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1 **Mode I cracking of three tropical species from Cameroon: the case of dabema,**  
2 **ilinga and padouk wood**

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20

21 **Abstract:**

22 This work aim to study the initial stress to cracking of Cameroonian tropical woods. The  
23 forests of the Cameroonian part of the Congo Basin (CB), abound in species highly sought after for  
24 structural applications. However, very little information is available on the Mode I cracking of these  
25 wood species. Specimens of sound wood from Dabema (*Piptadeniasmetrum africanum*), Padouk  
26 (*Pterocarpus soyauxii Taub*) and Bilinga (*Diderrichii nauclea*) were produced. These specimens  
27 were subjected to three-point bending tests. Physical (density and moisture content), mechanical  
28 (modulus of elasticity, bending stress at break) and energetic (restitution rate and stress intensity  
29 factor) properties were determined. The results gave a restitution rate of 581.11 j/m<sup>2</sup> for *Dabema*,  
30 519.72 j/m<sup>2</sup> for Bilinga and 201.61 j/m<sup>2</sup> for *Padouk*, and a stress intensity factor of 0.98 MPa\*m<sup>1/2</sup>  
31 for Dabema, 1.28 MPa\*m<sup>1/2</sup> for Bilinga and 1.0 MPa\*m<sup>1/2</sup> for *Padouk*. It can be seen that *Dabema*  
32 and *Bilinga* are more resistant to crack propagation than *Padouk*. On the other hand, *Bilinga* and  
33 *Padouk* absorb much more of the energy that causes micro cracks than Dabema.

34

35 **Key words:** energy restitution rate, mode I, cracking, tropical woods

## 36 **Introduction**

37           The Congo Basin (*CB*) forest covers almost 243 million hectares, accounting for a quarter of  
38 the world's tropical forest area(CIFOR 2014). These forests are spread across many African countries,  
39 including Cameroon, the Central African Republic, the Republic of Congo, the Democratic Republic  
40 of Congo, Gabon and Equatorial Guinea. The *CB* forests contribute to combating the greenhouse  
41 effect by absorbing carbon from the air. In each of these countries, the forest ecosystems are home  
42 to an exceptional biodiversity of trees, flora and fauna. By way of illustration, around 600 tree species  
43 have been inventoried in the Cameroonian part of the CB (FAO 2006). These woods are used in  
44 various construction applications, including parquet flooring, light and heavy timber frames,  
45 shipbuilding, bridges and railway sleepers. Despite their enormous potential *in constructing*  
46 structures, the technological properties of *CB*'s wood species are still little known by players on the  
47 international tropical timber markets. (Ravenshorst et al.,2013). The mechanical behavior of these  
48 species, specifically their fracture properties, remain poorly studied in the literature, which hinders  
49 the reliable design of such structures. This can lead, for example, to the sudden failure of structures,  
50 which is unacceptable and reduces their competitiveness and potential to be valued in international  
51 markets. It is, therefore, essential to carry out further studies to provide the missing properties such  
52 as cracking behavior.

53           Numerous studies have been conducted to evaluate fracture characteristics and their effects  
54 on timber constructions (Jungstedt et al. 2022, Romanowicz 2022, Yu et al. 2021). Toughness, the  
55 material's ability to resist crack propagation, is a fundamental property for characterizing a wood  
56 species (Yin et al. 2023, Zhu and Joyce 2012, Mall et al. 1983). It is influenced by temperature,  
57 growth habit and relative humidity (RH) (Kurul and Görgün 2022, Bertolin et al. 2021, Hassan and  
58 Brabec 2023, Merhar and Pitti 2023, Reiterer and Tschegg 2002).

59           The type of methods developed on identifying systems and detecting cracks in brittle materials have  
60 been carried out. These methods are divided into two general categories including destructive and  
61 non-destructive identification. Destructive methods using structural sampling examine the extent of  
62 cracks or even failures in material specimens. Non-destructive methods are also divided into local  
63 and general. Many researchers have used destructive methods based on linear elastic fracture  
64 mechanics to study the fracturing mechanism of concrete and rock structures (Ding and Lu 2016,  
65 Gomes et al. 2018). Methods based on the examination of the vibrational (dynamic) properties of a  
66 structure to detect and estimate possible cracks (Benedetti et al. 2018). For example, several  
67 experimental and numerical studies have been devoted to explaining the fracture and damage

68 mechanisms of rock and concrete structures (Fu et al. 2022, Fu et al. 2021, Zhou et al. 2022, Fu et al.  
69 2023, Wang et al. 2023)

70 Currently, in the literature, some authors maintain that wood cracking is strongly linked to its  
71 anatomical structure by considering the orthotropic morphology of wood. A closer look at the  
72 microstructure of wood reveals other features, such as growth rings, sap channels and radial channels  
73 (Moura and Dourado 2018, Ostapska and Malo 2020), which affect the mechanics of crack  
74 propagation in wood.

75 Maaß et al. (2020) showed that wood is a highly anisotropic structure that generates resistant  
76 interfaces and deflects and localizes cracks at these interfaces (Zhang et al. 2018). In addition, the  
77 velocity is highly sensitive to the fibre angle. On the other hand, other authors maintain that wood  
78 cracking is strongly linked to its density (Odounga et al. 2018, Odounga et al. 2019). Healthy  
79 specimens of *Iroko* and *Okume* were subjected to tensile tests and it was found that the fracture  
80 toughness of *Iroko* is higher than that of *Okume*. Nziengui et al. (2018) showed that for similar  
81 densities, the results of the various comparative analyses indicated no significant differences between  
82 the parameters highlighted in this study for these species despite the difference in their growth zones.

83 Other authors maintain that the acceleration of cracks and their propagation depend on the  
84 variation of the water content in the wood (Dourado et al. 2015, Engonga Edzang et al. 2021, Forsman  
85 et al. 2021, Phan et al. 2017). Despite numerous partial studies, there is no comprehensive study in  
86 the literature that links a number of factors and their influence on the fracture properties of tropical  
87 woods simultaneously. Therefore, this study aims to investigate the overall influence of different  
88 factors on the mode I (bending) fracture properties of Dabema, Bilinga and Padouk timbers, both for  
89 different crack lengths, different species, different basal density rate and, for the direction of tissue  
90 loading (longitudinal-tangential). Studying the fracture properties of tropical woods from Cameroon  
91 is crucial to guiding local engineers in their choice of construction materials and supporting local  
92 populations in their choice of construction materials other than concrete and steel.

93 This study aims to examine the fracture behavior of species produced in Cameroon, such as  
94 Bilinga (*Diderrichii nauclea*), Dabema (*Piptadeniasmetrum africanum*) and Padouk (*Pterocarpus*  
95 *soyauxii Taub*). This knowledge will represent an important step towards the optimal use of these  
96 species for structural applications. The design of such structures requires detailed understanding of  
97 the mechanical behavior of the constituent material, particularly with regard to cracking. This  
98 phenomenon precedes the final ruin of the structure. As such, it deserves special attention.

## 99 **Materials and methods**

### 100 ***Equipment***

101 In this study, three species of wood were sampled, namely Bilinga (*Diderrichii nauclea*),  
102 Dabema (*Piptadeniasmetrum africanum*) and Padouk (*Pterocarpus soyauxii Taub*), each with a  
103 diameter of 77-92 cm, within the Unité Forestière d'Aménagement (UFA) of the Bonaberi district,  
104 Wouri department, coastal region. Logs (Figure 1) were taken from each timber. These logs were  
105 sawn into quarters and then cut into the dimensions required for the various tests. Flawless wood  
106 samples were taken randomly from the sections obtained to determine the physical, mechanical and  
107 energetic properties. The samples were conditioned in a shed at room temperature and stored under  
108 these conditions for a month until they were tested. The study focuses on these three Central African  
109 tropical woods, given their great commercial importance and use in Figure 1.

