EFFECTIVENESS OF PRETREATMENTS ON *ACACIA MANGIUM* FOR CONVENTIONAL STEAM-HEATED KILN DRYING

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GAN KS, ZAIRUL AR & TAN JL. 2015. Effectiveness of pretreatments on *Acacia mangium* for conventional steam-heated kiln drying. Timber drying is an important manufacturing process for efficient timber utilisation. Time and cost can be substantial in the development of appropriate drying schedule for unfamiliar timber with unknown drying characteristics, for example refractory timbers. These include heavy hardwood species and plantation timbers that are prone to drying defects under inappropriate drying schedule. As such, a quick drying assessment protocol will be helpful to reduce the cost and time of developing suitable drying schedule. This study demonstrated the use of the protocol for drying rate test to evaluate the effectiveness of pretreatment processes on *Acacia mangium* timber. The conventional steam-heated kiln drying of this timber is known to produce high occurrence of wet pockets. Pretreatments processes tested included air drying, hot water bath and microwave treatments. Results from the drying trials suggested that hot water bath and microwave pretreatments with appropriate settings after air drying could expedite drying process and alleviate the occurrence of wet pockets in *A. mangium.*

Keywords: Timber drying, wet pockets, hot water bath treatment, microwave treatment, plantation timber

INTRODUCTION

Timber drying is an important unit process for efficient utilisation of timber. In Malaysia, this is normally accomplished by following through a drying schedule developed for timber species in a conventional steam-heated kiln. For drying of unfamiliar timber or timber of unknown drying characteristics, normally the density and air drying characteristics may be used as guide to start a drying schedule from a set of standard drying schedules prescribed in the timber drying guide or manual (Grewal 1988). The preliminary drying schedule will then be optimised through subsequent drying trials based on quality of the dried timber, such as surface and end checks, warping, uniformity in final moisture content and drying duration. Time and effort are needed in the drying schedule optimisation process for refractory timbers such as the heavy hardwood species and plantation timbers which are prone to drying defects (Gan & Zairul 2011a).

Standard methods for drying assessments of *Acacia mangium* include air drying, drying rate, quick drying and drying schedule tests (Tan et al. 2010). One of the difficulties of drying *A. mangium* is the wide variation in final moisture contents due to high incidences of wet pocket in dried timber especially boards with radial incline across its width (Gan & Zairul 2011a, Tenorio & Moya 2011). Wet pockets rarely occur in tangential or flat-sawn boards (Moya & Munoz 2008, Gan & Zairul 2011a, Tenorio et al. 2012). Each drying trial using the conventional steam-heated kiln at the Forest Research Institute Malaysia costs about RM10,000 (personal observation). This includes the costs of diesel consumption of the boiler and overtime claims by the boilerman throughout the drying duration. As time and cost are crucial in development of drying schedule, the protocol for drying rate test may be used to assess quickly the drying characteristics of various pretreatments on *A. mangium* before conducting a full-fledge experimental drying using conventional steam-heated kiln. The objective of this report is to demonstrate the suitability of using drying rate test to assess the drying quality particularly the occurrence of wet pockets in *A. mangium.*

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MATERIALS AND METHODS

Acacia mangium logs were purchased from open market in Ulu Sedili, Johore. The logs were cut to yield various types of sawn (Figure 1a) and only radial-sawn boards (Figure 1b). The first trial was conducted on flat-, diagonal- and radial-sawn boards. For all subsequent tests, only radial-sawn boards were tested because wet pocket occurred predominately in these boards. The boards were cut and planed to sample size of 20 mm × 100 mm × 200 mm. The boards were placed in the middle of a forced air ventilated 150-L electric oven set at 60 ± 1 °C to dry. The natural venting hole of the oven was open during the drying process.

Six samples were prepared for each pretreatment. Each trial may have samples from more than one pretreatment. Details of pretreatments for the various trials are shown in Table 1. Hot water bath pretreatment was conducted using laboratory hot water bath set at the required temperature for 6 hours. Microwave pretreatment was conducted by passing the sample through a microwave applicator with the microwave generator set at a fixed level. Microwave energy used was the division of microwave power applied by the volume flow rate of sample.

