INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

Development of Semi-Transparent Paper for Tamper-Proof Sustainable E-Commerce Packaging

Indian Pulp and Paper Technical Association (IPPTA)

Zonal Seminar-1 2026

on

FUTURE-READY PAPER INDUSTRY:

POLICY, SUSTAINABILITY AND TECHNOLOGY CONVERGENCE

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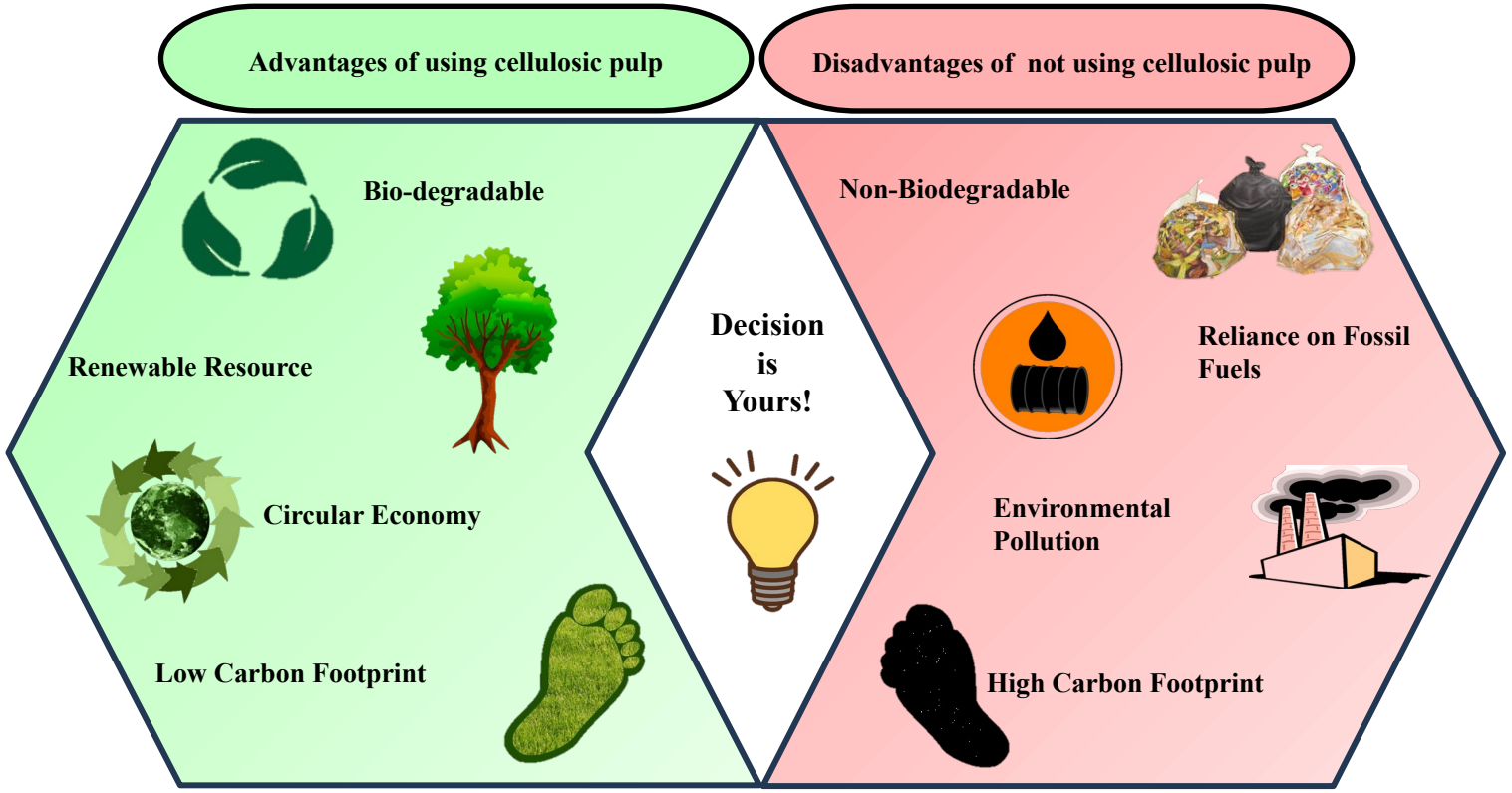
Content