## 110 **Experimental methods**

### 111 *Physical properties*

#### 112 *Water content*

113 To measure moisture content (TH), 20 samples (2 cm x 2 cm x 2 cm) per species were prepared  
114 and stored in polyethylene bags to prevent moisture loss after initial weighing. They were then dried  
115 in an oven at 103°C until a constant mass was obtained. Moisture content is defined as the ratio of  
116 the mass of water contained in the wood to the anhydrous mass, according to standard (NF B51- 004.  
117 1985). The water content of wood at a given moment is obtained using the following formula:

$$118 \quad H = \frac{m_H - m_0}{m_0} \quad (1)$$

119  $m_H$  mass of the test piece at humidity level h, in (g);

120  $m_0$  is the mass of the test piece in the anhydrous state, in (g) and  $H$  : water content, in (%)

#### 121 *Basal density*

122 The basal density is the ratio of the anhydrous mass ( $M_0$ ) to its volume in the saturated state  
123 ( $V_s$ ) of the sample, French standard (NF B51-005. 1985) allows the basal density to be calculated  
124 using the formula :

$$125 \quad D_b = \frac{M_0}{V_s} \quad (2)$$

126 Where ( $D_b$ ) = g /cm<sup>3</sup>,  $M_0$  in g and  $V_s$  in cm<sup>3</sup>

#### 127 *Determination of mechanical properties*

128 The longitudinal modulus of elasticity and breaking stress are determined by the three-point  
129 bending test in accordance with standard (NF B51 - 008. 2017). Figure 3 shows the experimental  
130 setup used to perform the test. The machine is equipped with two comparators.

131 The modulus of elasticity ( $E_f$ ) was calculated based on the principles of standard NF B 51-016 (1987).  
132 It is a function of load, displacement and stiffness coefficient. By recording the force-deflection curve,  
133 the bending stiffness  $K$  can be calculated within the linear zone:

$$134 \quad K = \frac{\Delta F}{\Delta f} \quad (3)$$

135 The modulus of elasticity ( $E_f$ ), expressed in (MPa) or ( $\text{N}/\text{mm}^2$ ) will be determined using the  
136 following equation:

$$137 \quad E_f = \frac{L^3}{4bh^3} \left( \frac{\Delta F}{\Delta f} \right) = \frac{L^3}{4bh^3} (K) \quad (4)$$

138 With  $E_f$ : modulus of elasticity in (MPa);  $\Delta F$ : variation in the load applied until failure  
139 (N);  $\Delta f$ : is the distance between the axes of the supports (mm);  $b$ : is the measured width of the  
140 specimen (mm);  $h$ : is the measured height of the specimen (mm).

141 Knowing the maximum braking force, we can obtain the breaking stress from the classic beam theory  
142 formulae

$$143 \quad \sigma_n = \frac{3SP}{2BW^2} \quad (5)$$

144 Where  $B$  and  $W$  are, respectively, the width and thickness of the beam,  $S$  is the span of the  
145 beam and  $P$  is the load.

## 146 ***Energy properties***

### 147 *Nominal bending stress*

148 Using the equation (5), the nominal stress on the specimens without primer and with primer  
149 of 4 and 8mm was calculated.

150 The following equation was used to calculate fracture toughness (ASTM E399-09, 2009)

### 151 *Stress intensity factor*

152 The energy properties (energy restitution rate, stress intensity factor and bending stress) of the  
153 SENB specimens were defined as follows:  $L = 360$  mm,  $a = 20$  mm and  $b = 20$  mm. A total of 15  
154 specimens per species were subdivided into three blocks: 05 specimens with no defect, 05 specimens  
155 with a defect 4 mm deep on the axis and 05 specimens with a defect 8 mm deep.

156 Three energy parameters were obtained from the P- $\delta$  curves, namely the stress intensity factor  
157 ( $K_{IC}$ ), nominal bending stress ( $\sigma_n$ ) and specific energy at failure (Gf). Figure 4 shows a schematic  
158 diagram of the three-point SENB test.

159

160 According to the theory of linear fracture mechanics, the stress intensity factor  $K_I$  of mode I  
161 is calculated as follows:

$$162 \quad K_{Ic} = \sigma_n \sqrt{\pi a} f\left(\frac{a}{W}\right) \quad (6)$$

163 Where  $f(a/W)$  is the crack geometry factor.

164 Fracture is initiated when  $K_I$  reaches the critical stress intensity factor, which is obtained by  
165 substituting the critical nominal stress *from* the nominal stress in equation (6) (Gross, B., & Srawley  
166 1965) derived a relationship  $f(a/W)$  - $a/W$  for an isotropic material as follows:

$$167 \quad f\left(\frac{a}{W}\right) = 1.09 - 1.735\left(\frac{a}{W}\right) + 8.20\left(\frac{a}{W}\right)^2 - 14.18\left(\frac{a}{W}\right)^3 + 14.57\left(\frac{a}{W}\right)^4 \quad (7)$$

168 *Energy restitution rate*

169 The fracture toughness  $G_{IC}$  ( $J.m^{-2}$ ), which represents the work required to separate the fracture  
170 surfaces, was calculated from the integrated area under the P- $\delta$  curve; divided by the fracture surface  
171 area using the following formula (Arif C Konukcu, Katip, and Universitesi 2022; Majano Majano,  
172 Hughes, and Fernández-Cabo 2010; Grandgirard et al. 2002) :

$$173 \quad G_{IC} = \frac{1}{(W-a) \times B} \int_0^{\delta_{max}} P(\delta) d\delta \quad (8)$$

174 Where  $a$  is the crack length at the origin,  $P$  is the load,  $\delta$  is the deflection at the loading point, and  
175  $(W-a) \times B$  is the fracture surface area.

176 ***Statistical analysis***

177 Data obtained from physical and mechanical properties measurements were first subjected to  
178 descriptive statistics to calculate means and standard deviation. Discriminant analysis was used to  
179 describe the influence of leader length on the energetic properties of wood cracking and the variation  
180 in energetic parameters between the three tropical woods. An analysis of variance (ANOVA) and  
181 Students' paired test were used to check that the mean values obtained varied significantly between  
182 the species. The results were considered significant at the  $p < 0.05$  confidence level.

183 **Results and discussion**

184 *Physical properties*

185 Table 1 shows the average values for the physical properties of Dabema, Bilinga and Padouk  
186 wood. The moisture content values obtained for the different species are 19.14% for Padouk, 22.1%  
187 for Bilinga and 25.63% for Dabema. This indicates that the different species concentrate a large  
188 quantity of free water a few months after felling, which could affect the dimensional stability of the  
189 wood and favour the growth of bio degraders (Boadu et al. 2017). Therefore, timber should be  
190 carefully dried before being used in a timber structure to avoid problems associated with high  
191 moisture in the wood (Gérard et al. 1998), which could destroy its structural rigidity in service. The  
192 minimum and maximum moisture contents of the three tree species followed Simpson's (1991)  
193 results, which stated that the moisture content of some species can be as low as 30% due to site  
194 variations and falling seasons.

195 Basal density is ( $0.73 \pm 0.03$ ) for Bilinga; ( $0.83 \pm 0.05$ ) for Padouk and Dabema ( $0.69 \pm 0.03$ ).  
196 This could be due to the complex interactions between many factors, including forming an auxin  
197 gradient (Jozsa et al. 1994). The basal density values of the three species could be classified as  
198 medium-heavy wood, according to Gérard et al. (2017).

199 *Mechanical properties*

200 Table 2 shows the mean values of the mechanical properties of Dabema, Bilinga and Padouk  
201 wood. The mean values of modulus of elasticity (MOE) obtained for the different species ranged  
202 from 8392.31 to 9905.29 MPa. The bending stresses ranged from 66.94 to 89.82 MPa. Dabema,  
203 Bilinga and Padouk are medium-strength woods, as suggested by (Gérard et al. 2017).

204 Figure 5 shows typical load-deformation curves from tests carried out on specimens of  
205 different crack lengths. The observations generated show two distinct behaviors for the specimens  
206 tested: (i) linear behavior that increases until a sudden crack appears; (ii) ductile behavior. For the  
207 different specimens, Padouk showed stable crack propagation until specimen failure. Dabema and  
208 Bilinga behaved differently. After initiation of macro-cracking at maximum horizontal bending force  
209 a sudden drop in load-displacement curve occurred, indicating unstable crack propagation. The curves  
210 for Padouk wood show smoother and more uninterrupted behavior than those for Dabema wood and  
211 Bilinga wood, which show more unstable and scattered behavior after crack initiation. The  
212 explanation could be linked to the complex structure of Dabema and Bilinga (Figure 7), consisting of  
213 a high fraction of radially oriented cells (rays, fibre) acting as a reinforcement that forces the crack to  
214 take a more sinuous path (Maaß et al. 2020, Reiterer and Sinn 2002). The specimen with an 8mm

215 deep flaw lowered the maximum loads, as shown in Figure 5. The bending behavior shifted to reduce  
216 the maximum stress during the decrease.

