Compatibility of UPR–Sengon Wood Bonding in NSM Reinforcement: A Qualitative Study of Four-Point Flexural Test

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Abstract- This paper presents a qualitative study on the compatibility of unsaturated polyester resin (UPR) bonding to Sengon wood (Falcataria moluccana) in a near - surface mounted (NSM) system . Four configurations were tested: TO (control), TP (groove + UPR), TPR (groove + Ø10 mm threaded steel bar + UPR), and TPSE (TPR + end restraint). Four-point flexural testing was conducted on simply supported beams with a span of L = 900 mm and a load spacing of 400 mm . The evaluation focused on visual observations (crack initiation/development, delamination of the UPR–wood interface, indication of bar slippage) without reporting numerical data. The results indicate that a mixture of UPR + MEKP 1.5% (w/w) with fly ash and sand fillers is able to form good encapsulation and support stress transfer in the TPR configuration ; the crack pattern tends to surround the encapsulation and is not visible. The end restraints in TPSE suppress diagonal shear cracks so that failure remains flexurally dominated . Practical implications include the importance of groove cleanliness/roughness , balanced working viscosity , and curing discipline . These findings provide a basis for further quantitative research (load–deflection curves, MOR/MOE , pull - out , and durability).

Index Terms- Falcataria moluccana, Sengon, Polymer, NSM, Beam

I. Introduction

Sengon wood (Falcataria moluccana) is a fast-growing wood abundant in Indonesia and has economic value for secondary structural elements (light beams, roof trusses, panels). However, its relatively low tensile strength and stiffness as well as moisture variability limit its use to medium spans. Simple, inexpensive strengthening techniques that are compatible with the hygroscopic nature of wood are needed. References on Sengon properties & applications: [21, 20] .

Near-Surface Mounted (NSM) technique —embedding reinforcing bars/plates in shallow grooves on the tension face—offers increased flexural capacity with minimal changes in cross-sectional dimensions and better reinforcement protection than Externally Bonded (EBR) [1, 18] . In wood structures, previous studies have utilized CFRP/FRP + epoxy and shown significant increases in strength/stiffness [5] . However, data on the use of unsaturated polyester resin (UPR) in fast-growing tropical woods is still limited, even though UPR has advantages in cost , ease of application , and short curing time [6, 12–14] .

The knowledge gap addressed by this study is the compatibility of UPR–Sengon wood bonding in NSM systems. The focus of this article is not on load–deflection quantification, but rather on visual observation of interfacial behavior (cracking initiation, delamination, slip indications, and failure modes). This paper: (1) describes the specimen configurations (TO, TP, TPR, TPSE) and the NSM fabrication procedure using UPR; (2) presents visual evidence of UPR–wood bond quality in a four-point flexural test (L = 900 mm; load spacing = 400 mm); (3) identifies qualitative indicators of bond success (minimal slip, crack pattern around the UPR encapsulation, end restraint effect); and (4) formulates practical implications for field work (groove preparation, UPR viscosity, curing, end detailing) and further research directions.

II. IDENTIFY, RESEARCH AND COLLECT IDEA

This section describes the materials used, the fabrication steps of the NSM system, the four-point flexure test setup, the visual observation procedure, the resin parameters (UPR + MEKP 1.5% with FA/sand filler), the process documentation, and the method limitations that limit the scope of the findings.

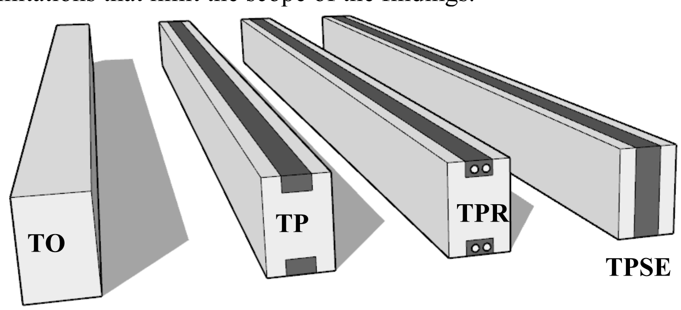


Figure 1. NSM Hole Configuration

A. Materials

All specimens used Sengon Wood (Falcataria moluccana) as the main element. The test beam cross-section was 70 mm × 12 mm (b × h), chosen to represent a common lightweight wood element in secondary structural applications. The embedded reinforcement system (NSM) utilized Ø10 mm threaded steel bars as the main reinforcement in both TPR and TPSE configurations. As the adhesive/encapsulation matrix, we used an unsaturated polyester resin (UPR) catalyzed by MEKP at 1.5% (w/w resin) . This catalyst rate was chosen to balance gel time and application comfort at tropical ambient temperatures, while reducing the risk of excessive exothermic effects during groove filling. To improve cavity filling and volume stability, the UPR was formulated with fly ash (FA) and sand as fillers so that the mixture viscosity was sufficient to resist drain-out in the 20×20 mm groove, but still able to wet the wood fiber walls. Literature related to UPR adhesion on lignocellulosic materials , the effect of catalyst/promoter composition on gel time , and the role of fillers on rheology/exotherm form the basis of this formulation [6, 12–14] .A summary of the specifications for the 4 specimen types can be seen in **Table 1**.

