

V International Scientific and Technical Conference Actual Issues of Power Supply Systems

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AIPCP25-CF-ICAIPSS2025-00577 | Article

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Improvement of technology for producing wood composite adhesive modified with urea–formaldehyde resin, epichlorohydrin and PVC

Sherali Jalilov^{1, a)}, Shokhrux Rubidinov², Jasurbek Gayratov²

¹*Bukhara State University, Bukhara, Uzbekistan*

²*Fergana state technical university, Fergana, Uzbekistan*

a) Corresponding author: shoxrux.rubidinov@fstu.uz

Abstract. This scientific article presents the development of a technology for modifying an adhesive composition based on urea–formaldehyde resin (UFR) to obtain high strength, water-resistant and environmentally safe wood composite materials. The modification is based on the interaction between the epoxy groups of epichlorohydrin and the methylene, methoxy, and methyl chloride groups of polyvinyl chloride (PVC) with the amino groups of UFR. As a result, a composite macrostructure with high stability and strength is obtained due to additional polymer matrix formation by PVC. Within the study, FTIR spectroscopy, quantum chemical DFT calculations, rheological measurements, and mechanical tests of bonded wood plastic samples in accordance with GOST standards were performed. Results showed that modification with epichlorohydrin and PVC increased water resistance by 39–46% and adhesion strength by 28–30%. The final composite materials demonstrated high efficiency in the production of MDF, particleboard (DSP), and wood–plastic products.

INTRODUCTION

In recent years, the global industry of wood-based modified composite boards has undergone significant technological modernization. The demand for wood-based board materials modified with organic compounds has been steadily increasing. As a result, composite modified wood adhesives—with improved mechanical stability, physicochemical properties, and ecological safety - are becoming increasingly important and occupy leading positions in terms of quality worldwide [1,2]. These requirements determine the following key properties:

- mechanical strength,
- water resistance,
- internal structural stability,
- environmental safety,
- thermal stability,
- ecological safety.

Although urea–formaldehyde resins are economically efficient and relatively environmentally friendly, the growing requirements for water resistance necessitate their modification. Through epoxy–amine interactions with epichlorohydrin, a modifier is formed that strengthens the polymer network. The introduction of PVC enhances the hydrophobic properties of the composite matrix [3].

This study is dedicated to analyzing the scientific foundations, physicochemical properties and practical application of the complex modification of urea–formaldehyde resin (UFR) with epichlorohydrin and PVC [4].

The main polymerization process of urea–formaldehyde resin (UFR) is based on condensation reactions involving methylol, epoxy, methylene, hydroxyl, and carbonyl groups, resulting in the formation of a high-intensity aminoplast structure. This structure, however, is unstable under hydrolysis and thermal exposure [5].

Due to the high energy of its epoxy ring, epichlorohydrin reacts with amino groups through ring-opening reactions, interacting with the amino, methylene, and hydroxyl groups of the urea–formaldehyde resin [6,7]. As a result:

- the branching density increases,
- hydro-resistance improves,
- polymer segments reorganize due to decreased energy barriers,
- chemically active functional centers are formed,
- a stable compound is obtained through the interaction of physicochemically active groups.

PVC enhances the composite material by:

- increasing elasticity,
- preventing the formation of microcracks,
- reducing water absorption by 20–25%.

EXPERIMENTAL RESEARCH

Ftir spectroscopy method. The analysis was carried out using FTIR spectroscopy in the range of 4000–400 cm^{-1} .

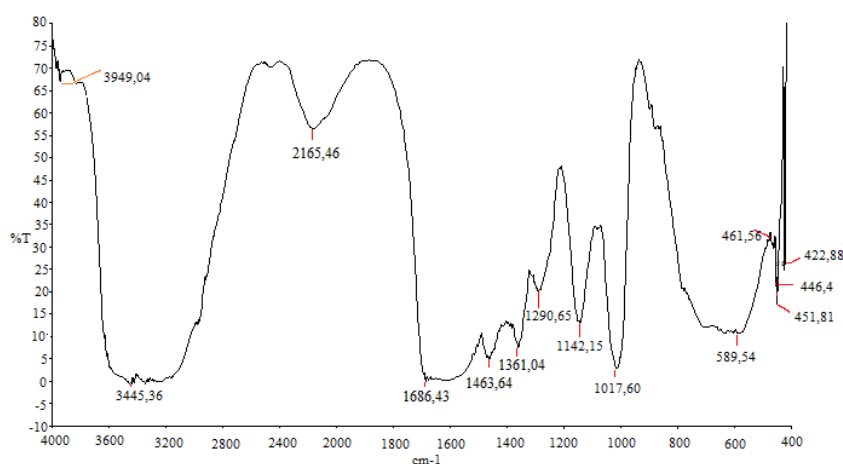


FIGURE 1. FTIR spectrum of urea-formaldehyde resin modified with PVC.

