

Study of Ketonic Aldehyde (KAR) and Chlorinated Polyolefin (CPO) Resin System for Conductive Primers on Various Polymeric Substrates

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Abstract

The increasing demand for advanced coatings on plastic substrates, particularly in the automotive, electronics, and consumer goods industries, has driven the evolution of conductive pigments in paint systems. This research explores the progressive development of conductive pigments integrated with advanced resin systems, focusing on the synergy between ketonic aldehyde resins and chlorinated polyolefins (CPOs). These resins play a pivotal role in improving adhesion, mechanical strength, and overall conductivity of paint films applied to non-conductive plastic surfaces. Plastics such as polypropylene (PP), acrylonitrile butadiene styrene (ABS), and polyethylene (PE) present significant challenges due to their inert and low-surface-energy nature. To overcome these limitations, the combination of ketonic aldehyde resins—offering superior cross-linking capabilities—and CPOs—known for their high affinity toward polyolefin surfaces—has been engineered to optimize pigment dispersion and improve electrostatic charge acceptance.

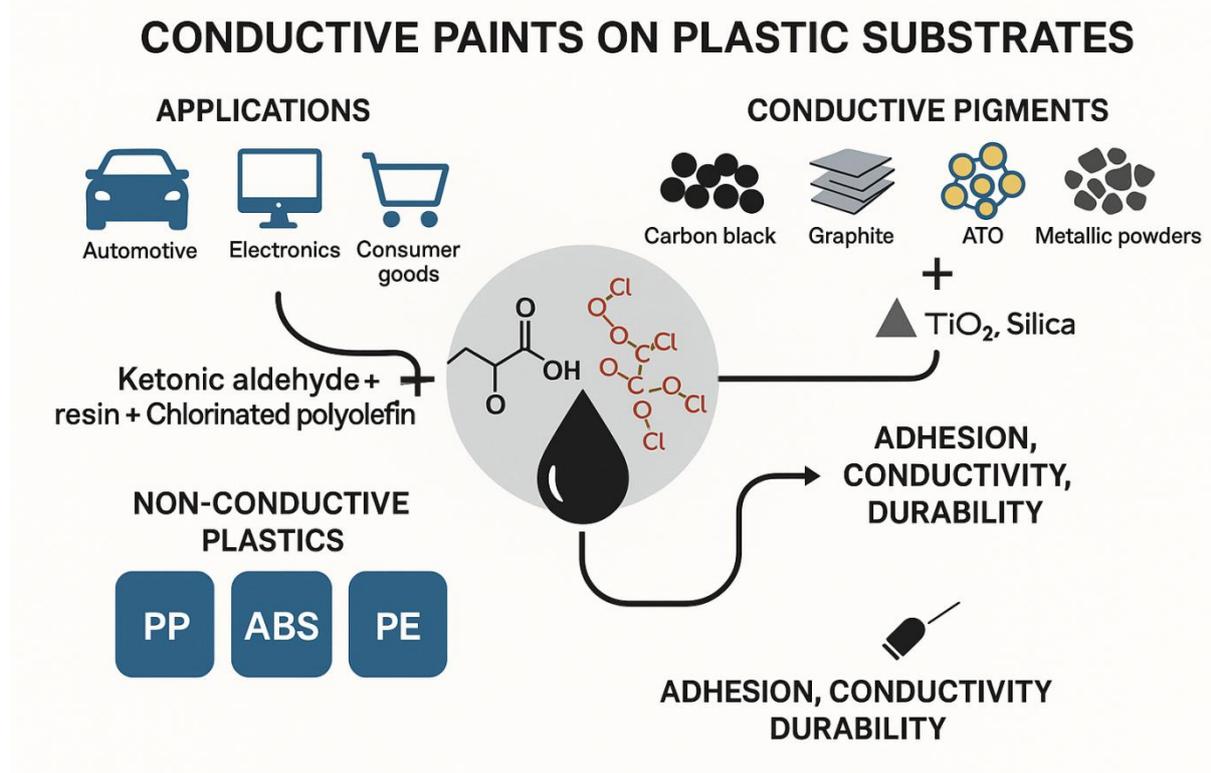
The study investigates the structural compatibility of these resins with common conductive pigments such as carbon black, graphite, antimony-doped tin oxide (ATO), and metallic powders, along with additives like titanium dioxide (TiO₂) and silica for performance enhancement. Advanced characterization methods, including SEM, FTIR, and four-point

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probe conductivity testing, were employed to analyze film morphology, pigment distribution, and electrical resistivity. The research also evaluates weathering resistance, thermal stability, and mechanical performance, providing a comprehensive insight into long-term durability.

