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Research Article

Replacement of Polyurethane Resin with Castor Oil-Based Alkyd Resin in Gloss Paint Production

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Abstract

Polyurethane resins give an excellent paint film when cured. However, because of the unsteady and rising cost of polyfunctional di-isocyanate which is a chief component of polyurethanes, it is imperative that polyurethanes are replaced with other resins which are relatively cheaper while still maintaining the quality of the paint film. The quality of the film formed from the replacement of polyurethane resin with castor oil based alkyd resin was examined in this research. Pigment Volume Concentration concept of paint formulation was used to produce two samples (A and B) of 100 cm^3 of gloss paints containing 45%, and 5% of polyurethane resin combined with 55% and 95% of alkyd resin respectively, and these were compared with a paint produced with only polyurethane resin (sample C). They were subjected to drying time, chemical resistance, solubility test, adhesion test and weathering test. Results from these tests showed that sample B had the shortest drying time, 0% adhesion failure, excellent weathering, solubility and chemical resistance. Hence, castor oil based alkyd resins are excellent film formers like their polyurethane counterpart and as such can be used as their replacement.

Keywords: Polyurethane resin; Castor oil based alkyd resin; Pigment volume concentration; Total binder volume.

Introduction

Alkyd resins are polyester [1] polymer of fatty acids, derived from the poly condensation of a polybasic acid (e.g phthalic anhydride), and a polyhydric alcohol, modified with monobasic fatty acid, or its triglyceride oil [2,3]. One of the commonly used vegetable oils in alkyd resin production is castor oil. However, the most important use of castor oil is in the form of dehydrated castor oil [4]. Castor oil based alkyd (COBA) resins was synthesised by the monoglyceride method by [5].

On the other hand, polyurethanes (PU) are a special group of heterochain polymers characterized by the structural unit -(-0C0NH-R-NHC00-R'-)-$_n$. These days, PUs are one of the most versatile materials, with applications cutting across so many aspects of our lives [6]. PU films are known for its excellent hardness, gloss, flexibility, abrasion resistance and adhesion. Unlike COBA resins, PU is not sold as ready-made polymers but as precursors usually polyols and diisocyanates that are mixed at the conversion stage [7]. The most important synthesis of PU is the reaction between an isocyanate and a polyol [8], and this reaction is exothermic [9].

Moreso, isocyanates, a chief material for PU synthesis are made mainly from petroleum resources [10]. However, [11] stated that the fast rising rate of petrochemical prices have led to an increase in polymers made from partially renewable resources, and these resources have been given importance due to the concern of sustainability [12].

Vegetable oils are one of such renewable resources, and for many years, different kinds of vegetable and non-edible oils have been used in paint industry because they can dry quickly [13] and are relatively affordable to local paint manufacturers. Hence, the need for a progressive replacement of PU resins in paint production is inevitable to enable local manufacturers strive like their bigger counterparts due to the high cost

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of PU precursors. COBA resin was used in this research and its film qualities were tested.

Materials and methods

Materials used

Polyol, toluene diisocyanate (TDI), COBA resin, TiO_2, xylene, ethanol, methanol, methylene chloride (MC), 0.5M NaOH, 0.5M H_2SO_4 , 5% w/w NaCl. These were gotten from the Research and Development Laboratory of Exotic Foams and Chemical Limited, Nkpor, Anambra State.

Equipment used

MH 887 electronic digital scale, muller, reaction containers, beakers.

Formulation adopted

Pigment Volume Concentration (PVC) was used for this work. For a gloss paint, the PVC range is between 25% - 35%. However, the lower the PVC, the better its exterior durability [14] hence a PVC value of 25% was used.

Volume of Pigment (TiO_2)

A fixed mass of 500g was used. Density of TiO_2 is 4.23g/cm^3 [15]. Hence, volume of pigment (TiO_2) is 118.20cm^3. This volume was constant all through this work.

