Example 3 - Shell Room Parameters & Inclusions (Investment Casting)

This study illustrates the effectiveness of p-matrix Data Visualizer 2013 software for tolerance optimization, where reduction in variation of process response is achieved by implementing simultaneous adjustments to multiple parameter settings in the shell room of an investment casting process.

The Problem: The foundry experts want to identify reasons that could have resulted in the ceramic breaking free from the shell and ending up in the casting forming the Inclusions defects. There could be a variety of causes. E.g. improperly dried shell that can crack, environmental conditions that give rise to cracks in slurry coating etc. The following parameters were identified.

Humidity - Final Drying	Viscosity - 2nd Coat (Intermediate)	pH - 2nd Coat (Intermediate)
Room Temperature - Final Drying	Viscosity - Final (Backup) Coat	pH - Final (Backup) Coat
Avg. Humidity - Intermediate Coats	Density - 1st Coat (Prime)	Drying time 1 (hrs)
Avg. Room Temperature - Intermediate Coats	Density - 2nd Coat (Intermediate)	Drying time 2 (hrs)
Robot Program	Density - Final (Backup) Coat	Drying time 3 (Final) (hrs)
Viscosity - 1st Coat (Prime)	pH - 1st Coat (Prime)	Pressurisation Time (sec)

The production data for 70 batches with 18 process parameters and %Inclusions rate was recorded. Each row in the Figure below presents a batch.

% Inclusion	Humidity -	Room Tem	Avg. Humi	Avg. Room	Robot Pro	Viscosity -	Viscosity -	Viscosity -	Density - 1	Density - 2	Density - F	pH - 1st C
0	31.2	23.8	52	24	1	17	29	37	3.05	1.57	1.68	9.7
3	30	22.7	48	23.2	1	22	27	34	3.2	1.63	1.67	9.6
1	29.2	23.1	49	22.8	2	24	28	37	3.3	1.57	1.7	9.7
3	28.9	22.7	61	23.8	1	23	29	38	3.24	1.67	1.64	9.6
1	30	24	55	23.5	1	19	29	34	3.34	1.62	1.67	9.8

The experts want to discover the good settings that can be maintained and the bad settings that need to be avoided for producing Inclusions free castings. The objective of this study is as follows.

Aim: To find out one or more shell room parameter settings that can best explain the variation in values of %Inclusions so that the defect can be eliminated by altering settings of the factors to their top, middle or bottom ranges within specifications of the component.

The Solution: By analysing the data using p-matrix Data Visualizer software, optimal and avoid ranges of various shell room parameters can be discovered. The results of this case study will show if there is any evidence in process data to suggest if settings of any of the parameters in the shell room or interactions between multiple settings are linked to occurrence (or non-occurrence) of Inclusions defect. The analysis penalises the deviation from desired response values depending upon severity. It does not apply any statistical methods and no pre-determined assumptions or fitting is applied to the data.

Penalty Function for Inclusions: p-matrix software applies 0 penalty value to desired response (0 %Inclusions values), 100 penalty value to undesired response (when %Inclusions exceeds 4%) and linearly scales the remaining values from 1 to 99.

p-matrix Report: p-matrix has discovered strong evidence to optimize tolerance limits of various process parameters. The ranges were compared against the trends reported in the literature before choosing them in the confirmation trail plan for the 7Epsilon Quality Control meeting.

Confirmation Trial Plan: It suggests Bottom 50% range of Pressurisation Time (sec), Middle 50% of Avg. Humidity – Intermediate Coats and Bottom 50% of Density – 1st Coat (Prime) can prevent cracking of shell and further minimize shell inclusions in the casting.

Pressurisation Time(sec)

Q1	Q2		Q3	Q4
Minimum		Median		Maximum
5	6	7	8	9

Q1: Optimal; Range: Bottom 25%, {>=5 & <=6}; Strength: 4.6; No. of Interactions: 0
Q1 & Q2: Optimal; Range: Bottom 50%, [>=5 & <=7]; Strength: 3.4; No. of Interactic
Q3 & Q4: Avoid; Range: Top 50%, [>7 & <=9]; Strength: 3.4; No. of Interactions: 0

Penalty	Q1	Q2	Q3	Q4
80-100		5		11
60-80		2		7
40-60	1	2		3
20-40		1		8
0-20	22	7		1

Avg. Humidity - Intermediate Coats

Q1	Q2		Q3	Q4
Minimum		Median		Maximum
43	51	56	59	68

Q2 & Q3: Optimal; Range: Middle 50%, {>51 & <59}; Strength: 3.4;

Penalty	Q1	Q2	Q3	Q4
80-100	6	1		9
60-80	3	2	1	3
40-60	3	1		2
20-40	2	4	2	1
0-20	4	12	7	7

Density - 1st Coat (Prime)

Q1	Q2		Q3	Q4
Minimum		Median		Maximum
2.9	3.02	3.13	3.21	3.37

Q1 & Q2: Optimal; Range: Bottom 50%, [>=2.9 & <=3.13]; Strength: 3.2;
Q4: Avoid; Range: Top 25%, {>=3.21 & <=3.37}; Strength: 3.2; No. of Inte
Q3 & Q4: Avoid; Range: Top 50%, [>3.13 & <=3.37]; Strength: 3.2; No. of

Penalty	Q1	Q2	Q3	Q4
80-100	2	2	2	10
60-80		1	3	5
40-60	2		2	2
20-40	5	1		3
0-20	9	13	7	1

C	D	E	F	G	H	I	J	K	L	M	N	O
Response	R	Low	High	Factor name	Level	Optin	Stre	No.	Max.	Min. Value	Max. Value	Level with Values
% Inclusions	*LB*	*0*	*4*	*Viscosity - 1st Coat (Prime)*	*Bottom 50%*	*Optimal*	*2.3*	*3*	*3.6*	*17*	*24*	*[>=17 & <=20]*
% Inclusions	*LB*	*0*	*4*	*Humidity - Final Drying*	*Top 50%*	*Optimal*	*1.6*	*1*	*2.9*	*27.1*	*33.7*	*[>30.3 & <=33.7]*
% Inclusions	*LB*	*0*	*4*	*Robot Program*	*1*	*Optimal*	*2.6*	*1*	*3.3*			
% Inclusions	*LB*	*0*	*4*	*Drying time 3 (Final) (hrs)*	*Bottom 50%*	*Optimal*	*1.7*	*2*	*3.6*	*19.2*	*24*	*[>=19.2 & <=21.2]*
% Inclusions	*LB*	*0*	*4*	*Viscosity - 2nd Coat (Intermed*	*Top 50%*	*Optimal*	*1.7*	*2*	*3.1*	*27*	*29*	*[>=28 & <=29]*

nmary | Penalty Matrix - Main Effects | Penalty Matrix - Interactions | Main Effects | Interact

It also highlights Bottom 50% of Viscosity for 1st Coat(Prime), top 50% of Humidity – Final Drying, Robot Program 1, Bottom 50% of Drying time 3 (Final) (hrs), Top 50% of Viscosity – 2nd Coat (Intermediate) as optimal parameter ranges when maintained at these settings have a combined effect of reducing the defect.

For more information, visit us at www.7Epsilon.org.