Durability of Modified Wood – Laboratory vs Field Performance

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ABSTRACT

One of the main challenges for modified wood and modified wood based WPCs (Wood Plastic Composites) is to predict accurate service life time in UC3 (Use class 3, above ground) and UC4 (in soil or fresh water contact). So far, data from in-service conditions are rare, while several studies have evaluated the durability in lab or field test exposure. However, there is still a lack of studies comparing replicate modified wood products in both field and lab exposure. This study evaluates the efficacy of modified wood and modified wood based WPCs in AWPA E10, three different types of soil in lab (ENV 807), three test fields in-ground (EN 252) and two test sites close to ground (horizontal double layer test). The test material includes furfurylated, acetylated and thermally modified wood in addition to reference treated and control samples. In laboratory, both furfurylated, acetylated and thermally modified pine (212 ºC) performed well. The modified wood samples performed at the same level, or better, than the reference CC and CCA preservatives in retentions for UC4 applications. In the horizontal double layer test, three years is too short time to be able to draw conclusions. However, all controls are slightly to moderately decayed in the most accelerated set-up whereas all preservative treated, furfurylated, acetylated and WPC with modified wood are sound. After 3 years of testing CCA-preserved wood performs better in-ground in field tests than in lab tests, whereas modified wood generally performs slightly poorer. Just like in the lab tests, however, acetylated wood performs equal to CCA-preserved wood in UC4. Furfurylated wood performs better than UC3 level preservative treated wood. Thermally modified wood actually performs much poorer than all preservative treated wood references. WPCs from modified wood perform well in all field tests with no visible decay. Finally, natural durability classification of the same treatment in different lab and field tests was surprisingly similar.

INTRODUCTION

Both modified wood and wood plastic composite (WPC) materials have had a continuous market growth over the last decade in Europe and North America, respectively. Wood modification involves the action of a chemical, biological or physical agent upon the material, resulting in a desired property enhancement during the service life of the modified wood (Hill 2006). WPC is a thermoplastic-wood-reinforced composite with more than 50% by weight of wood material (*e.g.* wood particles, sawdust or wood flour). Two of the main challenges for new wood based products are 1) durability in soil contact and 2) interpretation and comparison of accelerated test methods in relation to service life estimation. A range of studies have evaluated the properties of different products of modified wood and WPC in lab and field, but the number of studies comparing performance in different test methods are insufficient. There is also a need for more experience data from both case studies and long term field tests. The main objective of this study was to compare the performance of modified wood and WPC based on modified wood in different lab and field exposure situations.

MATERIALS AND METHODS

The wood modifications, WPCs, control and reference treatment samples used in this study are given in Table 1. Scots pine sapwood (*Pinus sylvestris* L.) was used for all the

Table 1: Modifications, references and control samples incl. abbreviations. Com = compost soil, Sim = Simlångsdalen soil, For = forest soil, TMC = terrestrial microcosms, HDL = horizontal double layer, WPG = weight percent gain.

