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Application of 2^3 Factorial Design for the Production of a Standard Flex Coat Paint

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Abstract

A 2^3 factorial experimental design was used to produce standard flex coat paint. The factors considered were Calcium Carbonate, Titanium Dioxide, and Acrylic Resin among other raw materials using their minimum and maximum quantities. It was aimed at determining the specific gravity, viscosity and weight of the paint produced; the process involved eight pair of experimental runs. The results were analysed statistically using the factorial design approach giving rise to three mathematical models for the determination of specific gravity, viscosity and weight. The results were compared with standard values used in Eagle paint for flex coat paint and it was revealed that the third and seventh experiments proved to be the best.

Keywords

Flexcoat paint, specific gravity, viscosity, weight, calcium carbonate, titanium dioxide, acrylic resin and factorial design.

1.0 Introduction

Paint, a fluid suspension spread in thin coasts to decorate and protect.
surfaces, consists of pigment or colouring matter and the vehicle in which the pigment is suspended (Speight, 2002). The function of the vehicle is to form a tough film when applied to a surface and to bind the pigment to the surface. Paint may be applied to metal, wood, stone paper, leather, cloth or other surfaces (William, 1982).

The technique of using paints originated during stone age when hunters painted the walls of the caves they lived in with ground charcoal from their wood fibres and ground earths such as red, browns, and others. The most famous of such care painting are at Lascaux, in south central France

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and at Altamira in Northern Spain which dated from 30000 to 10000 B.C respectively. At this time, people of Africa, Oceania, and America used these paints too, to decorate their temples and dwellings. Since then, the technology has immensel5y developed and now we have categories of paint for various purposes (William, 1982).

Paints are generally classified into: gloss paint (oil paints), water based gloss paint, textured paint, flex coat paint and so on. It can be sub-classified based on nature of products, nature of binders, field of application, and based on specialized function (Turner, 1998).

The classification of paints based on the nature of products includes dry powders, pastes, and liquids. Dry powders and pastes mixed with one or several components liquid is a form of paint in which a liquid coating material containing a resin dries to a hard transparent film. This liquid coating material is called varnishes. Examples of this include lacquer which is a varnish that solidifies by evaporation of the solvent contained within it rather than by one of the more complicated process of film formation. Lacquer may be clear and tinted or opaque and coloured.

The classification based on nature of binders includes examples like: encaustic, tempera, oil based paints, polymers, arquella, and water based (emulsion) paint. An encaustic paint uses molten bee wax as a binder and have its colours fused together by heat. Encaustic paintings appear luminous like human skin, extraordinary durable, and does not darken or crack. Tempera paints are made of pigments bound with egg and thinned with water. Their colour is opaque and remains bright for a long time. Oil based paints are bound with linseed or walnut oil and thinned with turpentine. It is a remarkable versatile medium and can be applied in glazes-thin transparent layers of paints through which light passes to the ground and reflects back to produce rich and luminous colour. Polymer paint are bound by synthetic resin and when wet, they are soluble in water. They can initiate the characteristics of most other kinds of paints but their chief virtue seems to lie in their more vivid colour and resistance to fading in ultraviolet light (Meryers, 1992). Acquella paints use gum Arabic as its binder.

The classification based on field of application can be grouped into three namely: architectural, industrial, and commercial paints. The classification based on specialized functions includes primers, exterior coatings, interior wall paintings, floor paints, fire retardant paint, and aerosol paints (Gardner, 1962).

Paints have a wide range of constituents/raw materials which includes: resins (natural/synthetic), pigments/colourants, extenders/fillers, driers, emulsifiers, thickeners, plasticizers, biocides, antifoams, floating agents, ant skinning agents, thinners, diluents and others. In a more concise and precise form, paint is primarily compose of three main constituents and two minor components which include pigment, medium (binder), solvent (thinner) and, additives and extenders respectively (Geng, 2004 and Annonymous, 2006).

