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► **To cite this version:**

Rosmi Biyo'o, Achille Bernard Biwole, Rostand Moutou Pitti, Charly Julien Nyobe, Benoit Ndiwe, et al.. Mode I cracking of three tropical species from Cameroon: the case of bilinga, dabema, and padouk wood. Wood Material Science and Engineering, inPress, 10.1080/17480272.2024.2314750 . hal-04617275

HAL Id: hal-04617275

<https://hal.science/hal-04617275v1>

Submitted on 19 Jun 2024

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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/m² for *Dabema*,
30 519.72 j/m² for Bilinga and 201.61 j/m² for *Padouk*, and a stress intensity factor of 0.98 MPa*m^{1/2}
31 for Dabema, 1.28 MPa*m^{1/2} for Bilinga and 1.0 MPa*m^{1/2} 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 /cm³, M_0 in g and V_s in cm³

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 (N/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); ΔF : variation in the load applied until failure
139 (N); Δf : 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- δ curves, namely the stress intensity factor
157 (K_{IC}), nominal bending stress (σ_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- δ 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, δ 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 ± 0.03) for Bilinga; (0.83 ± 0.05) for Padouk and Dabema (0.69 ± 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/m², for Bilinga
314 519.72 j/m², and for Padouk 201.61j/m² and the stress intensity factor for Dabema 0. 98 MPa*m^{1/2},
315 for Bilinga 1.28 MPa*m^{1/2}, and for Padouk 1.10 MPa*m^{1/2}. 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

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484

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

Species	Properties			
	Water Content% (%)	Standard deviation	Basal density g/cm ³	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/m²)</i>				
a = 0 mm	05	(1612.10 ±623.21) ^{ab}	(1747.91 ±520.14) ^a	(2958.63 ±918.92) ^a
a = 4 mm	05	(885.87±401.96) ^{ab}	(989.63 ±694.11) ^a	(2231.14±1272.14) ^a
a = 8 mm	05	(581.11±226.91) ^a	(519.72 ±91.46) ^a	(490.61±201.28) ^a
<i>Stress intensity factor Kic(MPa*m^{1/2})</i>				
a = 4 mm	05	(1.29 ±0.38) ^a	(1.51 ±0.42) ^a	(2.41±0.90) ^a
a = 8 mm	05	(0.98±0.44) ^a	(1.28 ±0.39) ^a	(1.10±0.20) ^a
<i>Flexural stress σ_n (MPa)</i>				
a = 0 mm	05	(66.94±17.82) ^a	(81.68 ±16.74) ^a	(89.82 ±6.45) ^a
a = 4 mm	05	(37.15±11.08) ^b	(43.46±11.98) ^{ab}	(69.34 ±25.94) ^a
a = 8 mm	05	(16.78 ±7.56) ^a	(21.85±6.56) ^a	(18.77 ±3.47) ^a

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 G_{ic}(j/m²)</i>				
a = 0 mm	05	(1612.096± 623) ^a	(1747.912±520.14) ^b	(2958.626± 918) ^b
a = 4 mm	05	(885.872 ±401.9) ^{ab}	(989.63±694) ^{ab}	(2231.136± 1272) ^b
a = 8 mm	05	(581.108± 226.91) ^a	(519.72±91.47) ^a	(490.610 ± 201) ^a
Pvalue		(0.00968)	(0.00746)	(0.00319)
<i>Stress intensity factor K_{ic}(MPa*m^{1/2})</i>				
a = 4 mm	05	(288± 0.383) ^a	(1.506± 0.416) ^a	2.406 ±0.9) ^b
a = 8 mm	05	(0.982± 0.441) ^a	(1.280± 0.385) ^a	1.098 ±0.2) ^a
Pvalue		(0.276)	(0.399)	(0.0134)
<i>Flexural stress σ_n (MPa)</i>				
a = 0 mm	05	(66.938± 17.817) ^b	(81.68± 16.73) ^c	89,82 (6,45) ^b
a = 4 mm	05	(37.148 ±11) ^a	(43.46± 11.98) ^b	69.34 (25.94) ^b
a = 8 mm	05	(16.778 ± 7.554) ^a	(21.85 ± 6.55) ^a	18.77 (3.47) ^a
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.

