COVERAGE RESPONSE MODELING FOR AUTO BASE PAINTS FORMULATION

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ABSTRACT
Response Surface Methodology (RSM) was used to investigate the effects of binder, solvent, and pigment concentrations on the coverage response. The optimum coverage response of the auto base paint formulated was $1.5m^2$. Statistical analysis of the results showed that the data were adequately fitted by a second-order polynomial model. Analysis of variance (ANOVA) also showed that the interactions between the independent parameters (binder, solvent, and pigment) have significant effects on the response (coverage). Diagnostics case statistics indicated that, the optimum experimental value of the cover age equal that of the predicted. This showed a good relationship between the actual and predicted response as evidenced in the R^2 value of 0.9204 and a standard deviation of 0.1 obtained.
Keywords: Auto base paint, Binder, Coverage, Pigment, Response Surface Methodology.

INTRODUCTION

Binder, solvent, pigment, and additives form the major components of auto base paint (Ali, 2005). The interactions of these components have effects on the application properties of paint such as drying time, coverage, abrasion resistance, and adhesion (Ali, 2005; Rodger, 2008).This makes them dependent on each other which in turn enhances the properties and performance of its product (Rodger, 2008). Binder being the main ingredient plays an important role which makes it the actual film-forming component (Nanvaee *et al.,* 2009). The common binders used in car paint formulation are polyurethane, epoxy, and alkyd resins. While the epoxy resin is only applicable for interior car top coat due to its tendency to fade and chalk when exposed to sunlight, polyurethane resin is known for its excellent chemical resistance and toughness which makes it a choice for some car paint formulators. However, alkyd resin is characterized for its lower volatile organic content (VOC) than polyurethane, good chemical resistance, excellent adhesion, fast-drying property, fairly inexpensive and its atitude of compatibility with organic solvent makes it a good choice in most industrial coatings (Nanvaee *et al.,* 2009). Alkyd resin comes in three forms; long oil, medium oil, and short oil alkyd resin. The medium oil alkyd resin identified as (45-60)% oil length is used in standard vehicle industrial coatings due to its ability to dry quickly under atmospheric conditions (Rodger, 2008;

Nanvaee *et al.,* 2009). The quality and application properties of paint formulation depend on the right proportioning of binder and other paint components (Nanvaee *et al.,*2009), however, no published work has stated their proportioning clearly in auto paint formulation and its effect on drying time. In 2006, Fatemi*et al.* carried out the optimization of water-based road-marking paint using a mixture method of experimental design in which abrasion resistance, hardness, and pigment volume concentration were the objective functions studied. Paint and adhesive cure in automotive application formulation were also modeled by Dickie*et al.* in 1997, using simplified kinetic, heat transfer and structure-performance models to gain a qualitative and directional understanding of the effects of material and process parameters on the cure of paints. Several other processes have also used experimental design most especially, the surface response methodology (RSM) "which is a dynamic tool in which set of statistical design of experiment (DOE) is used and capable of aiding the relationship between out put variables with process in put decision variables to accomplish the objective of maximization of the responses" (Montgomery, 2001; Bulent e*t al.,* 2003; Arunachalam and Annadurai, 2011; Galadima *et al.,* 2012; Uzoh*et al.,* 2013; Li*et al.,* 2014).

This method had been used in several processes due to its robust nature and its ability to investigate the effect of raw materials at different levels with experiments than a mixture, crossed, and factorial methods.

Fakhri (2014),optimized the process variables for fluoride ion removal with the aid of magnetite nano-particles using RSM. Keshani *et al.* (2010) also applied RSM in the optimization of the concentration process on pomelo fruit juice. The optimization of process conditions for tomato foam development was studied by Balasubramanian *et al.* (2012) using RSM. RSM was also used by Yamin *et al* (2013) to study lead ion removal from aqueous solution with the aid of intercalated tartrate-Mg-Al layered double hydroxides. Paint coverage as one of the important auto paint application properties has not been studied using RSM in any literature. This work, therefore, focused on the coverage response modeling for auto base paint formulation, using response surface methodology (RSM).

