sigma_2. \]

Introduction to Scientific Processing

Quality Requirements –
  • Meeting Specifications

Efficient Operation –
  • Optimized cycle times
  • Reduced scrap at startup
  • Zero scrap during production

Part out of spec
  • QA needs to be involved
  • Tech needs to be involved
  • Time loss, Material loss
**Question:**
If you want to drive your car in cruise control mode, which of the following roads will you prefer?

On the edge of a cliff?  OR  On a freeway with a wide lane?

A Molding Process Must Be:
1. Robust
2. Repeatable
3. Reproducible
AKA the 3Rs.

**Art to Part:**

All changes in molding should be Data Driven.
SCIENTIFIC MOLDING AND SCIENTIFIC PROCESSING

Plastic Pellet

- Plastic Enters The Facility
- Storage
- Pre-Conditioning
- Mold
- Molding Process
- Ejection Out Of The Mold
- Packaging
- Shipping

Scientific Molding

Scientific Processing

INJECTION MOLDING PARAMETERS

1. COOLING TIME
2. PACK & HOLD PRESS
3. PACK & HOLD TIME
4. MELT TEMP
5. INJ PRESS
6. SCREW ROTATION SPEED
7. BACK PRESS
8. INJ SPEED
9. SHOT SIZE
10. CUSHION
11. TRANSFER POSITION

INJ

PACK & HOLD

MOLD TEMP

DRYING TIME AND DRYING TEMP

Suhas Kulkarni www.fimmtech.com
SCIENTIFIC PROCESSING

Mold Trial No. 3

- Thick Section (needs to be packed)
- Thin Section (does not need to be packed)
- Underpacked section
- Overpacked section
- Section sticking in the mold during ejection

- Molder starts molding, the sink is eliminated, parts eject out beautifully
- Part and sent to the Quality Lab for inspection
- The results are ....OOOOOPPPPPPSSSSSS!!
DRIVING FROM DENVER TO LAS VEGAS

1. MAKE SURE CAR IS GOOD ENOUGH TO TRAVEL 1800 MILES
   - GET THE REQUIRED MAINTENANCE DONE
   - PLAN STOPS ALONG THE WAY

DISTANCE = 800 MILES

2. PUNCH IN THE ADDRESS IN THE GPS

---

**Stage 1: Mold Function Qualification & Part Cosmetics Qualification**

**6 Step Study**

1. Viscosity Study
   - OK
   - Part or Mold Issues
   - Fix Mold or Part Design
   - Recommended Mold Qualification Procedure

2. Cavity Balance
   - OK
   - Not OK
   - Pressure Drop
   - OK
   - Process Window
   - OK
   - Gate Seal Study
   - OK
   - Cooling Study

3. Gate Seal Study
   - OK
   - Not OK
   - Part or Mold Issues

---

**Stage 2: Part Dimensions and Quality Qualification**

**Select DOE Parameters**

- Perform DOE
- Select Process
- Run Process
- Adjust Mold Steel
- Determine DPW
- Run Short Production Run to Evaluate the Molding Process and Molding Process Capability

---

**Please Note:** This flow chart has been developed by FIMMTECH and is a recommended procedure. The users should use their own discretion and judgment in following the procedure especially keeping safety in mind. The user is solely responsible for all consequences.

-Suhas Kulkarni, www.fimmtech.com
THE INJECTION MOLDING CYCLE

- MELT TEMP
- MOLD TEMP
- INJ SPEED
- PACK & HOLD PRESS
- PACK & HOLD TIME
- SCREW SPEED
- BACK PRESS

INJECTION PHASE

PACK PHASE

HOLD PHASE

COOLING

MOLD OPEN

EJECTION

MOLD CLOSE

Screw Rec

Complete Cycle

UNOPTIMIZED

OPTIMIZED

SCIENTIFIC MOLDING - THE 6-STEP STUDY

(1) VISCOSITY CURVE
(2) CAVITY BALANCE DETERMINATION
(3) PRESSURE DROP STUDY
(4) WINDOW STUDY
(5) GATE FREEZE STUDY
(6) COOLING STUDY

INJECTION

PACK & HOLD

COOLING

SCREW RECOVERY

AIM: TO DEVELOP A ROBUST PROCESS AND ACHIEVE CONSISTENCY
STEP 1: VISCOSITY CURVE
- Shows effect of injection speed on viscosity
- Shows the most consistent region of viscosity
- Reduces lot to lot variation

