Preliminary Structural Reuse Assessment of Reclaimed *Juniperus excelsa* Timber after Approximately 42 Years of Service: Mechanical Response, Visible Defects, and SEM Observations

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This preliminary, limited case study compared reclaimed *Juniperus excelsa* (Greek juniper) wood—removed after approximately 42 years of service in a rural structure—with freshly cut samples from the same geographic region. Compressive strength parallel and perpendicular to the grain, full-section four-point bending, a study-specific visual defect index, and qualitative scanning electron microscopy (SEM) observations were used. Test results showed that parallel compression and bending strengths were of similar magnitude in the two groups, whereas perpendicular compression showed a larger difference. These differences were not interpreted as a loss or preservation of properties, as the initial properties and detailed service history of the reclaimed specimens are unknown. In the new group, a distinct trend of decreasing bending strength with increasing visible defect scores was evident, whereas the narrow score range in the reclaimed group did not support a similar relationship. Some reclaimed specimens fractured abruptly near the peak load. Local microcrack-like discontinuities observed in selected SEM fields were qualitatively consistent with this behavior but did not establish causality. Due to the small sample sizes, the results provide preliminary engineering trends rather than design values.

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Keywords: Reclaimed timber; Juniperus excelsa; Structural reuse; Compression; Four-point bending; Visible defects; Scanning electron microscopy; Case study

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INTRODUCTION

Circular construction aims to preserve the value of existing products and components by prioritizing direct reuse over low-value recycling (Kirchherr *et al.* 2017). Wood is particularly attractive because it is renewable, stores biogenic carbon throughout its service life, and can be reprocessed with relatively low energy (Ormondroyd *et al.* 2016; Hopkinson *et al.* 2019; Hemmati *et al.* 2024). However, reclaimed structural wood cannot automatically be considered equivalent to newly produced material. Reuse decisions require information on current mechanical response, visible and hidden defects, moisture content, and the consequences of an inadequately documented service history (Pitti *et al.* 2020; Novais Passarelli *et al.* 2025; Ranttila *et al.* 2025). This assessment is particularly important in regions with high seismic risk, such as Turkey (Aktaş 2017).

The seismic loading history of the reclaimed members was unknown; therefore, no retained seismic capacity was inferred. There are four factors that must be distinguished from one another. Aging refers to time-dependent chemical and cellular changes. Service history includes previous loading, creep, temperature and humidity cycles, drying history, changes in use, and damage that may occur during disassembly. Defect effects arise from knots, cracks, and fiber deviation, as well as their location relative to high-stress areas. Such defects can strongly influence member behavior, particularly when located in highly stressed regions. Species effects, on the other hand, reflect anatomy, density, growth characteristics, and natural durability. Because reclaimed and new specimens can differ in all four of these aspects, a comparison at a single test date cannot isolate an aging effect or quantify retained capacity without initial measurements (Cavalli *et al.* 2016; Kránitz *et al.* 2016; Arriaga *et al.* 2023).

This distinction is particularly important for *Juniperus excelsa*, a species rich in extractives and possessing natural durability that is used in traditional structures in Turkey (Atas *et al.* 2012; Sarangzai *et al.* 2012; Yücedağ *et al.* 2021). Previous old-versus-new studies on juniper and other structural species have shown that long-term service effects vary with species, defects, density, moisture history, and exposure conditions (Bektas *et al.* 2004; Sonderegger *et al.* 2015). The present preliminary study extends this literature by combining mechanical response, visible defects, fracture observations, and qualitative SEM examination within a structural-reuse context. Studies on aged wood also demonstrate that microstructural observations cannot be generalized without systematic sampling (Xin *et al.* 2022; Zhang *et al.* 2024).

Long-term environmental exposure can affect the constituents of wood's multiphase structure in different ways. Hemicellulose is generally more susceptible to moisture-related degradation, whereas the cellulose–lignin framework may remain comparatively more stable, depending on species and exposure history (Kránitz *et al.* 2016; Wang *et al.* 2021; Xin *et al.* 2022). Repeated wetting–drying cycles and long-term loads can lead to microcracks, particularly at cell wall corners and in the middle lamella region; these discontinuities can create stress concentration, thereby reducing the material's energy absorption and stress redistribution capacity (Luimes *et al.* 2018; García-Iruela *et al.* 2020; Peng *et al.* 2020; Mi *et al.* 2023).