Experimental design

Central composite design (CCD) was employed to optimize the chosen key factors namely: binder (A), solvent (B), and pigment (C), with the coverage response. These variables each at two levels, low and high: A(10g–160g), B(10g–70g), and C(10g–30g) are presented in Table 1. These levels were chosen based on observation from the experimental trial combination of key factors selected. The data showed in Table 1 were used as input

commands that resulted in a total of 20 runs of the experiment presented in Table 2. The experimental design specifications were adhered strictly to in the laboratory, starting with run 1, compositions where 70g (90 ml) of mineral spirit (solvent) was measured with measuring cylinder and transferred into a mixing unit containing 0.71g of an anti-settling agent to keep the solution on suspension while on mixing process with out settling down.

As the mixing process continued, 30g of pigment-containing (70% of red (ii) oxide and 30% of titanium (iv) oxide) were added and mixed until a consistent product without lumps was achieved, after which the solution was bound with 160g of medium oil alkyd resin. After paint film formation was observed, 0.71g each cobalt dryer, anti-skinning agent, and preservative were added to enhance the quick-drying process after application, prevent the paint from sticking to its container and also preserve it from microorganisms attack respectively. The additives added were 1.5% of the total paint formulation of raw materials used.

This procedure was repeated for the 19 other experimental runs as scheduled in Table 2. Then, 2 ml of the paint formulated were sprayed on substrates to determine their coverage according to ASTM 4214 standard specification (ASTM, 2009). The results obtained were inputted as a response into the design tool as shown in Table 3 and ran for analysis of variance (ANOVA).

Table 1: Design of experiment summary

Factors	Name	Units	Low Actual	High Actual	Low Coded	High Coded
A	Binder	g	10	160	-1	1
B	Solvent	g	10	70	-1	1
C	Pigment	g	10	30	-1	1

Table 2: Variation of parameters from the experimental design

Run	A (g)	B (g)	C (g)	Coverage (m^2)
1	160.00	70.00	30.00	
2	10.00	10.00	10.00	
3	85.00	40.00	20.00	
4	10.00	10.00	30.00	
5	10.00	70.00	30.00	
6	41.13	40.00	20.00	
7	160.00	70.00	10.00	
8	85.00	40.00	03.18	
9	160.00	10.00	30.00	
10	85.00	40.00	20.00	
11	85.00	40.00	20.00	
12	85.00	40.00	36.82	
13	160.00	10.00	10.00	
14	10.00	70.00	10.00	
15	85.00	40.00	20.00	
16	85.00	40.00	20.00	
17	85.00	10.45	20.00	
18	85.00	40.00	20.00	
19	85.00	90.45	20.00	
20	211.13	40.00	20.00	

RESULTS AND DISCUSSION

The results of coverage response studied in this work form variable binder, solvent, andpigment composition are presented in column five of Table3.

Table 3: Coverage response of the formulated paint used for ANOVA analysis

Run	A (g)	B (g)	C (g)	Coverage (m^2)
1	160.00	70.00	30.00	1.1
2	10.00	10.00	10.00	1.1
3	85.00	40.00	20.00	0.7
4	10.00	10.00	30.00	0.1
5	10.00	70.00	30.00	0.2
6	41.13	40.00	20.00	0.24
7	160.00	70.00	10.00	1.3
8	85.00	40.00	3.18	1.5
9	160.00	10.00	30.00	0.4
10	85.00	40.00	20.00	0.6
11	85.00	40.00	20.00	0.6
12	85.00	40.00	36.82	0.4
13	160.00	10.00	10.00	1.4
14	10.00	70.00	10.00	0.1
15	85.00	40.00	20.00	0.5
16	85.00	40.00	20.00	0.6
17	85.00	-10.45	20.00	0.4
18	85.00	40.00	20.00	0.4
19	85.00	90.45	20.00	0.4
20	211.13	40	20.00	0.7

As observed from the table, run 8 has the optimum coverage of 1.5 m^2 from 40g (51 ml) of solvent that is responsible for the spread of the paint film on the substrate as compared to run 1 whose solvent is 70g (90 ml) or other runs with a higher quantity of solvent. This may be due to the right proportioning of the paint composition used (Ali, 2005), which enhanced significant effects among the factors varied (binder, solvent, and pigment) in this work. This shows that the optimum paint application properties are a function of the right composition of its raw materials during formulation.