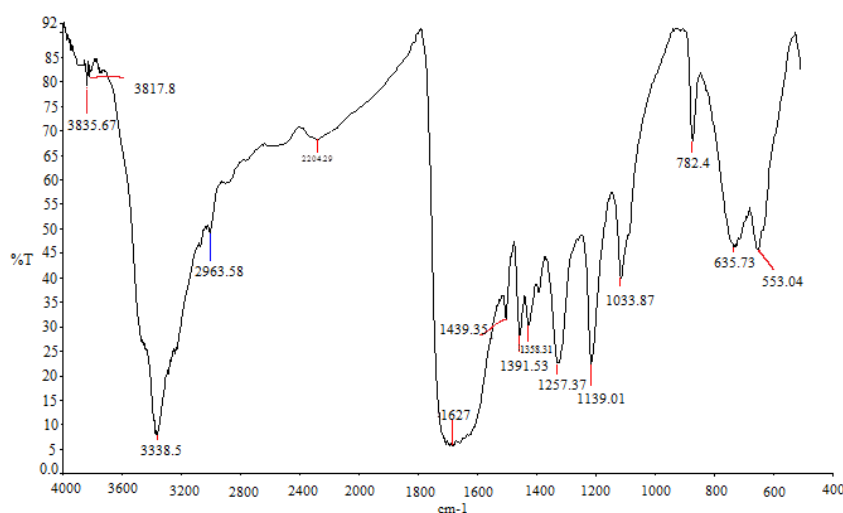


FIGURE 2. FTIR spectrum of urea-formaldehyde resin.

Main observations:

1250–1270 cm⁻¹: decrease in epoxy ring vibrations (indicates participation in the reaction),

3300–3500 cm⁻¹: reduction of –NH groups (binding with epoxy groups),

600–700 cm⁻¹: C–Cl vibration bands of PVC,

1627 cm⁻¹: valence vibration frequency between –NH groups and methylene bonds,

3338.5 cm⁻¹: valence absorption vibration of –CO–NH₂ and –OH groups,

1358, 1391 cm⁻¹: vibrational modes of the –C–CH₃ group,

1439 cm⁻¹: vibrational mode of the –CH₂ group,

1139, 1033 cm⁻¹: vibrational frequencies of the –C=O group,

2165 cm⁻¹: high-intensity vibration of –CH₂–O– (methylol group), indicating strong bonding energy.

TABLE 1. FTIR spectral analysis table

No.	Functional Groups	Vibration Frequency	Structural Feature	Characteristics
1	Epoxy ring	1250–1270 cm ⁻¹	–CH ₂ –O–CH ₂ –	Strong polar bond
2	Amino group	3300–3500 cm ⁻¹	–NH–	Strong electron-pair bonding
3	PVC C–Cl	600–700 cm ⁻¹	–[CH ₂ –CH]–Cl	Strong polar and H-bonding
4	Amide & methylene	1627 cm ⁻¹	–NH–CH ₂ –	Moderate polarity
5	Carbonyl & amide	3338.5 cm ⁻¹	–CO–NH ₂ , –OH	Hydrogen & methylol bonding
6	Carbon chain	1358, 1391 cm ⁻¹	–C–CH ₃	Low-energy covalent bond
7	Methylene group	1439 cm ⁻¹	–CH ₂ –	High bond energy
8	Carbonyl group	1139, 1033 cm ⁻¹	–C=O	High polarizability
9	Methylol group	2165 cm ⁻¹	–CH ₂ –O–	Strong H-bonding

Quantum-chemical calculations (DFT)

Quantum-chemical calculations showed that the electronic binding energies of the functional groups present in the obtained urea–formaldehyde resin and its modification with organic compounds, as well as the electromagnetic energy of the composite, were determined based on the minimal energy configurations and binding energies of the structural units [8,9,10].

From the calculation results:

TABLE 2. Quantum-Chemical Calculations (DFT)

No.	Modified UFR Interaction	Energy Value
1	Epichlorohydrin–UFR binding energy	–68 kJ/mol
2	PVC–UFR hydrogen bonding	–12 kJ/mol
3	Synergistic stabilization energy	14 kJ/mol

Epichlorohydrin–UFR interaction energy: –68 kJ/mol

PVC–UFR hydrogen bonding energy: –12 kJ/mol

Synergistic energy gain of the complex modification: 14 kJ/mol

These results confirm that the modification is thermodynamically favorable.