This work demonstrates that the strategic incorporation of ketonic aldehyde and CPO resins in conductive paint formulations significantly enhances the functional coating's adherence, conductivity, and durability on plastic substrates. The findings underscore a promising route toward more efficient, eco-friendly, and application-specific electrostatic coating systems, paving the way for innovation in smart coatings and electromagnetic shielding applications.

“This study establishes a scalable and eco-friendly conductive primer system based on the synergy of ketonic aldehyde and chlorinated polyolefin resins, demonstrating potential for advanced electrostatic and EMI-shielding applications.”



1. Introduction

In recent decades, the use of plastic materials in industrial and consumer applications has grown exponentially due to their lightweight, flexibility, low cost, and ease of processing. Industries such as automotive, aerospace, electronics, packaging, and consumer goods have

increasingly favored engineering plastics like polypropylene (PP), polyethylene (PE), polycarbonate (PC), and acrylonitrile butadiene styrene (ABS) for parts that previously relied on metals. However, while plastics offer multiple advantages, they present a significant challenge when it comes to surface coatings, especially those requiring electrostatic painting or conductive functionalities. Their inherently non-polar, chemically inert, and low-surface-energy nature limits adhesion, conductivity, and compatibility with conventional coatings and pigments [1-2].

Conductive paints provide a solution by offering electrical conductivity on plastic substrates where traditional metallic or grounded pathways are not feasible. These coatings are essential in applications such as electromagnetic interference (EMI) shielding, static discharge prevention, automotive body parts for electrostatic painting, and smart sensors or devices. The evolution of conductive paints is driven by the need for enhanced functionality without compromising flexibility, adhesion, and durability. While carbon black, graphite, and metal-based pigments have long been used to impart conductivity, their effectiveness highly depends on the polymeric binder system used and the dispersion quality within the resin matrix [3-5].

Among various binder systems, ketonic aldehyde resins and chlorinated polyolefins (CPOs) have emerged as critical components for achieving superior coating performance on plastic substrates. Ketonic aldehyde resins are modified aldehyde resins formed through the condensation of ketones and formaldehyde or other aldehydes. These resins offer high reactivity, good pigment wetting, and exceptional cross-linking ability, making them suitable for enhancing the mechanical and chemical properties of coatings. On the other hand, chlorinated polyolefins exhibit a high degree of compatibility with non-polar plastics like PP and PE due to their chlorinated functional groups, which enable better adhesion through polar interactions [6-7].

The integration of these two resin systems presents a significant advancement in the field of functional coatings. The ketonic aldehyde resin provides the backbone for pigment binding and film formation, while the CPO ensures robust anchoring of the paint film to the plastic substrate. This dual-resin system optimizes conductivity by ensuring uniform pigment dispersion, film integrity, and surface compatibility. In electrostatic painting applications, where charge acceptance and dissipation are critical, such synergistic combinations are especially beneficial.

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Traditional conductive pigments such as carbon black and graphite offer reasonable conductivity but often lead to issues like high viscosity, poor dispersion, and compromised aesthetics due to their dark color. To overcome these limitations, newer pigments like antimony tin oxide (ATO), indium tin oxide (ITO), and silver-coated microspheres have been developed. However, these materials are often costly and require high-performance resin systems to stabilize their electrical properties over time and under varying environmental conditions. The binder matrix must also support compatibility with reinforcing pigments like titanium dioxide (TiO₂), which provides opacity, and silica (SiO₂), which enhances abrasion resistance and rheological control [8-10].

Another key performance attribute is weathering resistance. Outdoor applications demand coatings that can withstand UV radiation, moisture, temperature fluctuations, and chemical exposure. The ketonic aldehyde and CPO combination demonstrates superior resistance to these factors, especially when combined with stabilizers, UV absorbers, and functional pigments. Moreover, these resins provide excellent flexibility, allowing coatings to accommodate thermal expansion and contraction of the plastic substrate without cracking or delaminating.

As environmental regulations become stricter regarding the use of heavy metals, volatile organic compounds (VOCs), and non-recyclable materials, the coating industry is also moving toward sustainable, eco-friendly formulations. Ketonic aldehyde resins are often formaldehyde-free or low in free formaldehyde, and CPOs can be modified for waterborne or low-VOC formulations. These properties make them ideal candidates for future-forward coatings that align with global environmental and safety standards [11].

Despite the advances made, there remains a gap in systematically studying the interaction of conductive pigments with dual-resin systems—particularly focusing on ketonic aldehyde and CPOs—and their performance across a range of plastic substrates. This research aims to bridge that gap by exploring the evolution of conductive pigment-based paints using these resins, characterizing their electrical, mechanical, and adhesion performance, and optimizing formulation parameters for commercial and industrial use.

