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Synthesis And Characterization Of Cardanol–Phenol–Formaldehyde Resin For Plywood Applications

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Abstract: This study presents the synthesis, characterization, and performance evaluation of cardanol–phenol–formaldehyde (CPF) resin as a sustainable alternative to conventional phenol–formaldehyde (PF) resin for plywood manufacturing. Cardanol, a renewable phenolic compound derived from cashew nut shell liquid (CNSL), was utilized as a partial substitute for petroleum-based phenol. CPF resins with varying cardanol substitution levels (10–50%) were synthesized via base-catalyzed polymerization, and their physicochemical properties, bonding performance, and curing behaviors were evaluated. Results demonstrated that up to 30% substitution provides optimal viscosity, solid content, gel time, and bonding strength comparable to commercial PF resins. The study confirms cardanol's potential as a bio-based feedstock for eco-friendly plywood adhesives.

***Index Terms* -** Component, formatting, style, styling, insert.

I. Introduction

Phenol–formaldehyde (PF) resins are widely used adhesives in plywood, laminates, and exterior-grade panel products due to their excellent thermal stability, moisture resistance, and mechanical durability. However, phenol is derived from non-renewable petroleum sources and is increasingly expensive and environmentally burdensome. Therefore, sustainable and bio-based alternatives are urgently required.

Cardanol, derived from cashew nut shell liquid (CNSL), offers a promising renewable substitute. It possesses a phenolic hydroxyl group capable of participating in PF resin synthesis, while its long aliphatic side chain imparts flexibility and toughness to the resulting polymer. Previous studies have reported its potential in coatings, friction materials, and polymeric systems; however, limited literature exists on optimizing cardanol–phenol–formaldehyde resins specifically for plywood adhesive applications.

This research focuses on synthesizing CPF resin with varying cardanol substitution ratios and evaluating its suitability for plywood fabrication.

2. Materials and Methods (Experimental Section)

2.1 Materials

- Cardanol (technical grade) obtained from CNSL distillation
- Phenol (AR grade)
- Formaldehyde solution (37–40%)
- Sodium hydroxide (NaOH) as catalyst
- Distilled water
- Commercial PF resin (for comparison)
- Hardwood veneer (for plywood testing)

2.2 Resin Synthesis

A standard base-catalyzed PF resin method was adopted with cardanol partially replacing phenol.

Procedure:

1. Phenol and cardanol were charged into a 1 L three-neck flask fitted with a mechanical stirrer, thermometer, and condenser.
2. NaOH catalyst (6–8% based on phenol weight) was added.
3. Formaldehyde solution was added dropwise maintaining temperature between 65–70°C.
4. The mixture was heated to 90°C and maintained for 1–2 hours until viscosity increased.
5. Resin was cooled to room temperature and stored for analysis.

2.3 Resin Formulations

Five CPF resin samples were prepared:

- CPF-10 (10% cardanol)
- CPF-20
- CPF-30
- CPF-40
- CPF-50

3. Resin Characterization Techniques

3.1 Physicochemical Properties

- **Viscosity** measured using Brookfield viscometer.
- **Solid content (%)** determined by oven drying at 105°C.
- **pH** measured using digital pH meter.
- **Gel time** evaluated at 150°C.

3.2 FTIR Analysis

Functional groups were identified to confirm resin formation:

- Phenolic O–H stretching
- C–O–CH2 linkages (methylene bridges)
- Aromatic C=C signals
- Cardanol aliphatic side-chain characteristics

3.3 DSC & TGA

Thermal behaviour was analyzed to understand curing and resin stability.

4. Plywood Manufacturing Methodology

Three-ply hardwood veneer panels were prepared.

- Spread rate: 180–200 g/m²
- Press temperature: 140–150°C
- Press pressure: 10–12 kg/cm²
- Press time: 6–8 minutes

Bonding performance was evaluated according to IS: 848 standards.

5. Results and Discussion

5.1 Resin Properties

Property	PF Resin	CPF-10	CPF-20	CPF-30	CPF-40	CPF-50
Viscosity (cP)	350	360	390	420	480	550
Solid Content (%)	48	47	46	45	44	42
Gel Time (s)	110	120	130	145	165	190
pH	9.8	9.6	9.5	9.3	9.2	9.0

Cardanol substitution increased viscosity and gel time due to its bulky aliphatic chain. Up to 30% substitution, resin properties remained within acceptable industrial range.

5.2 FTIR Analysis

Spectra confirmed:

- Formation of methylene bridges (CH2 peak at 1460–1470 cm^{-1})
- Phenolic O–H at 3300–3400 cm^{-1}
- C=C stretching of cardanol side chain at 1600 cm^{-1}

CPF-30 showed strong polymer network formation comparable to PF resin.

5.3 Thermal Stability

- CPF-10, CPF-20, CPF-30 showed similar curing peaks to PF.
- CPF-40 and CPF-50 showed reduced thermal stability.

5.4 Bonding Strength

Resin Type	Dry Bond Strength (MPa)	Wet Bond Strength (MPa)
PF	1.63	1.42
CPF-10	1.58	1.40
CPF-20	1.55	1.38
CPF-30	1.51	1.33
CPF-40	1.35	1.10
CPF-50	1.20	0.95

CPF-30 exhibited acceptable dry and wet bonding strength for exterior-grade plywood.

6. Conclusion and Future Scope

Cardanol can successfully replace phenol up to 30% in PF resin synthesis without significantly compromising performance. The resulting CPF resin showed comparable viscosity, solid content, thermal properties, and bonding strength to traditional PF resin. This provides a cost-effective and eco-friendly pathway for plywood adhesive formulation.

Future work may involve:

- Reducing formaldehyde emissions further
- Exploring nano-fillers to improve strength
- Life-cycle assessment of CPF resin

7. Highlights

- Cardanol partially replaces phenol (10–50%) in PF resin synthesis.
- Optimal substitution of 30% maintains industrial-grade adhesive properties.
- Resin exhibits comparable thermal stability and bonding strength to PF.
- Eco-friendly adhesive suitable for plywood manufacturing.
- Supports sustainable materials with reduced petroleum dependency.