This preliminary study examined a small set of *Juniperus excelsa* specimens removed from a rural structure after approximately 42 years of service and compared their current properties with those of newly harvested material from the same geographic region. The objective was to document preliminary trends in compression, full-section bending, visible defects, fracture morphology, and SEM observations rather than derive characteristic strengths or isolate aging effects. The study is therefore exploratory, aiming to identify preliminary response trends and reuse-related uncertainties rather than establish equivalence or design capacity. SEM observations were used solely in a qualitative context to provide microstructural context for mechanical observations; image-based quantification or micro-macro statistical correlations were not attempted. Previous studies have demonstrated the potential of CFRP-based techniques for strengthening damaged or aged timber beams under different loading conditions (Türer *et al.* 2024; Alaşalvar *et al.* 2025). However, the current mechanical condition of reclaimed timber should first be established before any strengthening or structural reuse strategy is selected.

EXPERIMENTAL

Reclaimed *Juniperus excelsa* components were sourced from a rural timber-frame structure located in the Taurus Mountains of Silifke, Mersin, Türkiye. The lumber pieces had been in service for approximately 42 years. Prior to sample preparation, areas exhibiting decay, significant insect damage, or visible dismantling damage were excluded. The source of the members and the sample extraction process are shown in Fig. 1, while the comparability of the material histories of the new and reclaimed groups is presented in Table 1.

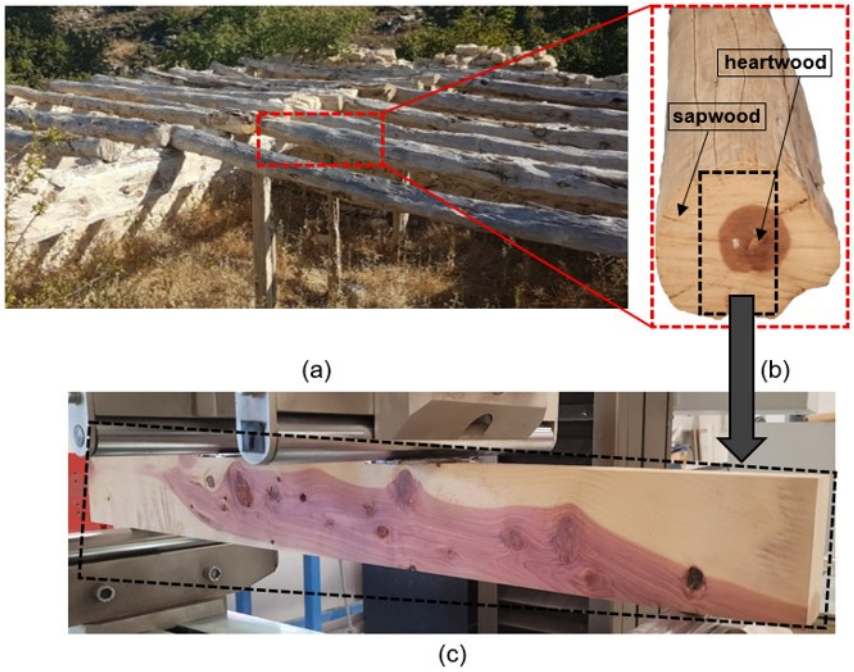

Fig. 1. Source and sampling of the reclaimed *Juniperus excelsa* members: (a) rural structure after removal of the roof covering, (b) representative cross-section showing heartwood and sapwood, and (c) a full-section bending specimen prepared from a reclaimed member