217 Figure 6 shows that, depending on the fibre direction, it is even possible for more than one  
218 crack path to be created simultaneously at different propagating locations. It shows the typical failure  
219 modes of SENB test blocks cracking at the interface in the LT flexural crack propagation system.  
220 This is explained by Zhang et al. (2018), who also showed a high sensitivity of the speed to the angle  
221 of the fibers.  
222

### 223 *Energy parameters*

224 Table 3 shows the mean values and results of the analysis of variance and Tukey test on the  
225 energy properties of three tropical woods, Bilinga, Padouk and Dabema. The energy restitution rate  
226 of Bilinga wood increases with increasing crack length. At crack lengths of 8mm and 4mm, the  
227  $G_{ic}(j/m^2)$  restitution energy rate of Dabema (581.11  $j/m^2$ ) was higher than that of Bilinga (519.79  
228  $j/m^2$ ) and Padouk (490.61  $j/m^2$ ). This makes a significant difference after the comparison test between  
229 Dabema and Padouk. This can be explained by the anatomical structure of the woods (Moura et  
230 Dourado 2018, Ostapska et Malo 2020). The effect of anatomical structure and wood species on the  
231 rate of energy restitution was determined based on direct mean comparisons of the main effect. The  
232 average comparison results of the energy parameters for the wood species are summarized in Table  
233 3. Arif Caglar Konukcu, Quin, and Zhang (2021) mentioned that a test specimen's mode I fracture  
234 behavior can be affected not only by its density but also by its microstructure.

235 The stress intensity factor increased with increasing crack length. Depending on the crack  
236 length of 8mm, the  $G_{ic}$  restitution energy rate ( $j/m^2$ ) of Dabema (0.98  $MPa \cdot m^{1/2}$ ) was lower than that  
237 of Bilinga and Padouk, which varied (1.10 to 1.28  $MPa \cdot m^{1/2}$ ). The K parametric was not significant  
238 between the three woods. These results agree with Maria et al. (2010) work, which found crack  
239 length-dependent stress intensity factors for several wood species in her literature overviews.  
240 However, wood being an orthotropic material, the values cannot be homogeneous on the three-  
241 dimensional scale.

242 The results showed that Dabema and Bilinga have more ductile behavior, i.e. the rate of energy  
243 restitution is much higher with extended initiation specimens than Padouk. However, Padouk and  
244 Bilinga have a higher stress intensity factor than Dabema. This could be because the specific fracture  
245 energy is not independent of a species's loading mode or crack propagation system. Hence, it can be  
246 influenced by other parameters, such as density. Indeed, previous research has mentioned that wood's  
247 mode I fracture behavior can be affected by its density and microstructure (Frühmann 2002, Konukcu

248 et al. 2021), and that could explain why Dabema and Bilinga are more resistant to crack propagation  
249 due to their wavy and counter fiber orientation, as illustrated in Figure 7.

250 Because of the more straightforward structure of wood, a crack can take a relatively straight path,  
251 whereas the more complex structure of wood could force the crack to take a more circuitous route  
252 (Figure 6). In addition, fibre bridging could play an important role in energy dissipation during the  
253 crack propagation phase.

254 Figure 8 shows the mean, maximum and standard deviation of the fracture energy parameters  
255 obtained for the three specimen combinations with different crack lengths (A0 to A2). Varying  
256 cracking parameters, such as crack length and different wood species.

257 Figure 8 shows the results that were tested by ANOVA (Figure 3 and Figure 4), which are  
258 consistent with previous studies that found similar results for the influence of crack length on these  
259 fracture mechanics properties (Maria et al. 2010). The bending energy restitution rate of cracked  
260 specimens was significantly lower than that of a specimen without a crack, even when the crack was  
261 extremely short (Konukcu 2022, Konukcu et al. 2022, Luimes et al. 2018, Maria et al. 2010, Nakao  
262 et al. 2012, Reiterer & Sinn 2002, Stanzl-Tschegg 2006). The maximum load is evident through  
263 angular peaks, typical of linear elastic brittle hardwoods (Stanzl-Tschegg 2006). In addition, the rays  
264 consume additional fracture energy, which acts as reinforcement, creating fibre bridges behind the  
265 crack base as the crack propagates (Majano Majano, Hughes and Fernández-Cabo 2010). Reiterer  
266 and Sinn (2002) have pointed out that increased specific fracture energy increases ductility. The rate  
267 of energy restitution of a cracked specimen will approach the bending energy of a specimen without  
268 a crack when the crack length is reduced (Irwin 1958).

269 Table 4 shows the mean values and results of the analysis of variance and Tukey test on the  
270 energy properties of Bilinga, Padouk and Dabema wood. The influence of crack length on energy  
271 parameters. The rate of energy restitution ( $G_{IC}$ ), the stress intensity factor ( $K_{IC}$ ) and the bending stress  
272 of Dabema, Bilinga and Padouk timbers on specimens with different initiation depths for each timber.  
273 For Dabema wood, this table shows no significant difference between the ( $G_{IC}$ ) of the first initiation  
274 value of a specimen and that of the third initiation value. On the other hand, this table shows a  
275 significant difference between the ( $G_{IC}$ ) of the first and third boot values of Bilinga and Padouk wood.  
276 With regard to ( $K_{IC}$ ) only the variation in the Padouk wood primers showed a significant difference.

277 Table 4 also shows the mean values of the bending stress for the three woods. This table shows  
278 a significant difference between the variation of the primers on each wood. The p-value of the  
279 comparison test is above the significance level of 0.05.

280 *Impact of density ( $D_b$ ) and primer variation ( $a_0$ ) on energy restitution rate ( $G_{IC}$ ) and stress*  
281 *intensity factor ( $K_{IC}$ )*

282 The histograms in Figure 9 show the evolution of the sample's energy restitution rate ( $G_{IC}$ )  
283 after each wood at different priming levels.

284 Figure 9 compares the histogram, showing a decrease in the amplitude of the energy restitution  
285 rate ( $G_{IC}$ ) with the different values of the baits. Between the first and third values of the primer depth  
286 of, a regression of  $G_{IC}$  of 177.45%, 236.60% and 503.67% for Dabema, Bilinga and Padouk. This  
287 comparative regression of  $G_{IC}$  can be explained by the typical tangential structure of three wood  
288 species indicating the fibre orientation and microstructure of Padouk, Dabema and Bilinga (Figure 7).  
289 Zhang et al. (2018) also show a high sensitivity of velocity to fibre angle. Figure 9 shows that Dabema  
290 has a higher  $G_{IC}$  value when the initiation is higher than Padouk and Bilinga. This is explained by  
291 the anatomical structure of the wood, where Dabema has entangled fibres (Figure 6 and Figure 7).

292 Figure 10 shows the effect on the amplitude of the energy restitution rate  $G_{IC}$  and the stress  
293 intensity factor  $K_{IC}$  (their maximum values) of the Padouk, Bilinga and Dabema specimens as a  
294 function of the density of each species. ( $a_0$ ) denotes the initial length  
295 In general, for the three species studied, we observed a difference in the amplitude of the rate of  
296 energy restitution from the value of initiation ( $a_0 = 4\text{mm}$ ) on each species and the value of  $G_{IC}$   
297 increases as a function of density. The  $G_{IC}$  of Padouk wood is higher than that of Bilinga and Dabema  
298 wood in the low-prime specimens. The high density of Padouk wood can explain this result. (Odounga  
299 et al. 2018, Rostand et al. 2019) showed that wood cracking is strongly linked to its density. The ( $G_{IC}$ )  
300 of Dabema and Bilinga wood are close together due to their similar density values.

301 Nziengui et al. (2018) showed that for similar densities, the results of the various comparative  
302 analyses indicate no significant differences between the parameters evaluated. With regard to ( $K_{IC}$ ),  
303 Padouk wood has higher values than Bilinga and Dabema wood on the low-prime specimens. The  
304 higher density of Padouk wood can explain this.