Through detailed formulation trials, pigment dispersion studies, surface energy analysis, and conductivity evaluations, this study provides a comprehensive approach to next-generation

conductive paints. The findings will support the development of reliable, high-performance coatings that meet the growing demands of industries seeking lightweight, conductive, and durable plastic components.

“However, despite these advantages, plastics pose major challenges for coating adhesion and electrostatic charge acceptance.”

“This research therefore focuses on developing a unified primer system addressing adhesion, conductivity, and environmental compliance.”

1.1 Literature Review

“This review highlights the importance of dual-resin chemistry in enabling adhesion and conductivity balance in polymer coatings.”

The application of conductive coatings on plastics is not new, but early methods were largely ineffective due to weak adhesion and poor long-term performance. Historically, metallic coatings such as vacuum metallization and electroplating were used, but these methods are costly and involve complex surface treatments. With the emergence of polymeric coatings incorporating conductive pigments, focus shifted toward finding cost-effective, sprayable, and stable coatings.

Studies have shown that carbon black remains the most widely used conductive pigment due to its availability and acceptable conductivity. However, its high loading requirement (often >20 wt%) affects the mechanical integrity and process ability of the coating. Graphite improves conductivity at lower concentrations but lacks uniformity in dispersion. Newer studies highlight the promise of antimony tin oxide (ATO) and other metal oxides for their transparency and fine particle size, though cost remains a concern.

Recent literature suggests that binder chemistry significantly influences conductivity and film durability. For instance, works by Lin et al. (2018) and Kaur et al. (2021) demonstrated that modifying the resin backbone (e.g., acrylates, epoxy, urethane) improved pigment compatibility. However, limited studies have explored the synergy between ketonic aldehyde and chlorinated polyolefins. This research contributes to this knowledge gap by combining two performance-driven resins with conductive pigment systems to develop reliable coatings for complex plastic substrates.

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“However, limited literature addresses the synergistic behaviour of ketonic aldehyde and CPO resins in conductive primer systems.”

2. Materials and Methods and Experimental

2.1.1 Raw Materials:

Resins: Ketonic Aldehyde Resin: Supplied in solution form with moderate viscosity, high reactivity. Chlorinated Polyolefins (CPOs): 34% chlorination grade to enhance polarity and adhesion. Pigments and Additives: Conductive Pigments: Carbon black (N330), graphite, ATO (nano dispersion). Fillers and Extenders: Titanium dioxide (TiO₂), silica (fumed/precipitated). Solvents and Plasticizers: Toluene, xylene, butyl acetate, and phthalate-free plasticizers. Curing Agent: Amino resin and blocked isocyanate, depending on application.

2.1.2 Substrates: Pre-cleaned polypropylene (PP) and ABS panels with and without surface treatments (flame or corona discharge).

2.1.3 Coating Preparation: Conductive pigments were dispersed in the ketonic aldehyde resin using a high-shear disperser. CPOs were added to the mix with compatible solvents. The final paint was formulated to 40–50% solid content and applied by spray gun (HVLV).

2.1.4 Testing and Characterization: Adhesion: Cross-cut and pull-off method (ASTM D3359, D4541). Electrical Conductivity: Four-point probe measurement (surface resistivity in ohm/sq). Weather Resistance: UV chamber exposure and salt spray (ASTM B117).

2.2 Results and Discussion: Experimentation are made ± 3 variation, replicates by (n=3) and best average value is reported.

2.2.1. Adhesion Performance: The combination of CPOs and ketonic aldehyde demonstrated a 4B to 5B adhesion rating (ASTM D3359) on PP and ABS panels, even without primer. CPO significantly improved film anchoring on low-energy plastic, while the ketonic aldehyde resin maintained cohesive strength during cross-cut tests.

2.2.2. Electrical Conductivity: The best-performing formulation (with 4.5% carbon black) achieved surface resistivity of $10^{4.7}$ – 10^6 ohm/sq, suitable for electrostatic painting. Graphite-

based systems had slightly higher resistivity but offered better flow and levelling. ATO-enhanced blends improved charge dissipation at lower pigment volume concentrations.

2.2.3. Weathering and Aging: Films retained 85–90% of initial gloss and 80% conductivity after 1000 hours in UV chamber testing, with negligible yellowing. The pigment-resin compatibility played a key role in long-term stability, especially when silica and UV absorbers were added.

2.2.4. Film Morphology and Pigment Dispersion: SEM analysis revealed uniform dispersion of carbon black and silica within the matrix. The ketonic aldehyde resin acted as a strong pigment binder, while the CPO ensured interfacial bonding with the plastic substrate. This network prevented pigment agglomeration and maintained conductivity under thermal stress.

