Advancing Enhanced Wood Manufacturing Industries in Laos and Australia

Development of EWPs - Rattan and Bamboo Mats as Cover for Non-Structural Constructions

Report Written By

Benoit Belleville

Johannes Fehrmann

Khamtan Phonetip

March 2022

This milestone report is a component of VALTIP 3 Activity 2.2 of Objective 2, “to develop and adapt innovative technologies for the production of high performance engineered wood products (EWPs) and composite products based on wood and other materials”, in the ACIAR co-funded aid project FST/2016/151 *Advancing enhanced wood manufacturing industries in Laos and Australia*.

The present report covers recommended adhesives, treatment, and recommended manufacturing methods for EWP to be manufactured using non-structural plywood panel and rattan or bamboo mats as cover for non-structural constructions. The document is divided into two sections. The first section discusses the QUV accelerated weathering testing results for five different types of bamboo and rattan mat. The second section presents recommended processing steps for the manufacturing of decorative paneling using rattan and bamboo mats as cover for non-structural constructions.

Executive summary

Various adhesives and manufacturing methods have been investigated for the fabrication of decorative paneling products using non-structural plywood panel and rattan or bamboo mats as cover for non-structural constructions.

A key challenge identified was the overlapping strands of the bamboo mats which did not provide enough hold to guarantee its integrity during machining. Individual strands moved easily or got pulled out of the assembly. This effect can be mitigated by application of a strong tape (quality masking or cloth tape) across the area where the cut is to be made. Smaller strands and a tighter weave of the rattan mats resulted in significant less tear out or disintegration. When using a circular saw it is recommended to add a sacrificial sheet on top of the mat to mitigate any potential tear out. A similar principal applies when a table saw is used to minimize the gap between the saw blade and table. In this way tear out is minimized and a clean edge could be achieved provided the mat is pressed downwards when passing the blade. Where the material thickness allowed for it, a guillotine proved to be the most efficient and safest way to produce clean sample edges with minimal disturbance to the bamboo strands.

Foaming is always going to be a problem with polyurethane (PUR) adhesives in areas that no pressure is applied such as the voids present in the rattan panels. There really is no way around this - especially with the EMC, temperatures and humidities in Laos. Consequently, an emulsion polymer isocyanate (EPI) which is suitable for bonding hard wood species and other materials with high resin content and moisture content is recommended for decorative paneling products.

Edging or trimming laminated decorative panels also proved difficult because of excessive tear out of fibres. Bamboo mats basically frizzles away when holding sandpaper against it. The weaving also doesn't help as individual strand around the edges are still prone to being pulled out. Tear out of fibres seems to be the nature of the material and therefore, having bamboo mats weaved to desired dimensions would be desirable. A similar conclusion can be made for the rattan mats although tear out was not as problematic as bamboo, especially when using a guillotine.

The overall trends in colour change for rattan mats, based on the greatest colour difference changes, were:

- A shift towards negative ΔL i.e., sample had become darker compared to unexposed reference sample, except for rattan mats design #5 which had become lighter.
- A shift towards positive Δa i.e., sample had become redder, except for rattan mats design #5 which had become greener.
- A shift towards positive Δb i.e., sample had become yellower, except for rattan mats design #5 which had become bluer.

The overall trends in colour change for bamboo mats, based on the greatest colour difference changes, were:

- A shift towards positive ΔL i.e., sample had become lighter compared to unexposed reference sample, except for the green areas of bamboo mat design #1 which had become darker.
- A shift towards negative Δa i.e., sample had become greener.
- A shift towards negative Δb i.e., sample had become bluer.

The study revealed that bamboo and rattans mats are similarly susceptible to UV discolouration but this discolouration tends to differ between the two materials and even within a specific group. The observed differences between the rattan groups can be explained by the fact that rattan, scientific name Calameae, is a general name for roughly 600 species of plant-climber from the palm family native to tropical regions especially in Asia. Ultimately, the discolouration could be retarded significantly through the appropriate choice of clear coating.

Key Points Bamboo Mat #1 after 2 weeks of UV exposure:

1. The **overall colour change** is significant after 24 hours for the yellow (pale) sections and after 48 to 72 hours for the green areas
2. Colour change is initially more pronounced for the yellow sections of the mats
3. Colour change for yellow areas stabilizes after 72 hours to 1 week
4. Colour change hasn't stabilized for the green areas after 2 weeks of UV exposure (see point #10)
5. There is more between mats colour change variability for the yellow sections (see point #8)
6. Green sections become **darker**
7. Yellow sections become **lighter**
8. Lightness change is more pronounced for yellow sections
9. Green and yellow sections both become **greener**
10. Green and yellow sections are both **bluer** - green sections haven't stabilized after 2 weeks of UV exposure.

Key Points Bamboo Mat #2 after 2 weeks of UV exposure:

1. The **overall colour change** is significant after 24 hours of UV exposure.
2. Colour change stabilizes after 72 hours to 1 week
3. Colour of bamboo mat design #2 is more stable than bamboo mat design #1
4. Mats become **lighter**
5. Mats become **greener**
6. Mats are **bluer**

Key Points Rattan Mat #3 after 2 weeks of UV exposure:

1. The **overall colour change** is the smallest observed across all the tested rattan designs after 24 hours. However, the overall colour change after 2 weeks is the largest observed across all the selected rattan mats.
2. The colour change becomes significant after one week
3. The colour change and lightness hasn't stabilized after 2 weeks
4. Mats become **darker**
5. Mats become **redder**
6. Mats turn **yellower**

Key Points Rattan Mat #4 after 2 weeks of UV exposure:

1. Very little and unsignificant **overall colour change** after 24 hours.
2. The overall colour change after 2 weeks is the smallest observed across all the selected rattan mats.
3. The colour change becomes significant after 1 to 2 weeks.

4. The colour change and lightness haven't stabilized after 2 weeks.
5. Mats become **darker**.
6. Mats become **redder**.
7. Mats become **yellower**.

Key Points Rattan Mat #5 after 2 weeks of UV exposure:

1. The **overall colour change** becomes significant after 24 hours
2. The overall colour change after 24 hours is the highest across all the rattan mats products
3. The overall colour change after 2 weeks is the smallest across all the rattan mats products
4. Smallest colour change variability between samples after 2 weeks across all the rattan products
5. Mats become **lighter** with lightness change stabilizing after 24 hours
6. Mats become **greener** with Δa^* colour component stabilizing after 72 hours
7. Mats become **bluer**

Contents

1. Background

Colour change of material upon UV exposure is a complex process, which involves photo-initiated reaction, subsequent chemical oxidation, decomposition of lignin and extractives. Furthermore, the discolouration caused by sunlight depends on the UV intensity and specific wavelength, photochemical reaction rate of lignin, and the chemical nature of the extractive.

