Process Data Analytical Method for Comparative Assessment and Determination of Limits of Viability of Various Experimental Techniques Applied

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Abstract: Process data analysis has been carried out to comparatively assess and determine the limits of viability of various experimental techniques applied. The analytical method used; DIGREP analysis, shows that the adoption of any technique for application in materials processing depends on the quantity and quality of the output expected. DIGREP analysis shows that all techniques have specific limits at which each is most viable and the associated output best guaranteed. [New York Science Journal. 2010;3(4):28-32]. (ISSN: 1554-0200).

Keywords: Process Data Analysis, Comparative Assessment, Limits of Viability, Experimental Techniques.

1. Introduction

Experimental designs are particularly applied to the study of process variables and how these variables affect the yield or product. It has been found (Bernard, 2005) that for experiments involving many factors and levels; the number of tests with factorial method is excessive. For in instance with three factors at five levels only, the number of experiments with factorial method is 5^3 which equal 125 tests. From this number of experimental runs, the interactions between factors as well as row and column effects can be determined. Quite frequently in research, it is necessary to compare an average of a set of data to some hypothetical (true) value or the average of another set of data to determine whether the observed differences between them might be due to chance (Aghadi,2002). Under these circumstances, the criterion for ascertaining whether an observed difference is real is to determine how large a difference might be due to chance alone. If the observed difference is larger than can be reasonably expected by chance alone, then the difference is said to be statistically significant (Aghadi, 2002). In statistical analysis of process data, two types of distribution/test generally used are the Student Distribution (t-Test) and the Inverted Beta Distribution (F-Test) (Bernard, 2005). The t-Test is used to test the validity of one or two sets of sample data. For one set of data, it is used to determine the reliability of x as an estimate of μ in the relationship (Aghadi, 2002);

$$t = \left(\frac{x - \mu}{S/\sqrt{n}} \right) \quad (1)$$

Thus for the n observations with x and S, assuming μ is known, t is calculated as shown in the formula (Aghadi, 2002);

$$F = \left(\frac{S^2_1}{S^2} \right) \quad (2)$$

A very useful area of statistical analysis in engineering is the development of mathematical models to represent the experimental data. Models have been found to be tools for the theoretical and experimental analysis of processes.

It has been reported (Iwu, 1996) that model can be used for estimation, prediction, optimization and calibration of process data. The values of output process-parameters in most engineering processes could be estimated predicted or optimized providing the values of the input parameters are known. These models are mostly presented as empirical relationships between the constituent parameters.

Model for predictive analysis of the concentration of dissolved iron during leaching of iron oxide ore in sulphuric acid solution was derived by Nwoye et al.(2009a). The model expressed as;

$$\%Fe = 0.987(\mu/T) \quad (3)$$

was found to predict %Fe dissolved with high degree of precision being dependent on the values of the leaching temperature and weight of iron oxide ore added. It was observed that the validity of the model is rooted in the expression %Fe = N(μ/T) where both sides of the relationship are correspondingly approximately equal. The positive or negative deviation of each of the model-predicted values of %Fe (dissolved) from those of the experimental values was found to be less than 19% which is quite within the acceptable range of deviation limit for experimental results, hence depicting the usefulness of the model as a tool for predictive analysis of the dissolved iron during the process.

Model for predictive analysis of the quantity of water evaporated during the primary-stage processing of a bioceramic material sourced from kaolin has been derived by Nwoye et al. (2009b). The model;

$$\alpha = e^{(\ln t/2.1992)} \qquad (4)$$

shows that the quantity of water α, evaporated at 110^0C, during the drying process is also dependent on the drying time t, where the evaporating surface is constant. It was found that the validity of the model is rooted on the expression $(\ln t/\ln\alpha)^N = \text{Log}\beta$ where both sides of the expression are correspondingly approximately equal to 3. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value was found to be less than 22% which is quite within the acceptable deviation range of experimental results.

Nwoye et al. (2009c) derived a model for predictive analysis of hardness of the heat affected zone in aluminum weldment cooled in groundnut oil . The general model;

$$\beta = 0.5997\sqrt{(\gamma\alpha)} \qquad (5)$$

is dependent on the hardness of the heat affected zone (HAZ) in mild steel and cast iron weldments cooled in same media. Furthermore, re-arrangement of these models could be done to evaluate the HAZ hardness of mild steel or cast iron respectively as in the case of aluminum. The respective deviations of the model-predicted HAZ hardness values β, γ and α from the corresponding experimental values was less 0.02% indicating the reliability and validity of the model.