Table 1. Material History and Comparability of the Two Timber Groups

Item	New Timber	Reclaimed Timber
Regional origin	Mersin / Silifke	Mersin / Silifke
Service history	Not applicable	Approximately 42 years in a rural structure
Environmental exposure	Pre-harvest history not documented	Seasonal temperature/humidity variation; details not documented
Drying history	Not documented before laboratory conditioning	Long in-service drying history; details not documented
Dismantling damage	Not applicable	Visibly damaged regions excluded
Heartwood/sapwood proportion	Not quantified	Not quantified
Mean density of full-section bending specimens	556.7 ± 86.5 kg/m³	506.5 ± 40.9 kg/m³

Although the groups are similar in terms of species and regional origin, the materials were not considered to have exactly matched initial properties. Heartwood and sapwood were not separated or quantified; therefore, the results do not represent heartwood-only properties. Original lumber preparation and in-service dimensions were not documented; however, both groups used the same nominal geometry within each test series.

The moisture content of the representative sample taken from the reclaimed wood was measured at approximately 4.35% upon arrival. All mechanical test specimens were conditioned for more than five months prior to testing under conditions of 20 ± 2 °C and 65 ± 5% relative humidity; the moisture content was determined using the oven-drying method in accordance with EN 13183-1 (2002).

Compression Tests

For each group, three 80 × 80 × 80 mm specimens were tested parallel to grain and three perpendicular to grain. The cube dimensions adapted ASTM D143-22 (2022) and TS 2470 (1976) procedures to the limited clear lengths; therefore, the results are comparative rather than standard strength values. The tests were conducted on a hydraulic universal testing machine with a capacity of 3000 kN at a displacement rate of 1.0 mm/min. Natural fiber orientation was visually checked; radial and tangential directions were not systematically separated. Compressive strength parallel to grain was determined from the maximum recorded load. The archived records identified the reported perpendicular-to-grain value as the onset of a distinct crushing/yielding response; however, the exact offset-based criterion could not be reconstructed retrospectively. The compression results are reported as group averages; Because individual values are not available, no statistics on variation can be provided.

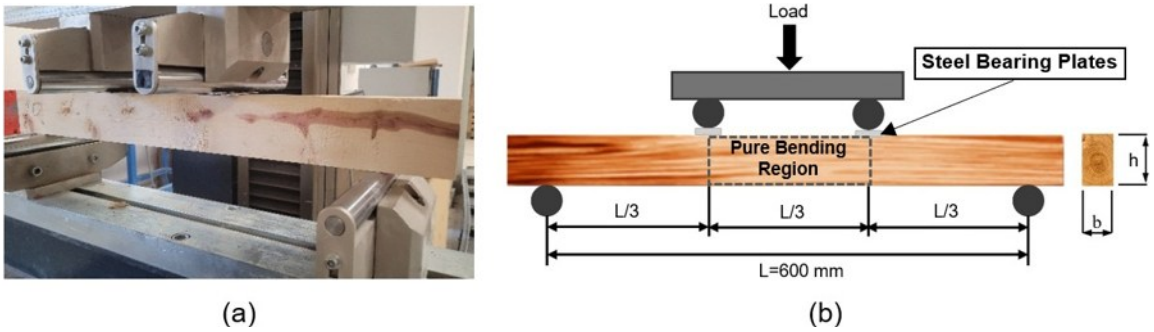

Fig. 2. Experimental setup for the bending tests: (a) Photograph of a reclaimed timber specimen and loading fixture under four-point loading; (b) Schematic diagram illustrating the test geometry, including the support span (L=600 mm), loading points (L/3), and the constant moment region used to assess defect influence

Four-Point Bending Tests

Six full-section specimens from each group (42 × 82 × 754 mm) were tested edgewise under four-point bending over a 600 mm span, with the loads applied at the third points (Fig. 2). Steel bearing plates were used to limit local indentation. The resulting span-to-depth ratio, L/h=7.32, was lower than that commonly used for standardized bending tests (approximately 18 in EN 408); therefore, the calculated properties were interpreted as test-configuration-specific values rather than standard bending properties. This geometry was selected due to the limited available member length and the need to preserve the full cross-

section, rather than to comply with standard EN 408 dimensions. Consequently, shear and the flexibility of the test system contribute to the measured displacement; stiffness is reported as the apparent modulus of elasticity (MOE_{app}) rather than the pure modulus of elasticity. Furthermore, due to the a/h ratio of 200/82 = 2.44 between the loading point and the support, the effect of shear and the bending–shear interaction cannot be completely ruled out. For this reason, the calculated MOR values are considered not as standard characteristic bending strength but as nominal bending stress indicators specific to the short-span geometry used.