	Lab in unsterile soil			Field above ground		Field in soil contact		
	TMC			HDL		EN 252		
Treatments (abbreviations)	**Com**	**Sim**	**For**	**Ås**	**Borås**	**Ås**	**Borås**	**Siml.**
Wood modifications:								
Furfurylation (FA):								
20 WPG (FA 20)							X	
25 WPG (FA 25)	X	X	X	X	X			X
30 WPG (FA 30)						X	X	X
35 WPG (FA 35)				X	X			
37 WPG (FA 37)	X	X	X					
40 WPG (FA 40)						X	X	X
Thermal modification (TM):								
Pine, 212°C, (TMp212)	X	X	X	X	X	X	X	
Spruce, 190°C, (TMs190)				X	X			
Spruce, 200°C, (TMs200)	X	X	X	X	X	X	X	X
Spruce, 225°C, (TMs225)						X	X	
Acetylation (Ac):								
23 WPG (Ac 23)	X	X	X					
25 WPG (Ac 25)				X	X	X	X	X
30 WPG (Ac 30)	X	X	X					
References:								
Copper-organic (C-org):								
NWPC AB retention, UC3 (C-org AB)				X	X	X	X	X
Copper chromium based (CC):								
2.5 kg/m^3 (CC 2.5)	X	X	X					
5 kg/m^3 (CC 5)	X	X	X					
10 kg/m^3 (CC 10)	X	X	X					
Copper, chromium, arsenic (CCA):								
2 kg/m3 (CCA 2)				X	X	X	X	X
4 kg/m^3 (CCA 4)	X	X	X					
9 kg/m^3 (CCA 9)	X	X	X			X	X	X
Semi-durable hardwood:								
Robinia pseudoaccacia ♥wood (Rob♥)	X	X	X	X	X	X	X	X
Control:								
Pinus sylvestris sapwood (Cont)	X	X	X	X	X	X	X	X
Wood plastic composites (WPC):								
70% FA WPG 30, 30% PP (FA/PP)	X	X	X					
70% TMs200, 30% PP (TM/PP)	X	X	X		X		X	
70% Ac WPG 23, 30% PP (Ac/PP)	X	X	X	X	X	X	X	X
70% Control pine, 30% PP (Cont/PP)	X	X	X	X	X	X	X	X

different modifications and preservative treatments except for the thermal modification with peek temperature 190, 200 and 225 ºC where Norway spruce (*Picea abies* L.) was used. Test samples with thermal modification, furfuryl alcohol modification and WPC were industrially produced. The acetylation modification was done in a large pilot plant. The whole material was first treated according to the respective industrial procedures and then distributed to the different lab and field tests. Hence, only one treatment batch was used for each modification, impregnation and WPC. When making the WPCs, boards were ground into particles in a two step process. First 190 mm long blocks were fed into a disk flaker (Bezner) and processed into thin veneer strands. In the second step the veneer strands were fed into a dry grinding knife-mill (Condux) and chopped into fine particles. The particles where characterised by standard sieve analysis (Segerholm 2007). The thermoplastic matrix used was polypropylene (PP, Moplen HF 500N), and 30% PP was mixed with 70% wood. The decay study in lab was a terrestrial microcosm (TMC) test (Edlund 1998), which is an expanded version of ENV 807 (2001). Three different types of soil were used: mixed soil from coniferous forest (50/50 from test fields in Ås, Norway and Ingvallsbenning, Sweden), garden compost from Sweden and soil from the Swedish test field in Simlångsdalen. Soil characteristics are given in Westin and Alfredsen (2007). The TMC samples were leached according to EN 84 before testing. Parts of these results were published in Westin and Alfredsen 2007, new information in the present paper is the WPCs and wood moisture content data. To provide information about sterile lab conditions, natural durability classifications based on AWPA E10 (1991) results in Westin and Alfredsen (2007) are included. Two field test methods were used, horizontal double layer – HDL (Rapp and Augusta 2004) and EN 252 (1989). The HDL was situated in Ås, Norway and Borås, Sweden, while the EN 252 was situated in Ås, Borås and Simlångsdalen test fields. Mean annual precipitation and air temperature are: Simlångsdalen 1053 mm and 6.4 °C, Borås 6.5 °C and 990 mm, Ås 5.3 °C and 785 mm. The two HDL setups differed in a very important way, in Borås test rig and spacing stakes were made of unmodified spruce whereas in Ås the test rig was made of inert material (aluminium profiles on concrete building blocks) and the test groups were kept apart with plastic spacing stakes. All the results were summarised calculating natural durability classes for each of the tests above. Since not all of the controls were rated 4 in HDL and EN 252, the natural durability classes were calculated from decay index according to the EN 113 (1996) criteria in EN 350-1 (1994) for these two test methods. This is a rough and improvised method, but was used to be able to compare the results in a simple way.