The standard ASTM G154 refers to operating procedures for using fluorescent UV light to reproduce the weathering effects that occur when materials are exposed to sunlight (either direct or through glass). ASTM G151 standard provides general procedures to be used when exposing non-metallic materials in accelerated fluorescent light test devices.

The ASTM G154 standard states that:

"*the main application for UV-A 351 nm lamps is for simulation of the short and middle UV wavelength region of daylight which has been filtered through glass*".

Figure 1 compares the spectral power distribution obtained from these lamps and natural sunlight through glass. The analysis of the graph reveals that low wavelength end cut-off for these lamps is similar to that of direct sunlight filtered through glass. It is also important to note that this wavelength also gives less severe results than using the shorter wavelength QUV lamps (*e.g.* 313 or 340 nm) which can lead to uncharacteristic results. Therefore, the selection of 351 nm wavelength for this study appeared to be easily justified.

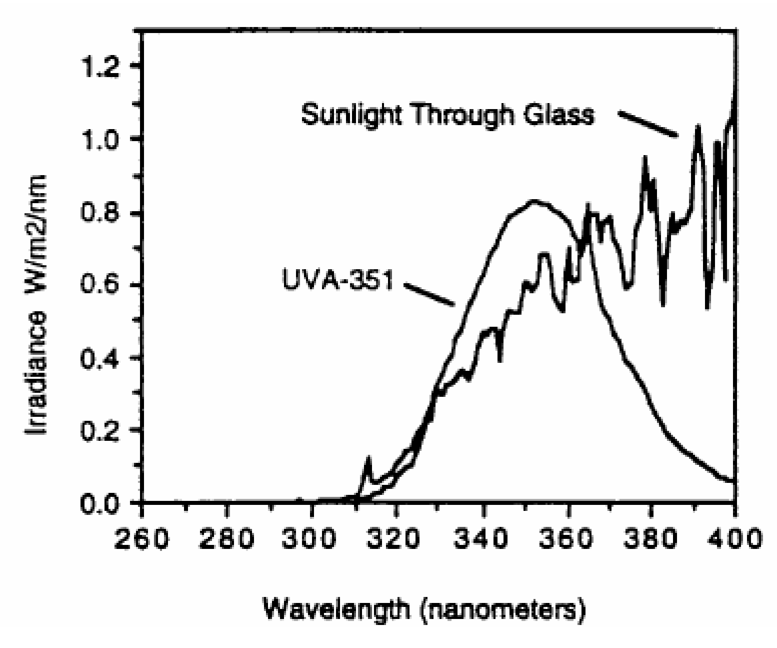


Figure 1. Comparison of the spectral power distribution obtained from 351 nm lamps and natural sunlight through glass.

The **CIELab colour system** consists of two axes (a* and b*) which are at right angles and represent the hue dimension or color (Figure 2). The third axis is the lightness (L*) and is perpendicular to the a*b* plane. Within this system, any color can be specified with the coordinates L*, a*, and b*.

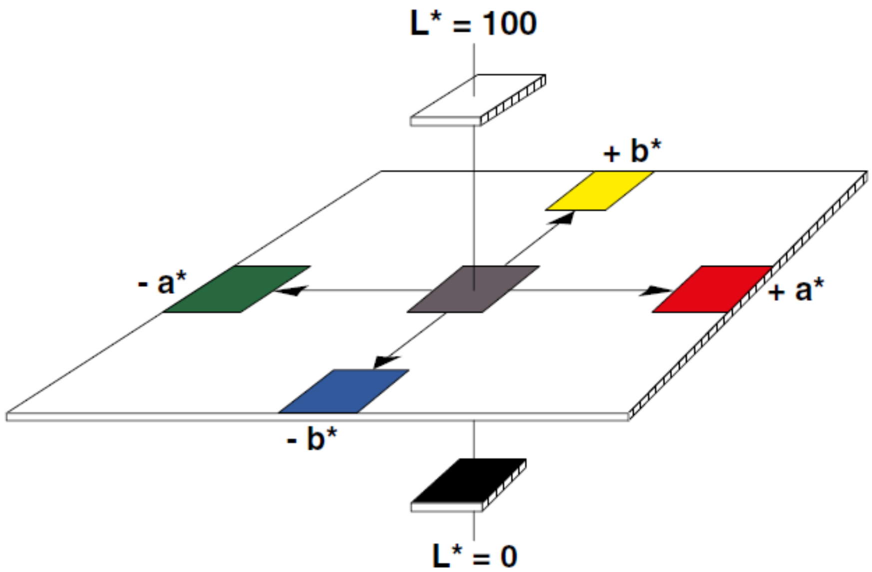


Figure 2. CIELab colour system.

2. Experimental

2.1 Material

The project team approached Ms. Bouavanh Phachomphonh, rattan and bamboo project manager for WWF Laos (http://www.wwflaos.org/), to purchase sustainable rattan and bamboo mats. Three different rattan mat designs (Figure 3) and two bamboo mat designs (Figure 4) have been selected for testing and prototype fabrication. Between 2 and 3 mats (dimensions approx. 1 m x 1 m) per design have been sourced. The selected mats were produced by Danlao, an FSC and CoC certified company located in Vientiane, Lao PDR, supported by WWF. Danlao provides opportunities for local families, villages and or whole communities and alleviates poverty in the country, especially in rural provinces (www.danlaorattan.com).

