Penalty Matrix
Visualize. Analyze. Reuse.

Example 5 - High Pressure Sand Moulding Parameters, Chemical Composition & Shrinkage (Gray Cast Iron)

This example shows how p-matrix Data Visualizer 2013 software can assist in achieving a robust process design that can reduce the variability in a process response in a precision sand casting foundry. In ISO9001:2008 context, process responses are the performance indicators that measure product's conformity with the desired product requirements or characteristics. This case study demonstrates how multiple process parameter ranges can be attributed to the variation in response values and simultaneously adjusted to reduce the variation.

The Problem: The foundry was generating enormous data with state-of-the-art control for sand parameters and frequent spectral analysis for chemistry. While identifying causes for Shrinkage defect in the castings that had risen to an unacceptable level, the experts noted down the following list of parameters which may have an effect.

Pouring Temperature	GCS	Dead Clay	Return Sand Moisture
Chemistry	Total Clay	Loss on Ignition	Prepared Sand Temp
Compactability	Active Clay	Prepared Sand Moisture	Return Sand Temp

Process data for 150 batches was recorded with %Shrinkage rate per batch. Every row in the Table below shows a batch.

% Shrink	Pouring Temp	C	Si	Mn	P	S	Cu	CE	Compactability	GCS	Total Clay	Active Clay	Dead Clay
2	1440	3.13	2.242	0.337	0.135	0.11	0.241	3.88	44	2415	13.4	9.18	4.22
0	1438	3.05	2.18	0.3421	0.135	0.113	0.247	3.78	44	2415	13.4	9.18	4.22
0	1338	3.06	2.221	0.337	0.139	0.11	0.257	3.81	44	2415	13.4	9.18	4.22
0	1438	3.01	2.206	0.456	0.135	0.18	0.1383	3.78	43	1995	13.2	9.11	4.1
0	1441	3.11	2.241	0.3387	0.124	0.111	0.1293	3.86	43	1995	13.2	9.11	4.1

Aim: When Shrinkage is of the sporadic type it is usually a result of a number of variables probably only slightly out of control. The objective of this study is to find out which parameters contribute to the variation in %Shrinkage values so that their settings can be simultaneously tweaked to their optimal ranges to eliminate Shrinkage.

The Solution: Production data provides insight into your process. p-matrix Data Visualizer software has the ability to identify parameter ranges that are already robust and need no further alterations. It also highlights changes to various process parameter limits that are required to achieve a robust process design which can be implemented in your foundry.

p-matrix discovers true correlations and interactions between a large number of factors and responses. It generates a list of hypotheses (potential corrective actions) to conduct a confirmation trial without any statistical assumptions or pre-conceived conclusions.

Penalty Function for Shrinkage: The analysis penalises the deviation from desired response values depending upon severity. p-matrix software applies 0 penalty value to desired response (up to 2% Shrinkage rate) , 100 penalty value to undesired response (i.e. when Shrinkage rate exceeds 10%) and linearly scales values for the remaining batches from 1 to 99.

p-matrix Report: p-matrix identified required adjustments in terms of optimal and avoid ranges of several factors to improve the process. The ranges were compared against the trends reported in the literature before choosing them in the corrective action plan for a confirmation trail.

Root Cause Analysis: The foundry engineers were able to evaluate all the ranges given in the various sheets of p-matrix report to recommend potential corrective actions that were discussed in the 7Epsilon Quality Control meeting to finalise a corrective action plan.

Chemistry is important. The report suggests that Top 50% range of Silicon is optimal i.e. values of [2.032 to 3.02]. The literature suggests that the higher proportion of graphitising elements such as Carbon and Copper is beneficial for reducing Shrinkage. However, the advantage of p-matrix reports is that it identifies robust ranges for factors that are product and foundry specific. E.g. it has identified evidence in the data that maintaining Carbon and Copper both in their Top 25% ranges i.e. values of [3.12 to 3.21] for Carbon and [0.177 to 0.257] for Copper will reduce the amount of Shrinkage formed for the product under consideration in this foundry.

Cu

Q1	Q2		Q3	Q4
Minimum		Median		Maximum
0.1116	0.134	0.163	0.177	0.257

Q4: Optimal; Range: Top 25%, {>=0.177 & <=0.257}; Strength: 3.6;

Q3 & Q4: Optimal; Range: Top 50%, [>0.163 & <=0.257]; Strength: 1.4;

Penalty	Q1	Q2	Q3	Q4
80-100	4	9	8	2
60-80	2		3	
40-60	3		1	1
20-40	9	5	1	1
0-20	20	25	21	35

Return Sand Moisture

Q1	Q2		Q3	Q4
Minimum		Median		Maximum
1.85	2	2.1	2.21	2.8

Q1: Optimal; Range: Bottom 25%, {>=1.85 & <=2}; Strength: 3.2; No. o

Q1 & Q2: Optimal; Range: Bottom 50%, [>=1.85 & <=2.1]; Strength: 2.4;

Q3 & Q4: Avoid; Range: Top 50%, [>2.1 & <=2.8]; Strength: 2.4; No. of In

Q4: Avoid; Range: Top 25%, {>=2.21 & <=2.8}; Strength: 2.7; No. of Inter

Penalty	Q1	Q2	Q3	Q4
80-100	2	8		13
60-80	1		1	3
40-60	4	1		
20-40	1	4	6	5
0-20	43	27	9	22

P

F1: P, Range:Bottom 25%,[>=0.112 & <=0.137]; Strength: 2.6

F2: Pouring Temp, Range:Bottom 50%,[>=1338 & <=1445]; Strength: 2.1

Strength of Optimal Interaction: 3.4

Penalty	F1:F2	F1:~F2	~F1:F2	~F1:~F2
80-100	1	1	8	13
60-80	0	2	0	3
40-60	0	2	3	0
20-40	1	0	5	10
0-20	24	8	34	35

The report has highlighted bottom 25% for the tolerance limit of the Return Sand Moisture as optimal. Lowering Pouring temperature to its bottom 50% range i.e. [>=1338 & <=1445] and reducing phosphorus content to bottom 25% i.e. [0.112 to 0.137] as identified in the interaction penalty matrix shown, is also considered in reducing the Shrinkage defect.

Using this analysis the foundry was able to quickly identify complex relationships and lower the number of defective castings produced. After the successful confirmation trial, a preventive action plan was developed and the case study stored as the evidence of continually improving the effectiveness of the ISO9001:2008 Quality Management System. For more information, visit us at www.7Epsilon.org.