B. Specimens Fabrication

(a) (b) (c)

Figure 2. (a) Wood drilling (tensile side groove), (b) Installation of steel rod in NSM groove, and (c) UPR surface after curing (NSM when dry)

Fabrication began with the creation of NSM grooves on the tensile face of the beam along 1.0L of the test span. The groove width and depth of 20 mm each were chosen to accommodate sufficient UPR matrix encapsulation while ensuring that the groove edges do not weaken significantly. After the routing/drilling process , the groove walls were cleaned of dust (brushing and/or vacuum) to minimize contamination that could interfere with resin wetting . A mixture of UPR + MEKP 1.5% (w/w) with fly ash (FA) and sand fillers was prepared immediately before application.

The specimens were divided into four configurations as in **Fig 1**. TO (control) received no treatment. TP received groove filling with UPR-FA-sand without rods, in order to evaluate the contribution of encapsulation to crack control . In TPR , Ø10 mm threaded steel rods were cut to effective length, degreased (if necessary), and placed into the grooves; the grooves were then filled to the surface level . TPSE followed the steps of TPR and added end restraints near the supports to limit diagonal shear cracking. All specimens were allowed to cure at room temperature to reach handling strength before testing. The process of making specimens and their conditions before testing can be seen in **Fig. 2** and **Fig. 3**.

Figure 3. All test objects before testing

Table 1. Specimen configuration & materials

Code	Cross section of wood	NSM flow	Length of the groove	Reinforcement	Resin & filler
TO	70 × 12 mm	–	–	–	–
TP	70 × 12 mm	20 × 20 mm	= L	–	UPR + MEKP 1.5% + FA + sand
TPR	70 × 12 mm	20 × 20 mm	= L	Ø10 mm threaded steel	UPR + MEKP 1.5% + FA + sand
TPSE	70 × 12 mm	20 × 20 mm	= L	Ø10 mm threaded steel (+ end restraint)	UPR + MEKP 1.5% + FA + sand

Note: L = 900 mm (load distance 400 mm).

Speciments Code = TO (control), TP (groove + UPR), TPR (groove + Ø10 mm threaded steel bar + UPR), and TPSE (TPR + end restraint).

C. Specimens Fabrication

Testing was conducted on a simply supported beam with a span of L = 900 mm and a constant moment zone formed by two load heads spaced 400 mm apart . Loading was applied using a manual hydraulic pump (hand-pump) so that the load rate followed the operator's pumping stroke; no mm/min rate was specified. The evaluation in this study was qualitative/visual based , so photographic documentation was the main output; numerical data (load–deflection/strain) were not reported in this paper.

D. Visual Observation

Observations were organized into three phases : pre-test, during-test, and post-test. In the pre-test phase, surface conditions and initial fractures were documented. During the test, observations focused on crack initiation in the tension zone , delamination of the UPR–wood interface , indications of apparent bar slip, and diagonal shear cracking around the supports for both end-restrained and unrestrained configurations. Post-test, the failure pattern of each specimen was photographed from several angles and compared across configurations. To facilitate reporting consistency, we used a qualitative scoring scheme (none: –, mild:

+, moderate: ++, severe: +++) which was then summarized in the Visual Observation Matrix in Section 3.1.

As a methodological note, the DIC technique was not used in this study; references to DIC in the manuscript are only for literature reference for further work [15, 16] .

E. Brief Literature Review (NSM on Wood/LVL/GLT)

To situate the present work within current knowledge, Table 2 consolidates representative studies on NSM strengthening of timber, glulam, and LVL—together with supporting literature on polymer adhesives and measurement techniques. Each entry reports the material/method, test setup and key variations, headline outcomes (strength/stiffness and failure mode), and qualifying notes. The synthesis underscores the recurring influence of bond quality and end detailing on flexural response and motivates our qualitative focus on UPR–wood compatibility under four-point bending. This review is selective rather than exhaustive, prioritizing studies with direct comparability to the present configurations.