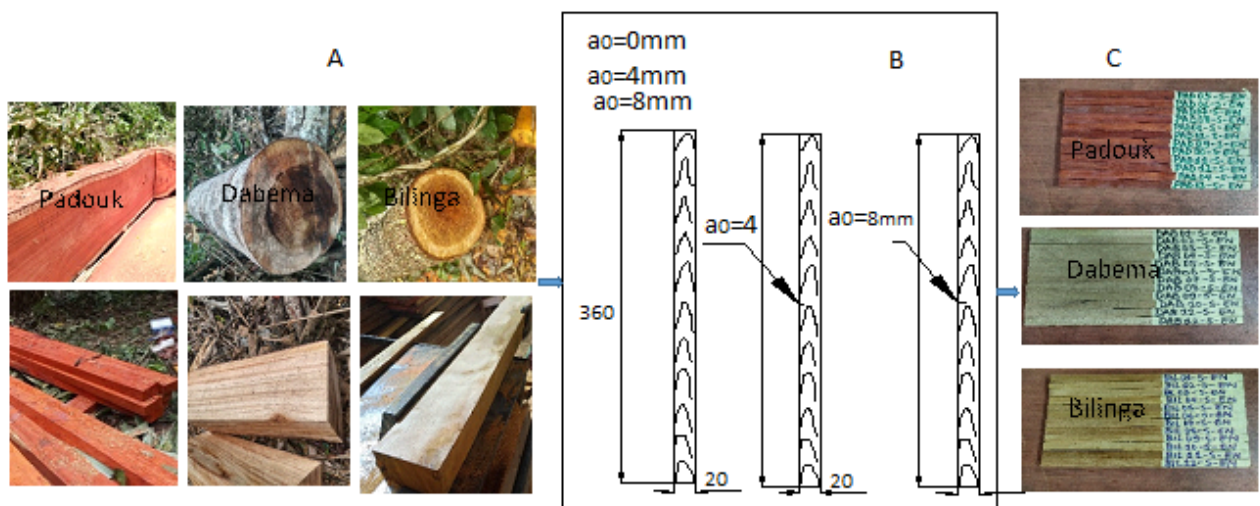
507 **Figure 6.** Failure of specimens in mode I

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.



