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DURABILITY OF WOOD IN GROUND CONTACT – EFFECTS OF SPECIMEN SIZE

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Abstract:
The durability of wood in ground contact is affected by its material resistance on the one hand, and the exposure situation in the ground on the other hand. The latter is considered to be one of the most severe not at least due to permanent wetting and direct contact to a well-established microbial flora. In addition to physical, chemical, biological, and ecological soil parameters, the design of a wooden commodity which is in contact with the ground can have an effect on its durability. This study examined the effect of size of specimens used for in-ground durability tests.

Standard EN 252 specimens, smaller mini-stake specimens, and larger double-size specimens were made from Scots pine sapwood and heartwood (Pinus sylvestris L.), Norway spruce (Picea abies Karst.), beech (Fagus sylvatica L.), and English oak (Quercus robur L.) and exposed in ground in a test field in Hannover-Herrenhausen, Germany. In addition, standard size specimens were exposed on the ground. Decay rates and corresponding durability classes according to European standards were determined. Decay proceeded slightly faster with decreasing specimen size, but for the majority of the tested materials no significant effect became apparent. However, the most durable material tested was English oak, for which durability was clearly affected by the specimen size. It was classified ‚durable' (durability class DC 2) using double size stakes, ‚moderately durable' (DC 3) using standard specimens, and ‚less durable' (DC 4) using mini-stake specimens. Specimens exposed on-ground decayed significantly less rapidly compared to specimens buried in the ground to half of their length.

The findings from this study recommend to use also test specimens, which are bigger dimensioned than standard specimens and thus closer in dimension to real size commodities. Otherwise, one might accept to underestimate the durability of particular wood-based materials.

Key words: *decay; dimension; durability testing; in ground exposure; soil contact.*

INTRODUCTION

The durability of wooden commodities such as fence posts, utility and foundation poles, support beams, and railway sleepers, which are used in or directly on the ground are exposed to almost permanent wetting and more or less well established fungal flora. Ground exposure is therefore considered to be one of the most severe use situation for timber products and refers to use class 4 (UC 4) according to EN 335 (CEN 2013). The durability in ground is affected by numerous influences such as climate, fungal flora established in the soil, soil parameters (e.g. pH, C/O ratio, nutritions, water holding capacity), soil moisture content, soil quality and ventilation, and the accumulation of organic litter on the ground (e.g. Pastor and Post 1986, Edlund and Nilsson 1998, Trofymow *et al.* 2002, Wakeling 2006, Brischke and Rolf-Kiel 2010, Brischke *et al.* 2013, 2014). In summary, optimum conditions for fungal and bacterial decay can be expected from warm, moist, but well ventilated soils with a well established microbial flora.

The in-ground decay hazard can therefore vary strongly, not only between locations (Edlund 1998), but also within one test field (Wakeling 2006, Brischke *et al*. 2013). Different measures of horticultural soil management have the potential to increase or to reduce the decay activity of soil, e.g. through melioration measures or the application of bark mulch.

Opposite to this very complex exposure situation stands the material resistance of the wood-based commodity. It is commonly agreed that due to permanent wetting and presence of decay organisms the reduced moisture uptake of wood-based materials is not sufficient to withstand the biological hazard in the ground. Materials such as refractory, but only moderately durable wood species and thermally modified wood do not provide sufficient durability in ground (Brischke and Meyer-Veltrup 2016) even though they might perform well in above ground situations. Chemically modified or preservative treated wood are

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generally considered to achieve sufficient resistance even under the harsh environment which is typical for in-ground exposures.