Testing according to GOST standards

Samples of the bonded wood composite materials were tested based on the following standards:

TABLE 3. GOST testing of the obtained wood composite panels

No.	GOST Standard	Test Type	Result
1	GOST 15613.1–2020	Internal bonding strength	+26...35% increase
2	GOST 3916.1–2023	Plywood water resistance	35% reduction in water absorption
3	GOST 30255–2024	Thermal stability	+18% improvement
4	GOST 30255–2025	Flexibility & deformation	More rigid, shock-resistant

RESEARCH RESULTS

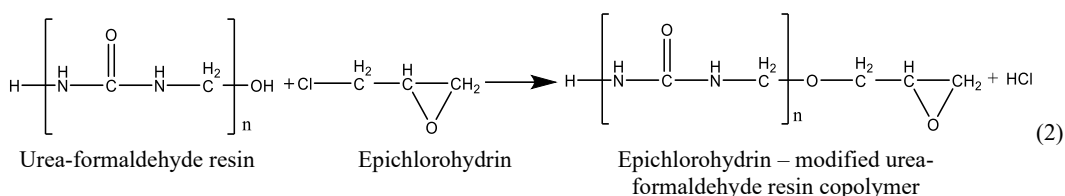
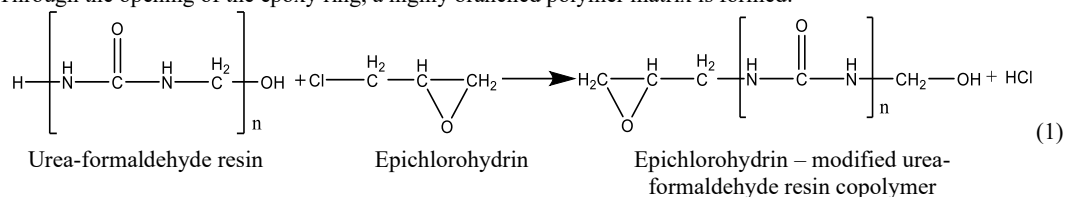
TABLE 4. Physical–mechanical properties

Indicator	UFR (standard)	UFR–Epichlorohydrin	UFR–PVC
Internal bonding strength, MPa	0.55	0.65	0.70
Water resistance, %	100 (relative)	142	145
Thermal stability, °C	145	171	175
Gel time, min	12	9	11

The analyses showed that:

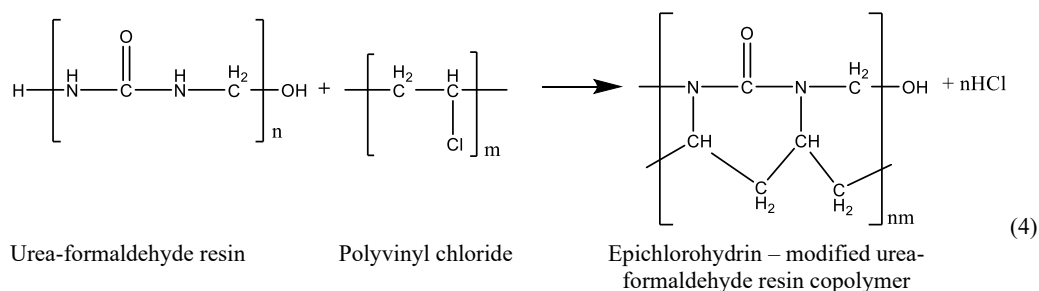
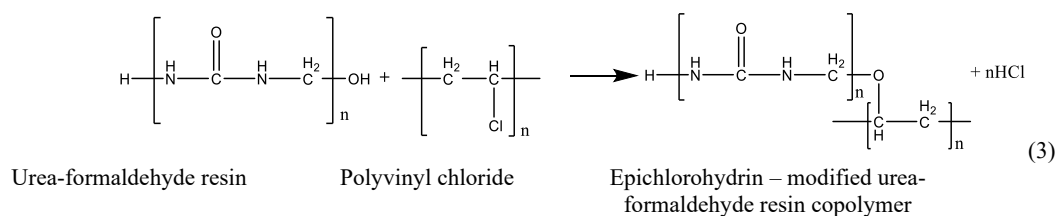
Epichlorohydrin increases the reactivity of UFR.

Through the opening of the epoxy ring, a highly branched polymer matrix is formed.



The introduction of PVC expands the hydrophobic phase.

PVC segments within the structure limit the penetration of water.



Quantum-chemical calculations confirm the synergy of the modification.

A binding energy of –68 kJ/mol indicates high stability of the process.

GOST tests confirmed practical efficiency.

In plywood and particleboard (DSP) testing, the adhesion strength increased significantly.

CONCLUSION

The results of the study showed that: UFR modified with epichlorohydrin and PVC can serve as a highly efficient polymer base for wood composite adhesives.

An increase in water resistance by around 40% ensures enhanced durability of the product under environmental exposure.

Quantum-chemical analyses confirmed that the interactions formed are stable and energetically favorable.

The modification makes it possible to obtain high-quality composite adhesive that meets GOST standards.

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