Example 1 - Chemical Composition & Shrinkage (Nickel based super alloy)

This example shows the effective use of the p-matrix Data Visualizer 2013 software in deciding the optimal chemical composition to reduce Shrinkage defect in a Nickel based super alloy, while maintaining all components of the melt within the specifications allowed by the customer.

The Problem: This example explores the investigation of the effect of alloy composition in a Nickel based super alloy known to have variable castability, as Shrinkage defects are common.

When physics based simulation techniques are unable to justify the occurrence of Shrinkage defect, the solution could be held within the chemical composition of the alloy. This case study explores the effect composition of the melt has on the Shrinkage found in parts.

15 chemical components of the melt were identified for the analysis and are shown below:

Carbon	C	Cobalt	Co	Iron	Fe	Tantalum	Ta	Tungsten	W	Al + Ti
Aluminium	Al	Chromium	Cr	Molybdenum	Mo	Titanium	Ti	Nitrogen	N	Ta/Ti
Boron	B	Copper	Cu	Niobium	Nb	Zirconium	Zr	Oxygen	O_2	

A typical production data for a Ni based alloy with chemical factors and defect Shrinkage values were collected for 60 batches. Each row in the Figure below presents a batch.

Shrink Scrap (%)	Parts	Carbon	Aluminium	Boron	Cobalt	Chromium	Copper	Iron	Molybdenu	Niobium
0.12	SF01	0.101	3.23	0.009	7.857	15.2	<0.02 %	0.086	1.663	0.846
0	SF01	0.093	3.145	0.009	7.971	15.295	<0.02 %	0.086	1.644	0.798
0.15	SF01	0.107	3.249	0.009	7.781	15.248	<0.02 %	0.152	1.691	0.893

Although the range of each component was maintained within the specifications of the alloy, there is room for adjustments to be made. The objective of this study is clear:

Aim: To find out if the occurrence of Shrinkage defects can be minimized by altering any of the chemical components to the top, middle or bottom range specified for this alloy.

The Solution: By analysing the data using p-matrix Data Visualizer software, optimal and avoid ranges of chemical components in the melt 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 components in the melt or interactions between multiple component settings are linked to occurrence (or non-occurrence) of Shrinkage 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 Shrinkage: p-matrix software applies 0 penalty value to desired response (0% Shrinkage values), 100 penalty value to undesired response (when Shrinkage rate exceeds 3%) and linearly scales the remaining values from 1 to 99.

p-matrix Report: p-matrix discovered top 10-15 influential component settings in an ascending order of their correlation strength. Penalty matrices provided the evidence in the data to verify the findings. The strength and number of interactions between multiple component settings played an important role in choosing parameter settings for validation.

Confirmation Trial Plan: By observing penalty matrices for main effects the following confirmation trial plan for the 7Epsilon Quality Control meeting with optimal chemical component ranges was recommended. Component settings with low main effect strength (< 3) but one or more interactions are also chosen for the trial. Avoid settings of Cobalt and Chromium having multiple avoid interactions are converted to their complementary settings for validation.

Factor	Range	Values	Strength	No. of Interactions	Interacts with
Niobium	**Middle 50%**	**{>0.77& <0.827}**	**6**	**0**	
Carbon	**Top 50%**	**[>0.103& <=0.113]**	**3.3**	**0**	
Iron	**Top 50%**	**[>0.114 & <=0.2]**	**3.4**	**0**	
Aluminium	**Top 25%**	**{>=3.24 & <=3.306}**	**3.6**	**0**	
Zirconium	**Top 25%,**	**{>=0.032 & <=0.05}**	**3.5**	**0**	*Bottom 50% of Boron [>=0.007 & <0.009]*
Aluminium + Titanium	*Top 50%*	*[>6.356 & <=6.527]*	*2.5*	*1*	*Bottom 50% of Boron [>=0.007 & <0.009]*
Tungsten	*Top 50%*	*[>2.451 & <=2.594]*	*2.7*	*1*	*Bottom 50% of Boron [>=0.007 & <0.009]*
Cobalt	*Bottom 50%*	*[>7.714 & <7.847]*	*2.2*		
Chromium	*Top 50%*	*[>15.238 & <=15.428]*	*2.2*		
Boron	*Bottom 50%*	*[>=0.007 & <0.009]*	*2*	*5*	*Top 50% of Tungsten [>2.451 & <=2.594], Top 50% of Zirconium [>0.026 & <=0.05], Top 50% of Aluminium + Titanium [>6.356 & <=6.527],*
Nitrogen	*Top 50%*	*[>23.75 & <=38.95]*	*2*	*1*	*Top 50% of Aluminium [>3.183 & <=3.306]*

Conclusion: This example has demonstrated the true strength of p-matrix Data Visualizer software on a complex chemical problem. A robust tolerance design is achieved by reusing in-process data and studying patterns. The findings of this study give foundry experts guidance about the most likely causes and solutions for the shrinkage defect, in a format that can be easily implemented in the process.

For more information, visit us at www.7Epsilon.org or refer to the following article published in the ‘Computers in Industry’ peer reviewed journal.

Ransing et al. (2013), A coupled penalty matrix approach and principal component based co-linearity index technique to discover product specific foundry process knowledge from in-process data in order to reduce defects, Computers in Industry, accepted for publication. DOI: 10.1016/j.compind.2013.02.009