Most of the important properties of paints depend on the nature and extent of the bonding surfaces between the pigment particles and vehicles. These properties can be categorized under three main categories namely physical, mechanical, and chemical properties. The physical properties which relates to the physical nature of the paints includes: covering power or opacity, glossiness, colouring intensity, oil absorption, hydroscopicity, weathering resistance, dry time, and bulk density. The mechanical properties which in the ability of paint to withstand external action involving application of force includes: tensile strength, abrasive strength/hardness, brush stability, viscosity, dispensability, thermal capacity and resistance. Chemical properties which relate to the property of paints to resist the action of chemical properties, atmospheric gases e.t.c. includes: alkalinity and acidity of paints (pH), reaction with atmospheric oxygen, hygroscopicity, reaction with corrosive substances, and reaction with substances (William, 1982; Matthews, 2006 and Annonymous, 2006).

Factorial experiment involves simultaneously more than one factor each at two or more levels. If the number of levels of each factor in an experiment is the same, the experiment is called symmetrical factorial; otherwise, it is called asymmetrical factorial or sometimes mixed factorial. These experiments provide an opportunity to study not only individual effects of each factor but also their interactions. They have the further advantage of economizing experimental resources. Factorial experiments involve three main stages which include planning an experiment, running an experiment, and analyzing the results obtained (Das, 1979).

This study is aimed at helping in producing paint using factorial experimental design of improved quality compared to those produced in other part of the world. The paint being investigated is flex coat paint. Factors such as calcium carbonate ($CaCO_3$), titanium dioxide, and acrylic resin will be considered amidst the various factors (raw materials) that can be used for its production.

The standard values used in Eagle paint for Flex coat paint is given in Table 1.

The statistical analysis of the 2^3 factorial approaches was carried out guided by the following conditions (Douglas, 1991):

The condition of homogeneity of experimental result is given as follows:

if $G_{cal} < G[\alpha, (r-1), N]$ …….. 1

then, the experimental results are accepted otherwise, rejected.

Where $G[\alpha, (r-1), N] = G(0.05,1,8) = G_{table} = 0.76$

N = number of experimental run

r = number of replicates

α = level of significance

$G_{cal} = y^2 max / \sum_{u=1}^{n} y_u^2$ = maximum dispersion/sum of dispersion 2

The significance of coefficients is considered accepted if $t_{cal} > t[\alpha, (r-1), N]$ 3

Where (r-1) is the degree of freedom, $t[\alpha, N(r-1), N] = t(0.05,1,8) =$

$t_{table} = 2.306$

The calculated F-ratio of individual coefficients is accepted when compared with the F_{table} values if $F_{ratio} > F[\alpha, N(r-1), N]$ 4

Where $F[\alpha, N(r-1), N] = F(0.05,1,8) = F_{table} = 5.32$

The condition of adequacy is met if $F_{ad} \leq F[\alpha, r, N(r-1),]$ 5

Table 1. Standard Value Used In Eagle Paint For Flex Coat Paint

Factors	Standard values
Specific gravity	1.34
Viscosity	65
Weight	Depending on the quantity produced

2.0 Experimental

Table 2. Raw materials used for the production of flex coat paint

Items	Standard mixture	Amount used	
		Minimum value	Maximum value
Water	1kg	1kg	1kg
Titanium dioxide	1.5kg	0.5kg	1kg
Calcium	2.5kg	2kg	3kg
Carbonate	2kg	0.25kg	0.5kg
Acrylic resin	3kg	3kg	3kg
Marble dust	$9.86x10^{-6}m^3$	$9.86x10^{-6}m^3$	$9.86x10^{-6}m^3$
Acticide	$3.45x10^{-5}m^3$	$3.45x10^{-5}m^3$	$3.45x10^{-5}m^3$
Natrosol			

1kg of water was poured into $12x10^{-3}$ drum; 2.5kg of TiO_2 was added to the water followed by 2kg of $CacCO_3$. This mixture was thoroughly mixed after which 2kg of Acrylic resin and 3kg of marble dust were added. Then, $3.45x10^{-5}m^3$ of Natrosol was added allowed to mix thereby $3.45x10^{-5}m^3$ of Acticide was followed. This mixture gave $3.9x10^{-6}m^3$ of paint.