## 305 **Conclusion**

306 This work aimed to study the fracture parameters of three tropical species from the Cameroon  
307 forest, namely Dabema (*Piptadeniasmetrum africanum*), Bilinga (*Diderrichii nauclea*) and Padouk  
308 (*Pterocarpus soyauxii* Taub). The physical properties (water content, basal density), mechanical  
309 properties (young's modulus, bending stress) and energy properties (energy restitution rate, stress  
310 intensity factor) were determined. The average values of the modulus of elasticity (MOE) obtained

311 for from the different species are between 8392.31 and 9905.29 MPa. The bending failure stresses  
312 are between 66.94 and 89.82 MPa. Dabema, Bilinga and Padouk are woods with medium mechanical  
313 resistance. The results show that the energy restitution rate for Dabema is 581.11 j/m<sup>2</sup>, for Bilinga  
314 519.72 j/m<sup>2</sup>, and for Padouk 201.61j/m<sup>2</sup> and the stress intensity factor for Dabema 0. 98 MPa\*m<sup>1/2</sup>,  
315 for Bilinga 1.28 MPa\*m<sup>1/2</sup>, and for Padouk 1.10 MPa\*m<sup>1/2</sup>. The results show that Dabema and Bilinga  
316 have more ductile behavior, i.e., the rate of energy restitution is much higher than Padouk's. However,  
317 Padouk and Bilinga have a higher stress intensity factor than Dabema for this reason, Dabema and  
318 Bilinga are more resistant to crack propagation than Padouk.

319 On the other hand, Bilinga and Padouk absorb much more of the energy at the origin of  
320 microcracks than Dabema. However, the differences observed between the three woods studied show  
321 the need to extend the study of cracking behavior to other tropical woods. In this respect, African  
322 tropical woods stand out with some confidence, given their exceptional characteristics. Finally, in a  
323 global context marked by strong competition between wood and other construction materials, we will  
324 opt for a strategy of applying our results. All our results will be published as they become available.  
325 Dissemination will be open to all contractors and will not be restricted by any pressure group. What's  
326 more, if we are successful, the necessary developments that will accompany the industrial transfer to  
327 Cameroon will make better use of the diversity of tree species. In future studies, different loading  
328 modes and three-dimensional effects will also be taken into account using the Mixed Mode Crack  
329 Growth Specimen in order to better study the effect of scale and its impact on wood failure. The  
330 impact of moisture variation on the cracking parameters of this type of wood will also be investigated

### 331 **Conflicts of interest**

332 The authors declare that they have no conflicts of interest to report regarding the present study

333

334 **References**

- 335 Benedetti, Andrea, Giacomo Pignagnoli, and Mirco Tarozzi. 2018. "Damage Identification of Cracked  
336 Reinforced Concrete Beams through Frequency Shift." *Materials and Structures/Materiaux et*  
337 *Constructions* 51 (6). <https://doi.org/10.1617/s11527-018-1275-z>.
- 338 Bertolin, Chiara, Poorya Karvan, Andrea De Rosa, Nima Razavi, and Filippo Berto. 2021. "Relation between  
339 Fracture Characteristics and Moisture Content along Longitudinal Direction in a Naturally Drying Scots  
340 Pine." *Theoretical and Applied Fracture Mechanics* 112 (November 2020): 102911.  
341 <https://doi.org/10.1016/j.tafmec.2021.102911>.
- 342 Boadu, K. B., Antwi-Boasiako, C., & Frimpong-Mensah, K. 2017. "Physical and Mechanical Properties of  
343 Klainedoxa Gabonensis with Engineering Potentia." *Journal of Forestry Research* 28 (3): 629–36.
- 344 CIFOR. 2014. "Priorités de Recherche Du CIFOR."
- 345 Ding, Z. H., M. Huang, and Z. R. Lu. 2016. "Structural Damage Detection Using Artificial Bee Colony  
346 Algorithm with Hybrid Search Strategy." *Swarm and Evolutionary Computation* 28: 1–13.  
347 <https://doi.org/10.1016/j.swevo.2015.10.010>.
- 348 Dourado, N, M F S F De Moura, J Xavier, and F A M Pereira. 2015. "A New Procedure for Mode I Fracture  
349 Characterization of Cement-Based Materials," 483–91. <https://doi.org/10.1111/str.12165>.
- 350 Engonga Edzang, A. C. S., Pambou Nziengui, C. F., Ekomy Ango, S., Ikogou, S., & Moutou Pitti, R. 2021.  
351 "Comparative Studies of Three Tropical Wood Species under Compressive Cyclic Loading and Moisture  
352 Content Changes." *Wood Material Science & Engineering* 16 (3): 196–203.
- 353 FAO. 2006. "Food and Agriculture Organization of the United Nations." *Global Forest Resources Assessment*  
354 *2005: Progress towards Sustainable Forest Management*. FAO Forest.
- 355 Forsman, Karin, Maria Fredriksson, Erik Serrano, and Henrik Danielsson. 2021. "Moisture-Dependency of the  
356 Fracture Energy of Wood: A Comparison of Unmodified and Acetylated Scots Pine and Birch."  
357 *Holzforschung* 75 (8): 731–41. <https://doi.org/10.1515/hf-2020-0174>.
- 358 Fröhmann. n.d. "Fracture Characteristics of Wood under Mode I, Mode II and Mode III Loading," no.  
359 November 2014: 37–41. <https://doi.org/10.1080/01418610208240441>.
- 360 Fu, J., H. Haeri, M. D. Yavari, V. Sarfarazi, M. F. Marji, and M. Guo. 2021. "A Linear Elastic Fracture  
361 Mechanics Analysis of the Pre-Cracked Concrete Failure Mechanism Under Modes I, II, III, and IV  
362 Loading Conditions." *Strength of Materials* 53 (5): 784–96. [https://doi.org/10.1007/s11223-021-00344-](https://doi.org/10.1007/s11223-021-00344-5)  
363 5.
- 364 Fu, J. W., H. Haeri, V. Sarfarazi, and M. F. Marji. 2022. "Modeling the Ligament Breakage Mechanism in  
365 Concrete Specimens Using a Four-Point Bending Test." *Strength of Materials* 54 (4): 671–80.  
366 <https://doi.org/10.1007/s11223-022-00445-9>.
- 367 Fu, J.W., Li, T., Haeri, H. 2023. "Acoustic emission monitoring of crack growth from echelon notches using  
368 numerical simulation." *Strength of Materials*, 55(1):128-145
- 369 Gérard, Jean., Daniel. Guibal, Sébastien. Paradis, and Jean-Claude. Cerre. 2017. *Tropical Timber Atlas:*  
370 *Technological Characteristics and Uses*.

371 Gérard, Jean, A Edi Kouassi, C Daigremont, P Détienne, D Fouquet, and M L B - Gerard1998 Vernay. 1998.  
372 *Synthèse Sur Les Caractéristiques Technologiques de Référence Des Principaux Bois Commerciaux*  
373 *Africains*. CIRAD-forêt.

374 Gomes, Guilherme Ferreira, Yohan Alí Diaz Mendéz, Sebastião Simões da Cunha, and Antônio Carlos  
375 Ancelotti. 2018. “A Numerical–Experimental Study for Structural Damage Detection in CFRP Plates  
376 Using Remote Vibration Measurements.” *Journal of Civil Structural Health Monitoring* 8 (1): 33–47.  
377 <https://doi.org/10.1007/s13349-017-0254-3>.

378 Grandgirard, Julie, Denis Poinso, Liliane Krespi, Jean Pierre Nénon, and Anne Marie Cortesero. 2002. “Costs  
379 of Secondary Parasitism in the Facultative Hyperparasitoid *Pachycrepoideus Dubius*: Does Host Size  
380 Matter?” *Entomologia Experimentalis et Applicata* 103 (3): 239–48. <https://doi.org/10.1023/A>.

381 Grédiac, M., & Hild, F. (Eds.). (2012). *Full-field measurements and identification in solid mechanics*. John  
382 Wiley & Sons.

383 Gross, B., & Srawley, J. E. 1965. “Stress-Intensity Factors for Single-Edge-Notch Specimens in Bending or  
384 Combined Bending and Tension by Boundary Collocation of a Stress Function.” *National Aeronautics*  
385 *and Space Administration*. 2603.

386 Hassan Vand, Mojtaba, Jan Tippner, and Martin Brabec. 2023. “Effects of Species and Moisture Content on  
387 the Behaviour of Solid Wood under Impact.” *European Journal of Wood and Wood Products*, no. 2015.  
388 <https://doi.org/10.1007/s00107-023-01986-9>.

389 Irwin, G. R. 1958. “Discussion of the Dynamic Stress Distribution Surrounding a Running Crack-A  
390 Photoelastic Analysis.” *In SESA Proc* Vol. 16: 93–96.

391 J.W.Fu, T.Li, and H. Haeri. 2023. “ACOUSTIC EMISSION MONITORING OF CRACK GROWTH FROM  
392 ECHELON NOTCHES USIN NUMERICAL SIMULATION.”

393 Jozsa, L. A., & Middleton, G. R. 1994. “A Discussion of Wood Quality Attributes and Their Practical  
394 Implications.”