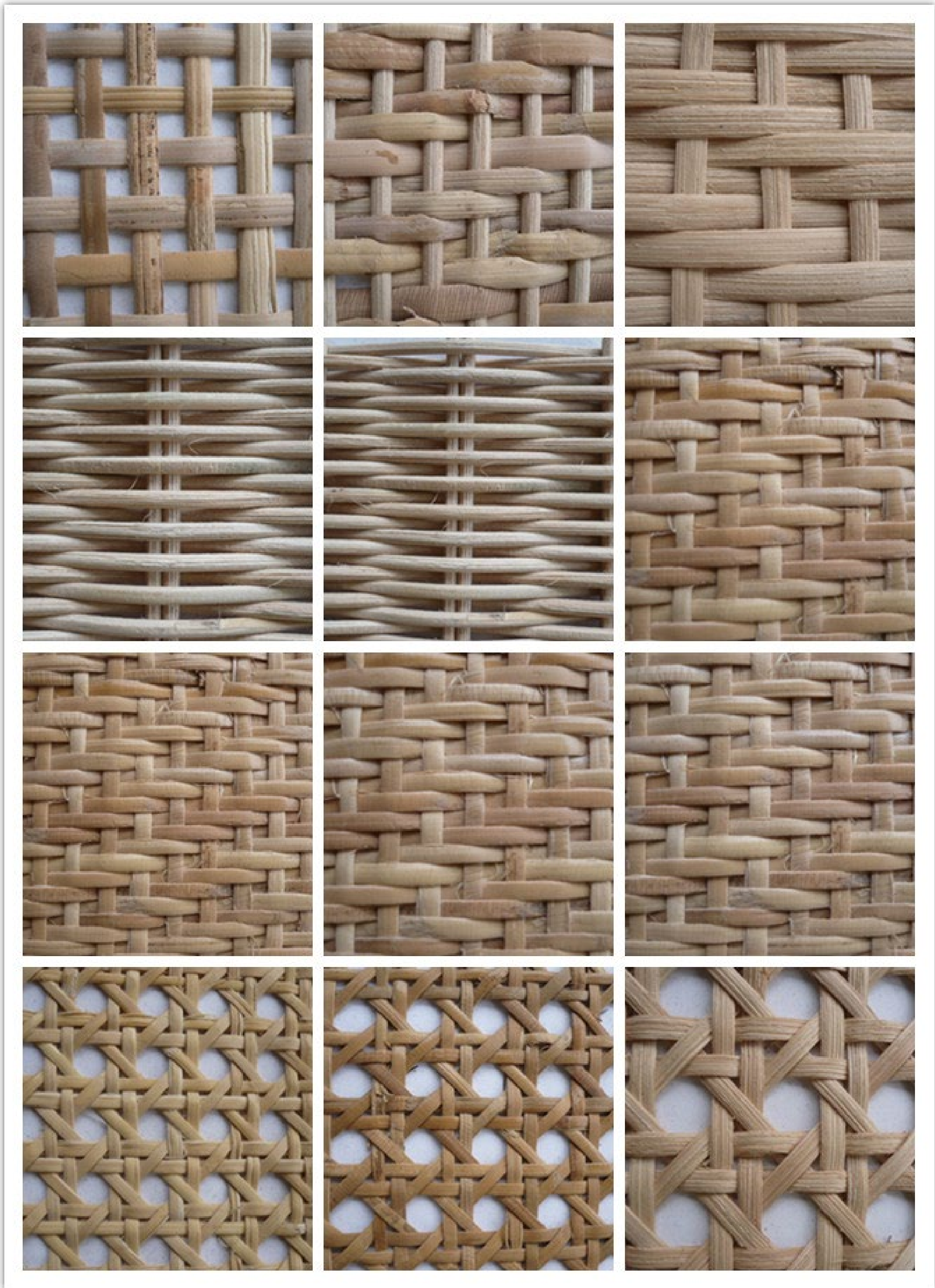


Figure 3. Selection of rattan weaving patterns (Photo montage provided by Bouavanh Phachomphonh).

Figure 4. Selected bamboo mat designs.

2.2 QUV accelerated weathering

Five different types of mat have been selected and assessed in the present study *i.e.*, 2 bamboo designs and 3 rattan designs (labelled as mat #1 to #5, Figure 5). Each bamboo design had two replicates (mats) where the rattan designs had 3 replicates each. The mats have been tested as received i.e., untreated and unprotected. Three samples strips per mat were cut and labelled e.g., 5.2.3 would be the third strip of the second replicate of panel #5. A thermosetting adhesive was applied on the edges of the strips to preserve their integrity while handling them (Figure 6).

Figure 5. Selected types of mat for the present study. From left to right: Mat #1 (Material: Bamboo), Mat #2 (Bamboo), Mat #3 (Rattan), Mat #4 (Rattan) and Mat #5 (Rattan)

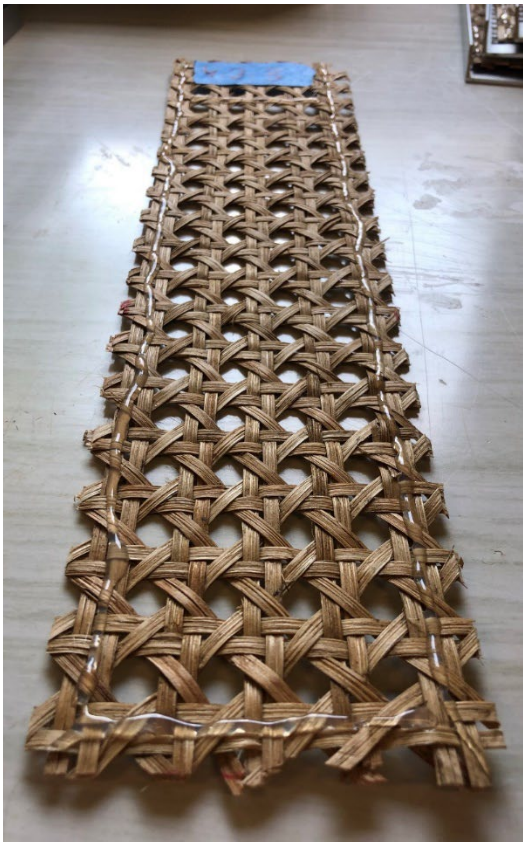


Figure 6. Example of machined strip for UV weathering.

The colour measurements were taken in eight different points on the UV exposed surface of each strip due to the very high variability within the same range colour displayed by the rattan and bamboo grain and the very narrow area the colour meter can read (about 4 mm^2). To ensure that all the colour readings were taken in the same spots at different stages during the QUV accelerated exposure test, a colour measurement template was used (Figure 7). The colour measurement was undertaken using a BYK-Gardner digital colour apparatus (Figure 8). The CIELab colour system ($\Delta E_{L^*a^*b^*}$, ΔL^*, Δa^* and Δb^*) and the following specifications were used:

- Light source type D65
- Observation angle of 10°
- Calibration with standards
- Sample averaging n= 8 (uniform mat colour) or 2 x 4 (where green and pale colors are present on a design)