Crosshead displacement was used without independent mid-span measurement; therefore, MOEapp includes machine, contact, shear, and bending deformations and is not a pure material modulus. The original program used 2, 5, and 10 mm/min with two specimens per group at each rate; the rationale was undocumented. Because rates were not independently replicated, they were treated as uncertainty rather than an experimental variable, and no rate effect was inferred. The maximum recorded load was taken as F_{max}. For curves that did not show a distinct post-peak load drop, the last recorded point was considered the end of the test rather than a definitive fracture point. MOR and MOE_{app} were calculated using Eq. 1 and Eq. 2, respectively. These equations follow linear-elastic beam theory for symmetric third-point loading. Because crosshead displacement was used, stiffness is reported as MOE_{app} rather than a standard material modulus,

$$MOR = \frac{F_{max}L}{bh^2} \quad (1)$$

$$MOE_{app} = \frac{23L^3\Delta F}{108bh^3\Delta\delta} \quad (2)$$

where $F_{\max}$ is the maximum recorded load, $L$is the support span, $b$and $h$are the specimen width and depth, respectively, and $\Delta F/\Delta\delta$ is the slope of the load–crosshead displacement curve within the selected linear region.

Visual Defect Indicator

Prior to bending, all specimens were examined on all four faces for knots, fiber deviation, and visible surface cracks. Defects were evaluated separately for the constant-moment and shear zones. These defects formed the basis of a study-specific 0 to 3 rating: 0, no visible defects reducing strength in the critical region; 1, minor or distant local defects; 2, medium-sized knots/local fiber deviation/small cracks near the critical region; 3, large knots, pronounced fiber deviation, or visible cracks in the high-stress region. Representative specimens with low and high defect scores are shown in Fig. 3. These categories were not calibrated against recognized visual grading standards and do not represent pass/fail classes; they were used solely as a study-specific indicator for exploratory comparisons within the dataset.

The original records are not suitable for retrospective quantitative determination of parameters such as knot area ratio, distance from the tensile edge, and fiber inclination. Therefore, the terms “small,” “medium,” and “close” are descriptive categories based on pre-experiment visual inspection, not calibrated numerical thresholds. This subjectivity is a limitation of the study. Defect scores are presented in Table 3 in the format “Moment/Shear.”

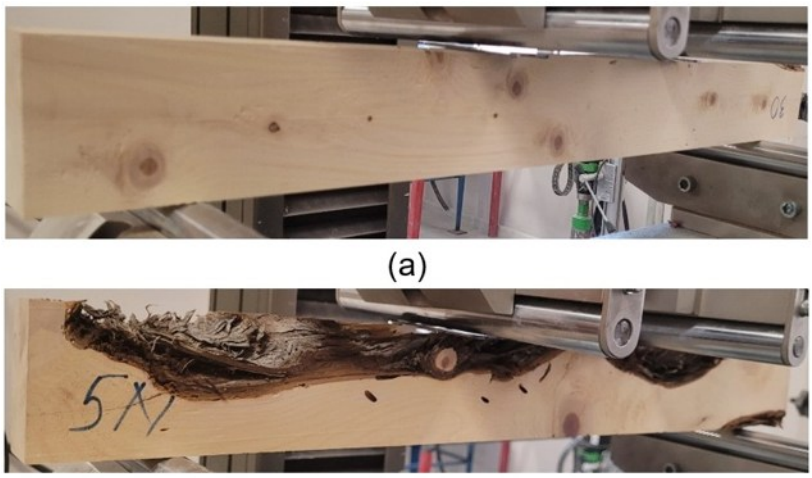

Fig. 3. Representative bending specimens illustrating the study-specific visual defect indicator: (a) low visible-defect severity and (b) severe local defect in a critical region.