395 Jungstedt, Erik, Sören Östlund, and Lars A. Berglund. 2022. “Transverse Fracture Toughness of Transparent  
396 Wood Biocomposites by FEM Updating with Cohesive Zone Fracture Modeling.” *Composites Science*  
397 *and Technology* 225 (July): 109492. <https://doi.org/10.1016/j.compscitech.2022.109492>.

398 Konukcu, Arif C, Izmir Katip, and Celebi Universitesi. 2022. “Determination of Mode I Fracture Behavior of  
399 Southern Yellow Pine ( *Pinus Taeda L .* ) Wood Using Single-Edge-Notched Bending Test,” no. April.  
400 <https://doi.org/10.37763/wr.1336-4561/67.2.280290>.

401 Konukcu, Arif Caglar. 2022. “Fracture Behavior of Wood Under Mode I Loading in Tangential Direction.”  
402 *Drvna Industrija* 73 (4): 445–52. <https://doi.org/10.5552/drvind.2022.2135>.

403 Konukcu, Arif Caglar, Franklin Quin, and Jilei Zhang. 2021. “Effect of Growth Rings on Fracture Toughness  
404 of Wood.” *European Journal of Wood and Wood Products* 79 (6): 1495–1506.  
405 <https://doi.org/10.1007/s00107-021-01738-7>.

406 Kurul, Fatih, and Hizir Volkan Görgün. 2022. “EFFECT OF THERMAL MODIFICATION ON SOME  
407 PHYSICAL AND MECHANICAL PROPERTIES OF YELLOW POPLAR (*Liriodendron Tulipifera*).”

408 *Drewno* 65 (209). <https://doi.org/10.12841/wood.1644-3985.380.01>.

409 Luimes, R. A., A. S.J. Suiker, C. V. Verhoosel, A. J.M. Jorissen, and H. L. Schellen. 2018. “Fracture Behaviour  
410 of Historic and New Oak Wood.” *Wood Science and Technology* 52 (5): 1243–69.  
411 <https://doi.org/10.1007/s00226-018-1038-6>.

412 Maaß, Mona-christin, Salimeh Saleh, Holger Militz, and Cynthia A Volkert. 2020. “The Structural Origins of  
413 Wood Cell Wall Toughness” 1907693. <https://doi.org/10.1002/adma.201907693>.

414 Majano Majano, M. Almudena, Mark Hughes, and José L. Fernández-Cabo. 2010. “A Fracture Mechanics  
415 Study of Thermally Modified Beech for Structural Applications.” *11th World Conference on Timber  
416 Engineering 2010, WCTE 2010* 3 (November 2014): 2103–8.

417 Mall, By S., and James E. Shottafer Joseph F. Murphy, M. ASCE. 1983. “Criterion for Mixed Mode  
418 Fracture in Wood” 109 (3): 680–90.

419 Maria, Cicilia, Erna Susanti, Tetsuya Nakao, and Hiroshi Yoshihara. 2010. “Examination of the Failure  
420 Behaviour of Wood with a Short Crack in the Tangential – Radial System by Single-Edge-Notched  
421 Bending Test.” *Engineering Fracture Mechanics* 77 (13): 2527–36.  
422 <https://doi.org/10.1016/j.engfracmech.2010.05.019>.

423 Merhar, Miran, Rostand Moutou Pitti, and Tom Argensse. 2023. “Mode I Fracture Properties of Thermally-  
424 Modified Spruce Wood (*Picea Abies*) at Different Moisture Contents.” *Wood Material Science and  
425 Engineering* 18 (6): 2093–2103. <https://doi.org/10.1080/17480272.2023.2228280>.

426 Moura, M F S F De, and N Dourado. 2018. “Mode I Fracture Characterization of Wood Using the TDCB  
427 Test.” *Theoretical and Applied Fracture Mechanics* 94 (December 2017): 40–45.  
428 <https://doi.org/10.1016/j.tafmec.2018.01.005>.

429 Nakao, Tetsuya, Cicilia Maria, and Erna Susanti. 2012. “Examination of the Failure Behavior of Wood with a  
430 Short Crack in the Radial – Longitudinal System by Single-Edge-Notched Bending Test,” 453–58.  
431 <https://doi.org/10.1007/s10086-012-1266-6>.

432 NF B51- 004. 1985. “Bois - Détermination de l’humidité.” *Afnor*, 8.

433 NF B51-005. 1985. “Détermination de La Masse Volumique.” *Afnor*, 8.

434 NF B51 - 008. 2017. “Essai de Flexion Statique - Détermination de La Résistance à La Flexion Statique de  
435 Petites Éprouvettes sans Défauts.” *Afnor*, 20.

436 Nziengui, C. P., Turesson, J., Odounga, B. 2018. “Détermination Des Principales Caractéristiques Physiques  
437 et Mécaniques Du Sapin Blanc Du Massif Central et de l’ Okoumé Du Gabon .,” no. May.

438 Odounga, Bernard, Moutou Pitti, Evelyne Toussaint, and Michel Grédiac. 2019. “Mixed Mode Fracture of  
439 Some Tropical Species with the Grid Method.” *Engineering Fracture Mechanics*, no. January: 0–1.  
440 <https://doi.org/10.1016/j.engfracmech.2019.04.018>.

441 Odounga, Bernard, Evelyne Toussaint, and Michel Grédiac. 2018. “Mode I Fracture of Tropical Woods Using  
442 Grid Method.” *Theoretical and Applied Fracture Mechanics* 95 (January): 1–17.  
443 <https://doi.org/10.1016/j.tafmec.2018.02.006>.

444 Ostapska, Katarzyna, and Kjell Arne Malo. 2020. “Wedge Splitting Test of Wood for Fracture Parameters

445 Estimation of Norway Spruce.” *Engineering Fracture Mechanics*, no. March: 107024.  
446 <https://doi.org/10.1016/j.engfracmech.2020.107024>.

447 Phan, Ngoc Anh, Myriam Chaplain, Stéphane Morel, and Jean Luc Coureau. 2017. “Influence of Moisture  
448 Content on Mode I Fracture Process of Pinus Pinaster: Evolution of Micro-Cracking and Crack-Bridging  
449 Energies Highlighted by Bilinear Softening in Cohesive Zone Model.” *Wood Science and Technology* 51  
450 (5): 1051–66. <https://doi.org/10.1007/s00226-017-0907-8>.

451 Ravenshorst, G. J. P., Gard, W. F. and van de Kuilen, J. W. G. 2013. “The Importance of Characterisation and  
452 Sampling of Tropical Wood Species with Regard to Strength and Durability Classification.” *HERON* 58  
453 (2/3): 195–222.

454 Reiterer, A., & Tschegg, S. 2002. “The Influence of Moisture Content on the Mode I Fracture Behaviour of  
455 Sprucewood,” no. January. <https://doi.org/10.1023/A>.

456 Reiterer, A, and G Sinn. 2002. “Fracture Characteristics of Different Wood Species under Mode I Loading  
457 Perpendicular to the Grain Fracture Characteristics of Different Wood Species under Mode I Loading  
458 Perpendicular to the Grain” 5093 (September 2017). [https://doi.org/10.1016/S0921-5093\(01\)01721-X](https://doi.org/10.1016/S0921-5093(01)01721-X).

459 Romanowicz, Marek. 2022. “Numerical Assessment of the Apparent Fracture Process Zone Length in Wood  
460 under Mode I Condition Using Cohesive Elements.” *Theoretical and Applied Fracture Mechanics* 118  
461 (April): 103229. <https://doi.org/10.1016/j.tafmec.2021.103229>.

462 Simpson, William T. 1991. “Dry Kiln Operator ’ s Manual Dry Kiln Operator ’ s Manual Edited by,” no. 188:  
463 41.

464 Stanzl-Tschegg, S. 2006. “Microstructure and Fracture Mechanical Response of Wood,” no. May.  
465 <https://doi.org/10.1007/s10704-006-0052-0>.

466 Stanzl-Tschegg, S. E. 2006. “Microstructure and Fracture Mechanical Response of Wood,” no. June 2006.  
467 <https://doi.org/10.1007/s10704-006-0052-0>.

468 Wang, Q., L. J. Sun, D. C. Wang, J. W. Fu, C. L. Guo, and H. Haeri. 2023. “Particle Flow Modeling for the  
469 Crack Growth Analysis of Non-Persistent Cracks.” *Strength of Materials* 55 (2): 371–83.  
470 <https://doi.org/10.1007/s11223-023-00531-6>.

