Splitting tendency of nailed roof battens under variation of different parameters

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Keywords: timber roof battens, connections, nails, end distance, minimum thickness, splitting, DIN 1052, Eurocode 5

1 Introduction

The splitting tendency of timber connections depends – amongst another factors - on the wood species and the density of the material (Blaß, H.J. & Uibel, T., 2009). (Blaß, H.J. & Schmid, M., 2002) relate requirements for minimum thickness *t* to wood species, inter alia, spruce. Furthermore, the nailing process can be interpreted as an impact process. The resistance of the material influences the energy release rate and, consequently, the splitting development. It can be observed that timber splitting starts at the side facing the nail tip (Ehlbeck, J. & Siebert, W., 1988).

The European timber design standard Eurocode 5 (2004) contains minimum spacing, edge and end distances for fasteners such as nails. The minimum distance to the unloaded end, $a_{3,c,}$ is 10*d*, given a characteristic timber density $\rho_k \leq 420$ kg/m³ and the holes are not predrilled. In the replaced German standard DIN 1052 (2008) minimum distance to the unloaded end, $a_{3,c}$, depended on the nail diameter. For nails featuring diameters ≤ 5 mm, the general limit of 10*d* was reduced to 7*d*. This reduced requirement was applied for nailed roof battens – comparatively small and rarely fully utilized elements – since a reduction of end distances enabled the use of counter battens of smaller cross section.

Requirements for end distances of fasteners are related to the splitting tendency of connections. This behavior is also incorporated in Eurocode 5 in form of requirements for minimum thickness of nailed connections without pre-drilling. In certain cases, the general requirement of a minimum thickness of 14*d* can be reduced to 7*d*. In DIN 1052 (and now in the German NA to Eurocode 5), subordinate elements such as roof battens are amongst these exceptions.

The German timber construction industry proposed to keep the lower required end distances and include them in Eurocode 5 or at least in the German NA to Eurocode 5 (2013). This proposal was justified with good practical experience. Since more specific information was not available, it was decided to start an experimental investigation at TUM to analyze the splitting tendency of roof battens depending on both end distances $a_{3,c}$ (10*d*, 7*d*) under variation of all parameters of practical reference.

2 Materials and methods

Considering former experimental investigations such as Kevarinmäki (2005), the investigation on the influence of end distance $a_{3,c}$ (10*d* / 7*d*) on splitting tendency was realized under variation of different parameters: cross section of the batten, timber moisture content (dry, semi-dry, moist), nail diameter, nail type (smooth shank or threaded shank nail) and nailing process (manually or by nail gun) (see Table 1).

Table 1. Test configurations.

cross section	moisture content [%]	nailing	nail 3,1 mm		nail 3,4 mm		nail 3,8 mm	
			smooth	threaded	smooth	threaded	smooth	threaded
30/50	12 ± 3	manual	3,1x80	3,1x80	3,4x90	3,4x90		
	18 ± 3							
	≥ 24	nail gun	3,1x80	3,1x75	3,4x90	3,4x100		
40/60	12 ± 3	manual			3,4x90	3,4x90	3,8x100	
	18 ± 3							
	≥ 24	nail gun			3,4x90	3,4x100	3,8x110	3,8x120

All variations were tested for two distances to the unloaded end $a_{3,c}$ (10*d*, 7*d*). Seven additional series were realised to investigate an inclination of the nail of 60° to the grain.

In each configuration, ten specimen featuring a length of 60 cm were tested. Two different suppliers from two distinctly different regions of Bavaria supplied the spruce specimens. One charge contained dry battens (supplier A) and another charge contained moist battens (supplier B). The specimens (spruce) featured a mean density (at *u* = 12 %) of 487 kg/m³ and a characteristic density of 427 kg/m³ according to EN 384 (2010). The main properties of the timber species at delivery are given in Table 2.

Table 2. Properties of timber specimen.

cross section	30/50 (supplier A)	30/50 (supplier B)	30/50 (supplier B)	40/60 (supplier A)	40/60 (supplier B)	40/60 (supplier B)
mean moisture content [%]	13,3	16,9	31,4	12,9	18,1	26,8
coefficient of variation [-]	0,07	0,08	0,20	0,06	0,08	0,07
mean density [kg/m³]	494	519		451	485	
characteristic density [kg/m³]	439	482		388	405	