SEM Examination and Data Evaluation

Small pieces taken from random locations and from regions near mechanically generated fracture surfaces were coated with gold/palladium and examined using a Hitachi SU5000 scanning electron microscope in secondary electron mode at 3 to 5 kV and a working distance of ~7.5 mm, at magnifications ranging from 220× to 4000×. Sampling was not systematic; no quantitative crack density measurements were performed, nor were any statistical correlations established with mechanical response. SEM images were therefore treated solely as qualitative observations based on a limited field of view. Because archived SEM counts could not be reconstructed, selected micrographs provide only qualitative context, not causal evidence.

Compression tests included n = 3 specimens per group and direction, while bending tests included n = 6 specimens per group. These sample sizes are insufficient for reliable confidence intervals, characteristic values, or generalizable inferential statistics. Bending data were summarized using mean, standard deviation, and range; compression results were reported as group means. The defect-score comparison was exploratory and was not used as a predictive regression model.

RESULTS AND DISCUSSION

Qualitative Microstructural Observations

While the cross-sections taken from the new wood exhibited a relatively regular cell wall geometry, the reclaimed sections contained local microcrack-like discontinuities near the cell wall corners and irregularities in the intercellular regions (Figs. 4a and 4b). The longitudinal sections of both groups retained visible fiber continuity; the reclaimed wood exhibited a rougher fracture surface (Figs. 4c and 4d). Similar local variations have been reported in studies of naturally aged wood; however, their occurrence and mechanical significance depend on species, exposure, sampling location, and preparation method (Xin *et al.* 2022; Zhang *et al.* 2024).