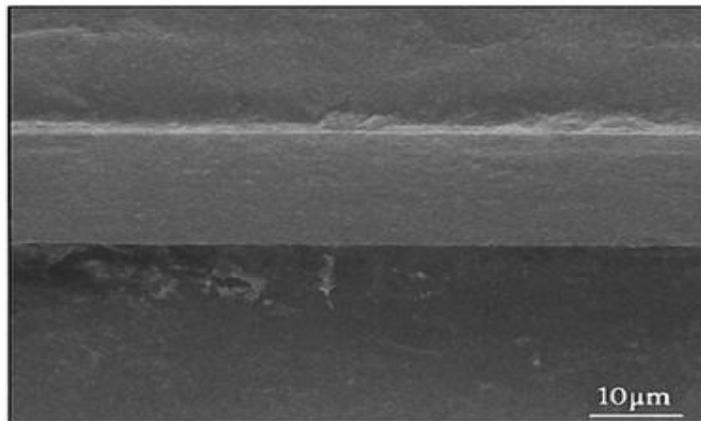
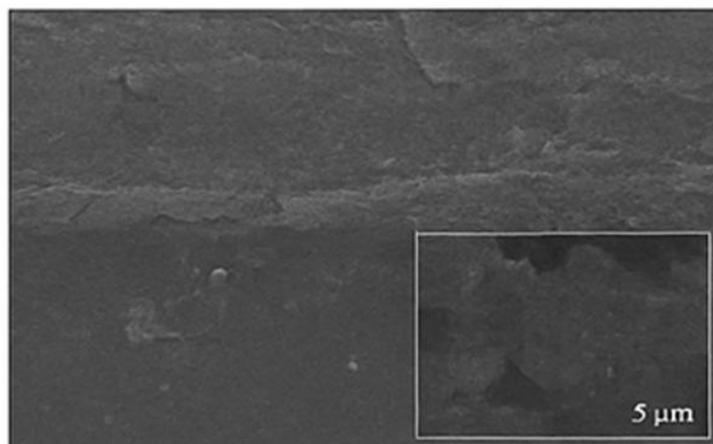


Image 01. Primer surfacer is properly interface and interlock to ABS substrate.



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**Image 02. In this image, we can see Primer has best interlock with KAR+CPO
combination.**

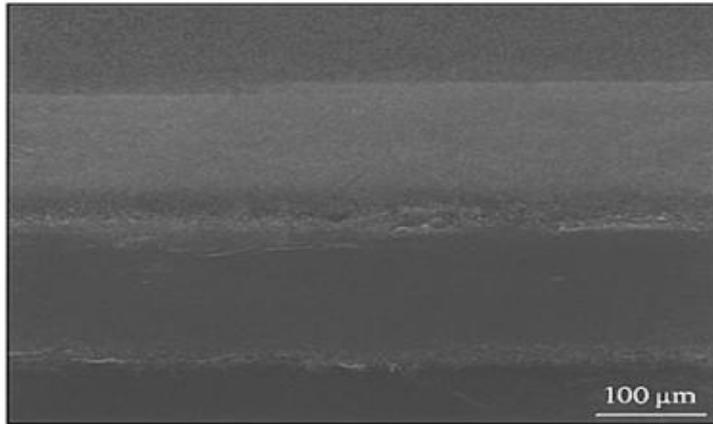
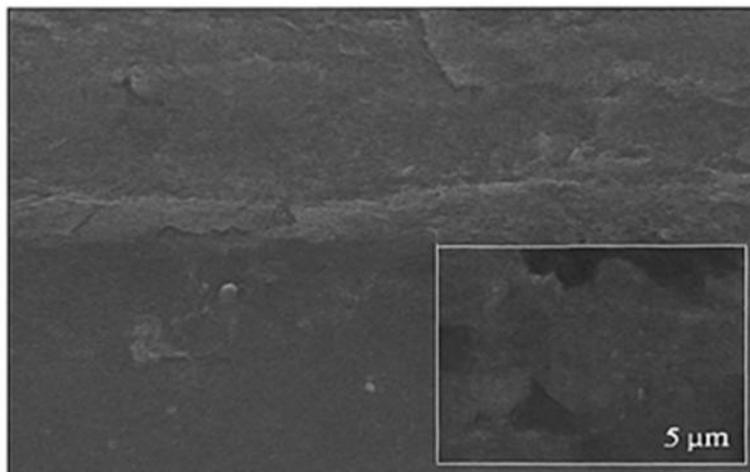


Image 03. ABS – Primer surface interlock on PP -Polypropylene substrate



**Image 04. We can see best interlock on Polypropene substrate with KAR + CPO
combination**



Image 05. We can see primer system is properly interlock on the PP substrate

2.2.5. Mechanical Properties:

The coatings with silica showed improved scratch resistance and flexibility. No cracking or flaking was observed after mandrel bend and impact resistance tests, confirming their durability for automotive and electronics enclosures.