Models for comparative analysis, assessment and adoption of preferred experimental techniques have been derived (Nwoye et al. (2009). The models were used to analyze and assess data culled from the varied electrical properties associated with the various techniques applied for the casting of Pb-Sb-Cu alloys (designated for use in the manufacturing of battery head terminals and plates) with the view to adopting the ideal and preferred experimental technique. Technique A, involved simultaneous addition of Cu powder and pouring of the molten Pb-Sb into the mould, Technique B involved addition of Cu powder intermittently as pouring of Pb-Sb into the mould was going on while Technique C involved pouring a stirred mixture of heated Pb-Sb alloy and powdered Cu into the mould. The results of the analysis carried out using these models agree completely with past experimental report that Technique A (having permitted greater amount of current flow through the associated alloys) is the most ideal and preferred technique (amongst the other three techniques) for casting Pb-Sb-Cu alloys expected to have enhanced electrical propertiesThe aim of this work is to carry out a process data analysis for comparative assessment and determination of limits of viability of various experimental techniques applied in generating the data. Experimental data from past reports (Nwoye, 2000) will be used to run the analysis.

2. Methodology

The values from Techniques Z, N and K as listed in Tables 3 and 5 were obtained by subtracting for each row in Tables 1 and 2 respectively, the lower value from the one directly on its top. The subtraction process is carried out down each column as indicated by the arrows. Assuming Table 1 shows increase in the associated parameter `electric current` down the column for all techniques used, it follows that based on the mode of subtraction; the values as presented in Table 3 must all be negative showing increment down the columns.

Similarly, assuming Table 2 shows decrement in the associated parameter `electrical resistance` down the column for all techniques used, it invariably follows that based on the mode of subtraction; the values as presented in Table 5 must all be positive, showing decrement down the column as indicated by the arrow. The Row Identification Symbol (RIS) designated for the experimental data of Tables 1 and 2 are x_1, x_2, x_3, x_4, x_5, x_6, x_7 and x_8.

Mathematically, in evaluating increment, the smaller value is subtracted from the bigger value. However, in this analysis, the values below which are bigger were subtracted from the smaller (on top of it). In consideration of this factor, each of the increment Φ_i which is negative is multiplied by negative sign to get a real value. Since the analysis carried out using this method involves evaluating the difference (DI) followed by graphical representation (GREP) of these differences (as the dependent variable) against the percentage concentration of Cu added (which is the independent variable), for convenience method is referred to as DIGREP analysis. A DIGREP plot of corrected Φ_i values (from Φ_1 to Φ_7) for electric current flow and θ_i (from θ_1 to θ_7) for electrical resistance against %Cu added respectively (from RIS; $x_2 - x_8$) depicts the limits of viability of the various experimental techniques applied. Percentage Cu added was considered from RIS; $x_2 - x_8$ because x_2 is the first step to which the %Cu (added) was increased to.

Table 1: Comparison of data (for electric current flow) obtained by application of Techniques Z, N and K

Tech. Z	Tech. N	Tech. K	RIS
q_1	d_1	a_1	x_1
q_2	d_2	a_2	x_2
q_3	d_3	a_3	x_3
q_4	d_4	a_4	x_4
q_5	d_5	a_5	x_5
q_6	d_6	a_6	x_6
q_7	d_7	a_7	x_7
q_8	d_8	a_8	x_8

Table 2: Comparison of data (for electrical resistance) obtained by application of Techniques Z, N and K

Tech.Z	Tech. N	Tech. K	RIS
f_1	w_1	h_1	x_1
f_2	w_2	h_2	x_2
f_3	w_3	h_3	x_3
f_4	w_4	h_4	x_4
f_5	w_5	h_5	x_5
f_6	w_6	h_6	x_6
f_7	w_7	h_7	x_7
f_8	w_8	h_8	x_8

Table 3: Variation in increments of electric current (obtained from application of Techniques Z, N and K) down the column of Table 1