The resistance of wood-based materials in ground contact is likely affected also by matters of design. In particular, the effect of the size of wooden components exposed to the ground is still controversially discussed (TRADA 1984, Westin *et al*. 2002, Lande *et al*. 2004, Wakeling 2006, Antwi-Bosasiako and Allotey 2010, Brischke *et al*. 2013). For testing the durability of wood products in ground several attempts were made to accelerate decay development and thus to reduce time, efforts, and costs for testing. For instance, specimens smaller than the standard stakes according to EN 252 (CEN 2015), so-called mini-stakes, were used in field tests (e.g. Westin *et al*. 2002, Lande *et al*. 2004). While decay developed partly faster and specimens failed earlier compared to the bigger standard specimens, it was still questioned how this acceleration affects the relative durability (i.e. compared to a non-durable reference such as Scots pine sapwood) and if and to what extent the results can be transferred to standard tests or even real life commodities. Comparative field tests by Brischke *et al*. (2013) showed that mini-stake in ground tests bear the risk of underestimating the durability of wood.

In contrast, comparative in-ground tests with small, standard, and bigger-sized components or even real commodities are rather rare. A few case studies on fence posts (e.g. Brischke and Rolf-Kiel 2010), utility poles (e.g. Vidor *et al.* 2010), and railway sleepers (e.g. Yella *et al.* 2009) are reported, but are usually lacking direct comparison with tests using small-sized or standard specimens under the same or at least similar environmental conditions.

OBJECTIVE

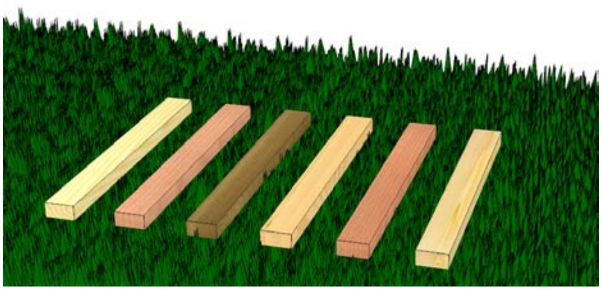
The objective of this study was to identify differences in decay activity and corresponding durability classification using differently dimensioned specimens for in ground exposure. Therefore, mini-stake specimens, EN 252 – standard specimens, and double size specimens made from six different wood materials should be exposed in ground. In addition EN 252 standard specimens should be exposed on the ground.

METHOD

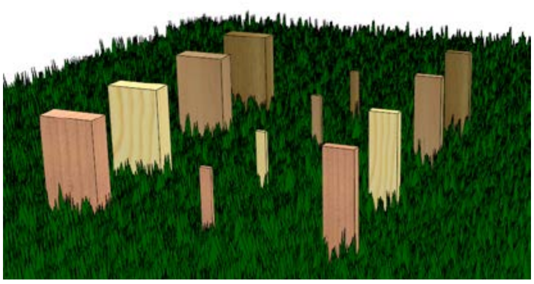
Wood material and field test methods

Specimens made from Norway spruce (*Picea abies* Karst.), Scots pine sapwood (*Pinus sylv*estris L.), Scots pine heartwood (low density ‚LD' average density 0.39g/cm³), Scots pine heartwood (high density ‚HD' average density 0.47g/cm³), European beech (*Fagus sylvatica* L.), and English oak (*Quercus robur* L.) were submitted to different ground contact field tests. Density of Scots pine heartwood assortments was determined logwise by Stora Enso AB, Sweden, using X-ray. Ten replicates of each test material were exposed in 2012 on a field test site in Hannover-Herrenhausen, Germany (Coordinates: 52.395067°N, 9.701913°E, elevation: 54m, mean annual temperature: 9.2°C, annual precipitation sum: 642mm, climate: temperate zone).

The following four test methods were applied: 1.) In-ground stake test according to EN 252 (CEN 2015); specimen size 25x50x500 (ax.) mm³; 2.) In ground mini-stake test; specimen size: 8x20x200 (ax.) mm³; In-ground double size test; specimen size: 50x100x500 (ax.) mm³; and 4.) On-ground test; specimen size: 25x50x500 (ax.) mm³. All in-ground test specimens were buried to half of their length in the soil of the test field with a minimum distance of approximately 250mm to each other. The on-ground test specimens were exposed on the ground with one of their broader side faces to the short cut grass growing on the test field. The set up is illustrated in Fig. 1.



a.



b.