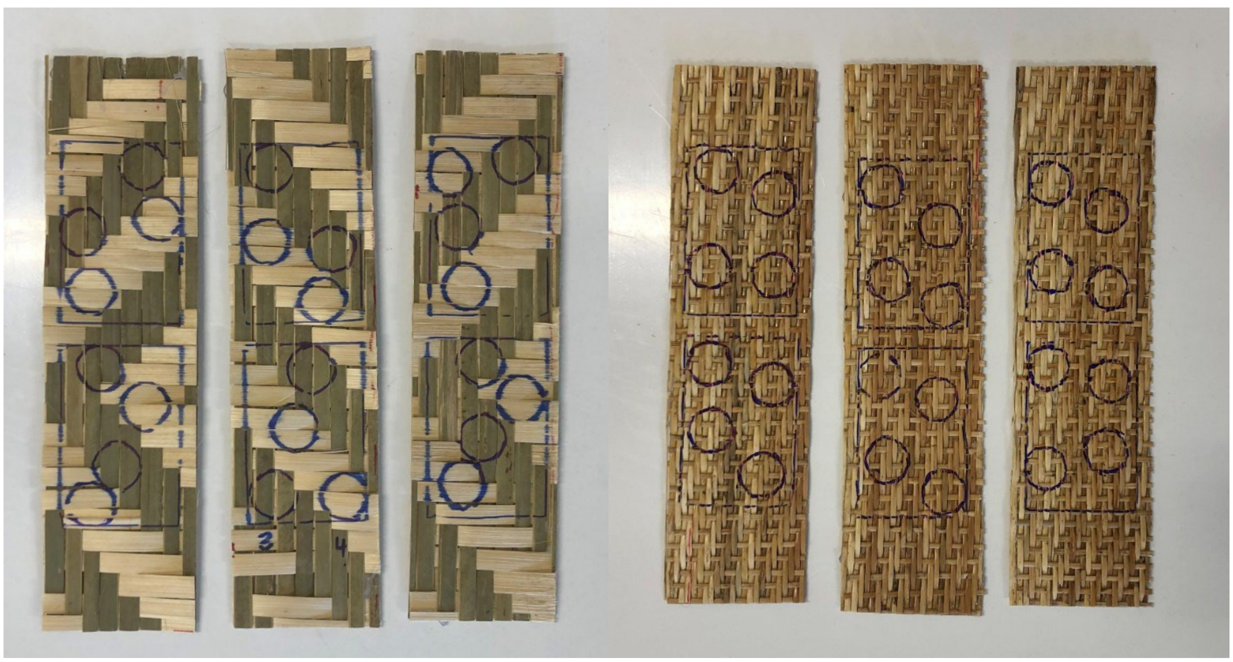


Figure 7. Examples of colour measurement template (left: Mat #1; right: Mat #3)

Colour change was measured prior to UV weathering (0 h), after 1 day (24 h), after 2 days (48 h), after 3 days (72 h), after 7 days (168 h), and after 14 days (336 h).

Figure 8. The spectrophotometer used to measure the colour of a sample.

L*, a* and b* colour coordinates for each sample were determined before and after exposure to accelerated weathering (Figure 9). These values were used to calculate the colour change (ΔE_{L*a*b*}) as a function of the UV irradiation period according to the following equations:

$$\Delta L^* = L_f^* - L_i^* \quad \text{[Eq. 1]}$$

$$\Delta a^* = a_f^* - a_i^* \quad \text{[Eq. 2]}$$

$$\Delta b^* = b_f^* - b_i^* \quad \text{[Eq. 3]}$$

$$\Delta E_{L*,a*,b*} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad \text{[Eq. 4]}$$

where ΔL*, Δa*, and Δb* are the changes between the initial and several interval values and ΔE* is the total change of colour.

- A positive (+) ΔL* means that the sample is lighter than the standard
- A negative (-) ΔL* means that the sample is darker than the standard
- A positive (+) Δa* means that the sample is redder than the standard
- A negative (-) Δa* means that the sample is greener than the standard
- A positive (+) Δb* means that the sample is yellower than the standard
- A negative (-) Δb* means that the sample is bluer than the standard

Note: A low ΔE * corresponds to a low colour change or a stable colour. It is generally considered that a colour change above five is perceived by the naked eye and depending on the application the change could be more or less significant.

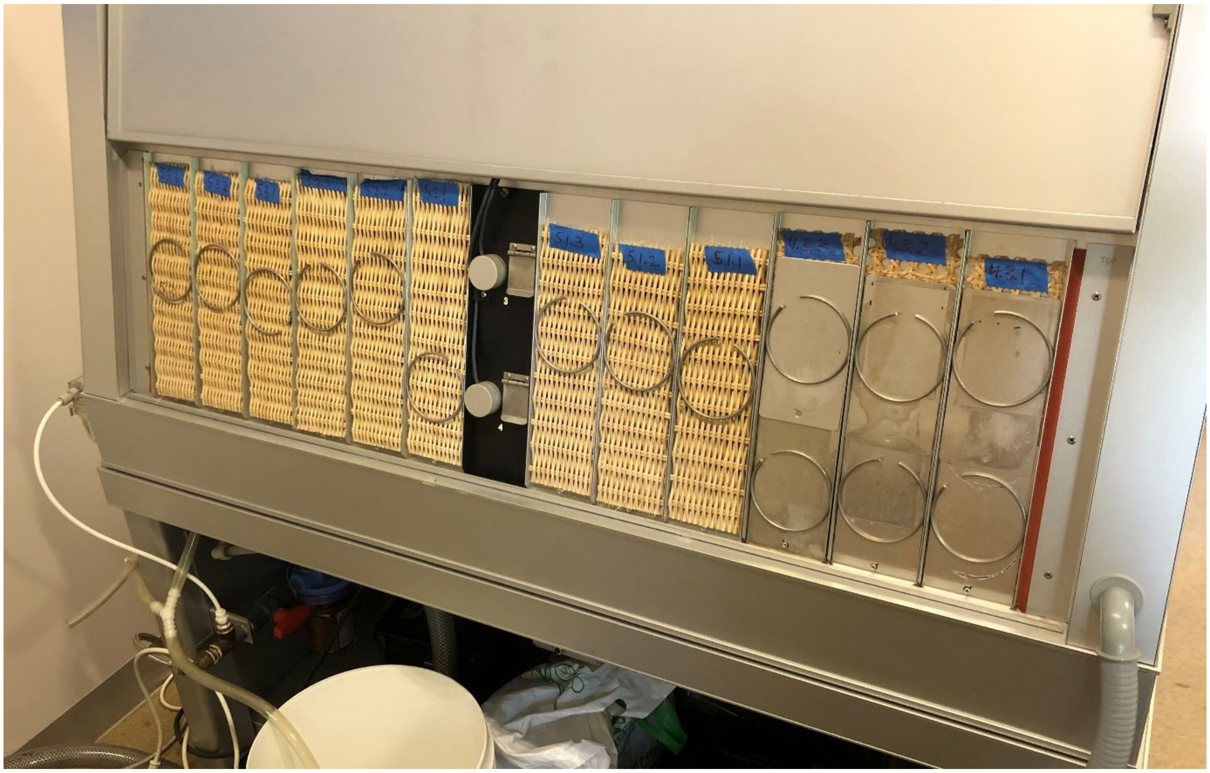


Figure 9. Experimental setup showing samples in the sample holders in the QUV weathering unit (UV lamps not visible on the photo).