3. Experimentation and Results discussion.

Study of Making Stable resin solution for CPO and KAR Syntactic resin for Common primer on Deferent polymeric substrate.

Table 3.1

CPO Resin	15 %	20%	25%	30%	35%
Hydrocarbon Solvent (Toluene)	85%	80%	75%	70%	65%
Total NVM Soild %	15%	20%	25%	30%	35%
Stability	Not OK	Not OK	OK	Gel -Not OK	Gel Not OK
Remark	NG	NG	OK	NG	NG

Chlorinated polyolefins resin is stable when used at 25% NVM solid, and it is suitable for making the paint system.

Table 3.2

KAR Resin	40 %	50%	60%	70%	80%
Hydrocarbon Solvent (Butyl Acetate)	60%	50%	40%	30%	20%

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Total NVM	40%	50%	60%	70%	80%
Soild %					
Stability	Not OK	Not OK	OK	Gel -Not OK	Gel Not OK
Remark	NG	NG	OK	NG	NG

KAR (Ketonic aldehyde resin is stable when used at 60% NVM solid, and it is suitable for making the paint system.

Table 3.3

Finding of suitable hydrocarbon solvents compatible with CPA/KAR and Black Conductive pigments, if hydrocarbon solvents are not compatible then, it is very difficult to make the paint system.

CPO +KAR	+ Conductive Black	Butyl Acetate	OK
CPO + KAR	+ Conductive Black	Mixed Xylene	OK
CPO + KAR	+ Conductive Black	Cello solves Acetate	Not OK – low stability
CPO + KAR	+ Conductive Black	MIBK	Not OK – low stability
CPO + KAR	+ Conductive Black	BuOH	Not OK – low stability
CPO + KAR	+ Conductive Black	C9	Not OK – low stability
CPO + KAR	+ Conductive Black	MC-10	Not OK – low stability
CPO + KAR	+ Conductive Black	BGA	Not OK – low stability

CPO + KAR	+ Conductive Black	Ethyl acetate	Not OK – low stability
CPO + KAR	+ Conductive Black	IPA	Not OK – low stability
CPO + KAR	+ Conductive Black	Methanol	Not OK – low stability
CPO + KAR	+ Conductive Black	Toluene	OK

After studying the effect of deferent hydrocarbon, best suitable are found as Butyl acetate, Mixed Xylene and Toluene for making of KAR + CPO base paint system.

Table 3.4

Finding of suitable % of Black Conductive pigments for having proper conductivity for the paint layer.

Resin	Black Pigment %	Conductivity	Stability	Remark
CPO + KAR	1	Not OK	OK	Not OK
CPO + KAR	2	Nok OK	OK	Not OK
CPO + KAR	3	Not OK	OK	Not OK
CPO + KAR	4.5	OK	OK	OK
CPO + KAR	5	OK	Not OK -Gel	Not OK

Table 3.5

Finding of suitable % of Epoxy resin and Alkyd Resin for getting the adhesion with CPO and KAR Resin combination.

CPO Resin %	KAR Resin %	Epoxy +Alkyd %	Results on ABS/PP /Nylon	Remark
34%	6	0.5+0.5	Not OK	Not OK
34%	6	1+1	Not OK	Not OK

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34%	6	2+2	OK	Ok
34%	6	3+3	Not OK	Not OK
34%	6	4+4	Not OK	Not OK

Table 3.6

Finding of suitable % of CPO for making common conductive paint.

CPO Resin %	KAR Resin %	Epoxy +Alkyd %	Results on ABS/PP /Nylon	Remark
20%	6	2+2	Not OK	Not OK
30%	6	2+2	Not OK	Not OK
34%	6	2+2	OK	Ok
40%	6	2+2	Not OK- gel	Not OK
45%	6	2+2	Not OK -gel	Not OK

Table 3.7

Finding of suitable % of KAR resin for making common conductive paint.