Introduction

- Plastic ban → urgent need for alternatives
- Cellulosic pulp = eco-friendly base
- Value-added papers = sustainable + functional solution



Global Packaging Scenario

Drivers	Plastic bans & strict environmental regulations
	Rising demand for sustainable packaging
	E-commerce & food delivery boom
Challenges	Dependence on petroleum-derived plastics
	Low recyclability of multilayer packaging structures
	Plastic waste accumulation and disposal concerns
Opportunities	Development of functional paper-based packaging
	Replacement of single-use plastics
	QR-enabled tamper-proof packaging systems

Flexible plastic packaging constitutes a major share of the global packaging market, particularly in pouches, films, and protective packaging applications.

👉 **Semi-Transparent Paper: A Sustainable Alternative for Next-Generation Packaging**

Ali, S. A. S., Ilankoon, I. M. S. K., Zhang, L., & Tan, J. (2024). Packaging plastic waste from e-commerce sector: The Indian scenario and a multi-faceted cleaner production solution towards waste minimisation. Journal of Cleaner Production, 447, 141444.

Need for Semi-Transparent Paper

Balancing Product Visibility, Sustainability, and Functionality

	Conventional Paper	Plastic Film	Semi-Transparent paper
			
Product Visibility	No Visibility	High Visibility	Good Visibility
Biodegradability	Biodegradable	Non-Biodegradable	Biodegradable
Recyclability	Recyclable	Limited Recyclability	Recyclable
Authentication Potential	Difficult	Moderate	QR-enabled
Environmental Impact	Low Impact	High Waste Generation	Sustainable solution

Key Requirement

- Product Visibility
- Water Resistance
- Sustainability
- Tamper-proof Functionality
- QR-code Readability

Research Gap

Existing Transparent Paper Technologies

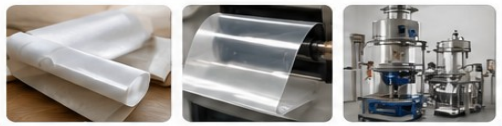

Nanocellulose-based films


Intensive Refining


Complex Chemical Modification


High Production cost


Energy-intensive Processing



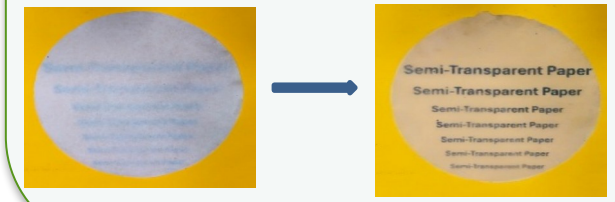
Limitations

- Limited industry scalability
- Reduced tear resistance
- Dependence upon specialized processing equipments
- Difficult adoption in conventional paper mills
- High cost and complex manufacturing

Research Gap

Present Work

- Simple carrier-assisted treatment approach
- Improved transparency without nanocellulose
- Enhanced water resistance
- Potential for QR-enabled tamper-proof packaging



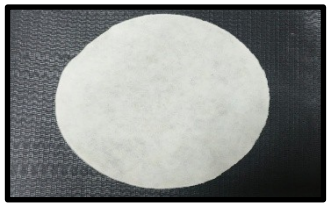
A simple, scalable, and industrially viable approach for developing semi-transparent paper remains largely unexplored

Materials and Methodology

Raw Material

Softwood Pulp (20° SR)

Base Sheet



Handsheet Preparation (50 gsm)

Sample Code	Treatment Concentration (%)
S0	0
S10	10
S20	20
S30	30
S40	40

1. **AKD addition**
   2% (w/w on OD pulp)
2. **Carrier assisted formulation prep.**
   0,10,20,30,40 % (w/w)
3. **Impregnation treatment**
   (Room Temperature)
4. **Removal of excess formulation**
5. **Oven Drying**
   105 °C
6. **Conditioning**
   23±1 °C, 50±2% RH
7. **Characterization**
   (Mechanical, Optical & Barrier properties)

