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Study of High-performance Coating System for Automotive Application

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ABSTRACT

Today, automotive coatings are considered as an important market and play a major role in automobile industries. The objective of this study is to make it simple and clear, and the majority of them not tried to compare with different binder/resin system. Hence, this project studies standard film-forming resins (alkyd, epoxy, and PUs) to compile and compare the processing ability and properties of different binder systems and its outcome to have a single solvent-borne coating system with majority of properties required for an automotive coating system. Based on the outcome results of solvent-borne system, further studies continue to waterborne coating system, where waterborne system overcomes the major environmental issue such as VOCs released by solvent borne. Experimental part majorly involves both short- and long-term properties such as wet paint properties (consistency, transparency, storage stability, floating, and viscosity), dry film properties (gloss and Haze), and system properties (accelerated weathering conditions WOM, QCT, corrosion test, hardness test, stone chipping, and adhesion).

Key words: *Alkyd coatings, Epoxy coatings, Polyurethane coatings, Eco-friendly coatings, Automotive coatings and accelerated weathering.*

1. INTRODUCTION

The car painting industry has undergone incredible changes by way of materials and processes development, early coating steps were executed manually which needed weeks for completion. Introduction of mass production requiring faster curing paints, better film performance in terms of corrosion and durability of colors, improved environmental compatibility, and fully automated. Refinishing material chemistry has changed drastically, so with longer shelf life of refinishing materials is developed which require more skill and safety measures for proper application [1]. Basic ingredients of paints are binder, pigment, solvent, and additives; binder is made of a natural resin, drying oils, or a polymer. It is a backbone or film-former polymer that acts as the adhesive component for bonding to the surface helps the color to stick to the surface and in a colorant that holds the pigment particles together [2,3]. The pigments are fine powders that impart color, opacity, durability, hiding, and other characteristics to the paint. The solvent/reducer is the liquid solution that carries the pigment and binder so that it can be sprayed [4].

Additives are ingredients added to modify the performance and characteristics of the paint, which have a wide variety of miscellaneous properties [5]. Basic layers of coating system are primer, base coat, and clear coat; primer is the first coat followed with base coat that contains the visual properties of color and effects. Clear coats are usually sprayed on top of colored base coats, and clear coat is a glossy and transparent coating that forms the final interface with the environment.

2. EXPERIMENTAL

2.1. Alkyd Resin

Key performance features include their ability to offer improved surface wetting and lower cost. Trade name is ETERKYD 3306-X-70 with extremely light color resin and non-drying, short-coconut oil alkyd resin solution designed for color retention [6].

2.2. Epoxy Resin

Solid epoxy resin produced from bisphenol A and epichlorohydrin, trade name is EPIKOTE™ Resin 1001-X-75, and it is available as a 75% solids solution in xylene [7].

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2.3. Polyurethane Resin
Low viscosity polyester polyol - 2P128. Isocyanate group can also undergo self-condensation [8].

2.4. Pigment
Irgazin Red L 3660 HD - PR 254, chemical name is diketo-pyrrolo-pyrrole. It is compatible with water and non-aqueous solvent with density 1.63 g/cc.

2.5. Process and Procedure
This project is for the study and research purpose, and the dispersion is done using Vibro shaker. Based on the formulation, prepare the dispersion and mix thoroughly for 90 min, add the let-down part for the above dispersion, and mix to get homogenous mixture and that will be the obtained paint toner. Hardener should be added to each paint sample before thinning to spraying viscosity, and later, each paint sample is sprayed with a RX20 spraying robot (Table 1).

3. RESULTS AND DISCUSSION
3.1. Dispersion/Wet Paint Properties
The measured fineness of grind by Hegman Gauge shows all the three samples achieved the gauge <10 µm, and total solid content (TSC) of these samples is not much difference between each of them as noted alkyd (64.32), epoxy (64.41), and PU (64.15).

3.2. Particle Size Analysis
Testing has been carried out immediately after the completion of mixing, where alkyd and PU achieved 2.82 µm and 4.76 µm, respectively. However, epoxy gave more than 10 µm (28.2 µm) took two more cycles of mixing to achieve gauge of <10 µm.

Table 1: Formulation of solvent-borne systems.