471 Yin, Xing, Qinghua Li, Qingmin Wang, Hans Wolf Reinhardt, and Shilang Xu. 2023. “The Double-K Fracture  
472 Model: A State-of-the-Art Review.” *Engineering Fracture Mechanics* 277 (December).  
473 <https://doi.org/10.1016/j.engfracmech.2022.108988>.

474 Yu, Ying, Ruixue Xin, Weihang Zeng, and Wen Liu. 2021. “Fracture Resistance Curves of Wood in the  
475 Longitudinal Direction Using Digital Image Correlation Technique.” *Theoretical and Applied Fracture  
476 Mechanics* 114 (August): 102997. <https://doi.org/10.1016/j.tafmec.2021.102997>.

477 Zhou, Y., J. W. Fu, D. C. Wang, H. Haeri, L. J. Sun, and C. L. Guo. 2022. “Numerical Investigation of the  
478 Influence of Circular Fillings on the Failure Mechanism in Samples Containing Nonpersistent Joints  
479 Under Shear Loading Conditions.” *Strength of Materials* 54 (5): 880–88. [https://doi.org/10.1007/s11223-  
480 022-00465-5](https://doi.org/10.1007/s11223-022-00465-5).

481 Zhu, Xian Kui, and James A. Joyce. 2012. “Review of Fracture Toughness (G, K, J, CTOD, CTOA) Testing

482 and Standardization.” *Engineering Fracture Mechanics* 85: 1–46.  
483 <https://doi.org/10.1016/j.engfracmech.2012.02.001>.  
484

485 **Table 1.** Physical characteristics of the three species studied

Species	Properties			
	Water Content% (%)	Standard deviation	Basal density g/cm <sup>3</sup>	Standard deviation
Padouk	19.14	7.32	0.83	0.05
Bilinga	22.10	9.67	0.73	0.03
Dabema	25.63	11.79	0.69	0.03

486

487 **Table 2.** Mechanical characteristics.

species	Properties					
	Young's modulus(MPa)	Standard deviation	Covariance% (%)	Bending stress (MPa)	Standard deviation	Covariance% (%)
Padouk	9905.29	601.09	1016.37	89.82	6.45	1016.37
Bilinga	9565.36	1112.7	821.28	81.68	16.74	821.28
Dabema	8392.31	2081.09	692.57	66.94	17.82	692.57

488

489 **Table 3.** Variation in energy parameters between three tropical woods

Designation	Number of samples tested per wood	Dabema	Bilinga	Padouk
<i>Energy recovery rate Gic(j/m<sup>2</sup>)</i>				
a = 0 mm	05	(1612.10 ±623.21) <sup>ab</sup>	(1747.91 ±520.14) <sup>a</sup>	(2958.63 ±918.92) <sup>a</sup>
a = 4 mm	05	(885.87±401.96) <sup>ab</sup>	(989.63 ±694.11) <sup>a</sup>	(2231.14±1272.14) <sup>a</sup>
a = 8 mm	05	(581.11±226.91) <sup>a</sup>	(519.72 ±91.46) <sup>a</sup>	(490.61±201.28) <sup>a</sup>
<i>Stress intensity factor Kic(MPa*m<sup>1/2</sup>)</i>				
a = 4 mm	05	(1.29 ±0.38) <sup>a</sup>	(1.51 ±0.42) <sup>a</sup>	(2.41±0.90) <sup>a</sup>
a = 8 mm	05	(0.98±0.44) <sup>a</sup>	(1.28 ±0.39) <sup>a</sup>	(1.10±0.20) <sup>a</sup>
<i>Flexural stress <math>\sigma_n</math> (MPa)</i>				
a = 0 mm	05	(66.94±17.82) <sup>a</sup>	(81.68 ±16.74) <sup>a</sup>	(89.82 ±6.45) <sup>a</sup>
a = 4 mm	05	(37.15±11.08) <sup>b</sup>	(43.46±11.98) <sup>ab</sup>	(69.34 ±25.94) <sup>a</sup>
a = 8 mm	05	(16.78 ±7.56) <sup>a</sup>	(21.85±6.56) <sup>a</sup>	(18.77 ±3.47) <sup>a</sup>

490 The same letter in the subscript indicates that the mean values provided by each wood for the same primer  
 491 value are not significantly different at the significance level  $\alpha = 0.05$  (Tukey test).

492

493 **Table 4.** Results of the analysis of variance testing the effect of fracture parameters (wood species, crack  
 494 length) on cracking resistance

Designation	Number of samples tested per wood	Dabema	Bilinga	Padouk
<i>Energy recovery rate <math>G_{ic}</math>(j/m<sup>2</sup>)</i>				
a = 0 mm	05	(1612.096± 623) <sup>a</sup>	(1747.912±520.14) <sup>b</sup>	(2958.626± 918) <sup>b</sup>
a = 4 mm	05	(885.872 ±401.9) <sup>ab</sup>	(989.63±694) <sup>ab</sup>	(2231.136± 1272) <sup>b</sup>
a = 8 mm	05	(581.108± 226.91) <sup>a</sup>	(519.72±91.47) <sup>a</sup>	(490.610 ± 201) <sup>a</sup>
Pvalue		(0.00968)	(0.00746)	(0.00319)
<i>Stress intensity factor <math>K_{ic}</math>(MPa*m<sup>1/2</sup>)</i>				
a = 4 mm	05	(288± 0.383) <sup>a</sup>	(1.506± 0.416) <sup>a</sup>	2.406 ±0.9) <sup>b</sup>
a = 8 mm	05	(0.982± 0.441) <sup>a</sup>	(1.280± 0.385) <sup>a</sup>	1.098 ±0.2) <sup>a</sup>
Pvalue		(0.276)	(0.399)	(0.0134)
<i>Flexural stress <math>\sigma_n</math> (MPa)</i>				
a = 0 mm	05	(66.938± 17.817) <sup>b</sup>	(81.68± 16.73) <sup>c</sup>	89,82 (6,45) <sup>b</sup>
a = 4 mm	05	(37.148 ±11) <sup>a</sup>	(43.46± 11.98) <sup>b</sup>	69.34 (25.94) <sup>b</sup>
a = 8 mm	05	(16.778 ± 7.554) <sup>a</sup>	(21.85 ± 6.55) <sup>a</sup>	18.77 (3.47) <sup>a</sup>
Pvalue		(0.000182)	(0.0000233)	0.0000323

495

496 **Figure captions**

497 **Figure 1.** (A) Billets and quarterlots of the species used, (B) Procedure for cutting the specimens; (C) specimens  
498 of the three species of wood.

499 **Figure 2.** A) External view of the oven; B) Weighing of our test specimens.

500 **Figure 3.** Kinematic diagram of the bending test device consisting of the following elements:1. Elastic ring,  
501 2. Digital comparator, 3. Force, 4Fixed support,5. Digital comparator, 6 Comparator support lever, 7 Hand  
502 wheel, 8. Comparator fixed support, 9. lever rotation speed indicator, 10. frame, 11. test tube, 12. plate and 13.  
503 piston.

504 **Figure 4.** The general configuration of the test set-up for the SENB test ( $S=320$ ,  $B=20$ ,  $W=20$ )

505 **Figure 5.** Representative load-displacement curves for the different primer values and for each wood: (a)  
506 Padouk, (b) Bilinga and (c) Dabema.

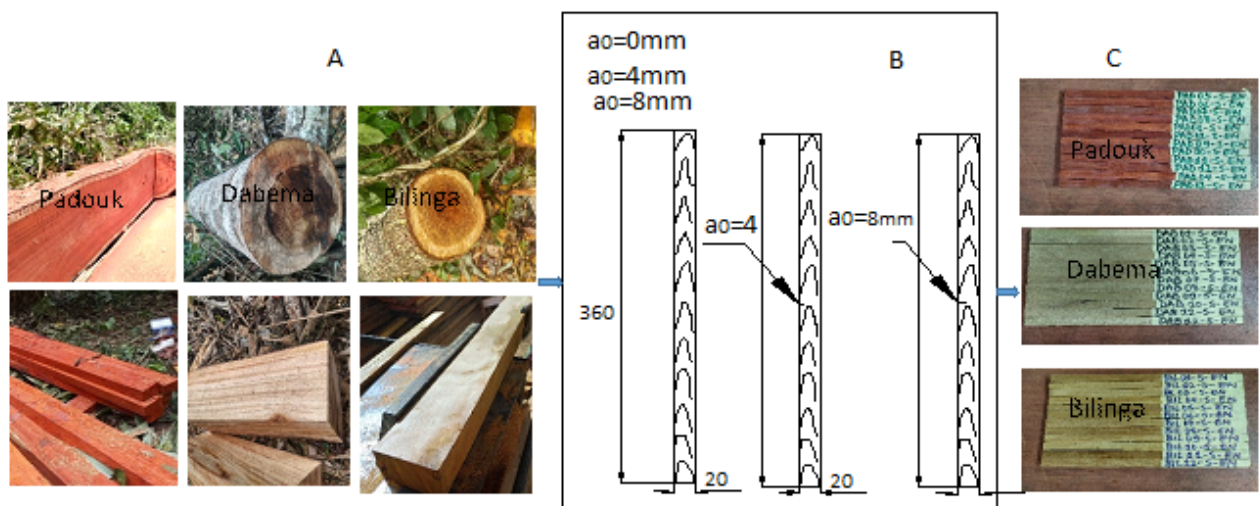
507 **Figure 6.** Failure of specimens in mode I

508 **Figure 7.** Typical tangential structure profiles of three wood species showing fibre orientation and  
509 microstructure Padouk (a), Dabema(b) and Bilinga(c).