RESULTS AND DISCUSSION

In TMC, compost soil gave the highest mass loss and forest soil the lowest mass loss of the test samples (Table 2). Even though the different soil types did give differences in degree of decay, the relative performance of the test samples, compared to each other and compared to the references, was generally the same for all soil types. However, thermally modified pine and FA modifications had the highest mass loss in forest soil even though this soil generally was the least virulent soil. This soil had the highest moisture content at water holding capacity and the lowest pH. The forest soil is dominated by white rot fungi, Simlångsdalen soil by brown rot and compost soil by soft rot and bacteria. In TMC furfurylation, acetylation and thermally modified pine (peak temperature 212 ºC) performed well. No obvious effect was found on mass loss with increasing furfuryl alcohol (FA) content. Thermal modification of pine (212 ºC) performed better than thermal treatment of spruce (200 ºC). The modified wood performed at the same level, or better, than the reference CC and CCA preservatives in retentions for use class 4 applications. An interesting result is the poor performance of the CC preservative in compost- and Simlångsdalen soil in this test. The WPCs with modified wood performed well, with a maximum mass loss of 4% (6% mass loss of wood component). The control samples had a maximum mass loss of 7% (9% mass loss of wood component). The wood moisture content was highest in the control, CC, CCA, and thermal modifications. WPCs and acetylated wood had the lowest wood moisture content.

Table 2: Mean mass loss and wood moisture content (MC) ± standard deviation in TMC after 40 weeks in compost-, Simlångsdalen– and forest soil. For WPCs corrected mass loss and wood moisture content for the WPC wood component are given in brackets.

	Compost soil		Simlångsdalen soil		Forest soil	
	Mass loss	MC	Mass loss	MC	Mass loss	MC
FA 25	4±1	91±10	3±0	77±9	5±1	115±13
FA 37	2±0	89±5	3±1	76±10	5±0	114±9
TMp212	3±1	121±9	2±1	86±15	5±1	181±8
TMs200	11±5	132±19	21±8	78±14	11±1	238±39
Ac 23	1±0	75±8	1±0	25±1	1±0	107±4
Ac 30	1±0	39±4	1±0	25±1	0±0	102±10
CC 2.5	51±6	154±11	35±13	125±21	10±1	162±6
CC 5	36±8	149±14	21±7	88±13	9±2	143±14
CC 10	20±5	145±11	7±3	51±7	6±1	107±11
CCA 4	20±8	143±8	5±3	49±6	6±0	128±14
CCA 9	12±5	93±16	1±0	41±2	5±4	87±15
Rob♥	45±6	90±6	12±1	89±5	10±1	93±7
Cont	74±9	152±34	50±16	181±76	27±24	180±24
FA/PP	1±0 (2±0)	25±4 (35±5)	4±0 (6±0)	25±1 (36±1)	2±0 (2±0)	28±4 (40±6)
TM/PP	2±0 (3±0)	16±0 (23±0)	2±0 (3±0)	16±0 (23±0)	2±0 (3±0)	16±0 (22±0)
Ac/PP	0±0 (1±0)	9±0 (12±0)	0±0 (1±0)	8±0 (12±0)	0±0 (1±0)	9±0 (12±0)
Cont/PP	7±0 (9±1)	29±0 (42±1)	4±1 (6±1)	26±0 (37±0)	3±0 (5±1)	27±1 (38±1)

In HDL no decay was found at the Norwegian test site at Ås after three years (Table 3). Experience from other Norwegian HDL test sites show that more than four to five years are needed before Scots pine sapwood control samples are rated 4. At the Swedish test

Table 3: Decay index in horizontal double layer after 3 years in Borås (Sweden) and Ås (Norway).