After air drying and pretreatment, both exposed ends and side faces of the sample were sealed with silicon glue. Only the two wide faces were exposed and stacked with stickers in the electric oven. Samples were weighed at the various stages: green, air dried, pretreatment and during drying in the oven. Samples were monitored by weighing at 8 a.m. and 4 p.m. daily until the end of the trial. At the end of

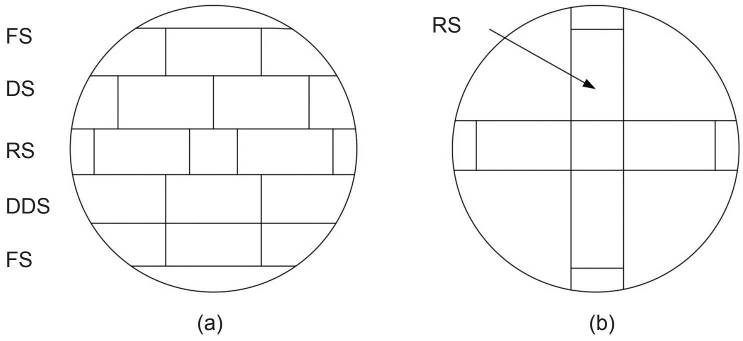

Figure 1 Sawing patterns for (a) flat-sawn (FS), diagonal-sawn (DS), radial-sawn (RS), double-diagonal-sawn (DDS) and (b) radial-sawn (RS) boards

Table 1 Untreated (green) or/and pretreatments conducted on the set of samples

Trial	Pretreatment		
	Untreated (green)/ air drying	Air drying followed by hot water bath	Untreated/air drying followed by microwave treatment
1	Green	–	–
2	–	–	Green + MW (900 M J m^{-3})
3	AD (15 days)	–	AD (15 days) + MW (600 M J m^{-3})
4	–	AD (7 days) + HWB (95 °C, 6 hours)	AD (7 days) + MW (900 M J m^{-3})
5	–	AD (7 days) + HWB (60 °C, 6 hours)	AD (7 days) + MW (200 M J m^{-3})
6	AD (20 days)	AD (20 days) + HWB (95 °C, 6 hours)	AD (20 days) + MW (400 M J m^{-3})

Green = freshly sawn boards from the sawmill, AD = air drying, HWB = hot water bath, MW = microwave the test, two specimen strips (25-mm length each) were cut from the middle of the sample: one specimen was for the determination of final moisture content while the other was cut into five slices of equal thickness to establish moisture contents of the core and shell over the cross-section of the specimen (Figure 2). The first and fifth slices (top and bottom) were used to calculate the shell moisture content and the middle (i.e the third) slice was used to calculate the core moisture content. Occurrence of wet pockets was evaluated by calculating the difference between the core and shell moisture contents. Wet pockets occurred in all samples that had differences in moisture content of more than 5%. Weight loss of each sample with time was used to establish the drying curves for trials 1 and 2. For the rest of the trials, average of six samples for each treatment group was used to establish the respective drying curves.

RESULTS AND DISCUSSION

Trial 1: Green samples

Drying curves of six samples of various sawn are presented in Figure 3. The initial and final moisture contents and the differences between the core and shell are presented in Table 2. Initial moisture content varied from 81 to 124% and the final, from 6 to 35%. Flat-sawn boards dried to about 5% moisture content and the differences in moisture content between the core and shell were less than 5%, indicating the absence of wet pocket but normal moisture gradient over the cross-section of the boards. However, for diagonal- and radial-sawn samples, high and varied final moisture content values indicated that the samples were not dried thoroughly and this was confirmed by the high moisture content difference between the core and shell (Table 2). These results concurred with results obtained from drying trials using experimental steam-heated kiln by Gan and Zairul (2011a). It has been reported that final moisture content of *Acacia mangium* is not uniform after drying in conventional oven and is influenced by the percentage of radial wood (Tenorio & Moya 2011). From results of this study, subsequent trials were conducted on radial-sawn planks only in order to gauge the effectiveness of the various pretreatments applied**.** The current oven-drying trial demonstrated that the drying rate test could be used to quickly assess the effectiveness of pretreatment on timber prior to drying using conventional steam-heated kiln.