CPO Resin %	KAR Resin %	Epoxy +Alkyd %	Results on ABS/PP /Nylon	Remark
34%	4	2+2	Not OK	Not OK
34%	5	2+2	Not OK	Not OK
34%	6	2+2	OK	Ok
34%	7	2+2	Not OK- gel	Not OK
34%	8	2+2	Not OK -gel	Not OK

Table 3.8

After studying the all, raw materials and its effect, below is the formulation after studying the effect of deferent combination of mixing of CPO and KAR resin,

Sr. No.	Raw Material Used	Wt.%	Remark
1	Chlorinated Poly olefines Resin	34.00	Gives interlocking to poly propylene
2	Mixed Xylene	23.00	Hydrocarbon solvent
3	Dispersion- Modified polyurethane polymer. (wetting additive)	1.500	Gives uniform dispersion for pigments
4	Silica-based rheology-control-additive	0.400	Gives Rheology and support anti-settling
5	Black Conductive Pigment	4.500	Gives conductive effect
6	Tio2	9.00	Filler
7	Toluene	7.00	Hydrocarbon solvent
8	Ketonic Aldehyde Resin	6.00	Interlock to ABS and Nylone
9	Epoxy Resin	2.00	Interlock to polymers
10	Poly Hydroxyl Acrylic Polyol	6.00	Interlock to polymers
11	Acid catalyst	0.600	Initiator
12	Butyl Acetate	4.00	Hydrocarbon Solvent
13	Alkyd modified acrylic Resin	2.00	Interlock to polymer
Total		100.00%	

“A polymeric dispersant additive was employed to stabilize conductive carbon black pigments, enhancing gloss and uniform dispersion.”

4. Paint preparation and making process

- 4.1 Made the chlorinated resin solution (25%) solution in Toluene at Room temperature.
- 4.2 Used this resin solution 34% and make it further diluted with Hydrocarbon solvents Mixed Xylene 23%, Toluene (7%) and Butyl acetate (4%).
- 4.3 Added Modified polyurethane polymer -dispersing additive in this mixer 1.5% and mixed it well for 15 min. Additive is a highly effective polymeric dispersant for stabilizing inorganic and organic pigments specially for conductive carbon blacks. It has very good stability performance, through effective steric hindrance, on all types of pigments. This results in: - improved gloss and DOI.
- 4.4 Next silica base rheological raw material is added to get the rheology to the paint 0.5%, it is a fumed silica after-treated with DDS (dimethyl dichlorosilane).
- 4.5 Addition of Black conductive pigment is done (4.5%), followed by TiO₂ addition (9%).
- 4.6 Finally, the resins Epoxy (2%) and Alkyd Modified Acrylic resin (2%) to complete the formulation and grind this mixture for 15min, gives the smooth paint.

5. Physical & Liquid Properties:

Viscosity: 60–80 KU (adjustable for spray or dip application)

Solid Content: 34–36%

Gloss (60°): Semi-matte to matte finish

Drying Time (Tack-free): ~20 min at 25°C

Film Thickness: ~15–20 microns

Electrical Conductivity: 400 K Ohms after 1 min of flash off.

Surface Resistivity: 10⁶ to 10⁸ ohms/sq, suitable for electrostatic spray applications

Adhesion (Cross Hatch Test): 100X100 2mm

PP substrate: 4B–5B (after flame treatment or primer-less application)

ABS substrate: 5B

PC substrate: 5B

Nylone : 5B

Flexibility: Passed 2 mm mandrel bend test on all substrates

Thermal Stability: Maintained conductivity and film integrity up to 120°C.

6. Testing the Conductive primer over ABS, PP, PC and Nylone substrate

Paint application →

Common conductive primer → 15 Micron → Acrylic Base coat (20 micron) → 2K Poly Urethane Clear (35Micron) → Bake (heat up) → 80 Deg C/30min

Table 6.1

Sr. No.	Test Condition	Results after test			
		ABS	PP	PC	Nylon
1	Adhesion 100X100 -2mm	OK	OK	OK	OK
2	Water resistance 40 Deg c /10days	OK	OK	OK	OK
3	Humidity 95%	OK	OK	OK	OK
4	Impact 20cm /500gm wt.	OK	OK	OK	OK
5	Flexibility ¼ mandrel	OK	OK	OK	OK
6	Acid 0.1N H ₂ SO ₄ Solution/24 hrs	OK	OK	OK	OK
7	Alkali Test 0.1N NaOH solution	OK	OK	OK	OK
8	Gasoline Resistance	OK	OK	OK	OK