Material	Percentage
Dispersion part	
Resin	21.66
Pigment	6.5
Wetting and dispersion agent (high-MW block copolymer)	10.83
Solvent (butyl acetate)	17.69
Cosolvent	7.22
Let-down part	
Resin	28.16
Reactor/activator	3.25
UV stabilizer	0.81
Dibutyltin dilaurate (DBTDL) - catalyst	1.17
Flow and leveling additive	2.35
Solvent (butyl acetate)	0.36
Dispersion + let down	100%

Flow time studies by the use of flow cups for Newtonian fluids, the viscosity could be measured with simple instruments. Viscous nature of epoxy (43.5s) is showing high as compared to PU (28.32s) and alkyd (35.75s) dispersions, so epoxy requires more thinner to achieve spray viscosity.

3.3. Dry Film Properties
Dry film thickness (DFT) measuring method is based on magnetic induction method; all the three samples obtain DFT ranges from 65 µm to 75 µm. The initial gloss readings have been taken and it showing comparatively high gloss with epoxy film as shown in Figure 1.

Cupping test method specifies an empirical test procedure for assessing the resistance of a coating system on a metal substrate to cracking and/or detachment from a metal substrate when subjected to gradual deformation. The cupping test results of alkyd, epoxy, and PU coatings are 12.1, 12.2, and 13.5 mm, respectively, which indicates that PU coating last long as compared to epoxy and alkyd which shows the elasticity of PU film is good.

Impact test describes a method for evaluating the resistance of a dry film to cracking or peeling from a substrate when it is subjected to a rapid deformation caused by a falling weight. Obtained results show that epoxy and PU withstand crack, but alkyd cracked 0.75 and 1.2 mm at 75 and 100 cm, respectively, for the load of 1000 g.

3.4. System Properties
Crosscut adhesion test mainly gives the adhesion failure depends on the nature and compatibility between the substrate and the consecutive layers of coating, the results obtained shows that the alkyd coating fails to hold the adhesion leads to loss of 65% of its coated area, where epoxy and PU stand good in its adhesion properties (Figure 2).

Water immersion test mainly determines the resistance of a coating system to the effects of water by immersion,

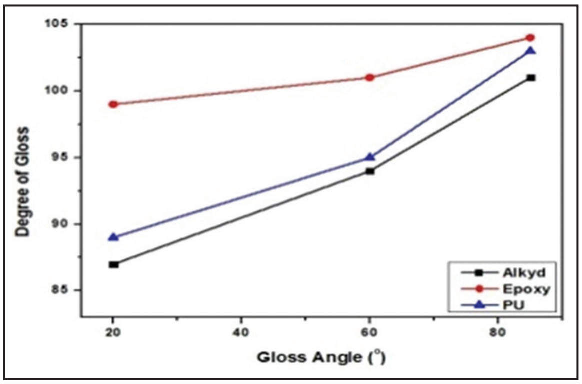

Figure 1: Initial gloss values as a function of angle, for alkyd, epoxy, and PU films.

and the failure depends on the nature and reactivity toward the water by exposed coated area. The samples will be immersed for 250 h, after 1 h check, and the adhesion and presence of blister and same analysis will be repeated after 24 h for any recoveries. Poor resistance to water leads to water penetration causing adhesion failure in alkyd coating, resulting nearly 95% loss of layer as shown in Figure 3a. The attractive forces between the solid surfaces of the epoxy and PU are greater than the attractive forces between the surface and the water, which helps the coated layer to show better water resistance, as shown in Figure 3b and c.

Cyclic corrosion test: This method determines the corrosion resistance of a coating system on a substrate by cycle of salt spray, condensation, and dry environment. The obtained results show that all three coatings have good resistance to cyclic corrosion, but observation shows PU and epoxy coating have little better corrosion and delamination resistance compared to alkyd (Table 2).

Conical bending: This method describes the measurement of the resistance to cracking when subjected to bending around a conical mandrel. All the three samples are bent around a conical mandrel, but only little crack of 1 mm was observed at epoxy-coated sample and no cracks were observed at alkyd and PU coating system.

Stone chipping: In this method, the resistance of dry paint systems to stone chipping is determined by the impact of chilled iron grit, the coated panels are grit blasted twice on the same spot, this test results in a loss of adhesion in the alkyd system rated 3.5 with 29% affected area, coated layers and the interface paint metal substrate were good with epoxy and PU rated 1 with 1% affected area.