Trial 2: Green samples and microwave pretreatment

For this trial, only the radial-sawn samples were used. Drying curves of microwave-pretreated green *A. mangium* are shown in Figure 4. Moisture content values at the different stages of the trial are listed in Table 3. It was noted that green samples lost an average of 26.9% moisture after microwave pretreatment. Initial moisture content at the start of the oven drying trial ranged from 72 to 94% and the final moisture content, from 13 to 24%. However, moisture

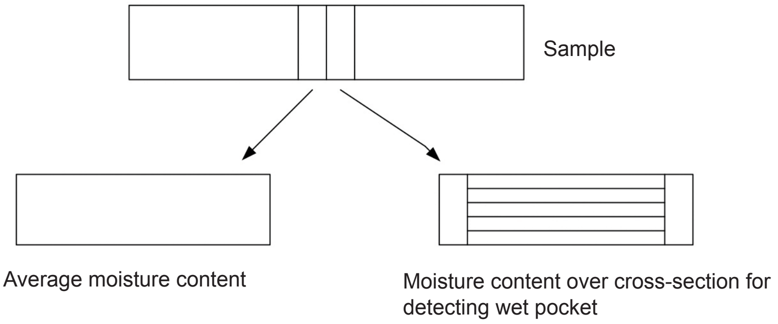

Figure 2 Specimens for determination of final moisture content and moisture content distribution over cross-section of the samples

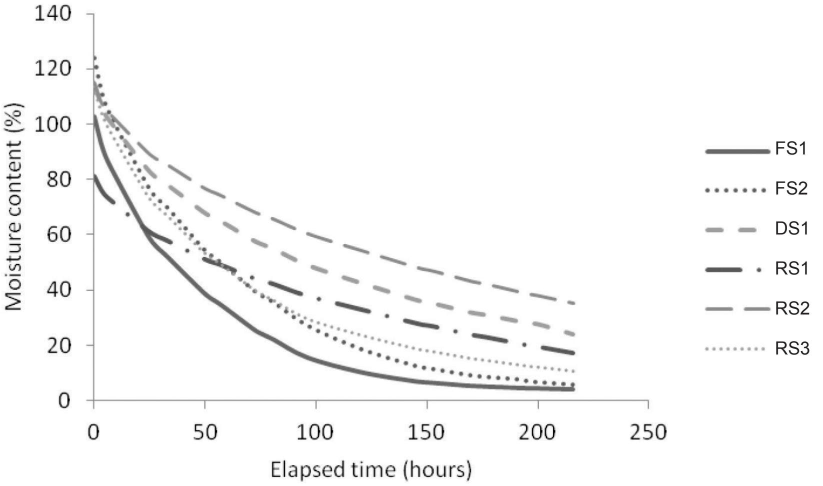

Figure 3 Drying curves of *Acacia mangium* samples with different sawn patterns; FS = flat-sawn, DS = diagonal-sawn and RS = radial-sawn boards

Table 2 Initial, final and difference in core and shell moisture contents of samples in trial 1

Sample	Initial moisture content (%)	Final moisture content (%)	Moisture content difference between core and shell(%)
FS1	102.9	4.3	2.0
FS2	123.8	5.8	3.3
DS1	114.5	24.1	31.8
RS1	81.2	17.2	70.2
RS2	115.5	35.1	60.5
RS3	113.6	10.5	16.4

FS = flat-sawn, DS = diagonal-sawn and RS = radial-sawn boards

content differences between the core and shell were still high, ranging from 8.7 to 31.3%. These indicated the presence of wet pockets in the dried *A. mangium* samples and the pretreatment applied was not effective.