Total Binder Volume (TBV)

This is the total volume of COBA and PU resin in the paint sample. This was calculated from PVC. Using PVC as 25%

$$25\% = \frac{118.20\text{cm}^3 \times 100\%}{(118.20 + \text{TBV})\ \text{cm}^3}$$

TBV= 354.60 cm^3

For gloss paint having 55% COBA and 45% PU resin,

COBA resin= 55% × TBV = 55% × 354.60 = 195.03cm^3

PU resin= 45% × 354.60 = 159.57 cm^3. This procedure was repeated for 95% COBA with 5% PU resins. These values are presented on table 1.

Alkyd and PU resin weights

PU have a density of 1.140 g/cm^3 [16] while COBA resin have a specific gravity of 0.9299 [17]. The masses of PU and COBA resins were calculated using the formula; mass = volume × density. These values are shown on table 1.

Table 1. Volumes of COBA and PU resins and their corresponding masses

Percentage (%)	Volume (cm^3)	Mass (g)
55% COBA	195.03	181.36
95% COBA	336.87	313.26
45% PU	159.57	181.91
5% PU	17.73	20.21
100 PU	354.60	404.24

Polyol and TDI masses

Polyol and TDI were combined in the ratio 2:1. For 181.91 g of PU, mass of polyol= 2/3 × 181.91 =121.27 g, while that of TDI= 1/3 × 181.91 = 60.64 g. This procedure was repeated for 20.21 and 404.24 g of PU, and the values are shown on table 2.

Table 2. Weight of Polyol and TDI

PU (g)	Polyol (g)	TDI (g)
181.91	121.27	60.64
20.21	13.47	6.74
404.24	269.49	134.75

Production of Gloss film

55% (181.36 g) of COBA resin and 45% (181.91 g) of PU resin were poured into a reaction container and mixed with the aid of a muller until a single blend was formed. 100 cm^3 of xylene was added to the mixture while stirring. 500 g of TiO_2 was added and stirred thoroughly to ensure it dissolved properly. This was poured into a beaker labeled A. The above procedure was repeated for 95% (313.26 g) COBA resin and 5% (20.21 g) of PU resin, and was labeled B. A third sample labeled C was prepared by using 100% PU resin only (404.24 g).

Film analyses

Drying time

5 g of each sample were casted evenly on the surface of a 2cm × 2cm steel metal sheet which had been cleaned with methylene chloride. These samples were left to dry for 72 hours and the time it took for the samples to dry was noted.

Chemical resistance

100 cm^3 of 0.5M NaOH, 0.5M H_2SO_4 , 5% w/w NaCl, and distilled water were poured in different beakers and 5 g of each dried sample were dissolved separately in each of these

solvents and left for 18 hr. These samples were removed, air dried for 2 hr and compared with dried samples that were not immersed.

Solubility test

5 g of each sample were casted on a 2 cm × 2 cm steel metal and left to dry completely for 72 hours. These were dissolved in 100 cm^3 of ethanol, methanol, and methylene chloride separately and left to stand for 18 hr. These samples were removed, air dried for 7 hr and their paint films observed.

Adhesion test

The Cross Hatch Adhesion Test was adopted. 5 g of each sample were casted on the surface of a steel metal and left to dry for 72 hr. In a space of about 2 square inches, parallel lines were drawn on the surface of the samples and another series of line were drawn perpendicular across the first lines. Masking tape was firmly placed over the section for 90 seconds and then pulled off at a consistent speed at an angle of 45^0.

Weathering Test

5 g of each sample were casted evenly on the surface of a steel metal and exposed to sunlight for 8 hr to dry. These samples were later retrieved and the physical appearances of the films were noted. They were then kept outside for 24 and 72 hr and their film appearances were checked.

Results and discussion

Sample B had the shortest drying time of 15 hr while samples A and C took 23 hr and 17 hr respectively to dry completely. It was observed that B had a drying time closer to C than A. This can be attributed to the fact that B had more COBA resin in its formulation than A. This supports the reports that non edible oils are used in paint industry because they can dry quickly [13]. More so, COBA resin can be used as substitute for linseed and soybean oil because of its quick drying time [15] as its drying time is one property that is very critical to its application as binders in paint [18].