Fig. 1.
Field test set up for testing wood durability in ground contact.
a – On–ground test; b – In–ground test with differently sized specimens.

Decay assessment

Decay was assessed every six months during the first three years and every year after the third year of exposure. Therefore, the specimens were evaluated according to EN 252 (CEN 2015) using a pick-test where a pointed knife is pricked into the specimens and backed out again. The fracture characteristics of the splinters as well as depth and appearance were assessed visually, and referred to the evaluation scheme according to EN 252 (CEN 2015). For test set ups with cross sections deviating from the cross sections given in the standard (50x25mm²) the rating scheme was adapted to the respective dimensions (Table 1). Therefore, the maximum decay depth [mm] was approximated in 0.5mm steps to reach the minimum intact cross section [%] given for the ratings according to the EN 252 (CEN 2015) specimen dimensions.

Table 1

Adapted maximum decay depth (mm) and minimum intact cross section (%) [given in brackets] according to the rating scale given in EN 252 (CEN 2015)

Rating	**Maximum decay depth (mm) [minimum intact cross section (%)]**				
	0	**1**	**2**	**3**	**4**
	(Sound)	(Slight attack)	(Moderate attack)	(Severe attack)	(Failure)
Test method					
In-ground EN 252 / On-ground test	0 [100]	1 [88]	2 [67]	5 [48]	50 [0]
In-ground mini-stake	0 [100]	0.5 [83]	1 [68]	1.5 [53]	20 [0]
In-ground double size	0 [100]	2 [88]	6 [67]	10 [48]	100 [0]

Durability classification

Since neither the mean nor the median lifetime of the specimens (Eq. 1) was yet obtained for all tested materials in all tests after five years of exposure, the durability factor *f* was calculated based on the mean decay rate v_{mean} (Eq. 2), i.e. the decay rating [0–4] according to EN 252 (CEN 2015) divided by the exposure time [years], was calculated instead as previously reported by Brischke *et al.* (2013) and used for classifying the durability according to EN 350 (CEN 2016) as shown in Table 2. For instance, a decay rate v_{mean} = 2.0 ratings/year would mean that on average the specimens reached failure (rating 4) after 2 years of exposure.

$$x = \frac{SL_{median,testedtimber}}{SL_{median,reference}} \quad [-] \qquad (1)$$

where: $SL_{median,\ tested\ timber}$ is the median service life of the tested timber, in years;
$SL_{median,\ reference}$ is the median service life of the reference timber, in years.

$$f = \frac{v_{mean,reference}}{v_{mean,testedtimber}} \quad [-] \qquad (2)$$

where: $v_{mean,\ tested\ timber}$ is the mean decay rate of the tested timber, in ratings per year;
$v_{mean,\ reference}$ is the mean decay rate of the reference timber, in ratings per year.

Table 2

Durability classes according to EN 350 (CEN 2016) based on x-values calculated as relative median service life of test specimens and on f-values calculated based on relative decay rates in field tests

DC	**Description**	**Durability factor *f***	**Relative median service life *x***
1	Very durable	$f > 5$	$x > 5$
2	Durable	$3 < f \leq 5$	$3 < x \leq 5$
3	Moderately durable	$2 < f \leq 3$	$2 < x \leq 3$
4	Slightly durable	$1.2 < f \leq 2$	$1.2 < x \leq 2$
5	Non durable	$f < 1.2$	$x < 1.2$

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RESULTS & DISCUSSION

The decay activity in the test field in Hannover – Herrenhausen was rather high in both, in ground and on-ground exposures (Fig. 3). The control specimens made from beech and Scots pine sapwood decayed within 2-3 years in ground and within 3-5 years on ground. This coincides with previous findings reported by Stirling *et al.* (2016), who compared decay of reference materials at various in-ground test locations in Europe and North America. The Herrenhausen test site was among those, where in particular beech and pine sapwood decayed the fastest, which might to some extent be attributed to the presence of all major rot types, i.e. soft, white and brown rot, whereby an aggressive brown rot attack caused by *Leucogyrophana pinastri* had been observed previously (Brischke *et al.* 2013). In addition to fungal decay, severe attack by wood-destroying red-brown longhorn beetle larvae (*Leptura rubra* L.) was found in many double – size specimens after five years of exposure (Fig. 2a).