Trial 3: Air dried and air dried followed by microwave pretreatment

Average moisture content drop after microwave pretreatment was 16.0%. Moisture contents at various stages of the drying process are listed in Table 4. Air drying did not seem to alleviate the occurrence of wet pockets as demonstrated in Figure 5 with the final moisture content being still very high at about 27.4% (Table 4). However, air drying followed by microwave pretreatment seemed to be able to lessen the occurrence of wet pockets. This suggests that microwave pretreatment may be effective for air-dried *A. mangium* but not for green boards.

Trial 4: Air dried followed by either hot water bath or microwave pretreatment

In this trial, the air drying period was reduced to 7 days to explore if air duration could be shortened. On average, moisture content dropped between 24.3 and 32.4% (Table 4) after 7 days of air drying. Hot water bath pretreatment resulted in increased of moisture content of about 7.6%, whereas microwave pretreatment using 900 MJ m^{-3} resulted in reduction of moisture content by 29.3%. Under the same drying condition, hot water bath-pretreated samples dried faster compared with microwave-pretreated

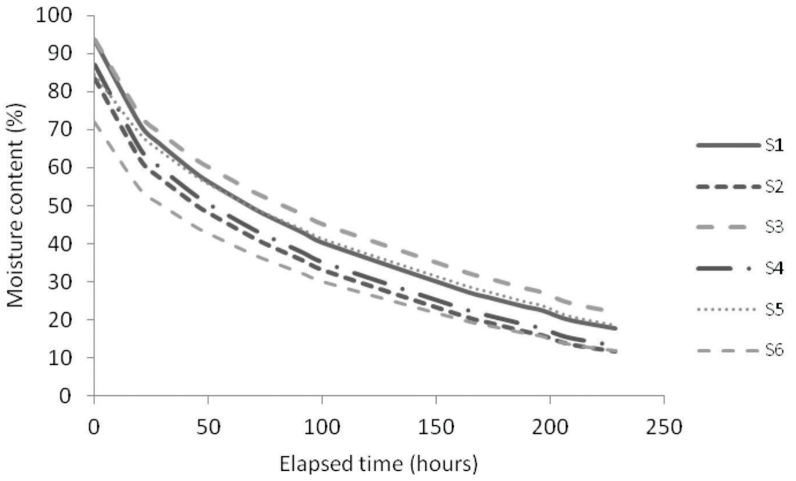

Figure 4 Drying curves of green samples (S) pretreated using microwave

Table 3 Moisture contents at various stages of the pretreatment and drying process for trial 2

Sample	Green moisture content (%)	Moisture content drop due to microwave pretreatment (%)	Initial moisture content (%)	Final moisture content (%)	Moisture content difference between core and shell (%)
1	116.8	23.6	93.3	17.9	20.1
2	111.6	28.1	83.5	12.9	8.7
3	118.6	24.8	93.8	24.2	31.3
4	115.3	28.2	87.1	14.0	15.3
5	114.2	29.9	84.3	18.8	28.8
6	98.8	26.6	72.2	12.5	10.5
Average	112.6	26.9	85.7	16.7	19.1

samples to below 10% moisture content (Figure 6). Differences in moisture contents between the core and shell of the dried samples were below 5% for both pretreatments (Table 4). These suggested that both pretreatments were equally useful in minimising the occurrence of wet pockets in *A. mangium*.