2.3 Prototype manufacturing

The adhesion of the bamboo mats on a carrier material was to be investigated. Three adhesive types were trialed, and the following processing parameters documented: sample machining, adhesive application, glue spread, pressing process. The adhesives were:

1. A liquid one -component polyurethane adhesive typically used for load-bearing structural wood bonding (Jowapur 686.70, long open time: 50-70 min),
2. An emulsion polymer isocyanate (EPI) suitable for bonding hard wood species with high resin content and moisture content up to 15% (Jowacoll 102.49), and
3. A waterborne single component polyvinyl acetate emulsion (PVA) featuring good water resistance and heat resistance (Aquence KL 442.3051).

A range of methods were trialed to identify feasible equipment to separate sample sections from respective mats. Equipment trialed included: circular saw, table saw, band saw, and guillotine.

The mat sections were prepared to an average dimension of 75 mm x 137 mm. These sections were to be glued onto a high-density fibre board as the carrier material. All samples were pressed 0.48 MPa which was enough pressure to ensure sufficient contact of all materials (squeeze out) but not to damage the mats. The adhesive was applied one-sided on the carrier sheet. Despite all adhesives being able to cure at room temperature (cold setting) the platen temperature was slightly raised in batch 3 and 4 to speed up the curing time for this experiment. The serrated edge of an adhesive spreader with 4 mm V-shaped notches was first used for batch 1 but found to be wasteful/inefficient considering the small glue area. Consequently, all adhesives were applied with the flat edge of the same spatula i.e., mimicking application with a glue roller. Sheets of baking paper were inserted on top and under the sample assemblies inside the press to prevent contamination of the platens. Adhesive characteristics are presented in Table 1 and the processing parameters are shown in Table 2.

Table 1. Adhesives characteristics.

Type	**Product name**	**Component**	**Colour Wet / Dry**
PUR	JOWAPUR 687.70	Single	Light beige/ Light beige/
EPI	JOWACOLL 102.49 JOWAT 195.60	Two	Beige / beige
PVA	AQUENCE KL 442-3051	Single	White / translucent

Table 2. Processing parameters.

Batch	Adhesive	ID	Sample width	Sample length	Sample area	Glue applied	Glue spread	Press time	Platen temp	Temp/RH	Spatula shape
			cm	cm	cm^2	g	gsm	min	°C	C/%	
1	PUR	#1	7.6	13.8	104.88	2.1	200	210	20	24/40	4 mm V
1	PUR	#2	7.5	13.6	102.00	2.9	284	210	20	24/40	4 mm V
1	PUR	#3	8.0	13.3	106.40	4.5	423	210	20	24/40	4 mm V
1	PUR	#4	7.6	13.0	98.80	2.2	223	210	20	24/40	4 mm V
2	EPI	#1	7.6	13.2	100.32	1.9	189	45	20	23/45	flat
2	EPI	#2	7.6	13.2	100.32	3.2	319	45	20	23/45	flat
2	EPI	#3	7.6	13.2	100.32	2.2	219	45	20	23/45	flat
2	EPI	#4	7.6	13.2	100.32	2.2	219	45	20	23/45	flat
3	PVA	#1	7.6	14.0	106.40	1.6	150	50	35	24/42	flat
3	PVA	#2	7.6	14.0	106.40	1.8	169	50	35	24/42	flat
3	PVA	#3	7.6	14.0	106.40	3.0	282	50	35	24/42	flat
3	PVA	#4	7.6	14.0	106.40	2.3	216	50	35	24/42	flat
4	PUR	#1	7.0	14.0	98.00	1.9	194	40	45	24/40	flat
4	EPI	#2	7.0	14.0	98.00	2.1	214	40	45	24/40	flat
4	EPI	#3	7.0	14.0	98.00	2.0	204	40	45	24/40	flat
4	PVA	#4	7.0	14.0	98.00	1.6	163	40	45	24/40	flat

3. Results and Discussion

3.1 UV weathering

A summary of the colour change for unprotected rattan and bamboo mats is presented in Table 3. The discoloration of selected designs when exposed to UV light is also discussed and presented graphically in the following pages.

Table 3. Average colour change ($\Delta E_{L^*a^*b^*}$) of unprotected *rattan* and *bamboo* mats as a function of UV exposure time.

UV Exposure Time

Mat #1 - Bamboo

	24 h	48 h	72 h	168 h	336 h
Avg Green	**4.11**	**6.05**	**7.31**	**10.42**	**13.27**
STD Green	1.25	1.40	1.55	1.58	2.06
Min Green	1.73	3.54	4.65	8.32	10.09
Max Green	5.41	7.53	8.95	12.28	15.62
Avg Yellow	**9.34**	**10.94**	**11.42**	**12.27**	**12.34**
STD Yellow	3.44	3.02	2.86	3.16	3.05
Min Yellow	5.40	7.52	8.32	8.82	8.95
Max Yellow	14.54	15.96	16.06	17.10	16.52

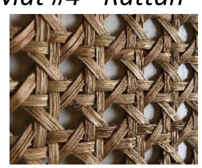
Mat #2 - Bamboo

	24 h	48 h	72 h	168 h	336 h
Avg	**7.95**	**9.03**	**9.47**	**9.90**	**10.08**
STD	0.77	0.89	0.89	0.84	0.90
Min	6.51	7.35	7.91	8.72	8.63
Max	8.98	10.49	10.78	11.11	11.25

Mat #3 - Rattan

	24 h	48 h	72 h	168 h	336 h
Avg	**1.53**	**1.52**	**2.37**	**5.94**	**11.23**
STD	0.63	0.87	1.27	2.04	2.51
Min	0.70	0.18	0.98	0.96	5.30
Max	2.80	2.77	4.77	8.70	15.02

Mat #4 - Rattan



	24 h	48 h	72 h	168 h	336 h
Avg	**2.00**	**1.42**	**1.49**	**4.12**	**8.47**
STD	0.79	0.57	0.48	1.52	1.98
Min	0.80	0.78	0.77	2.16	5.36
Max	3.25	2.32	2.30	6.48	12.44

Mat #5 - Rattan

	24 h	48 h	72 h	168 h	336 h
Avg	**11.93**	**12.49**	**12.23**	**10.13**	**8.46**
STD	0.77	0.88	0.89	1.21	1.11
Min	10.89	11.06	10.83	7.96	6.56
Max	13.16	13.80	13.37	12.02	10.27

[a] Average of 3 samples/strips (4 to 8 measures per sample/strip)

3.1.1 Bamboo design (Mat #1)

Key Points:

- **The overall colour change is significant after 24 hours for the yellow (pale) areas and after 48 to 72 hours for the green areas.**
- **Colour change is initially more pronounced for yellow areas of the mats.**
- **Colour change for yellow areas stabilizes after 72 hours to 1 week.**
- **Colour change hasn't stabilized for the green areas after 2 weeks of UV exposure.**
- **There is more colour change variability between mats for the yellow areas compared to the green areas.**
- **Lightness change after 2 weeks is more pronounced for yellow areas than green areas.**
- **The green areas become darker as the test progress where the yellow areas become lighter.**
- **Lightness variability between samples is less pronounced for the green areas.**
- **Both the green and yellow areas become greener as the test progress.**
- **Both yellow and green areas are bluer after 2 weeks of UV exposure and green areas haven't stabilized after 2 weeks of UV exposure.**