Φ_i	Tech. Z	Tech. N	Tech. K
Φ_1	$-e_1$	$-b_1$	$-k_1$
Φ_2	$-e_2$	$-b_2$	$-k_2$
Φ_3	$-e_3$	$-b_3$	$-k_3$
Φ_4	$-e_4$	$-b_4$	$-k_4$
Φ_5	$-e_5$	$-b_5$	$-k_5$
Φ_6	$-e_6$	$-b_6$	$-k_6$
Φ_7	$-e_7$	$-b_7$	$-k_7$

Table 4: Corrected increments of electric current from Table 3 (obtained from application of Techniques Z, N and K)

Φ_i	Tech. Z	Tech. N	Tech. K
Φ_1	e_1	b_1	k_1
Φ_2	e_2	b_2	k_2
Φ_3	e_3	b_3	k_3
Φ_4	e_4	b_4	k_4
Φ_5	e_5	b_5	k_5
Φ_6	e_6	b_6	k_6
Φ_7	e_7	b_7	k_7

Table 5: Variation in decrements of electrical resistance (obtained from application of Techniques Z, N and K) down the column of Table 2

θ_i	Tech. Z	Tech. N	Tech. K
θ_1	y_1	s_1	n_1
θ_2	y_2	s_2	n_2
θ_3	y_3	s_3	n_3
θ_4	y_4	s_4	n_4
θ_5	y_5	s_5	n_5
θ_6	y_6	s_6	n_6
θ_7	y_7	s_7	n_7

3. Validation of process data analytical method

This method of process data analysis was validated by using experimental data from past report (Nwoye, 2000). This was done by applying the values from the experiment (Nwoye, 2000) as presented in Tables 6 and 7 through the methodology earlier described. The results of this analysis regarding the limits of viability of the various experimental techniques used were then compared with the limits reported in the experiment (Nwoye, 2000).

Table 6: Effect of copper addition on electric current flow through the Pb-Sb-Cu alloy

% (Cu)	Tech. A	Tech. B	Tech. C
0.990	0.215	0.215	0.215
1.961	0.235	0.232	0.238
2.912	0.238	0.238	0.238
3.475	0.240	0.238	0.242
4.762	0.244	0.246	0.242
5.123	0.255	0.253	0.257
6.542	0.264	0.264	0.264
8.257	0.290	0.288	0.286

Table 7: Effect of copper addition on electrical resistance of the Pb-Sb-Cu alloy

%(Cu)	Tech. A	Tech. B	Tech. C
0.990	13.4884	13.4884	13.4884
1.961	12.3404	12.5000	12.1850
2.912	12.1849	12.1849	12.1849
3.475	12.0833	12.1849	11.9835
4.762	11.8852	11.7886	11.9835
5.123	11.4625	11.2840	11.3730
6.542	10.9848	10.9848	10.9848
8.257	10.0000	10.0694	10.1399

Source for Tables 6 and 7: Nwoye (2000)

4. Results and discussion

Results of evaluation of Tables 6 and 7 to assess any increments are shown in Tables 8-12. Tables 10 and 11 are the results of assessment of Table 8 which shows the result of current flowing through the alloys produced using Technique A, B and C. Table 12 is the result of evaluation of Table 9 which was assessed for any decrements.

Figure 1 shows that at 8.26 % Cu addition (to the Pb-Sb matrix to form Pb-Sb-Cu alloys), higher electric current was evaluated to have flowed through the alloys cast by Technique A (compared to Techniques B and C), implying higher drop in electrical resistance as in Figure 2. However, at 1.96, 3.48 and 5.12% Cu addition (to the Pb-Sb matrix to form Pb-Sb-Cu alloys), higher electric current was evaluated to have flowed through the alloys cast by Technique C (compared to Techniques A and B) invariably implying higher drop in electrical resistance as shown Figure 2. While at 2.91 and 4.76%Cu addition (to the Pb-Sb matrix to form Pb

Sb-Cu alloys), higher electric current was evaluated to have flowed through the alloys cast by Technique B (compared to Techniques A and C) also implying higher drop in electrical resistance (Figure 2). This DEGREP analysis agrees in Table 12 which is the result of the evaluative assessment of the experimental data presented in Table 7.