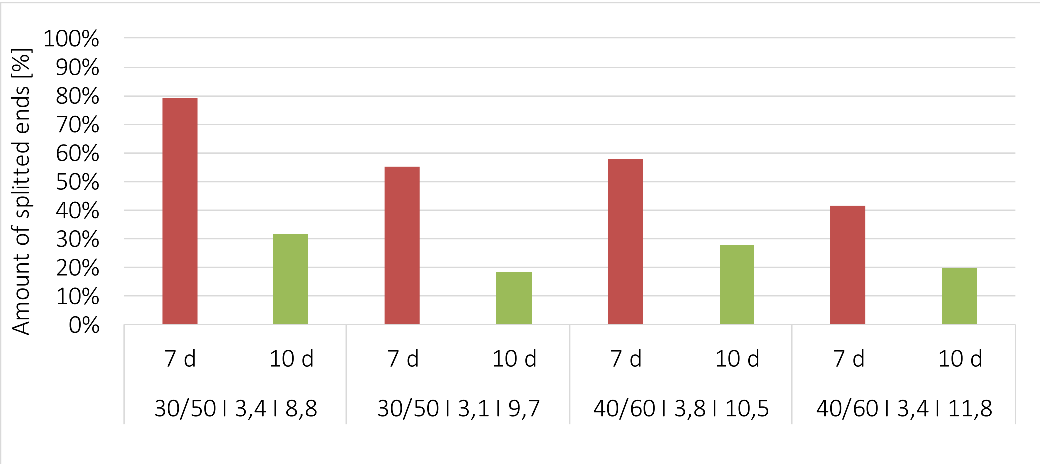
After each nailing process, a potential crack development was examined. The observations were classified into one of five categories (no splitting, split length ≤ 0,25*t*; split length ≤ 0,5*t*; split length ≤ 0,75*t*; fully splitted). For analysis, all cracks covering more than 50 % of the specimen depth *t* were classified “splitted”.

After this, the specimen were kept in standard climate (20°C, 65 %) for a period of four months. Within this period, the development of moisture content (semi-dry and moist specimen) and potential crack development were examined periodically.

3 Results

During the nailing process, a common observation was, that the crack initiation started at the side facing the nail tip. The majority of observations fell in either one of the categories "no splitting" or "fully splitted". The drying process from category "moist" (≥ 24 %) to "semi-dry" (18 ± 3 %) took 12 days (30/50) respectively 10 days (40/60), while it took 30 days (30/50) respectively 40 days (40/60) to dry from category "semi-dry" to "dry" (12 ± 3 %). No further crack initiation was observed. The number of cracks with further development during the drying process was small (≤ 1 % in "dry" and "semi-dry"; 5 % in "moist"). It was therefore decided to only show the results for the observations made four months after nailing.

The main results of the observations are summarised in Figure 1, showing the influence of end distance $a_{3,c}$, cross section, nail diameter d and slenderness t/d.



Cross section I ø I slenderness *t/d*	30/50 I 3,4 I 8,8		30/50 I 3,1 I 9,7		40/60 I 3,8 I 10,5		40/60 I 3,4 I 11,8	
End distance	7 *d*	10 *d*	7 *d*	10 *d*	7 *d*	10 *d*	7 *d*	10 *d*
Number of splitted ends *t* = 0	95	38	64	21	52	23	49	23
Number of splitted ends *t* = 4 mon.	95	38	66	22	52	25	50	24
Maximum	120	120	120	120	90	90	120	120
Amount of splitted ends t = 4 mon. [%]	79%	32%	55%	18%	58%	28%	42%	20%

Figure 1. Amount of splitted ends depending on end distance, cross section and nail diameter

Configurations with end distance $a_{3,c} = 10d$ showed much less splitting than configurations with $a_{3,c} = 7d$ (factor 2,4). The amount of splitted ends decreased with increasing cross section thickness t or decreasing nail diameter d. Even the highest slenderness at $a_{3,c} = 7d$ showed no better results than the series featuring the lowest slenderness at $a_{3,c} = 10d$.

The timber moisture content had no clear influence on the splitting tendency. The same observation was made for the inclination of the nail (60°). Slightly lower splitting tendency could be observed when nailing by hand instead of using a nail gun (11 %) and when using threaded instead of smooth shank nails (13 %). The mean density of all splitted specimen (506 kg/m³) was higher than the mean density of the unsplitted specimen (478 kg/m³) supporting previous examinations, that the splitting tendency is influenced by the timber density (Ehlbeck, J. & Siebert, W., 1988).

4 Conclusion

Based on the results received in the experimental campaign, a reduction of distance to the unloaded end from $a_{3,c}$ = 10*d* to 7*d* based on splitting tendency cannot be supported. If such a reduction shall be enabled, it is recommended to link this to a minimum required thickness of $t > 12\ d$ (compare $t \geq 14d$ in Eurocode 5).

5 Acknowledgement

The authors wish to thank the students David Palotas and Sevan Rashid for supporting the experimental campaign in the frame of their Bachelor Thesis. Gratitude is extended to Andreas Kraft (VBZH), Dieter Kuhlenkamp (Holzbau Deutschland), Jens Hödel (ITW) and Armin Lachmann (MPA BAU TUM) for their input and support.

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