510 **Figure 8.** Distribution of the energy restitution rate, the stress intensity factor and the average and maximum  
511 stress resistance of the three groups: A0 specimens without notches; A1 specimens with 4mm deep notches  
512 and A2 specimens with 8mm notches.

513 **Figure 9.** Comparison of the amplitudes of the energy restitution rate ( $G_{ic}$ ) of three different lengths of primers  
514 on the Padouk, Bilinga and Dabema specimens.

515 **Figure 10.** Effects on the amplitude of the energy restitution rate  $G_{ic}$  and the stress intensity factor  $K_{ic}$  (their  
516 maximum values) of Padouk, Bilinga and Dabema specimens as a function of the density of each species. ( $a_0$ )  
517 denotes the initiation length.



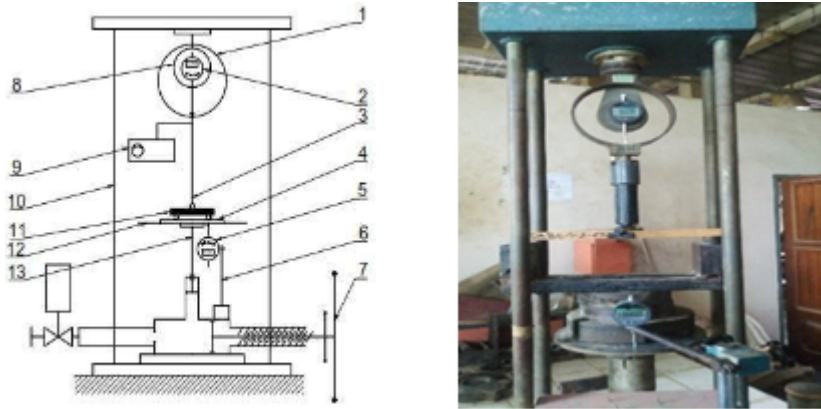
518

519 **Figure 1.**



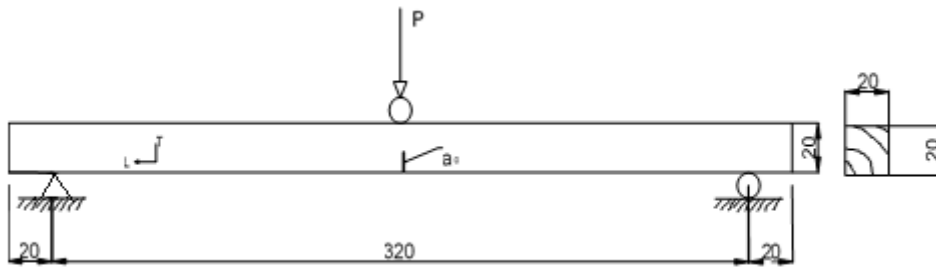
520

521 **Figure 2.**



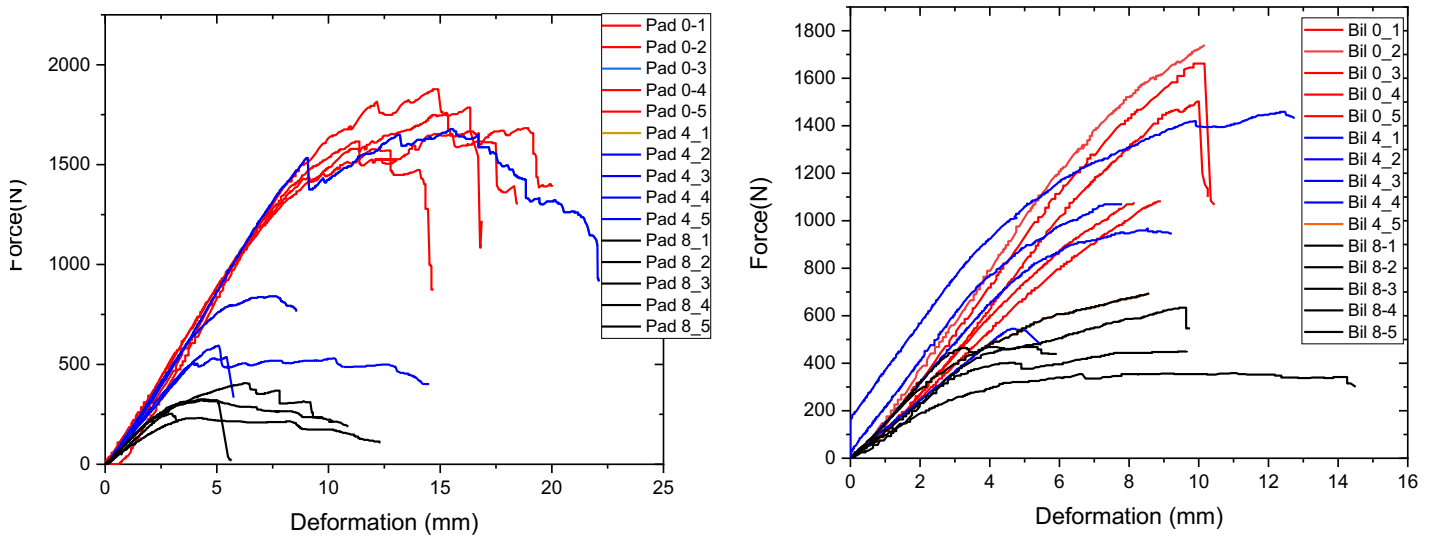
522

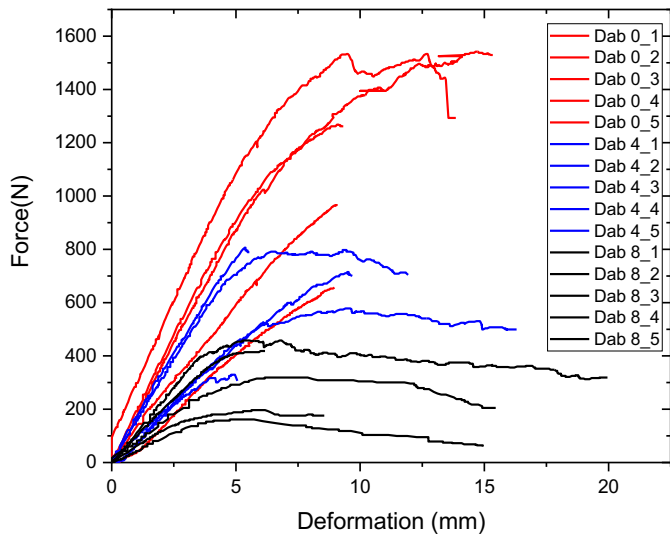
523 **Figure 3.**



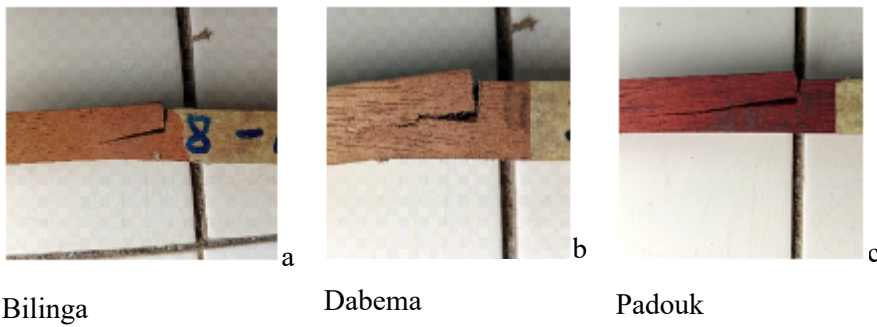
524

525 **Figure 4.**



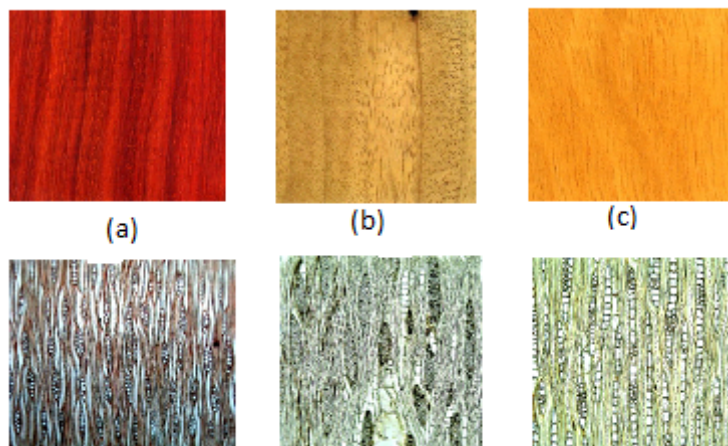


526 **Figure 5.**



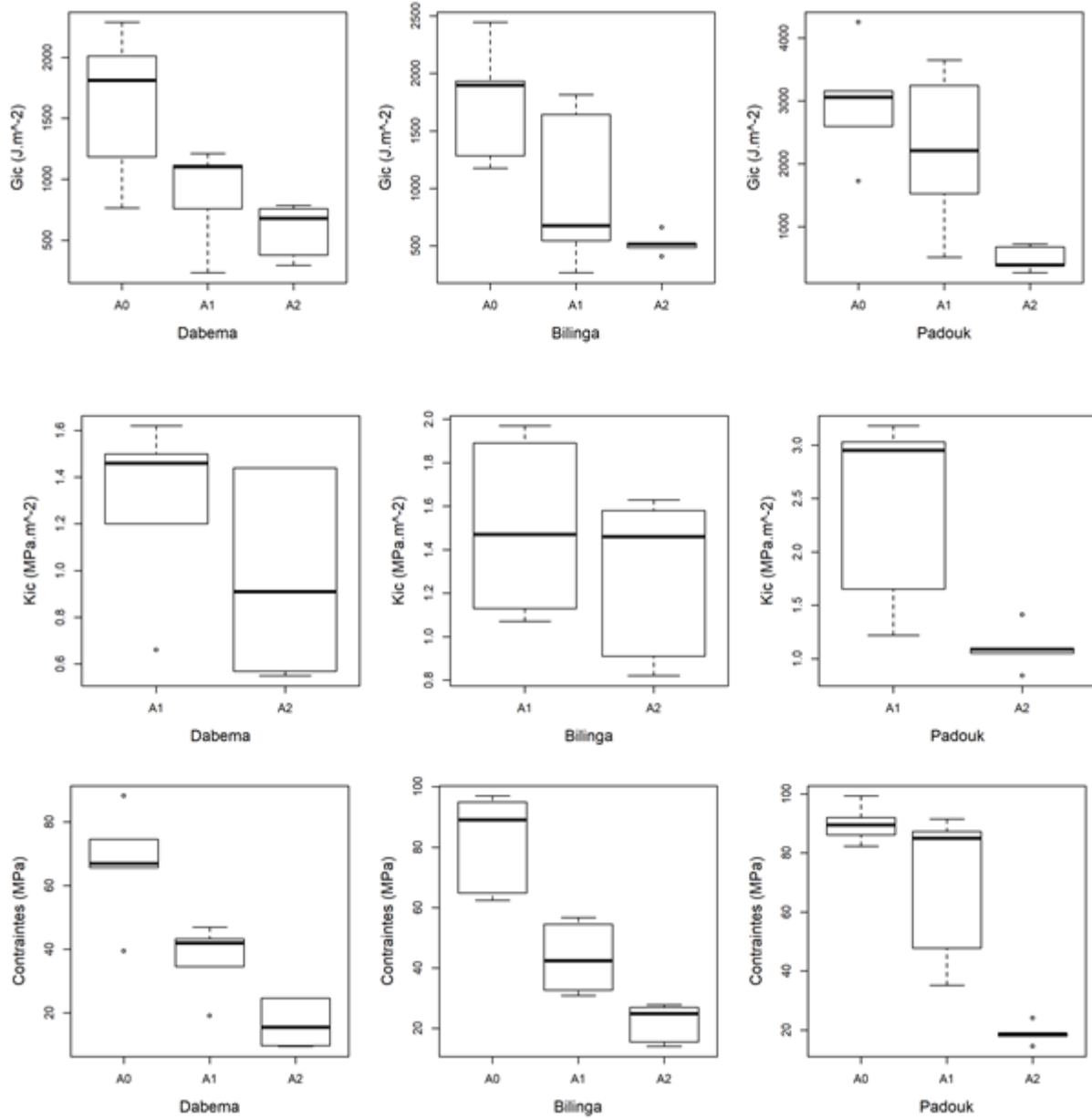
527

528 **Figure 6.**

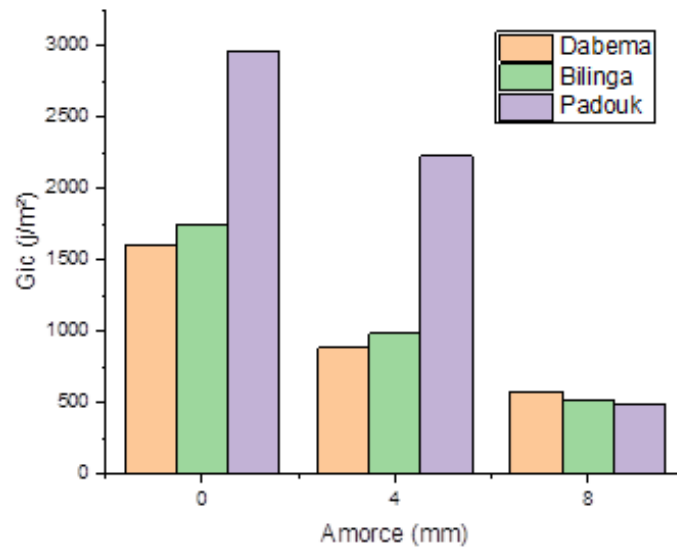


529

530 **Figure 7.**

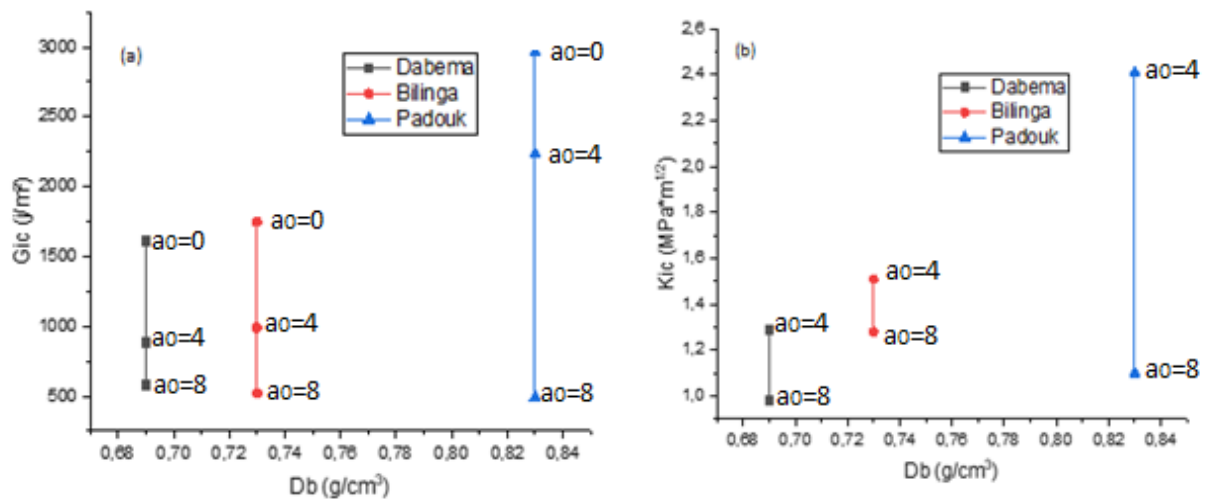


531 Figure 8.



532

533 **Figure 9.**



534 **Figure 10.**