Table 2. Summary Literature Review

Studies	Materials/ Methods	Setup & Variations	Main Impact	Vital Records
Yeboah (2021, *Structures*)	Spruce wood + NSM BFRP/GFRP bars	4-point; span 2.3 m; 20 specimens	Ultimate load +33–69%; stiffness +22–33%	The theoretical model of bending moment is in good agreement with the experiment.
Al-Zu'bi (2024, *J. Building Eng.*)	NSM-FRP concrete with nano-modified epoxy	FRP: CFRP/GFRP/BFRP; groove 8×8–12×12 mm; NE vs NMEA	Silica/Clay/Graphite NMEA > NE for capacity; groove affects capacity & ductility	Insight into adhesive selection & groove dimensions for NSM systems
Farsane (2020, *Rev. Chimie*)	UPR curing : MEKP, cobalt octoate, ceramic filler	Composition variations; gel time, exotherm	MEKP & promoter accelerates gel; filler ↑thermal conductivity & viscosity, ↓total heat of reaction	UPR exothermic control & working time guide
Quarterly (2022, *JMRT*)	Modified epoxy-PU (one-pot, without prepolymer)	Reaction time 30–90 minutes	↑ BM & viscosity , ↑ tensile strength , change EEW & pot life	Relevant for *toughening of* epoxy adhesives
Ghozali (2014, *JUSAMI*)	Epoxy-PU without prepolymer	Isocyanate conversion, FT-IR, tensile & adhesion tests	NCO Conversion ~99.45% ; Adhesion ~6.5 MPa	Recommended local Indonesian formulation
Dietsch (2015, *ConBuildMat*)	GLT integrity (glue-line, MC, cracks)	NDT/SDT; crack mapping & MC	Glue-line assessment procedure & moisture effects	Reference practice for wood element inspection
Raheem (2023, *Mat. Today Proc.*)	VE-hybrid composite review	–	VE is popular for humid/maritime environments	Strengthening VE/UPR arguments in structural applications

Note: The numbers in the "Main Impact" column are summaries from the original sources; they are used as context for the literature , not as results of this study.

F. Implications for this Research (NSM UPR-Sengon)

The majority of wood reinforcement research uses FRP/epoxy combinations —especially CFRP —and reports convincing capacity and stiffness improvements. On the other hand, the application of UPR to fast-growing tropical woods such as Sengon in NSM configurations with steel bars is still rarely discussed. Therefore, this study is positioned to assess the compatibility of UPR–wood bonds through visual indicators (initial cracking, interfacial delamination, slip indications, and failure patterns) without extrapolating to capacity figures. The practical implications drawn—including groove cleanliness/roughness , UPR working viscosity (MEKP 1.5% + FA/sand) , and end restraint detailing —are intended as initial fabrication guidelines , not numerically based design guidelines. These qualitative findings provide a basis for subsequent quantitative programs (load–deflection curves, MOR/MOE , tensile–bond tests) with wood moisture control .

G. Resin Parameters & Viscocity Measurement (for Reproducibility)

The matrix formulation followed a UPR + MEKP 1.5% (w/w) approach with FA and sand fillers to achieve an adequate working viscosity —high enough to resist drain-out in 20×20 mm grooves while still being able to wet the groove walls and close the pores. The adjustment of the catalyst and (if used) cobalt promoter levels aimed to balance gel time and exotherm , referring to the general behavior of unsaturated polyester resins [6, 12–14] .

Viscosity assessment was conducted qualitatively , namely through (i) visual observation during mixing and filling (indication of flow, wetting, sagging), (ii) process observation (appearance of pores/bubbles, drain-out or local shrinkage), and (iii) preliminary testing of 50×50×50 mm compression cubes of the same mixture to ensure adequate hardening before mass fabrication. This paper does not use an instrumental viscosity meter or epoxy comparator ; the references related to epoxy/VE in the literature review only serve as a theoretical basis for wood-polymer composite materials.

H. Method Limitations & Futher Plans

This paper does not present load–deflection/strain data; all findings are qualitative based on visual documentation. The

A. Visual Observation Matrix

To organize the qualitative findings, Table 3 presents a visual observation matrix that codes damage evolution across the four configurations (TO, TP, TPR, TPSE). Entries synthesize evidence from pre-, during-, and post-test photographs, tracking crack initiation in the tension zone, UPR–wood interfacial delamination, apparent bar slip, and diagonal shear cracking near

moisture content and density characteristics of the wood were not measured quantitatively, so material variability cannot yet be evaluated. In the future, a targeted research program—including quantitative testing (MOR/MOE), tensile–bond testing—will be conducted . UPR–wood, as well as environmental resistance (humidity/temperature cycling)—is required to translate visual indicators into design parameters.

III. Result and Duscussion (Qualitaitive/visual)

supports. Severity is ranked on a four-level ordinal scale—none (–), slight (+), moderate (++), severe (+++)—to enable consistent cross-comparison. The matrix underpins the narratives in Sections 3.2–3.3 and foregrounds the influence of polymer encapsulation and end restraint in maintaining flexure-dominated failure.