Fig. 2.
Evaluation of in-ground specimens.
a – Failure of double-size in ground specimen made from Scots pine heartwood after five years of exposure; b – Wood-destroying red-brown longhorn beetle larvae (Leptura rubra L.).

The specimen dimension had a rather small effect on the decay rates obtained in ground contact. Solely, decay of English oak was slowed when using double size specimens and increased when using mini-stakes (Fig. 3 a-c). In general, differences in decay rates between different dimensions had been expected to be more prominent (e.g. TRADA 1984).

However, even though the durability classification was slightly divergent between test methods, a clear trend became visible for English oak. The smaller the specimen dimension the more severe was fungal degradation, which contradicts findings reported by Antwi-Bosasiako and Allotey (2010), who studied the in ground durability of three tropical hardwoods and observed that the smaller the stake dimension the smaller was its visual durability rating. They examined stake-shaped specimens which were smaller than EN 252 (CEN 2015) specimens and compared them with the latter regarding decay, hardness, and mass loss during five years of exposure in the ground. The apparent discrepance might be explained by the use of the EN 252 rating scheme for specimens of each dimension without an adaptation to smaller cross sections. Furthermore, Antwi-Bosasiako and Allotey (2010) pointed out that the smallest specimens were frequently buried in the ground, which can restrict the supply of oxygen and thus hinder fungal activity in the wood. In contrary, the smaller the above ground specimen portion the lower is its re-drying potential, which is expected to have a negative effect on durability. This assumption is supported by Brischke and Rolf-Kiel (2010) and Brischke *et al.* (2017) who both found that fence posts made from English oak showed most severe decay not at the groundline, but deeper in the soil, where the supply of oxygen is lower.

Higher durability of bigger dimensioned components might be expected due to reduced vulnerability to leaching of extractives or preservatives (Cockcroft and Laidlow 1978), the formation of protective outer barriers, which can be wood decayed by soft rot fungi that do not further develop into the interior part of the component (Brischke *et al.* 2013). Such protective shells had been found on fence posts made from durable or very durable heartwoods, where decayed sapwood portions formed a ring around the heartwood that was still intact (Brischke and Rolf-Kiel 2010, Brischke *et al.* 2017). In contrary, sapwood can also be the starting point for fungal decay which can then infect the heartwood portions.

As shown in Table 3 based on the median lifetime of the test specimens English oak was classified ‚durable' if using double size specimens, ‚moderately durable' if using standard size specimens, and only ‚slightly durable' if using mini-stakes. Consequently, not only the absolute lifetime of stakes in ground contact, but also the relative measure of durability seems to be affected by the specimen dimension at least for the most durable species examined within this study. For all other species such a dimension effect was not observed.