Trial 5: Short air drying duration, lower settings for hot water bath and microwave pretreatments

This trial was similar to trial 4 except that temperature of the hot water bath was lower, i.e. 60 °C and so was the microwave energy, i.e. 200 MJ m^{-3}. The drying curve for hot water-pretreated samples seemed parallel and moisture content was about 15% higher than the microwave-pretreated samples, indicating high variation in moisture content or occurrence of wet pockets at the end of drying in the hot water-pretreated samples (Figure 7). This was confirmed by the high moisture content difference between the core and shell (Table 4). This trial demonstrated that the hot water bath must be set at a temperature higher than 60 °C to be effective. For microwave-pretreated samples, average difference in core and shell moisture content was 5.6% (Table 4). At lower microwave energy per unit volume,

Table 4 Moisture contents (%) at different stages of drying

		Air drying (AD)			Pretreatment processes			Oven drying trial		
Trial	Sample	Green MC (%)	Air-dried MC	MC drop after AD	MC after HWB	MC after MW	MC drop after treatment	Initial MC	Final MC	MC difference core and shell
3	AD (15 days)	123.5	63.7	59.8	–	–	–	63.7	27.4	58.4
	AD (15 days) + MW (600 MJ m^{-3})	112.0	56.3	55.7	–	40.3	16.0	40.3	7.2	4.8
4	AD (7 days) + HWB (95 °C, 6 hours)	86.4	62.1	24.3	69.7	–	-7.6	69.7	7.3	3.9
	AD (7 days) + MW (900 MJ m^{-3})	89.8	57.4	32.4	–	28.1	29.3	28.1	5.4	3.3
5	AD (7 days) + HWB (60 °C, 6 hours)	93.1	52.9	40.2	60.4	–	-7.5	60.4	20.4	32.8
	AD (7 days) + MW (200 MJ m^{-3})	86.7	47.6	39.1	–	37.5	10.1	37.5	8.7	5.6
6	AD (20 days) + HWB (95 °C, 6 hours)	97.5	44.6	52.9	65.5	–	-20.9	65.5	5.1	1.7
	AD (20 days) + MWE (400 MJ m^{-3})	94.8	44.8	50.0	–	27.5	17.3	27.5	4.3	2.4
	AD (20 days)	94.0	45.4	48.6	–	–	–	45.4	9.9	13.0

Negative values mean increase in moisture content; AD = air drying, HWB = hot water bath, MW = microwave, MC = moisture content

the effectiveness of drying was not as good compared with higher microwave energy input as in Trial 4.

Trial 6: Comparative test using pretreatment settings deduced from previous trials

After microwave pretreatment at 400 MJ m^{-3}, air-dried samples lost a further 17.3% moisture (Table 4). However, the air-dried samples picked up moisture by about 20.9% after hot water bath pretreatment. The hot water bath-pretreated samples dried more quickly than microwave-pretreated samples but their final moisture contents were almost similar (Figure 8). However, it should be noted that microwave-pretreated samples might dry at harsher conditions as the starting (initial) moisture content was much lower than the other two pretreatments and may dry at a faster rate. Drying rate for untreated air-dried samples was lower than the two pretreated samples but final moisture content was about 5% higher, indicating the occurrence of wet pockets. This was confirmed by the difference in moisture content between the core and shell at 13%.

The six drying trials with different pretreatments and settings demonstrated that the drying rate test protocol could be used successfully to quickly assess the effectiveness of the applied pretreatment. Each drying trial took between 160 and 350 hours using a normal electric oven. The size of sample was small (20 mm × 100 mm × 200 mm) and easy to manage. As only an oven was used, the operating cost was negligible compared with the need to operate a boiler for the experimental drying trial using conventional steam-heated kiln. Each drying trial of *A. mangium* can take about 450 to 600 hours using the experimental kiln (Gan & Zairul 2011b). The authors used a bigger sample size (25 mm × 120 mm × 990 mm) which took a longer time for preparation and pretreatment prior to the experimental drying.