Table 3 shows the percentage adhesion failure of each sample. A high percentage failure signifies that the film sample has poor adhesion property and vice versa. The results on table 3 showed that COBA resin have excellent adhesion property like their PU counterparts as samples B and C have the same value of percentage failure (0%). The high value of percentage failure recorded in A can be attributed to the fact that A have a lower percentage of COBA resin when compared with B. This further goes to prove that using only COBA resin is a perfect replacement for PU resins in gloss paint production. This supports the report that castor oil has a high degree of flexibility and adhesion in protective coatings [17]. Also, for a good paint, the coating must have excellent adhesion [20] and this have be proven in sample B. The percentage adhesion failure was calculated using the eq. (1) [19].

$$\% \text{ adhesion failure} = \frac{\text{Number of flaked square}}{\text{Total number of square}} \times 100\% \quad (1)$$

Table 3. Percentage adhesion failure of each sample

Sample	flaked squares	Total squares	% failure
A	7	36	19.44
B	0	36	0
C	0	36	0

In table 4, the chemical resistance of each of the sample is presented as a function of its physical appearance after being immersed in various media. A, B and C were not affected by acid, water and salt solution. While C was not attacked by NaOH because it contained only PU resins, A and B were attacked. This is because PUs are resistant to acids and alkalis [21]. It is important to note that the extent of the attack in B was reduced as compared with A. This is because of the high percentage of COBA resin in B. This supports the findings that the poor resistance to alkali medium by castor oil modified resin is mainly due to the presence of alkali hydrolysable ester groups in the alkyd resin [22]. More so, these results still conforms to the fact that COBA resin have high chemical resistance [4].

In table 5, the solubility resistance of each sample was recorded. The table 5 shows that B has an excellent solubility resistance as compared with A and C. While methanol and ethanol had no effect on C, methylene chloride caused the peeling of C. This shows that PU resin can be attacked by chlorinated solvents [21]. The film of sample A also peeled off after being immersed in methylene chloride and this is

because of its high PU resin content as against the low PU resin content in B. Hence, dried paint films of COBA resins are not easily affected by methanol, ethanol or methylene chloride, and as such are excellent for outdoor applications [23].

Table 4. Chemical resistance of A, B and C in various media

Sample	Medium	Appearance
A	0.5M NaOH	Removal
	0.5M H_2SO_4	No effect
	Distilled H_2O	No effect
	5% w/w NaCl	No effect
B	0.5M NaOH	Peeling
	0.5M H_2SO_4	No effect
	Distilled H_2O	No effect
	5% w/w NaCl	No effect
C	0.5M NaOH	No effect
	0.5M H_2SO_4	No effect
	Distilled H_2O	No effect
	5% w/w NaCl	No effect

Table 5. Solubility resistance of samples A, B and C

Sample	Solvent	Effect on film
A	Methanol	Film becomes plastic and peels off
	Ethanol	Peeling
	MC	Peeling
B	Methanol	No effect
	Ethanol	No effect
	MC	No effect
C	Methanol	No effect
	Ethanol	No effect
	MC	Peeling

In table 6, the results of the weathering test are presented as a function of the physical appearances of the samples. Unlike sample B, C turned yellow after 72 hr. This is as a result of the presence of an aromatic diisocyanate (toluene diisocyanate) in the PU resin. Hence PU resins are not advisable for applications to surfaces that are prone to sunlight exposure. This is because visible light can affect the variation of some physical properties of PU made with aromatic isocyanates as they contain chromophores [24]. The colour retention observed in B is higher than that observed in A and this is as a result of the high percentage of COBA resin in B. This is because COBA resin is known for its non-yellowing film and outstanding colour retention [17].

Table 6. Results of weathering test on A, B and C

Sample	Time (hours)	Film Appearance
A	18	No effect
	24	No effect
	72	Mild Yellow
B	18	No effect
	24	No effect
	72	No effect
C	18	No effect
	24	Mild Yellow
	72	Yellow

Conclusions

The present study has shown that COBA resins can without doubt be suitably used in place of PU resins for gloss paint production and will still give the required film stability that PU resins offer. This is a huge plus to local and small scale paint manufacturers as they can also produce gloss paint with outstanding and excellent film qualities like their big scale counterparts who use PU resins. In addition, COBA resins are relatively affordable and readily available in this part of the world.

Conflicts of interest

The authors declare no conflict of interest.

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