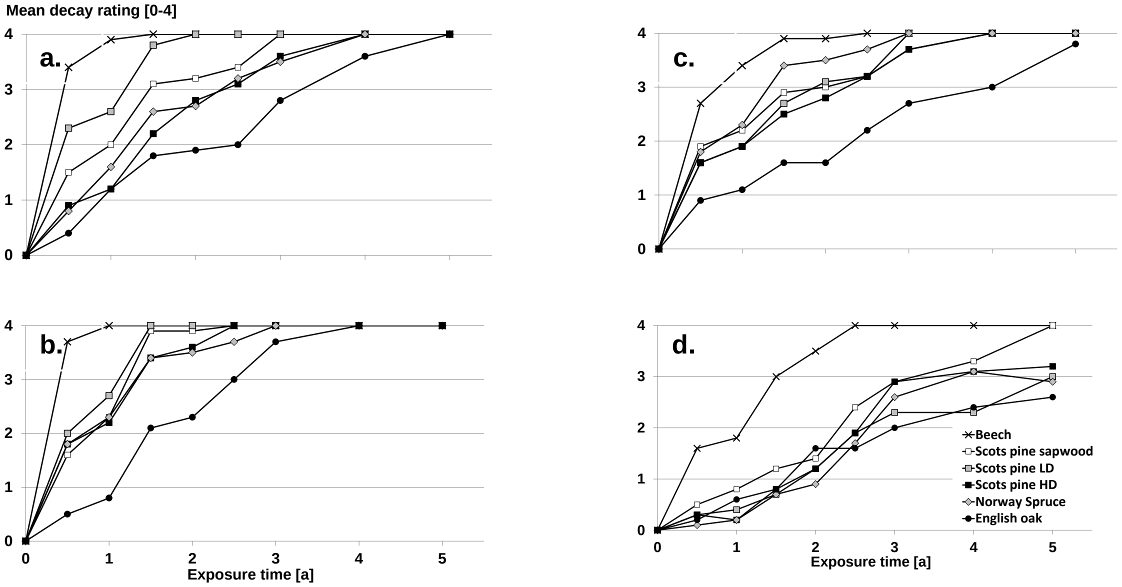

Fig. 3.
Mean decay ratings of field test specimens exposed in and on ground.
a – In-ground EN 252 test; b – In-ground mini-stake test; c – In-ground double size test; d – On-ground test.

On-ground exposure led to generally slower decay progress compared to in-ground exposure as shown in Fig. 3d, which might be related to the fact that only less than half of the specimen side surfaces had been in direct contact to the soil, which reduced moistening and the inoculum potential through soil-inhabiting micro-organisms. Similar to the in-ground exposure, beech wood specimens decayed the fastest and were completely gone after only 2.5 years. All other wood species performed slightly better, but no significant differences between them became evident. After five years of exposure even English oak, which on average performed best, showed moderate to severe decay.

Durability classes were derived either from the relative median lifetime of the specimens or the respective decay rates compared to those of the reference species Scots pine sapwood (Table 3 and 4). Scots pine heartwood was classified between ‚less and non durable' (DC 4 and 5), whereby no difference between sets with higher (HD) and lower densitiy (LD) became evident. Similarly, Norway spruce achieved DC 4-5, which coincides with the durability classification according to EN 350 (CEN 2016). Beech wood turned out to be ‚non durable' as expected in all tests and independent from the classification scheme.

Both durability classification procedures need to be considered preliminary, since the mean lifetime of the specimens had not been reached for all materials. However, even though the durability classes differed slightly between both classification procedures, this could neither mask the effect of dimension on durability of English oak nor the fact that all tested softwoods and beech turned out to be ‚less durable' or worse if exposed in or on the ground.

Table 3

Median service lives (SL_{med}) and corresponding durability classes (DC) according to EN 350 (CEN 2016) of different wood species under different field test regimes

	Test method							
Wood species	**In ground EN 252**		**In ground mini-stake**		**In ground double size**		**On-ground**	
	SL_{med} (a)	DC	SL_{med} (a)	DC	SL_{med} (a)	DC	SL_{med} (a)	DC
Scots pine sapwood	1.50	5	1.50	5	1.50	5	4.50	5
Scots pine HD	3.00	4	1.50	5	2.50	4	-	-
Scots pine LD	1.50	5	1.00	5	2.50	4	-	-
Norway spruce	2.00	4	1.50	5	2.25	4	-	-
Beech	1.00	5	0.50	5	1.00	5	2.25	5
English oak	4.00	3	3.00	4	4.50	2	-	-