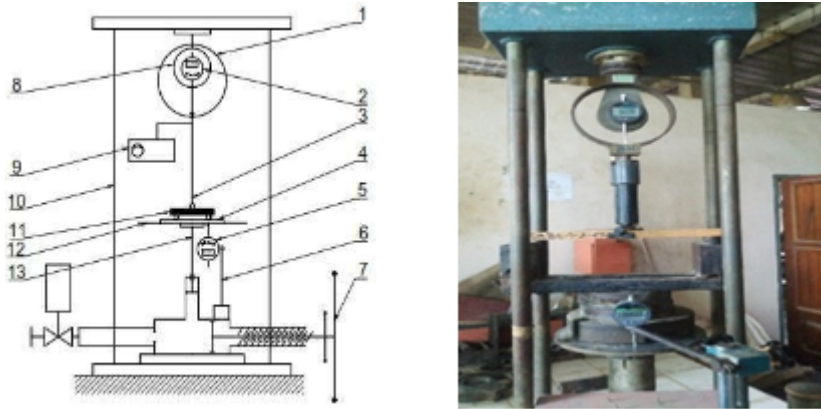
518

519 **Figure 1.**



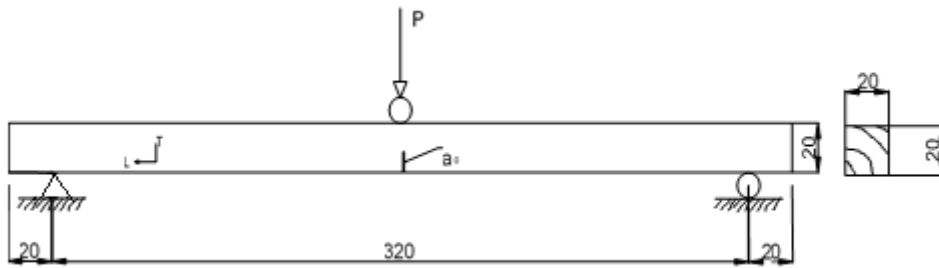
520

521 **Figure 2.**



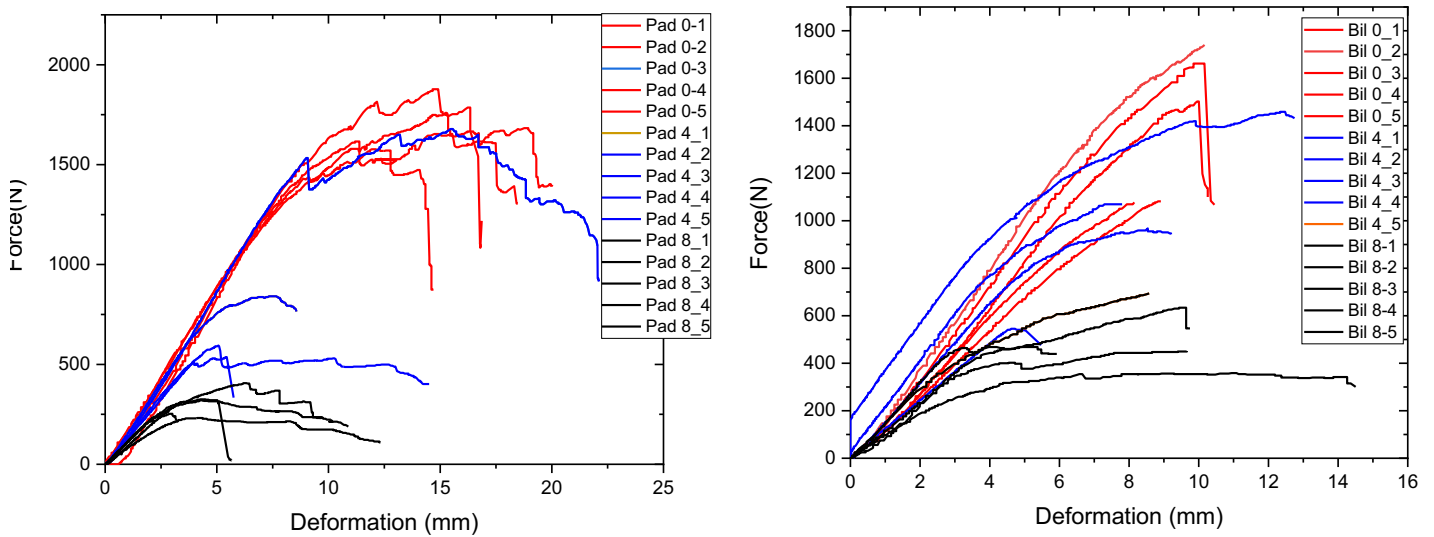
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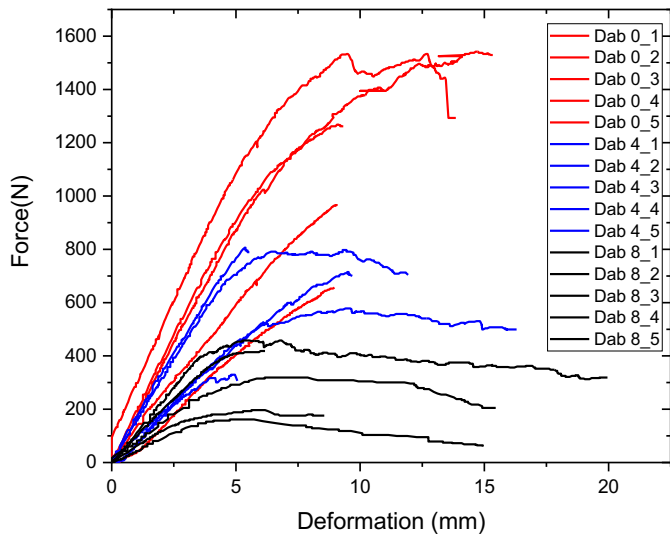
523 **Figure 3.**