Table 3. Visual Observation Matrix

Configuration	Tensile zone crack initiation	Wood delamination–UPR	Rod slip	Diagonal shear crack	Concise visual notes
TO (control)	+++	–	–	+	Fast flexural cracking in the tensile zone; brittle tensile failure
TP (groove + UPR, without stem)	++	–/+(local)	–	+	Delayed cracking; polymer pathway limits crack opening but without internal restraint
TPR (NSM steel + UPR)	+	+ (minor)	–	+	Cracks encircle the polymer path; no rod slippage observed ; indication of effective stress transfer
TPSE (TPR + end restraint)	+	+ (minor)	–	–/+ (very limited)	End restraint suppresses diagonal shear cracking near the support; flexural crack pattern is dominant

Note: Qualitative scores: Nil (–), Mild (+), Moderate (++), Severe (+++), observation sources are visual, namely four-point test documentation (before–during–after photos) and field notes. No load/deflection/strain figures are reported in this paper.

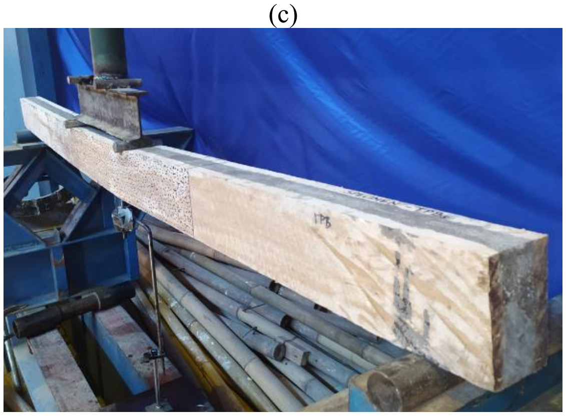
B. Typical Failure Description

Visually, the TO (control) exhibits an initial tension crack in the mid-span that rapidly progresses to brittle failure, consistent with the absence of internal confinement in the tension zone (see **Fig. 4 (a)**). In TP , filling the grooves with UPR-FA-sand delayed crack formation and helped limit crack opening; however, without internal reinforcement the effect remained limited (see **Fig. 4 (b)**). The TPR configuration exhibits an adequate UPR–wood interface: cracks tend to surround the UPR encapsulation and there is no visible indication of pull -out or slip , consistent with the tendency for increased stiffness/flexure in the NSM configuration in the literature [5] (see **Fig. 4**). In TPSE , in addition to the TPR behavior, end confinement suppresses diagonal shear cracks near the supports so that the failure pattern remains flexurally dominated; this is consistent with the effect of detailing at the ends of the elements in the NSM system [4] (see **Fig. 4**).

(a)

(b)

(c)



(d)

Figure 4. Cracks after testing on (a) TO, (b) TP, (c) TPR, and (d) TPSE

C. *Practical Implications (Without Statistics)*

Visual findings highlight three fabrication aspects that most influence bond quality. First, groove cleanliness and roughness : thorough powder removal and a moderately smooth groove wall texture promote UPR–wood mechanical interlocking . Second, UPR working viscosity : a composition of 1.5% (w/w) MEKP with FA/sand filler produces a mixture thick enough to prevent drain-out in a 20×20 mm groove , yet still capable of wetting the fiber; this is evident from the reduction of voids and flow traces in successful specimens. Third, curing discipline : control of exotherms (through batch control and groove fill thickness) and stable environmental conditions minimize early pores and delamination.

In the support area, end restraint details help suppress diagonal shear cracking , so that the failure mode remains predominantly flexural. Beyond that, operator skill during mixing and filling (e.g., mixing time, filler distribution, prevention of entrapped air) contributes significantly to the visual quality of the bond. These recommendations are preliminary practices based on qualitative observations and require quantitative verification in further work [6, 12–14, 4] .

IV. CONCLUSION

Here This qualitative study indicates that UPR with 1.5% MEKP and FA/sand filler is able to form a compatible bond with Sengon wood (Falcataria moluccana) in the NSM configuration using Ø10 mm threaded steel bars . Visual indicators— minimal bar slippage , mild interfacial delamination , and a crack pattern surrounding the UPR encapsulation—indicate effective stress transfer. The addition of end restraints also suppresses diagonal shear cracking , so that the failure mode remains flexurally dominated .

From a practical perspective, these findings suggest three primary focuses during fabrication: (i) groove cleanliness and roughness to promote mechanical interlocking ; (ii) determination of the working viscosity of the UPR mix (1.5% MEKP with FA/sand) to allow sufficient flow but not drain-out ; and (iii) curing discipline to minimize initial voiding/delamination. Because the results are visual and do not include quantitative data, further systematic research—including load–deflection (MOR/MOE) curves , UPR–wood interface tensile–bond testing , and durability testing (moisture/temperature cycling)—is needed to translate these recommendations into design parameters and field repair protocols.

APPENDIX

None

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