Table 4

Mean decay rate (v_{mean}) and corresponding durability classes (DC) according to EN 350 (CEN 2016) of different wood species under different field test regimes

	Test method							
Wood species	**In ground EN 252**		**In ground mini-stake**		**In ground double size**		**On-ground**	
	v_{mean} (a^{-1})	DC	v_{mean} (a^{-1})	DC	v_{mean} (a^{-1})	DC	v_{mean} (a^{-1})	DC
Scots pine sapwood	2.32	5	3.76	5	2.87	5	1.00	5
Scots pine HD	1.56	4	3.88	5	1.75	4	0.66	4
Scots pine LD	2.80	5	5.07	5	1.80	4	0.60	4
Norway spruce	2.56	5	3.56	5	1.82	4	0.65	4
Beech	5.47	5	6.80	5	4.16	5	2.00	5
English oak	1.31	4	1.29	3	0.93	2	0.52	4

As shown in a previous study by Brischke *et al.* (2013) in most cases decay proceeded more rapidly in mini-stake specimens compared to standard stakes, but in some cases, e.g. for Douglas fir heartwood (*Pseudotsuga menziesii* Franco.), decay rates were found to be very similar. This coincides fairly well with the results from this study, where neither decay rates nor durability classes obtained for Scots pine heartwood differed significantly between standard and mini-stake specimens, but both did for English oak.

In summary, very small field test specimens such as mini-stakes bear the risk of underestimating not only the expected lifetime of wood exposed in ground, but also the relative measure of durability, i.e. the durability classification. Furthermore, at least for English oak the results from double size specimens indicated that also standard specimens might underestimate the durability provided that bigger sized commodities are supposed to get used in real life applications.

Apart from affecting the durability classification and limited transferability of service life expectations from small to bigger sized components, the use of non-standard specimens revealed a couple of problems related to practical testing procedures. Mini-stake specimens frequently got lost due to their small dimensions; they were either completely buried in the ground or simply disappeared, which both might be due to the activity of rabbits and other mammals and birds living on or close by the test site.

To distinguish between a decay rating 3 and 4, i.e. ‚severe attack' and ‚failure' a manual impact bending test is applied on-site accroding to EN 252 (CEN 2015). For the use of double size specimens the manual stroke requires some adaptation, but is still possible. The smaller mini-stake specimens do not allow an impact-bending test, and alternatively a manual four-point bending test needs to be applied using four fingers. The force applied is strongly affected by subjective sensation of the person evaluating the specimens. The importance of such practical and technical criteria for evaluating durability field test methods has been described in detail by Meyer *et al.* (2016) and Meyer-Veltrup *et al.* (2017).

Using mini-stake specimens significantly reduces the amount of defect free material needed for manufacturing the test specimens and the space needed on the test field (Westin *et al.* 2002). In contrast, the use of double-size specimens increases the volume needed per specimen. In particular, manufacturing specimens from permeable sapwood portions to be impregnated with wood preservatives will drastically increase the timber volume needed, since stems with a sapwood thickness of more than 100mm are rare. However, in particular the positive effect of specimen size on wood durability as observed in this study for English oak might justify additional costs and efforts.

CONCLUSIONS

Decay activity and resulting lifetime of the differently sized in-ground specimens differed only very slightly. In particular, the less or non durable materials did not reveal any significant difference, neither in decay rate nor in durability classification. However, at least for English oak a clear positive effect of bigger dimensions on both, average absolute lifetime of the specimens and relative durability in terms of durability classes became apparent.

Therefore, the findings from this study recommend to use also test specimens, which are bigger dimensioned than standard specimens and thus closer in dimension to real size commodities. Otherwise, one might accept to underestimate the durability of particular wood-based materials. The size effect might be even more pronounced using very durable wood species with contents of extractives or preservative treated wood which is prone to depletion of active ingredients due to leaching, which is also affected by the component size.

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