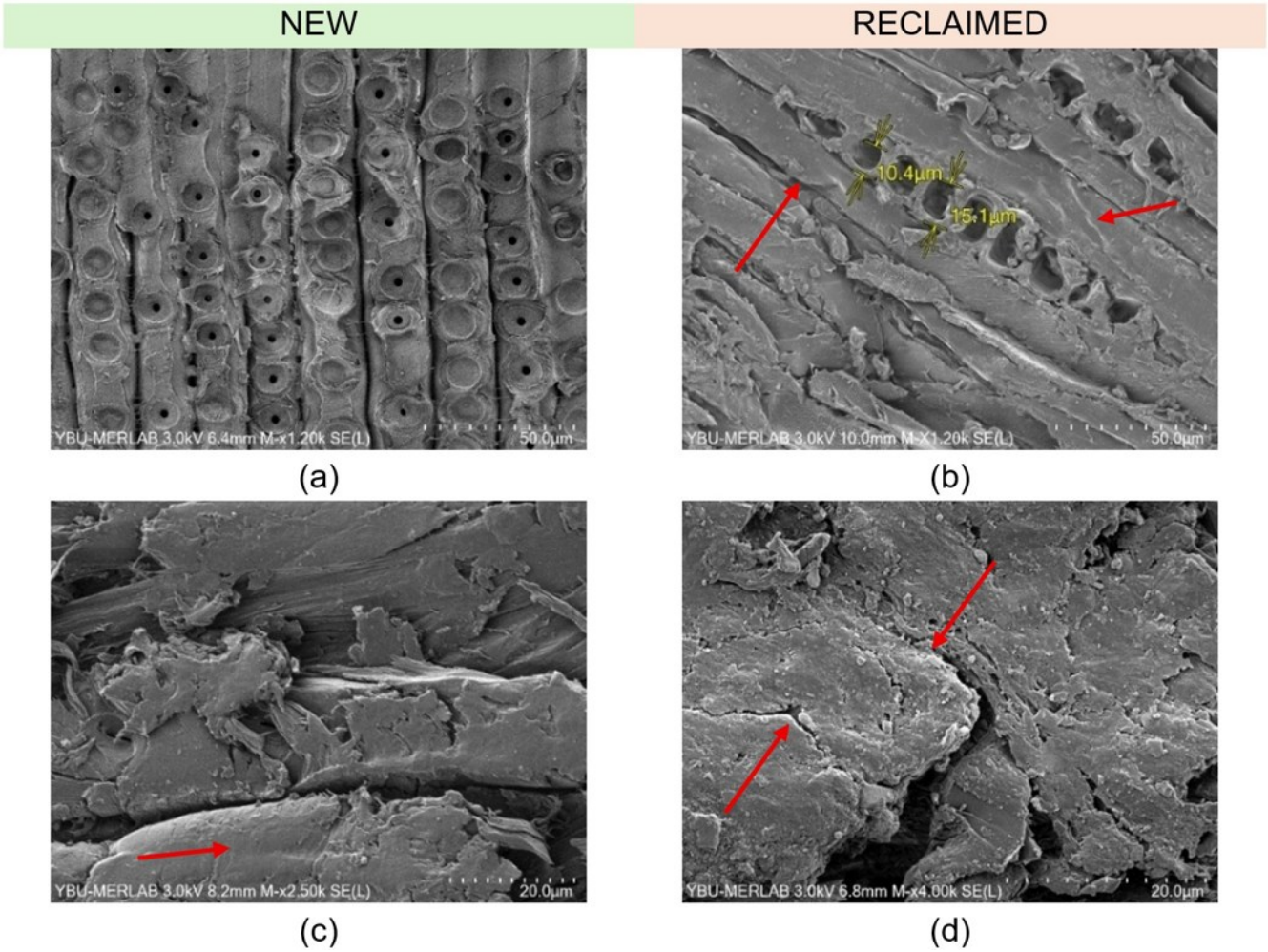

Fig. 4. Selected SEM fields from new and reclaimed *Juniperus excelsa*: (a and b) transverse and (c and d) longitudinal/fracture-surface views. The images are qualitative and are not statistically representative. (Scale bars: 50 µm for transverse, 20 µm for longitudinal)

These limited qualitative images cannot establish causality or sample-level correlations; they provide only descriptive microstructural context consistent with mechanisms reported for aged and historic wood (Kránitz *et al.* 2016; Luimes *et al.* 2018).

Compression Response

On the test date, the mean compressive strengths parallel to grain were 56.1 MPa for the new group and 49.6 MPa for the reclaimed group; the corresponding perpendicular-to-grain averages were 21.2 and 15.7 MPa, respectively (Table 2). Because initial properties and individual values are unavailable, these differences cannot be attributed to age or service exposure or tested statistically. Nevertheless, the larger numerical discrepancy in the direction perpendicular to the grains points to the bearing and support regions as a practical focus for future element-level evaluation; this direction is sensitive to growth-ring orientation, density, contact geometry, moisture, and local defects (Arriaga *et al.* 2023). Therefore, the result should be interpreted not as a design reduction factor, but as a preliminary engineering indicator.

Table 2. Mean Compression Strengths at the Test Date (n = 3 per group and direction)

Loading direction	New (MPa)	Reclaimed (MPa)
Parallel to grain	56.1	49.6
Perpendicular to grain	21.2	15.7
Note: As individual compression values were not available, standard deviations and ranges are not reported; the values are current-state comparisons, not loss or retention. Given the limited data and adapted geometry, they should not be interpreted as characteristic or design strengths.		

Bending Strength and Apparent Stiffness

Table 3 summarizes the full-section results and Fig. 5 the load–displacement curves. MOR and MOE_{app} were calculated consistently using Eqs. 1 and 2. Accordingly, the average MOR values for the new and reclaimed groups were 21.4 ± 13.3 and 24.3 ± 8.8 MPa, respectively. The wide range in the new group is largely influenced by a single, highly defective specimen (NJ-5). Therefore, the averages do not indicate equivalence, improvement, loss, or preservation; they merely characterize the tested specimens at a single point in time.

The average MOE_{app} values were 2432 ± 1178 MPa for the new group and 2566 ± 596 MPa for the reclaimed group. These short-span, crosshead-based values include shear, contact, and machine flexibility and therefore represent setup-specific apparent stiffness rather than a pure flexural modulus.