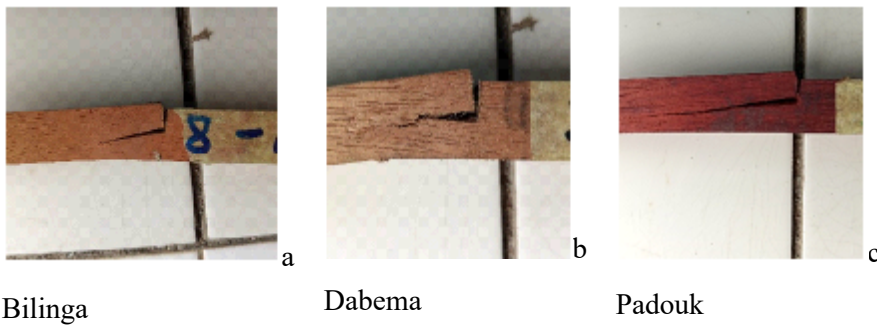
524

525 **Figure 4.**



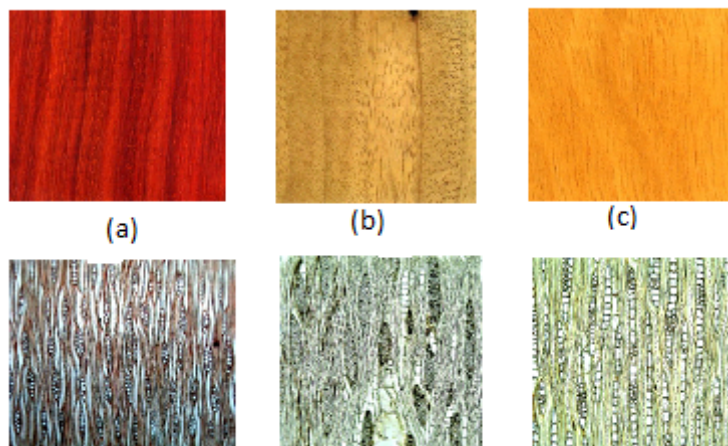


526 **Figure 5.**



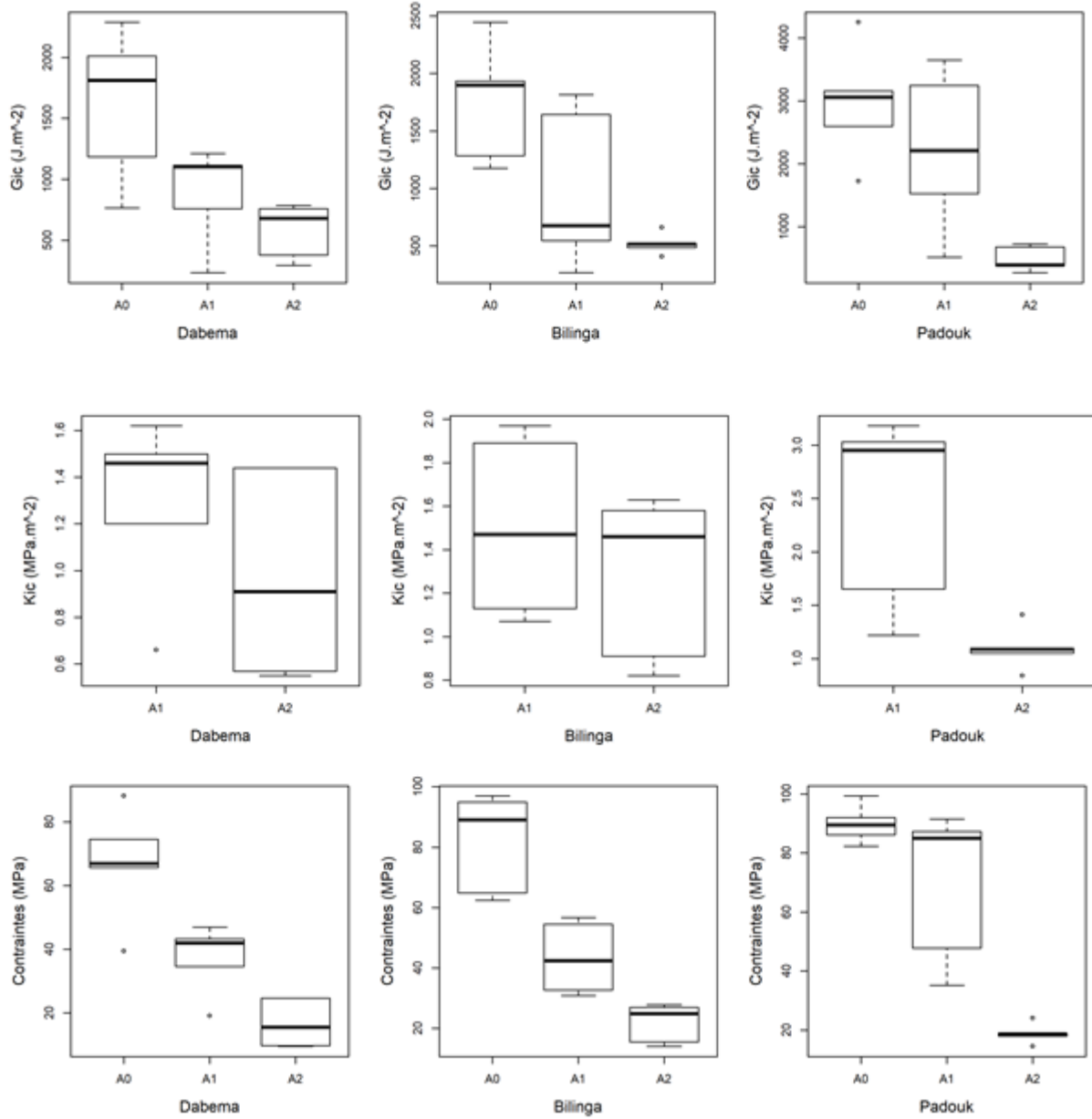
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528 **Figure 6.**