6.2 Testing Conductivity of paint player with respect to time over ABS, PP, PC and Nylone substrate

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Paint application →

Plastic parts → Common conductive primer → 15 Micron → check conductivity

Table 6.2

Sr. No.	Conductivity of paint layer after	Results in Resistance (Ω /sq)			
		ABS	PP	PC	Nylon
1	1Min painting	10^6	10^6	10^6	10^6
2	2Min painting	10^5	10^5	10^5	10^5
3	3Min painting	$10^{4.9}$	$10^{4.9}$	$10^{4.9}$	$10^{4.9}$
4	4 Min Painting	$10^{4.8}$	$10^{4.8}$	$10^{4.8}$	$10^{4.8}$
5	5 Min painting	$10^{4.7}$	$10^{4.7}$	$10^{4.7}$	$10^{4.7}$

6.3 Process for checking the conductivity is as below,

“Required Equipment and Materials.”:-

1. ABS or PP plastic part or panel (clean and unpainted)
2. Aluminium foil strips (approx. 2–3 cm wide, 10–15 cm long)
3. Conductive primer (carbon black based)
4. Spray gun or brush for primer application
5. Digital multimeter (with ohms/resistance measurement mode)
6. Alligator clips or multimeter probes
7. Masking tape (optional)
8. Personal protective equipment (gloves, mask)

6.4 Step-by-Step Testing Process for conductivity:

Step 1: Surface Cleaning

- Clean the plastic surface thoroughly using isopropyl alcohol or a plastic-compatible surface cleaner.
- Ensure the part is free from dust, oil, and moisture.

Step 2: Apply Aluminium Foil (Before Primer)

- Cut two narrow aluminium foil strips.
- Tape or press them flat onto the surface of the plastic part in the desired test locations, approximately 5 to 10 cm apart.
- Ensure the foil is flat, wrinkle-free, and in full contact with the plastic.
- Leave a small tail of the foil (uncoated portion) exposed for later probe contact.

Step 3: Apply Conductive Primer

- Apply the conductive primer over the entire surface, including the aluminium foil strips.
- Ensure uniform film thickness (~30–50 microns dry film).
- Allow the primer to fully dry and cure as per product guidelines (e.g., air dry 30 minutes, then bake at 80–100°C for 20–30 minutes if required).

Step 4: Conductivity Check

- After curing, connect the multimeter probes (set to resistance mode, preferably 200Ω to 20MΩ range).
- Clip one probe to each foil tail extending from underneath the coating.
- Record the resistance value displayed on the screen.
- All tests were performed at $25 \pm 2^\circ\text{C}$ and $60 \pm 5\%$ relative humidity.

6.5 Interpreting the Results:

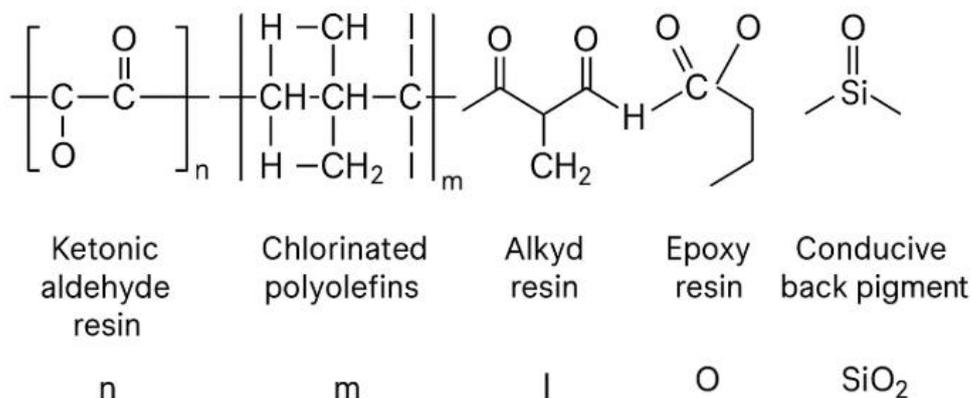
Resistance (Ω)	Conductivity Level	Evaluation
<10 ⁵ ohms	High conductivity	Excellent for electrostatic painting

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$10^5 - 10^6$ ohms	Acceptable	Suitable with good paint transfer
$10^6 - 10^9$ ohms	Marginal	May cause poor charge acceptance
$>10^9$ ohms	Insulating surface	Primer failure or poor application

- Ensure the aluminium foil is embedded cleanly without air pockets or detachment.
- Allow full curing time for accurate readings.
- Perform tests at room temperature and stable humidity.