STEP 2: CAVITY BALANCE STUDY
- Shows the fill balance between all the cavities
- Helps in achieving better cavity to cavity consistency

STEP 3: PRESSURE DROP STUDY
- Does the machine have enough pressure?
- Is the process pressure limited?
- Helps in consistency

STEP 4: PROCESS WINDOW STUDY
- Shows the extent of capability of the mold to make cosmetically acceptable parts
- Bigger the window, better are the chances of consistency
SCIENTIFIC MOLDING 6-STUDY AND DOE STUDIES

STEP 5: GATE SEAL STUDY

- SHOWS WHEN THE GATE SEALS
- SINCE PLASTIC WEIGHT IS CONSTANT
  CONSISTENCY IS BETTER

![Gate Seal Study Chart]

STEP 6: COOLING TIME STUDY

- SHOWS THE EFFECT OF COOLING TIME
- IMPROVES EFFICIENCY

![Cooling Time Study Chart]

PROCESS DEVELOPED USING 6-STEP STUDY

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Settings</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Melt Temp</td>
<td>380 deg F</td>
<td>Window Study</td>
</tr>
<tr>
<td>2</td>
<td>Mold Temp</td>
<td>70 deg F</td>
<td>Window Study</td>
</tr>
<tr>
<td>3</td>
<td>Inj Speed</td>
<td>2.5 in/sec</td>
<td>Viscosity Curve</td>
</tr>
<tr>
<td>4</td>
<td>Inj Pressure</td>
<td>925 psi</td>
<td>Pressure Drop Study</td>
</tr>
<tr>
<td>5</td>
<td>Hold Press</td>
<td>525 psi</td>
<td>Window Study</td>
</tr>
<tr>
<td>6</td>
<td>Back Pressure</td>
<td>50 psi</td>
<td>As min reqd</td>
</tr>
<tr>
<td>7</td>
<td>Screw Speed</td>
<td>50 rpm</td>
<td>Homogeneous melt, part weight</td>
</tr>
<tr>
<td>8</td>
<td>Cooling Time</td>
<td>4.0 sec</td>
<td>Cooling Time Study</td>
</tr>
<tr>
<td>9</td>
<td>Hold Time</td>
<td>6.5 sec</td>
<td>Gate Freeze Study</td>
</tr>
<tr>
<td>10</td>
<td>Shot Size</td>
<td>1.0 inches</td>
<td>95 - 98 %</td>
</tr>
<tr>
<td>11</td>
<td>Transfer Posn</td>
<td>0.40 inches</td>
<td>95 - 98%</td>
</tr>
</tbody>
</table>
DESIGN OF EXPERIMENTS

HOW DO YOU KNOW …

• WHAT ARE THE DIMENSIONS OF THE PART?

• WHAT PROCESS PARAMETER TO CHANGE WHEN THERE IS A PROBLEM?

• WHAT IS THE OPTIMUM PROCESS SETTINGS TO GET ALL THE DIMENSIONS WITHIN SPECIFICATIONS?

• WHAT IS THE CAPABILITY OF THE PROCESS? – CAN YOU MOLD PARTS CONSISTENTLY OR DO YOU NEED TO KEEP ADJUSTING THE PROCESS?

ANSWER …

• ‘PLAY’ WITH THE PROCESS AND SEE WHAT HAPPENS. – WE ALL DO THIS

• DOING THIS SYSTEMATICALLY IS ‘DESIGN OF EXPERIMENTS’.
DESIGN OF EXPERIMENTS:

Definition: A planned experiment to find the effect of a parameter on the quality of the part.

An increase (or decrease) of the Holding Pressure by 400 psi, increases (or decreases) the Length by 0.009".

Number of Experiments = 2

<table>
<thead>
<tr>
<th>No</th>
<th>HoP</th>
<th>MeT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

DESIGN OF EXPERIMENTS:

1 – Holding Press   2 – Melt Temp

Number of Experiments = 4

<table>
<thead>
<tr>
<th>No</th>
<th>HoP</th>
<th>MeT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>3</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>
DESIGN OF EXPERIMENTS:

1 – Holding Press  2 – Melt Temp  3 – Mold Temp

Number of Experiments = 8

<table>
<thead>
<tr>
<th>No</th>
<th>HoP</th>
<th>MeT</th>
<th>MoT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>3</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>5</td>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>6</td>
<td>H</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>7</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

DESIGN OF EXPERIMENTS:

1 – Holding Press  2 – Melt Temp  3 – Mold Temp  4 – Cool Time

Number of Experiments = 16

<table>
<thead>
<tr>
<th>No</th>
<th>HoP</th>
<th>MeT</th>
<th>MoT</th>
<th>CoT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>3</td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>5</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>6</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>7</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>9</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>10</td>
<td>H</td>
<td>L</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>11</td>
<td>L</td>
<td>H</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>12</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>13</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>14</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>15</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>16</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>
Relation between number of Experiments and Factors:

<table>
<thead>
<tr>
<th>No</th>
<th>Factors</th>
<th>Levels</th>
<th># of Expts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>G</td>
<td>3</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>F</td>
<td>4</td>
<td>3</td>
<td>81</td>
</tr>
</tbody>
</table>

Number of Expts = \((\text{Number of Levels})^{\text{Number of factors}}\)
**ANALYSIS:**

Analysis of the data can be done manually but is mostly done with the help of computer programs. A number of computer programs are available.

- **MINITAB** – Most commonly used program – Very powerful, but complex
- **WISDOM** – Designed specifically for Injection Molding – Very easy to use
- **NAUTILUS** – Mold Qualification and DOE software

The analysis gives information such as the:

- Factors that most influence the quality of the part
- The robustness of the quality of the part
- Prediction of the most optimized process
- How far away are the dimensions from the nominal or spec limits

**STEP 3: SOFTWARE GENERATES THE EXPERIMENTAL MATRIX**

MOLD THE PARTS, ENTER DATA AND CLICK ON THE ANALYSIS BUTTON TO VIEW THE RESULTS
DIMENSIONAL PROCESS WINDOW

GREEN CONTOURS – PARTS IN DIMENSION  RED – PARTS OUT OF SPEC

YOU CAN DRAW A BOX AS SHOWN TO DETERMINE ALARM AND TOLERANCE SETTINGS

DIMENSIONAL PROCESS WINDOW

MOLD PARTS BETWEEN THE PROCESS WINDOWS TO MAINTAIN THE PARTS WITHIN THE DIMENSIONS.

DIMENSIONAL PROCESS WINDOW
DIMENSIONAL PROCESS WINDOW

WITH A DIMENSIONAL PROCESS WINDOW AS SHOWN IT WILL BE IMPOSSIBLE TO MOLD PARTS CONSISTENTLY TO THE REQUIRED DIMENSIONS.

VISUAL PREDICTION EQUATION

THE DIMENSION CAN GO OUT OF SPEC

EXTENT TO WHICH THE DIMENSION CAN BE INFLUENCED BETWEEN THE EXTREMES OF THE DOE PARAMETERS
**Visual Prediction Equation**

- **Simulated Process**
  - Mold Temperature | Cooling Time | Holding Pressure
  - 100 | 12 | 899

- **Process Gold Spot**
  - Predicted process that will bring the following dimensions closest to nominal
  - Mold Temperature | Cooling Time | Holding Pressure
  - 100 | 12 | 899

Note: Place the mouse pointer on black and red spot to view marking points.

**THE DIMENSION CAN GO OUT OF SPEC**

**STABLE DIMENSION - WILL ALWAYS BE IN SPEC**

**Process Gold Spot** - Best process to bring all dimensions closest to nominal.
VISUAL PREDICTION EQUATION

Simulated Process

<table>
<thead>
<tr>
<th>Mold Temperature</th>
<th>Cooling Time</th>
<th>Holding Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>12</td>
<td>870</td>
</tr>
</tbody>
</table>

Process Gold Spot

Note: Place the mouse pointer on each and red spot to view holding points.

Simulated process:
Change the process and see what it does to the part dimensions. The black X will move with process changes.
Numerical Prediction Equation

Use the arrows to change the process and see the effect on the dimensions. Dimensions are displayed numerically.

Achieving dimensions:
Making steel and/or nominal – tolerance changes

Good Cp but Bad Cpk??
Your choices are
• Modify the steel dimension and/or
• Modify the nominal – spec limits

Robust process

Modify mold and/or nominal-spec limits by this number to hit the nominal value.
CONTACT INFORMATION:

SUHAS KULKARNI

EMAIL: suhas@fimmtech.com

TEL: (760) 525 9053

www.fimmtech.com

www.InjectionMoldingOnline.com

WISH YOU ALL THE BEST AND A SUCCESSFUL CAREER!

THANK YOU!