	1 year		2 years		3 years	
	Borås	Ås	Borås	Ås	Borås	Ås
FA 25	0±0	0±0	0±0	0±0	0±0	0±0
FA 35	0±0	0±0	0±0	0±0	0±0	0±0
TMp212	0±0	0±0	3±9	0±0	19±18	0±0
TMs190	0±0	0±0	3±9	0±0	16±19	0±0
TMs200	0±0	0±0	0±0	0±0	7±12	0±0
Ac 25	0±0	0±0	0±0	0±0	0±0	0±0
C-org AB	0±0	0±0	0±0	0±0	0±0	0±0
CCA 2	0±0	0±0	0±0	0±0	0±0	0±0
Rob♥	0±0	0±0	6±12	0±0	9±13	0±0
Cont	3±9	0±0	27±6	0±0	50±13	0±0
TM/PP	0±0	-	0±0	-	0±0	-
Ac/PP	0±0	0±0	0±0	0±0	0±0	0±0
Cont/PP	3±9	0±0	6±12	0±0	28±16	0±0

In Simlångsdalen the control stakes failed after only two years in soil exposure according to EN 252 (Table 4). After three years the decay index was 98 in Borås and 90 at Ås. At all test sites the treatments with a decay index of 15 or less were samples with acetylation, CCA with high retention, furfurylated samples and WPC with modified wood. Robinia heartwood, thermal modification (with exception of pine at Ås), copper-organic, CCA with low retention and WPC control had higher decay index than acetylation and furfurylation, but lower than the control. Again no conclusive increase in durability was found with increasing FA content. Huge differences were found in durability of samples treated with copper-organic preservative between test sites.

Table 4: Decay index in EN 252 after 3 years in Borås and Simlångsdalen (Sweden) and Ås (Norway).

	2 years			**3 years**		
	Borås	**Simlång**	**Ås**	**Borås**	**Simlång**	**Ås**
FA 20	8±12	-	-	5±11	-	-
FA 25	-	5±11	-	-	13±13	-
FA 30	0±0	5±11	23±15	10±13	13±18	8±13
FA 40	5±11	3±10	23±18	5±11	10±13	8±12
TMp212	15±17	-	23±45	30±11	-	8±11
TMs200	20±20	40±27	43±24	43±12	55±28	53±14
TMs225	3±8	-	33±12	18±12	-	33±12
Ac 25	3±8	5±13	3±8	3±8	5±11	0±0
C-org AB	3±8	20±11	13±18	0±0	28±14	18±21
CCA 2	23±14	10±13	20±11	33±12	23±18	20±11
CCA 9	0±0	3±8	5±11	0±0	10±13	3±8
Rob♥	25±0	23±8	28±8	28±8	38±13	30±11
Cont	83±16	100±0	63±19	98±8	100±0	90±15
TM/PP	0±0	-	-	0±0	-	-
Ac/PP	0±0	0±0	0±0	0±0	0±0	0±0
Cont/PP	48±8	35±13	25±0	45±11	38±13	35±13

In Table 5 natural durability classes according to EN 350-1 are calculated for each of the tests above. Generally the durability classification was surprisingly similar within and between the treatments using different lab and field tests. It is, however, important to keep in mind that these calculations only provide a rough categorisation, since the HDL and EN 252 were only exposed for three years in field, and because of the improvised calculation method. All the acetylated material was rated 1. This is in agreement with results reported in literature, where weight percent gain (WPG) levels of acetylation above 20% are commonly found to give full decay protection in both laboratory as well as field trials (Larsson Brelid *et al.* 2000, Papadopoulos and Hill 2002, Hill *et al.* 2007;). More variation was found within and between treatments of thermally modified wood, and thermally modified pine gave overall the best results. The thermal modifications in these tests do not seem to be very well suited for soil contact exposure. FA got durability class 1 in all tests except for AWPA E10 with brown rot and TMC with forest soil. Given the range of FA treatments, there were surprisingly small differences between FA levels and small or no effect of increasing WPG. This might strengthen the hypothesis of Venås (2008) that there might be some kind of threshold for FA modified samples around a WPG of 25. Venås found that up to approximately 25% WPG the mass loss percentage in FA modified samples following incubation in EN 113 was inversely proportional to WPG, which in turn was inversely proportional to the final moisture content. CCA was generally performing as expected, increase in decay with decreasing concentration, class 1 and 2. CC in TMC did, as mentioned above, not perform as good as expected. Robinia heartwood was classified 4 in TMC compost soil, 2 and 3 in the rest of the tests. Performance of WPC with modified wood were quite similar in all tests when comparing with the control samples of solid Scots pine sapwood.