The coverage result obtained was used to model coverage response for auto base paint as discussed in the next subsections.

Model developed

Equation 1 showed the coverage model developed for car paint formulation. The model was developed to predict the response from the combined variable parameters that can be related and compared with the experimental response studied. A, B, and C as shown in the equation represented binder, solvent, and pigment respectively.

$$
Coverage = \left(
\begin{array}{l}
1.68667 + 1.13239E - 033(A) - 0.012974(B) - 0.065304(C) \\
- 4.48614E - 006(A)^2 - 4.01470E - 005(B)^2 + 6.85707E \\
- 004(C)^2 + 5.41616E - 005(A)(B) - 6.75529E - 006(A)(C) \\
+ 5.51234E - 004(B)(C)
\end{array}
\right)^2
$$

...... 1

The model relates the response (coverage) with the variable parameters such as a binder, solvent, and pigment.

ANOVA analysis

Table 4 showed the analysis of variance for coverage response. In the RSM study, if the value of prob> F is less than 0.0500, the model studied is said to be significant (Bulent et al., 2003; Arunachalam and Annadurai, 2010; Galadima et al., 2012). As shown in Table 4, the prob>F-value of 0.0002 signifies a significant model. Thus, the model terms A,C,C^2, AB, and BC whose prob> F-value are less than 0.0500 are significant. The lack of fit as also shown in the table is not significant which is desirable in describing a good model. However, the model has a satisfactory level of adequacy whose standard deviation was 0.1 and had an R^2 value of 0.9204.

Table 4: Analysis of variance (ANOVA) to identify significant factors affecting the coverage response

Source	Sum of square	DF	Mean Square	F-Value	Prob> F	
Model	1.26	9	0.14	12.84	0.0002*	Significant
A	0.44	1	0.44	40.68	< 0.0001*	
B	3.816E-003	1	3.316E-003	0.35	0.5670	
C	0.37	1	0.37	33.74	0.0002*	
A^2	9.177E-003	1	9.177E-003	0.84	0.3802	
B^2	0.019	1	0.019	1.73	0.2180	
C^2	0.068	1	0.068	6.22	0.0317*	
AB	0.12	1	0.12	10.91	0.0080*	
AC	2.054E-004	1	2.054E-004	0.019	0.8935	
BC	0.22	1	0.22	20.10	0.0012*	
Residual	0.11	10	0.011			
Lack of Fit	0.084	5	0.017	3.36	0.1049	Not significant
Pure Error	0.025	5	4.996E-003			
Cor Total	1.37	19				

Values of "Prob> F" less than 0.0500 indicate model terms are significant.
Where A = binder, B = solvent and C = Pigment

Three-dimensional surface relationship curve

Figures 1a, 1b, and 1c show the relationship between the variable parameters (binder, solvent, and pigment) with their respective coverage response. Figure 1a shows the interaction of solvent and binder on the response, Figure 1b represented the variation of pigment and binder on the response while Figure 1c is the pigment and solvent interactions on the response.

As observed from Figure 1a, as the binder contents increase with a decrease in solvent contents, the coverage response increases, this is as evidenced from the coverage response of 1.1 m^2 from 160g of binder and 70g of solvent compositions as compared with 211.13g of binder and 40g of solvent compositions whose coverage response is 0.7 m^2. Also, as shown in Figure 1b, at 160g binder and 30g of pigment combinations amounted to 0.4 m^2 as compared to 1.3 m^2 coverage response with 160g binder and 10g of pigment combinations.

The same trend was observed in Figure1c.