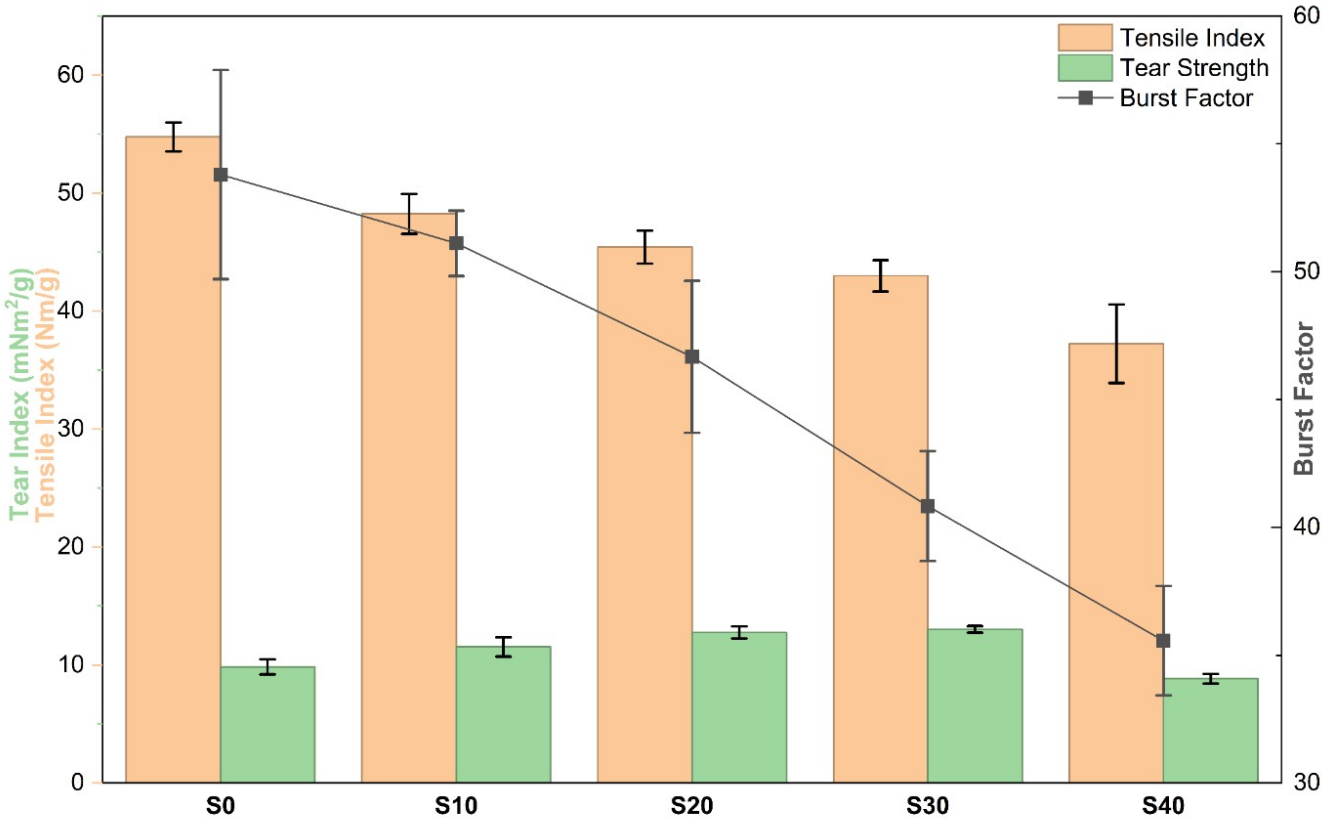
Treated Paper Sample Series

Increasing Treatment Concentration

Characterization Parameters

- Transparency
- Burst Factor
- Cobb45
- Tensile Index
- Tear Strength Index
- Gloss

Mechanical Properties



OPTIMUM BALANCE AT S30

Tear Index	Tensile Index	Burst Factor
13.02 mN.m²/g	42.99 Nm/g	40.83

S30 provided the most balanced combination of mechanical properties

Key Observations

Tensile Index

- Decreased from 54.76 to 37.23 Nm/g.
- Indicates reduced inter-fiber bonding due to treatment penetration within the fiber network.