Table 5: Natural durability classes of modifications and references, AWPA E10 16 weeks (white rot) and 8 weeks (brown rot) in lab, TMC 40 weeks in lab and 3 years of field exposure for HDL and EN 252. For WPC, classification is calculated both compared to control and to WPC control (in brackets). ND = no decay detected incl. control, Com = compost soil, Sim = Simlångsdalen soil, For = forest soil, TMC = terrestrial microcosm, HDL = horizontal double layer, B = brown rot, W = white rot.

	Lab sterile		**Lab in unsterile soil**			**Field above ground**		**Field in soil contact**		
	AWPA E10*		**TMC**			**HDL****		**EN 252****		
Treatments	**B**	**W**	**Com**	**Sim**	**For**	**Ås**	**Borås**	**Ås**	**Borås**	**Sim**
Wood mod.:										
FA 20									**1**	
FA 25	**3**		**1**	**1**	**2**	**ND**	**1**			**1**
FA 30								**1**	**1**	**1**
FA 35-37	**2**		**1**	**1**	**2**	**ND**	**1**			
FA 40	**1**	**1**						**1**	**1**	**1**
TMp212	**1**	**1**	**1**	**1**	**2**	**ND**	**3**	**1**	**3**	
TMs190						**ND**	**3**			
TMs200	**3**	**3**	**2**	**4**	**3**	**ND**	**1**	**3**	**3**	**3**
TMs225	**1**	**1**						**3**	**2**	
Ac 23			**1**	**1**	**1**					
Ac 25						**ND**	**1**	**1**	**1**	**1**
Ac 30	**1**	**1**	**1**	**1**	**1**					
References:										
C-org AB						**ND**	**1**	**2**	**1**	**2**
CC 2.5			**4**	**4**	**3**					
CC 5			**3**	**3**	**3**					
CC 10			**2**	**1**	**2**					
CCA 2						**ND**	**1**	**2**	**3**	**2**
CCA 4			**2**	**1**	**2**					
CCA 9			**2**	**1**	**2**			**1**	**1**	**1**
Rob♥	**1**	**1**	**4**	**2**	**3**	**ND**	**2**	**3**	**2**	**3**
WPC:										
FA/PP	**1**	**1**	**1**	**1**	**1**					
TM/PP	**1**	**1**	**1**	**1**	**1**		**1**		**1**	
Ac/PP	**1**	**1**	**1**	**1**	**1**	**ND**	**1**	**1**	**1**	**1**

** AWPA E10 results from Westin and Alfredsen (2007), **Because not all of the controls had reached rating 4, the natural durability classes were calculated from decay index according to the EN 113 criteria in EN 350-1.*

CONCLUSIONS

- In TMC furfurylation, acetylation and thermally modified pine (212ºC) gave the highest decay resistance together with WPC with modified wood. The modified wood performed at the same level, or better, than the reference CC and CCA preservatives in retentions for use class 4.
- In HDL no decay was found after three years at the test site at Ås, Norway. In Borås, Sweden, no decay was found for samples with furfurylation, acetylation, WPC with modified wood, CCA and copper-organic containing preservatives.

- The HDL decay hazard was much higher in Borås than Ås. In the Borås set-up unmodified spruce was used in the rig and spacing stakes, while inert materials were used in the Ås set-up. Also, the climate was warmer and wetter in Borås than Ås.
- In EN 252 the sample treatments with a decay index of 15 or less were acetylation, CCA with high retention, furfurylated samples and WPC with modified wood.
- Natural durability classification of the same treatment in different lab and field tests was surprisingly similar.

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