Relationship between the predicted and actual response

Figure 2 shows the parity plot for the predicted and actual coverage relationships. The data points as shown in the figure were well distributed close to the regression line. This signified that the actual response agrees closely with the predicted response which shows that the model developed was significant and adequate to represent the actual relationship between input variables and output response.
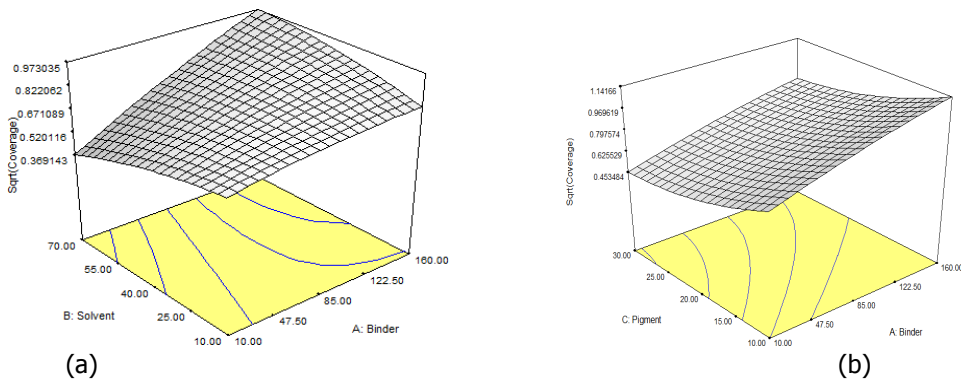

(a)
(b)

Figure 1: (a). Solvent-binder interaction on coverage response and (b) Pigment-binder interactions on coverage response.

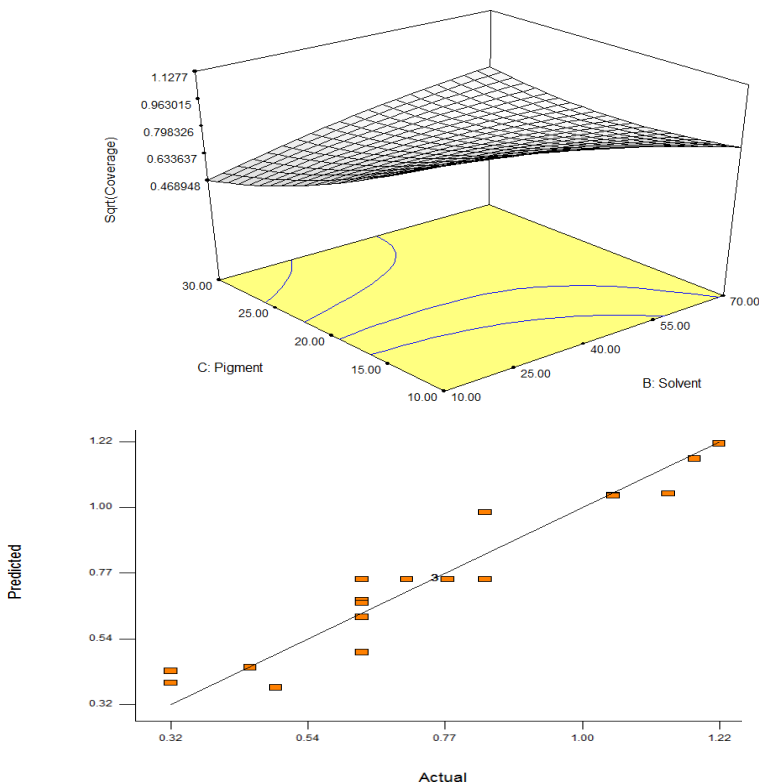Figure 1c. Pigment-solvent interaction on coverage response

Figure 2: Predicted and actual coverage response relationship

CONCLUSION

A model was developed for auto base paint coverage whose optimum value was $1.5m^2$ using response surface methodology. The model fits experimental data, owing to the interactions between the major parameters involved that were found to significantly influence the coverage response. The statistical parameters such as the R^2 value of 0.9204 and a standard deviation of 0.1 obtained from ANOVA suggested good reliability of the model.

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