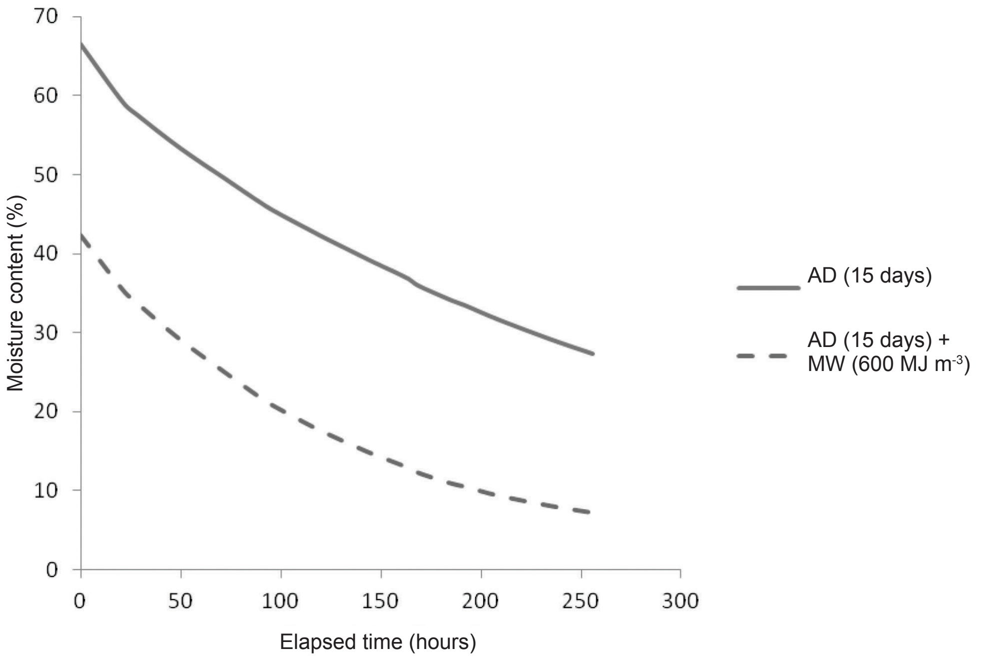

Figure 5 Drying curves of samples subjected to air drying and air drying followed by microwave pretreatment; AD = air drying, MW = microwave treatment

Overall, there was reasonable time saving and lower cost involved in the assessment of the pretreatment processes.

Experimental drying trials conducted to evaluate the characteristics of *A. mangium* in relation drying schedule and kiln treatment applied took between 500 and 650 hours to accomplish (Gan & Zairul 2011b, Gan et al. 2011). Shorter drying time of about 340 hours was required using high temperature schedule in the evaluation by Tenorio and Moya (2011). These studies were conducted on actual timber sizes (25 mm thickness of different widths and lengths) depending on the size of the experimental dryer. The drying conditions were varied according to the schedule applied using steam. The time required for each evaluation was long and costly because the boiler was operated continuosly.

CONCLUSIONS

The procedure for drying rate test may be used for quick assessment of the effectiveness of pretreatment for *A. mangium* prior to full-scale experimental drying using conventional steam heated-kiln. The six drying trials with different pretreatments and settings demonstrated that the drying rate test protocol was successful in quickly assessing the effectiveness of the applied pretreatment. This study has demonstrated the applicability of this simple procedure to reduce time and cost rather than conducting full-scale experimental drying trials incorporating the various pretreatments. The effectiveness of hot water bath and microwave pretreatments to alleviate occurrence of wet pockets was demonstrated through the various trials conducted.