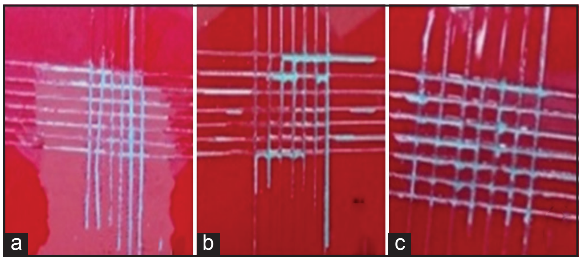

Figure 2: Results of crosscut adhesion of the coatings (a) alkyd, (b) epoxy, and (c) PU

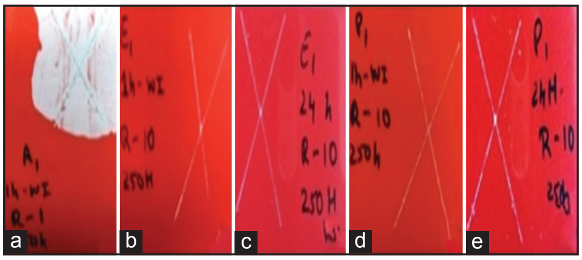

Figure 3: Digital images of water immersed (a) alkyd, (b) epoxy, and (c) PU coatings.

Car wash resistance: This method is to determine the coating resistance against damage as a result of car wash. A brush turns 10 min with 300 rpm while the hairs of the brush sweep over the test panel. A wash fluid is added to simulate dust and sand, and the determined gloss loss after brushing is a measure of the scratch resistance. There was a gradual decrease of 8% in alkyd and PU film coatings, but in epoxy system, gloss lost up to 45% which shows leaching of color (Figure 4).

Accelerated condition - weather O Meter: This method is used to create accelerated weathering. Moisture and temperature are major factors in the degradation of products exposed outdoors. Results show that epoxy lost its 85% of gloss for 250 h and almost 98% for 1000 h (Figure 5). Topcoat alkyd showed good resistance to weathering and PU stood well but gradual decrease of gloss up to 8%.

Resistance to humidity, continuous condensation - QCT: This method is for determining the resistance of paint films to conditions of high humidity, as results obtained show that epoxy

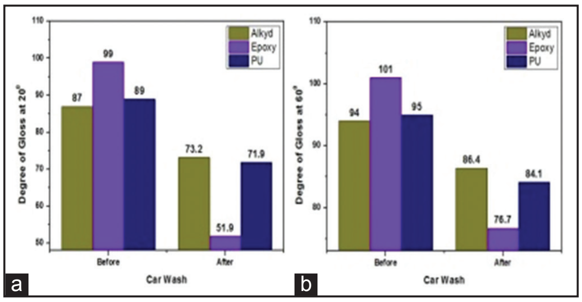

Figure 4: (a and b) Effect of wash on gloss values.

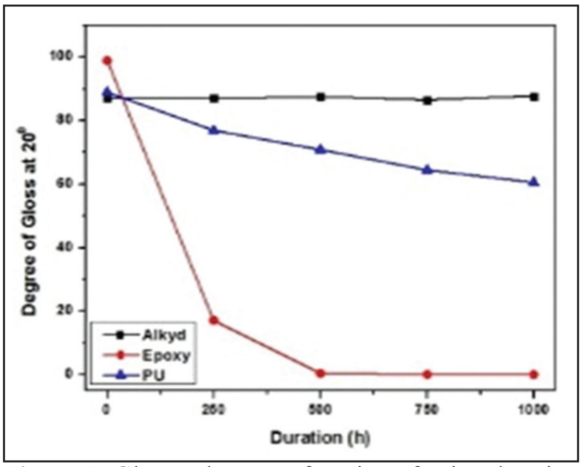

Figure 5: Gloss values as a function of aging duration of coating films in WOM.

Figure 6: Adhesion test images of (a) alkyd, (b) epoxy, and (c) PU coating systems.

coating exhibits superior adhesion and alkyd lost completely at 500 h as shown in Figure 6a and b, and PU stands good but showed 25% loss of adhesion immediately after an hour of removal for the chamber, but results after 24 h drying showed complete recovery as shown in Figure 6c. There were too fine blisters observed in all the three systems which rated as 8F during 500 h but not observed at 1000 h. The blisters identified at 500 h were recovered by drying at room temperature for an hour.