Table 3. Full-section Bending Results and Study-specific Defect Scores (n = 6 per Group)

Code	Rate (mm/min)	Defect (M/S)	Density (kg/m³)	F_{max} (kN)	Crosshead displ. at peak load* (mm)	MOE_{app} (MPa)	MOR (MPa)
New timber							
NJ-4	2	1/0	524	18.5	14.9	3220	39.2
NJ-3	2	1/0	547	12.0	9.4	2910	25.4
NJ-1	5	1/0	608	14.8	9.7	3670	31.3
NJ-2	5	2/2	516	4.5	6.0	1640	9.6
NJ-6	10	1/1	447	8.8	7.3	2690	18.7
NJ-5	10	3/3	698	1.9	9.3	470	4.0
Reclaimed timber							
OJ-4	2	0/1	551	17.0	14.8	2880	36.2
OJ-3	2	1/0	485	12.4	12.8	2380	26.4
OJ-2	5	0/0	462	13.2	10.9	2960	28.0
OJ-1	5	1/0	501	12.0	8.4	3370	25.6
OJ-6	10	0/1	478	9.1	1.9	1860	19.4
OJ-5	10	1/0	562	4.7	6.4	1970	10.0
NJ = new Juniperus; OJ = old/reclaimed Juniperus. Matching numerical suffixes are specimen identifiers only and do not indicate paired samples. M/S: defect score in the constant-moment/shear region. *Crosshead displacement was zeroed at the initial position; mid-span deflection was not measured independently.							

Failure Mode and Visible Defects

Strength and apparent stiffness were represented by MOR and MOE_{app}, respectively; post-peak behavior was assessed qualitatively because no ductility or fracture-energy parameter was defined. A visual examination of the curves and fracture photographs revealed that some new specimens developed progressive fiber damage, while some reclaimed specimens fractured abruptly near the peak load, particularly near the knots on the tension side (Fig. 5). However, both groups exhibited heterogeneous responses, and the small data set does not support a general claim that all reclaimed wood is less ductile.

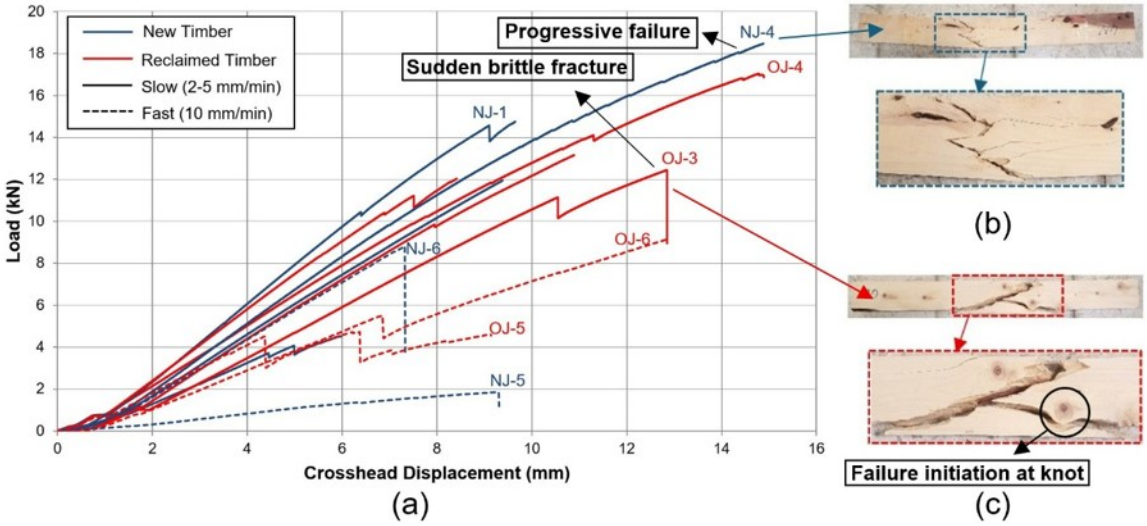

Fig. 5. Bending observations: (a) recorded load-crosshead-displacement curves at the three test rates, shown descriptively rather than as a rate-effect experiment, (b) representative progressive fiber damage in a new specimen, and (c) representative knot-associated fracture in a reclaimed specimen. The photographs show individual cases rather than group-wide failure classes.