Table 8: Modified form of Table 1 showing symbols assigned to each row of values

%(Cu)	Tech. A	Tech. B	Tech.C	RIS
0.990	0.215	0.215	0.215	x_1
1.961	0.235	0.232	0.238	x_2
2.912	0.238	0.238	0.238	x_3
3.475	0.240	0.238	0.242	x_4
4.762	0.244	0.246	0.242	x_5
5.123	0.255	0.253	0.257	x_6
6.542	0.264	0.264	0.264	x_7
8.257	0.290	0.288	0.286	x_8

Table 9: Modified form of Table 2 showing symbols assigned to each row of values

%(Cu)	Tech. A	Tech. B	Tech. C	RIS
0.990	13.4884	13.4884	13.4884	x_1
1.961	12.3404	12.5000	12.1850	x_2
2.912	12.1849	12.1849	12.1849	x_3
3.475	12.0833	12.1849	11.9835	x_4
4.762	11.8852	11.7886	11.9835	x_5
5.123	11.4625	11.2840	11.3730	x_6
6.542	10.9848	10.9848	10.9848	x_7
8.257	10.0000	10.0694	10.1399	x_8

Table 10: Variation in increments of electric current (obtained from application of Techniques A, B and C) down the column of Table 1

Φ_i	Tech. A	Tech. B	Tech. C
Φ_1	-0.020	-0.017	-0.023
Φ_2	-0.003	-0.006	-0.000
Φ_3	-0.002	-0.000	-0.004
Φ_4	-0.004	-0.008	-0.000
Φ_5	-0.011	-0.007	-0.015
Φ_6	-0.009	-0.011	-0.007
Φ_7	-0.026	-0.024	-0.022

Table 11: Corrected increments of electric current from Table 5 (obtained from application of Techniques A, B and C)

Φ_i	Tech.A	Tech.B	Tech. C
Φ_1	0.020	0.017	0.023
Φ_2	0.003	0.006	0.000
Φ_3	0.002	0.000	0.004
Φ_4	0.004	0.008	0.000
Φ_5	0.011	0.007	0.015
Φ_6	0.009	0.011	0.007
Φ_7	0.026	0.024	0.022

Table 12: Variation in decrements of electrical resistance (obtained from application of Techniques A, B and C) down the column of Table 2

θ_i	Tech. A	Tech.B	Tech. C
θ_1	1.1480	0.9884	1.3034
θ_2	0.1555	0.3151	0.0001
θ_3	0.1016	0.0000	0.2014
θ_4	0.1981	0.3963	0.0000
θ_5	0.4227	0.5046	0.6105
θ_6	0.4777	0.2992	0.3882
θ_7	0.9848	0.9154	0.8449

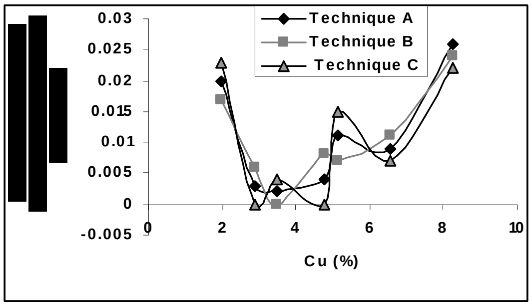

Figure 1 Comparison of the variation of increments in electric current with concentration of copper addition for Pb-Sb-Cu alloys cast using Techniques A, B and C.

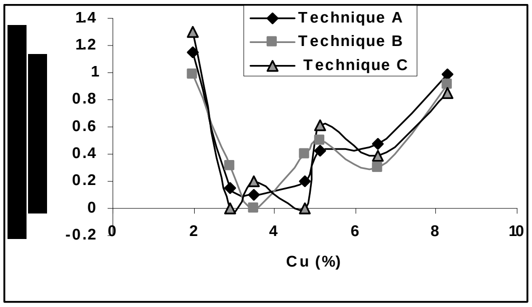

Figure 2 Comparison of the variation of decrements in electrical resistance with concentration of copper addition for Pb-Sb-Cu alloys cast using Techniques A, B and C.

Conclusion

Following DIGREP analysis of experimental results (Nwoye, 2000) associated with casting Pb-Sb-Cu alloys using Techniques A, B and C, the analytical method shows that the adoption of any technique for application in materials processing depends on the quantity and quality of the output expected. It was also found that all techniques have specific limits at which each is most viable and the associated output/yield best guaranteed.

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12/8/2009