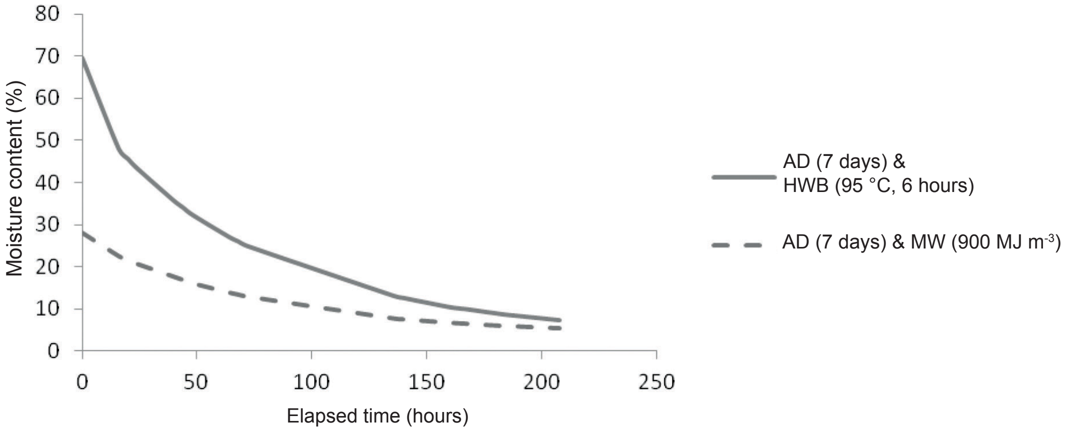

Figure 6 Drying curves of air dried (AD) boards followed by either hot water bath (HWB) or microwave (MW) pretreatments

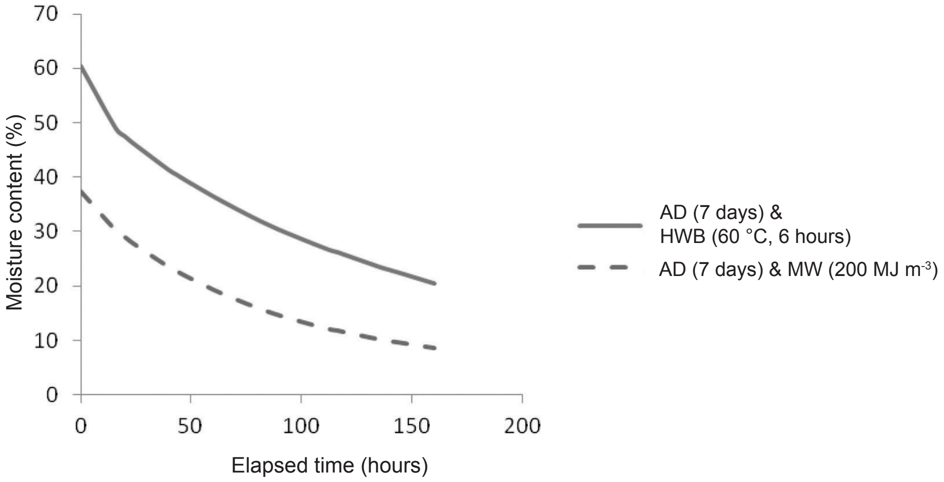

Figure 7 Drying curves of air dried (AD) samples followed by either hot water bath (HWB) or microwave (MW) pretreatments

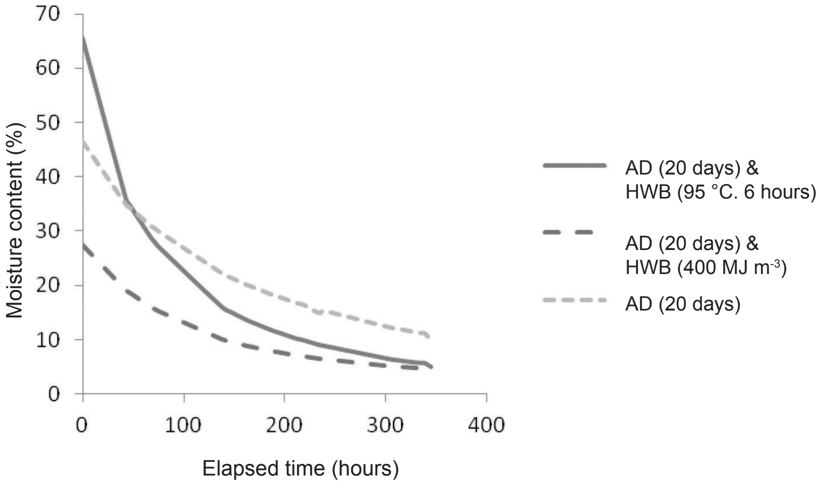

Figure 8 Drying curves for three sets of samples—air dried (AD) and air dried followed by either hot water bath (HWB) or microwave (MW) pretreatments

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