The essence of the production was to determine the followings: specific gravity, viscosity, and weight.
Determination of weight of a sample: A digital weighing balance (Ohaus, Japan) was used to weigh weight of empty container M_1, weight of container with the substance M_2 and the weight of the substance was obtained by subtracting weight of empty container from weight of the container with the substance (M_2-M_1).
Determination of specific gravity: A density bottle was used which has a ground stopper with a fine hole through it, so that when it is filled and the stopper inserted, the excess liquid rises through the hole and runs down the outside (Abbot, 1983).

Mass of empty bottle = M_1

Mass of bottle full of paint = M_2

Mass of bottle with water = M_3

Mass of paint = $M_1(M_2-M_1)$

Mass of water = $M_w(M_3-M_1)$

Relative density = specific gravity (numerically) = $\frac{Ml}{Mw}$

Viscosity: The viscosity of the paint was measured using a viscometer.

2.1 2^3 Factorial Design

This experiment involves the study of the effect of three variable namely:
Calcium Carbonate X_1, Titanium Dioxide X_2, and Acrylic Resin X_3 to give a 2^3 full factorial design. The design for 2^3 full factorial which indicates the run by run experimental design is shown in Table 3 with three variables, two levels of minimum (-) and maximum runs (+). The complete design leads to a total of 8 runs.

Table 3:2^3 Factorial Experimental Design

Run	X_0	X_1	X_2	X_3	1st run, Y_1	2nd run, Y_2	Mean, Y
1	+	-	-	-			
2	+	+	-	-			
3	+	-	+	-			
4	+	+	+	-			
5	+	-	-	+			
6	+	+	-	+			
7	+	-	+	+			
8	+	+	+	+			

3.0 Results and Discussions

Table 4 and 5 are that of the experimental and analytical results. The results of regression equations obtained from statistical analysis are presented below.

Table 4: Specific Gravity, Viscosity, and Weight of Flex cost paint

Run	X_1	X_2	X_3	Specific gravity			Viscosity			Weight		
				Ys_1	Ys_2	Yav	Yv_1	Yv_2	Yav	Yw_1	Yw_2	Yav
1	2	0.5	0.25	1.23	1.27	1.25	60.514	60.754	60.634	5.103	5.423	5.263
2	3	0.5	0.25	1.43	1.53	1.48	71.691	71.891	71.791	5.864	5.954	5.909
3	2	1	0.25	1.34	1.34	1.34	65.000	65.000	65.000	5.565	5.425	5.495
4	3	1	0.25	1.57	1.57	1.57	71.040	71.160	71.100	6.095	6.095	6.095
5	2	0.5	0.5	1.29	1.25	1.27	61.604	61.604	61.604	5.323	5.323	5.323
6	3	0.5	0.5	1.22	1.22	1.22	59.259	59.099	59.179	5.252	5.252	5.252
7	2	1	0.5	1.38	1.34	1.36	65.930	65.930	65.970	5.555	5.555	5.555
8	3	1	0.5	1.49	1.69	1.59	77.127	77.127	77.127	6.220	6.090	6.155

Where Yav is the average value of Yi_1 and Yi_2

Table 5. Analysis of specific gravity, viscosity and weight of flex coat paint

Test	Specific	viscosity	weight
Cochran test, G_{cal}	0.73	0.29	0.59
Significance test, t_{cal}	All value>2.306, Except t_3 = 1.712	All values>2.306	All values>2.306
Coefficients of Significance test, F_{ratio}	All values>5.32, Except F_3=2.9197	All values>2.306	All values>2.306
Fisher's criteria test, $F_{adequacy}$	3.68	0	0.0017

3.1 ***Regression equation results***

The fitted regression model for calculation of specific gravity for the production of flex coat paint using 2^3 factorial designs is:

$Y = 1.385 + 0.08x_1 + 0.08x_2 + 0.035x_1x_2 + 0.035x_1x_2x_3$......... 6

The fitted regression model for calculation of viscosity in the production of flex coat paint using 2^3 factorial designs is:

$Y = 66.4256 + 3.2486x_1 + 3.2486x_2 - 0.5806x_3 + 1.0656x_1x_2 + 2.3299x_2x_3 + 2.3299x_1x_2x_3$ 7

The fitted regression model for calculation of weight in the production of flex coat paint using 2^3 factorial designs is:

$Y = 5.6209 + 0.2119x_1 + 0.2075x_2 - 0.0696x_3 + 0.0881x_1x_2 - 0.0996x_1x_3 + 0.006x_2x_3 + 0.0996x_1x_2x_3$ 8

3.2 For determination of specific gravity

The G_{cal} was found to be 0.73 which is less than G_{table} therefore the experimental result was homogeneous.

The t_{cal} absolute values for the whole coefficients were greater than t_{table} except for t_3 which was found to be 1.712 and therefore was rejected from the proposed fitted model.

Comparing the calculated fitted F-ratio individually with the appropriate table value F_{table}= 5.32 reveals that all the coefficients were significant except F_3 calculated to be 2.9197.

Applying the fisher's criteria (F-test) to determine the condition of adequacy, the model equation satisfied the condition for acceptance as $F_{adequacy}$=3.68 was less than F_{table}= 4.46.

Equation 6 reveals that specific gravity of flex coat paint increases when more of calcium carbonate and titanium dioxide is introduced in the process separately or when added together. The system did not favour addition of both calcium carbonate and acrylic resin to the system since addition of the two substances resulted to decrease in specific gravity. The optimal condition of the system was when either calcium carbonate or titanium dioxide was added separately to give product with high specific gravity.

3.3 Determination of viscosity

The calculate cochran test (G) value was 0.29 which is less than G_{table} value, therefore the data is homogeneous.

In testing the statistical significance of the regression coefficients, the calculated absolute values (t_{cal}) were greater that t_{table}=2.306, therefore they were all accepted.
The comparison of the calculated F-ratio individually with the appropriate critical table value F_{table}=5.32 revealed that all the coefficients were significant since the F_{ratio} values were greater.
The application of fisher's criteria (F-test) to the regression model tended towards acceptability since the $F_{adequacy}$ was less than F_{table} value.

More of viscosity is gained when either calcium carbonate or titanium dioxide is added to the system separately, and the least of viscosity is realized when calcium carbonate mixed with either titanium dioxide or acrylic resin is added as revealed by equation 7. The interaction of either titanium dioxide with acrylic resin or calcium carbonate and acrylic resin gave similar effect. The equation also revealed that increase in viscosity was indirectly proportional to increase in acrylic resin.

3.4 Determination of weight

The G_{cal} calculated was 0.59 which was less than the G_{table}, therefore the data is homogeneous.
Statistical significance of the regression coefficients were tested and accepted as all the absolute value (t_{cal}) was greater than t_{table}.
The F_{ratio} values obtained individually compared with the appropriate critical table values F_{table}=5.32 reveals that all the coefficients are significant as they were all greater than the table value.
The fisher's criteria (F-test) carried out revealed adequacy of the fitted regression model as the $F_{adequacy}$=0.0017 which is less than F_{table}=4.46.

The increase in weight of the paint produced from equation 8 was due to the positive effect of addition of calcium carbonate and titanium dioxide separately; calcium carbonate with titanium dioxide; titanium dioxide with acrylic resin; and calcium carbonate with titanium dioxide and acrylic resin; with the separate addition of the former (calcium carbonate) giving the highest effect. The increase in addition of acrylic resin separately or with calcium carbonate gave rise to reduction of the weight of the paint produced.

Generally, Table 4 shows that after performing eight different experiments that is 2^3 factorial experiments, the values of the results were compared with the standard value as seen in Table 1. It was discovered that for specific gravity, viscosity, and weight, runs 3 and 7 were found suitable (Davies, 2002). This was done by varying three main raw materials used in the production of standard coat paint.

4.0 Conclusion

We can say from the research carried out to investigate the best process for flex coat paint produc with total absolute customer satisfaction using 2^3 factorial design approaches, the third and seve experiments proved to be the best.

5.0 Acknowledgement

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