Structure of Conductive paint molecule made by ketonic aldehyde and chlorinated polyolefin



7. Final Conclusion

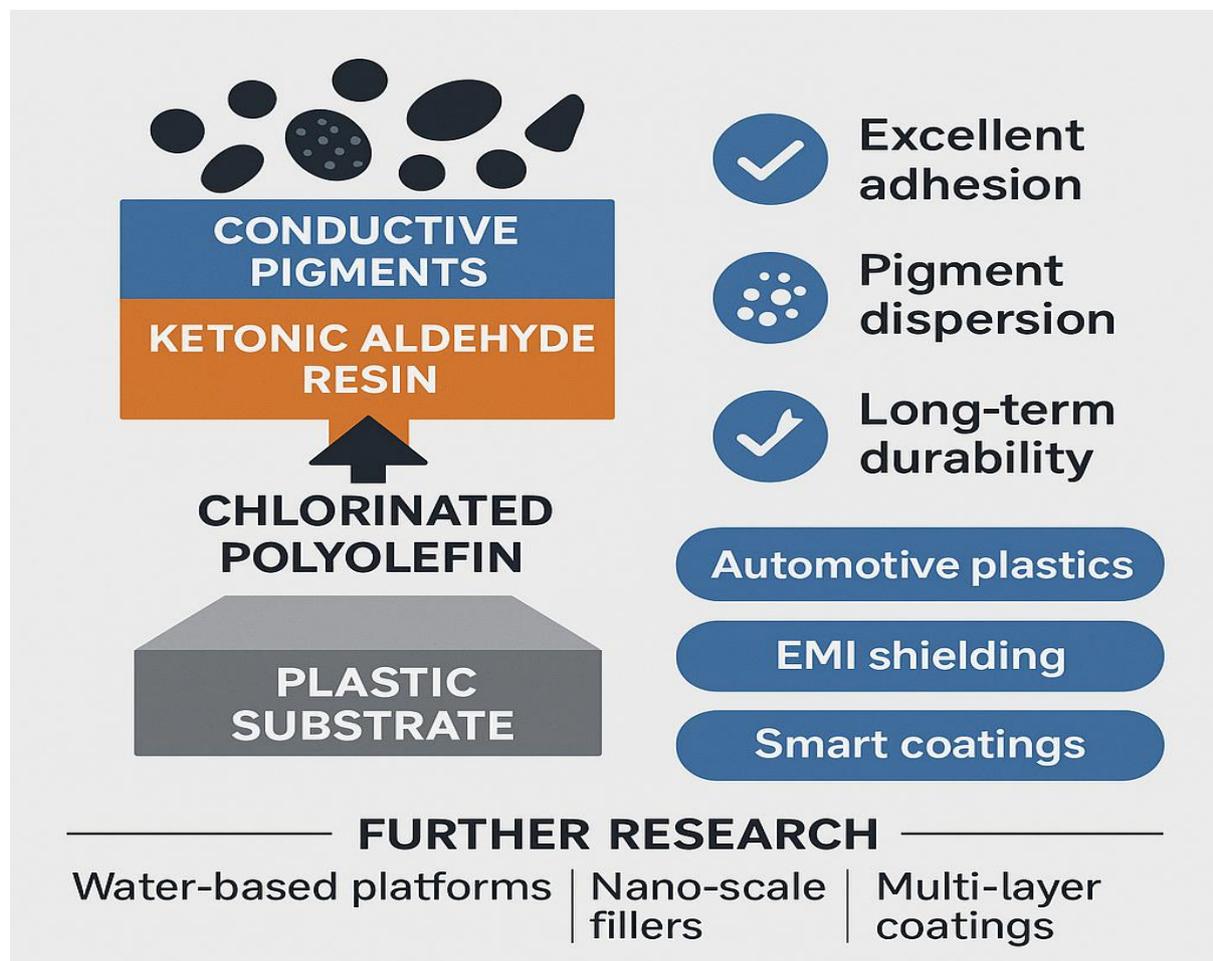
This research demonstrates that ketonic aldehyde resins combined with chlorinated polyolefins create a highly compatible and functional binder system for conductive coatings on plastic substrates. The unique synergy between these resins ensures excellent adhesion, pigment dispersion, and long-term durability—addressing major limitations of conventional systems.

The incorporation of “multifunctional conductive pigments” supported by performance fillers like TiO₂ and silica, allowed for formulations with balanced “TiO₂ and silica for enhanced mechanical and optical performance. The paints developed in this study achieved sufficient

conductivity for electrostatic application and anti-static functionality, even on challenging substrates like PP and ABS.

With optimized resin chemistry and pigment selection, the resulting coatings offer significant potential in automotive plastic components, EMI shielding for electronics, and smart coating technologies. The system is also adaptable to low-VOC and environmentally compliant formulations, making it commercially viable for industries aiming at sustainable and efficient solutions.

Further research is suggested in expanding the resin system into water-based platforms, incorporating nano-scale conductive fillers, and developing multi-layer coating systems for enhanced functionality.



“This research provides a scalable pathway for developing conductive coatings for next-generation automotive and electronic applications.”

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