MOR tended to decrease with defect score in the new group, but the subjective indicator and six specimens did not support regression. The narrow 0 to 1 score range in the reclaimed group likewise prevented a meaningful defect–strength relationship. Despite OJ-5's 1/0 score, its relatively low result indicates that the simplified visual score fails to capture all relevant variability; possible contributing factors include hidden cracks, local fiber orientation, density distribution, and effects of previous service loading and dismantling; however, these were not measured independently.

These observations are consistent with the reuse literature, which emphasizes evaluation at the member level and cautions against assigning new-wood properties to reclaimed members without grading or non-destructive verification (Zhang *et al.* 2015; Pasca *et al.* 2025; Ranttila *et al.* 2025). They are also consistent with reviews showing that while the current mechanical properties of old or reclaimed wood may be useful, they remain strongly dependent on species, defects, moisture content, and service history (Cavalli *et al.* 2016; Novais Passarelli *et al.* 2025).

Engineering Interpretation and Study Limitations

Despite these limitations, the study provides preliminary information on response trends, defect effects, and reuse-related uncertainties for future assessment. The practical implication is not that the tested reclaimed members are universally suitable or unsuitable; average values alone are insufficient for reuse decisions. The present small dataset does

not provide characteristic strengths, safety factors, or calibrated lower-bound design values.

The main limitations are as follows: small sample sizes ($n = 3$ per compression direction and $n = 6$ per bending group); a single species and a single source of reclaimed material; unknown tree ages and growth conditions; incomplete service and drying histories; unmatched defect distributions; study-specific visual scoring; three bending rates; a short span-to-height ratio and low a/h ratio; crosshead-based displacement; missing post-peak records in some tests; and qualitative SEM sampling. These factors preclude the determination of confidence intervals, reliability calibration, or the attribution of group differences solely to aging.

Reclaimed *Juniperus excelsa* that has been in service for a long time should not be viewed simply as waste; however, similar-looking average values should not be taken to imply equivalence with new wood. Larger datasets, non-destructive evaluation, and reliability-based calibration are required to establish generalizable design values or to recommend primary structural use (Dietsch *et al.* 2025; Müller *et al.* 2025).

CONCLUSIONS

1. The compression-parallel-to-grain and full-section bending results for the reclaimed and new *Juniperus excelsa* groups were of the same general order of magnitude, while the average perpendicular-to-grain compression values showed a wider divergence. Because the initial properties are unknown, these observations did not quantify either the retention of strength or age-related loss.
2. Full-section calculations yielded average MOR values of 21.4 ± 13.3 MPa for new wood and 24.3 ± 8.8 MPa for reclaimed wood; average MOE_{app} values of 2430 ± 1180 MPa for new wood and 2570 ± 600 MPa for reclaimed wood. These short-span, crosshead-based values are not design properties, and similar group averages do not demonstrate equivalence or improvement, particularly given the influence of NJ-5.
3. A defect-strength trend appeared in the new group, but subjective scoring and limited reclaimed-group variability prevented broader interpretation. Visual inspection did not explain all specimen differences.
4. Some reclaimed specimens fractured abruptly near the peak load. Local microcrack-like features in selected SEM areas were qualitatively consistent with this behavior; however, the limited SEM sampling did not establish causality or a statistical microstructure-mechanical relationship.
5. The preliminary results support only member-specific reuse decisions after appropriate visual, non-destructive, and engineering assessment. Members with decay, insect damage, section loss, dismantling damage, major grain deviation, critical knots or cracks, abnormal moisture, or bearing damage require further verification. Primary or seismically critical use cannot be recommended from the present dataset.

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Conflict of Interest

The author declares that no known competing financial interests or personal relationships could have influenced the work reported in this paper.

Use of Generative AI

During the preparation of this work, the author used ChatGPT and Claude to improve the language, grammar, and readability of the manuscript. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article. Generative AI was not used to create or alter experimental data, photographs, micrographs, figures, graphs, or diagrams.

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