The colour change for bamboo design mat #1 is significant (i.e., ΔE * > 5) after 24 hours for the yellow (pale) areas (ΔE * = 9.34) and after 48 to 72 hours for the green areas (ΔE * = 6.05 and 7.31, respectively) (Figures 10 and 11). Colour change is initially more pronounced for yellow areas of the mats when compared to the green areas of the mats. The colour change for yellow areas stabilizes after 72 hours or 1 week. It is worth noting that colour change hasn't stabilized for the green areas after 2 weeks of UV exposure, suggesting that colour change would be even more important if the test was continued. There is slightly more variability between mat design #1 samples for the yellow areas (standard deviation after 2 weeks: 3.05) as opposed to the green areas (standard deviation after 2 weeks: 2.06).

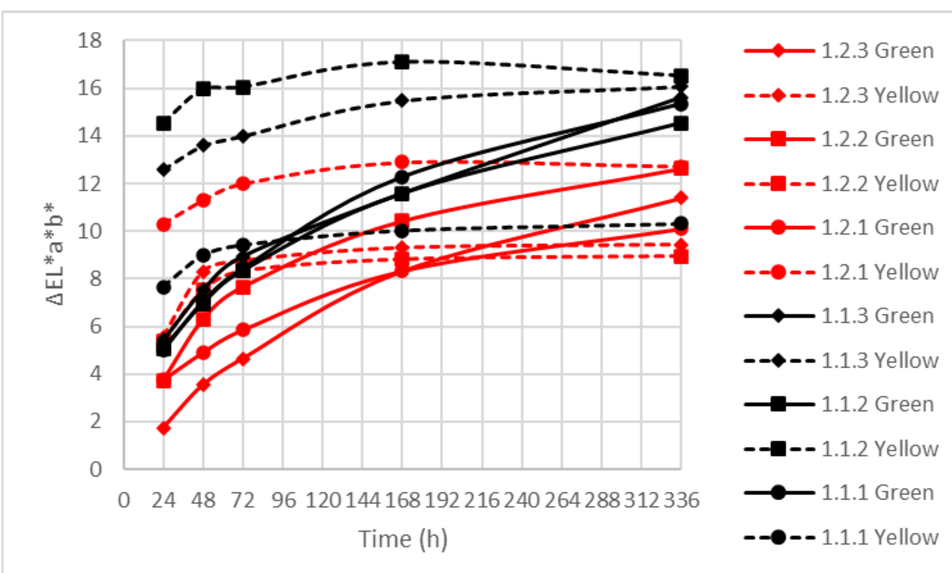


Figure 10. Colour change (ΔE_{L*a*b*}) of Mat #1 samples as a function of UV exposure time. A colour change above five (5) is perceived by the naked eye and depending on the application the change could be more or less significant.

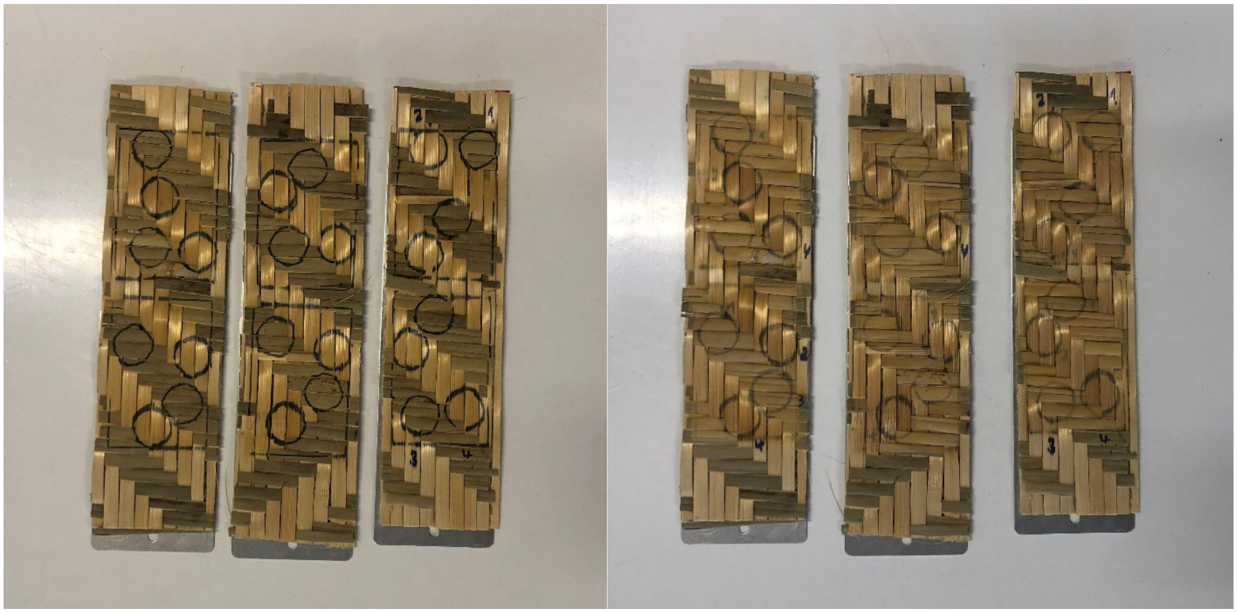


Figure 11. Mats #1 (from left: 1.1.3, 1.1.2, and 1.1.1) after 24 hours (left) and 336 hours (right) of UV exposure.

The green areas become darker as the test progress i.e., from a ΔL* of -2.60 after 24 hours to -7.42 after 2 weeks) (Figure 12). The yellow areas become lighter as the test progress from a ΔL* of 5.33 after 24 hours to 9.32 after 2 weeks). The lightness change after 2 weeks is more pronounced for yellow areas than green areas (ΔL* of 9.32 vs 7.42). The variability between samples is less pronounced for the green areas than yellow areas.