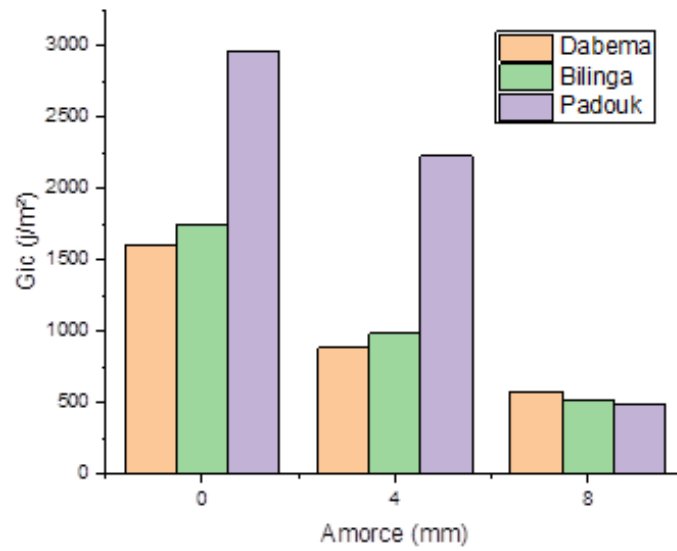


529

530 **Figure 7.**

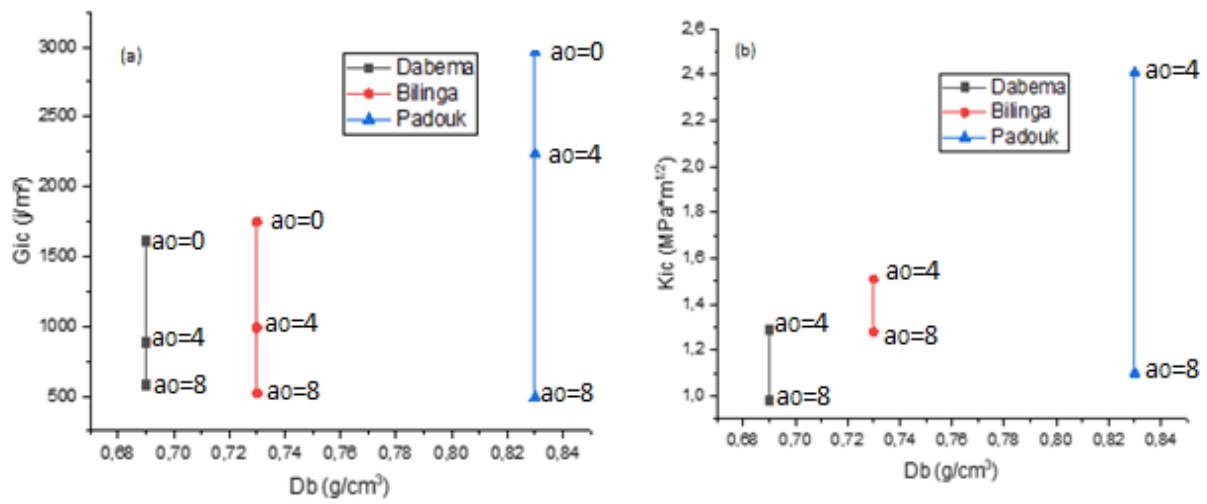


531 **Figure 8.**



532

533 **Figure 9.**



534 **Figure 10.**