3.5. Summary of Solvent-borne Coating Systems

For epoxy and PU coatings, properties are almost similar, but due to the failure of epoxy coating system in accelerated conditions and also leaching out color in wash resistance, it is not advisable to use epoxy as a topcoat system. Even though alkyd has passed WOM, it is failed to be used as a topcoat system because of its poor water resistance and poor adhesion properties which cause blistering and corrosion. By analysis of results obtained, it may recommend that PU system is good to be used as high-performance topcoat binder system for automotive application and epoxy as a primer or the layer beneath the topcoat layer because of its good adhesion and good corrosion resistance. Many countries are adopting new rules, regulating the use of VOCs in spray paint, as a new generation system, the WB system can overcome the major environmental issues.

3.6. Waterborne Coating System

Ready-to-use conventional base coats have a VOC solvent content of around 84% (and 16% solids), whereas a typical waterborne base coat is composed of about 70% water, 20% solid, and 10% cosolvent. The traditional solvent-borne PUs have long set standard for high-performance coatings. Under the twin demands for high-performance coatings and more environmentally favorable alternatives, the development of WPU technologies has offered new solutions to the coatings formulators. Aqueous PU dispersion is a colloidal system in which particles of PU are dispersed in a continuous water phase.

Table 2: Corrosion and delamination data by cyclic corrosion test of the paints.

Sample	Corrosion penetration (mm)	Delamination (mm)
Alkyd	1-5	2-6
Epoxy	1-2	2-5
PU	1-3	2-4

Table 3: Comparison of results obtained for solvent-borne and waterborne coating systems.

Test methods	Solvent borne	Waterborne
Fineness of grind	<10 µm	<10 µm
Solid content	64.15 g	55.24 g
Gloss measurement	89	80
Cupping test	13.5 mm	12.8 mm
Pendulum damping	26 osc	24 osc
Crosscut test	4B (5% area loss)	4B
Water immersion	10	9
Blisters	-	-
Cyclic corrosion	1-6 mm	1-8 mm
Weathering - WOM at gloss 20°	71 at 500 h 61 at 1000 h	80 at 500 h 64 at 1000 h
Condensation - QCT	10	10

3.7. Procedure and Formulation of Waterborne Coatings

Dispersion is prepared in glass bottle using zirconium beads for 4 cycles with a regular cooling interval of 15 min. As it is for laboratory scale, dispersion is prepared by Vibro shaker as used in solvent-borne dispersion.

The obtained results for waterborne coatings are narrated in Table 3, which indicates the difference in the properties between the solvent-borne PU system and WPU system for automotive application. Results of WPU are almost nearer to the solvent-borne PU system to give maximum properties required for the automobile industries. By the results of WOM, QCT, and corrosion resistance, WPU coating system satisfies the requirement to be used as a topcoat coating system.

4. CONCLUSION

As evident from the results obtained, all the three binder dispersions achieved the particle size of less than 10 µm and TSC of respective dispersion are nearly same (alkyd - 64.32, epoxy - 64.41, and PU - 64.15). The study shows that alkyd coating resists color and other properties like dispersion and weathering but mainly failed at crosscut adhesion (65% loss), continuous condensation adhesion, water immersion (95% loss), and stone-chipping resistance with 29% affected area, which cause blistering and corrosion leads to failure of coating. Hence, alkyd coating may be used for decorative paints such as trim paint, wood care, wall paint, and metal care products. Epoxy and PU coating system properties are almost similar, but due to the failure of epoxy coating system in accelerated weathering conditions such as WOM and also leaching out of color in car wash, it is not advisable to use epoxy system as a topcoat system. Hence, epoxy-based coatings can be preferred for cathodic electrodeposition of automotive primers, marine, industrial maintenance coatings, and interior coatings of metal container. From the results, it is noticed that PU system is good to be used as high-performance topcoat binder system for automotive application and epoxy as a primer or the layer beneath the topcoat layer because of its good adhesion and good corrosion resistance. This further study continues to eco-friendly coatings which compares solvent-borne and waterborne coating system. As per the results, WPU coating system is neither inferior nor superior but comparably at par to the solvent-based PU coating system. By the WOM, QCT, and corrosion resistance results, WPU coating satisfies the requirement to be used as a topcoat coating system. Hence, the reduction in solvent use has benefits such as better for the environment as less toxic paint is important, elevated concentrations can persist in the air long after painting or repainting is completed. Waterborne paint reduces the emission of VOCs, improving air quality, and reduces the health risk. New and improved products as transition to waterborne paint have prompted paint companies to develop new products. Additional advantage of PU system is the biodegradation. Two species of the Ecuadorian fungus pestalotiopsis are capable of biodegrading PU in aerobic and anaerobic conditions.

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