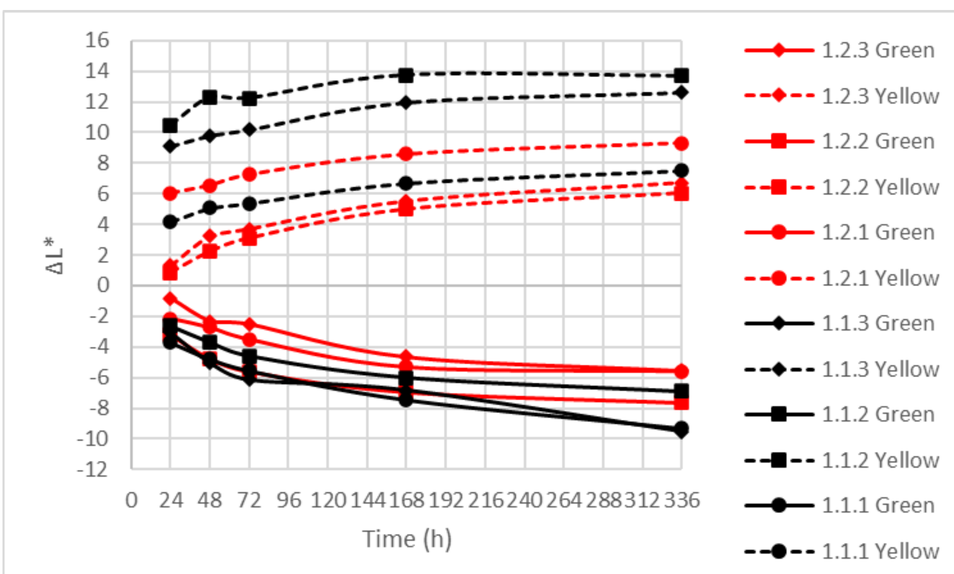


Figure 12. Lightness (ΔL*) colour component of Mat #1 samples as a function of UV exposure time. A positive (+) ΔL* means that the sample is lighter than the standard. A negative (-) ΔL* means that the sample is darker than the standard.

Figure 13 shows that both the green and yellow areas become greener as the test progress. The Δa* colour component appears to stabilize after 2 weeks. Both yellow and green areas are bluer after 2 weeks of UV exposure (Figure 14). The yellow areas quickly become bluer (i.e., more pronounced than green areas) but then tend to become yellower as the test progress where green samples continue to get bluer as the test progress. Green areas haven't stabilized after 2 weeks.

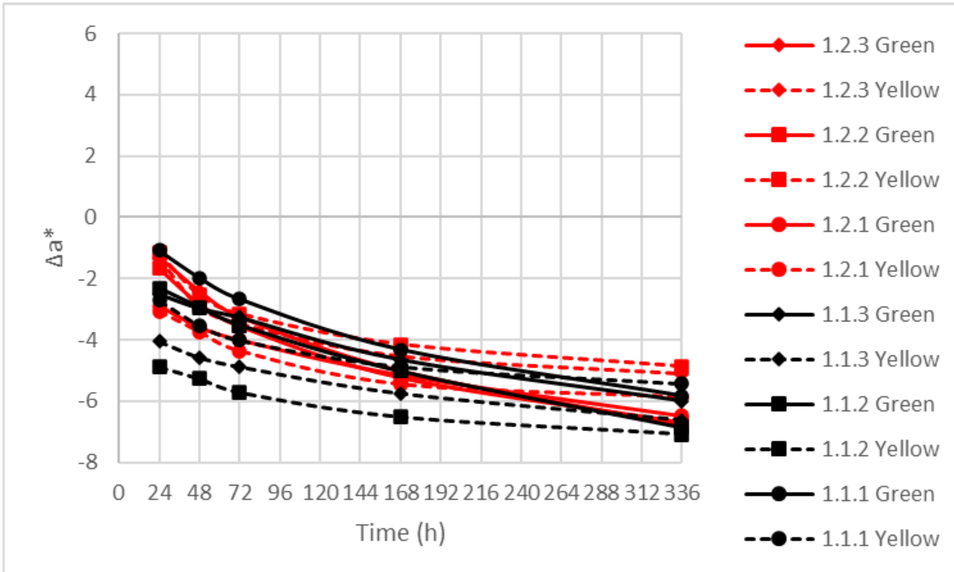


Figure 13. Δa* colour component of Mat #1 samples as a function of UV exposure time. A negative (-) Δa* means that the sample is greener than the standard. A positive (+) Δa* means that the sample is redder than the standard.

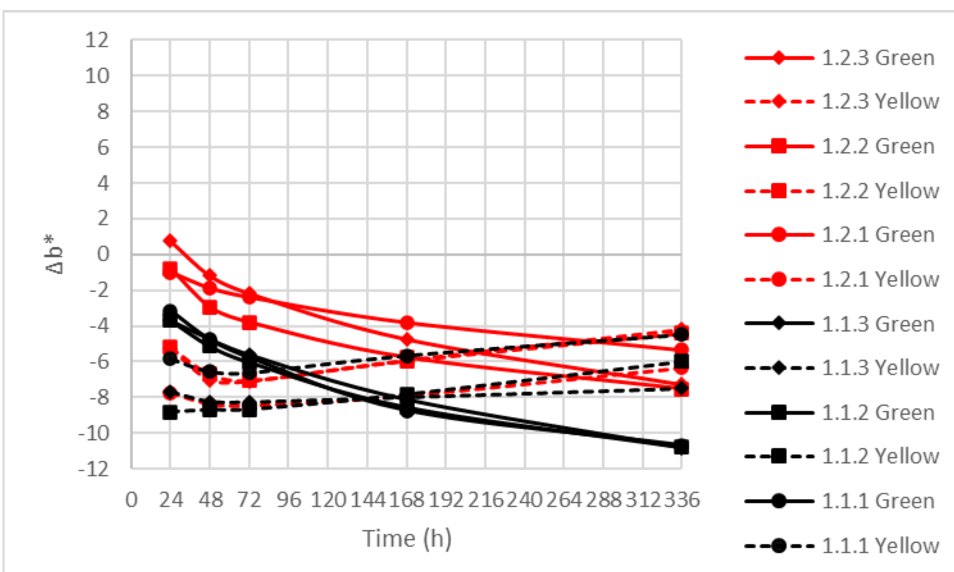


Figure 14. Δb* colour component of Mat #1 samples as a function of UV exposure time. A negative (-) Δb* means that the sample is bluer than the standard. A positive (+) Δb* means that the sample is yellower than the standard.

3.1.2 Bamboo design (Mat #2)

Key Points:

- **The overall colour change is significant after 24 hours of UV exposure.**
- **The colour change stabilizes after 72 hours to one week.**
- **The colour of bamboo mat design #2 is more stable than bamboo mat design #1.**
- **Mats become lighter.**
- **Mats become greener.**
- **Δa* colour component for bamboo mat design #1 and #2 are within the same range but variability between samples is lower for mat design #2.**
- **Mats are bluer after 2 weeks.**

The overall colour change is significant after 24 hours of UV exposure (ΔE * of 7.95) (Figures 15 and 16). The colour change stabilizes after 72 hours to one week of UV exposure. The average ΔE * after 2 weeks is 10.08. The overall colour change after 2 weeks for bamboo mat design #2 is lower than bamboo mat design #1.