Burst Factor

- Reduced from 53.80 to 35.56.
- Associated with weakening of the bonded fiber structure

Tear Index

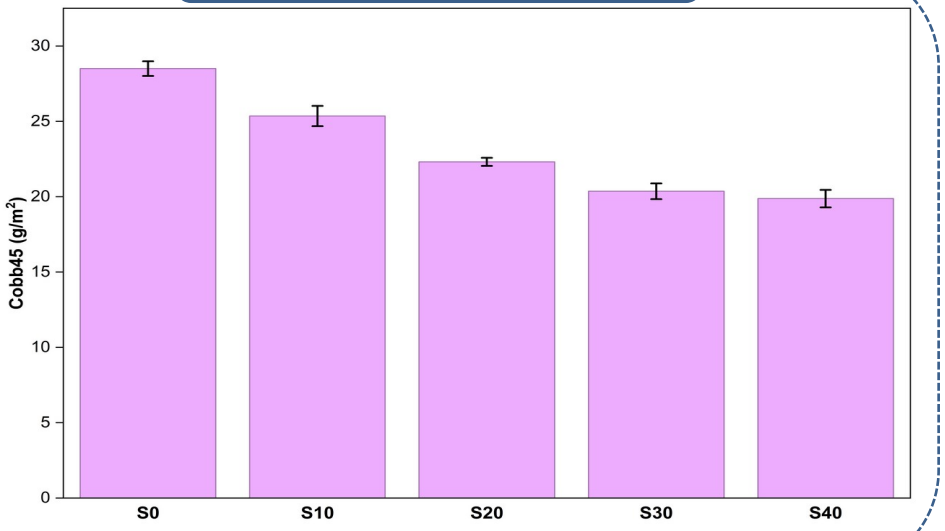
- Increased initially from 9.84 to 13.02 mN.m²/g (S30)
  Suggested improved energy dissipation during crack propagation.
- Declined at S40 due to excessive treatment loading.

Optical and Barrier Properties

TRANSPARENCY (Visual Observation)

Visual appearance of semi-transparent paper developed at different treatment concentrations

Water Resistance (Cobb45)



Transparency

- Transparency increased from 40.18% to 61.65%.
- Progressive increase observed with increasing treatment concentration.
- Reduced light scattering due to partial filling of interfiber voids and decreased refractive index mismatch within the porous fiber network.

Water Resistance (Cobb45)

- Cobb45 decreased from 28.50 to 19.87 g/m².
- Reduced water absorption indicates improved hydrophobicity.
- The hydrophobic sizing system combined with increasing functional phase loading restricted water penetration through capillary pathways.

Key Findings

Property	S0	S40	Improvement
Transparency (%)	40.18	61.65	53.43% (Increase)
Cobb45 (g/m²)	28.50	19.87	30.28 % (Decrease)

Practical Assessment

Practical functionality of the developed semi-transparent paper

1. QR CODE SCANNING

Practical Assessment

2. Tamper-Proof QR Authentication

Demonstration:

The inner-surface placement of the QR code enabled successful external authentication while restricting direct access from the package exterior. Any attempt to manipulate or replace the QR code would require disruption of the package structure, demonstrating the tamper-proof potential of the developed semi-transparent paper.

These practical assessments confirm that the developed semi-transparent paper is suitable for smart labeling and tamper-proof packaging applications.

Conclusion

Transparency

- Increased from 40.18% to 61.65%
- Demonstrated enhanced light transmission through the paper structure

Water Resistance

- Cobb45 reduced from 28.50 to 19.87 g/m²
- Improved resistance to water absorption

Mechanical Performance

- Moderate reduction in tensile and burst properties
- Tear strength improved up to 13.02 mN·m²/g

Practical Applicability

- Increased from 40.18% to 61.65%
- Demonstrated enhanced light transmission through the paper structure

Optimum Formulation: S30

Transparency	Cobb45	Burst Factor	Tensile Index	Tear Index
54.63%	20.36 g/m²	40.83	42.99 Nm/g	13.02 mN.m²/g

Semi-transparent paper was successfully developed through a simple carrier-assisted treatment approach using commercially available softwood pulp

The developed paper combined enhanced transparency, improved water resistance, acceptable mechanical performance, and QR-enabled functionality.

The developed paper shows strong potential for sustainable and tamper-proof e-commerce packaging applications.

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