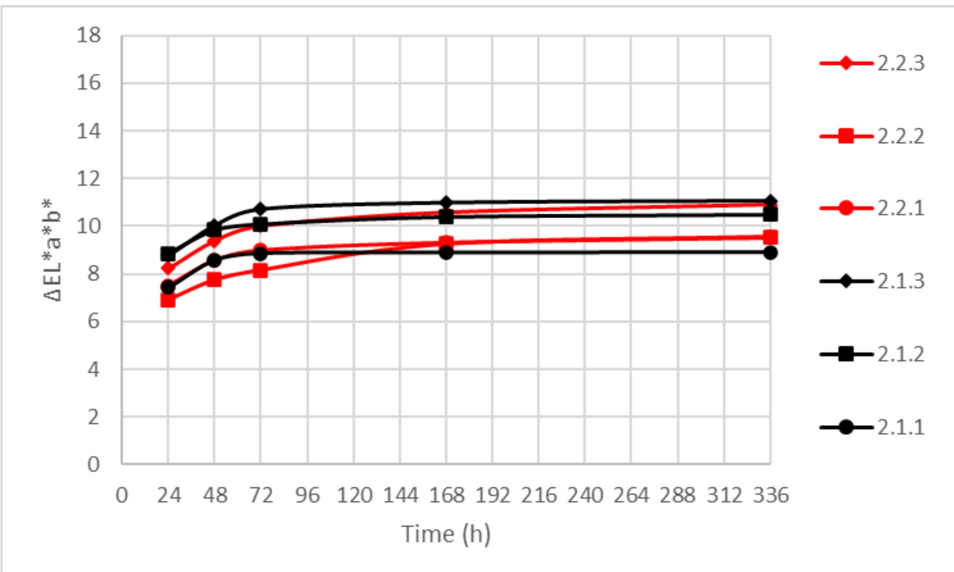


Figure 15. Colour change ($\Delta E_{L^*a^*b^*}$) of Mat #2 samples as a function of UV exposure time. A colour change above five (5) is perceived by the naked eye and depending on the application the change could be more or less significant.

Figure 16. Mats #2 (from left: 2.1.3, 2.1.2, and 2.1.1) after 24 hours (left) and 336 hours (right) of UV exposure.

All the mats become lighter as the test progress (Figure 17). The lightness (ΔL*) colour component of bamboo mat design #2 appears to be more stable when comparing with bamboo mat design #1.

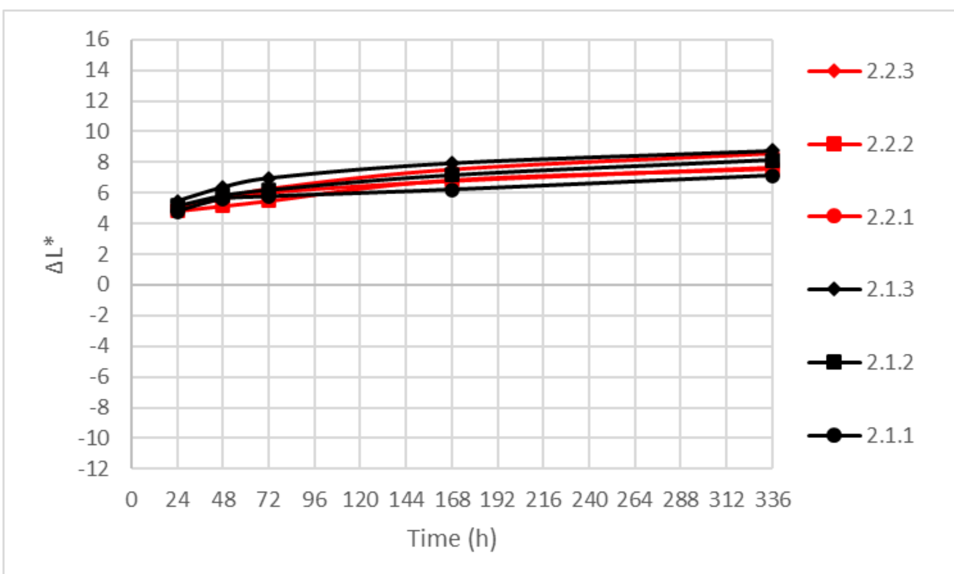


Figure 17. Lightness (ΔL*) colour component of Mat #2 samples as a function of UV exposure time. A positive (+) ΔL* means that the sample is lighter than the standard. A negative (-) ΔL* means that the sample is darker than the standard.

The mats become greener as the test progress (Figure 18). The Δa* colour component stabilizes after 1 week. The Δa* colour component for bamboo mat design #1 and #2 are within the same range although variability appears slightly lower for the mat design #2. The mats are bluer after 2 weeks (Figure 19).

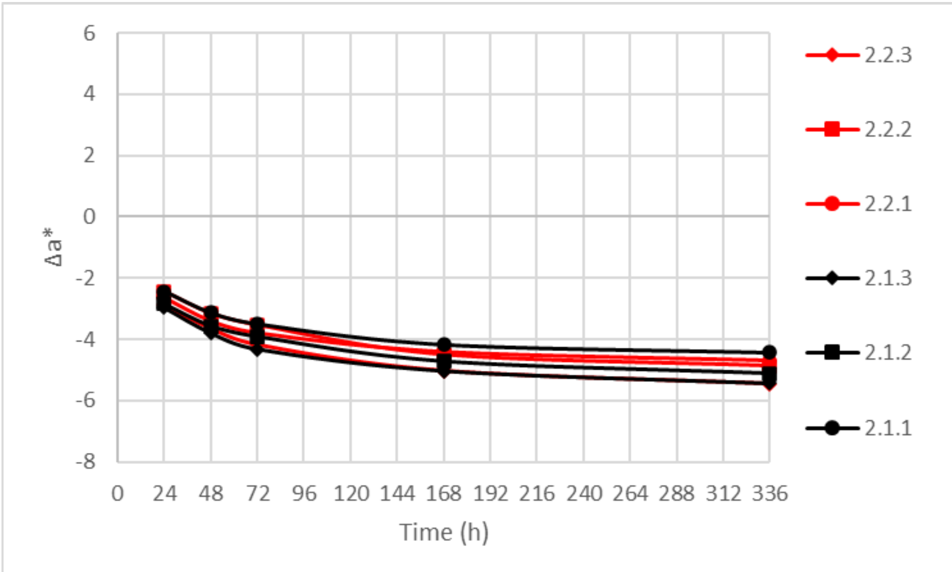


Figure 18. Δa* colour component of Mat #2 samples as a function of UV exposure time. A negative (-) Δa* means that the sample is greener than the standard. A positive (+) Δa* means that the sample is redder than the standard.

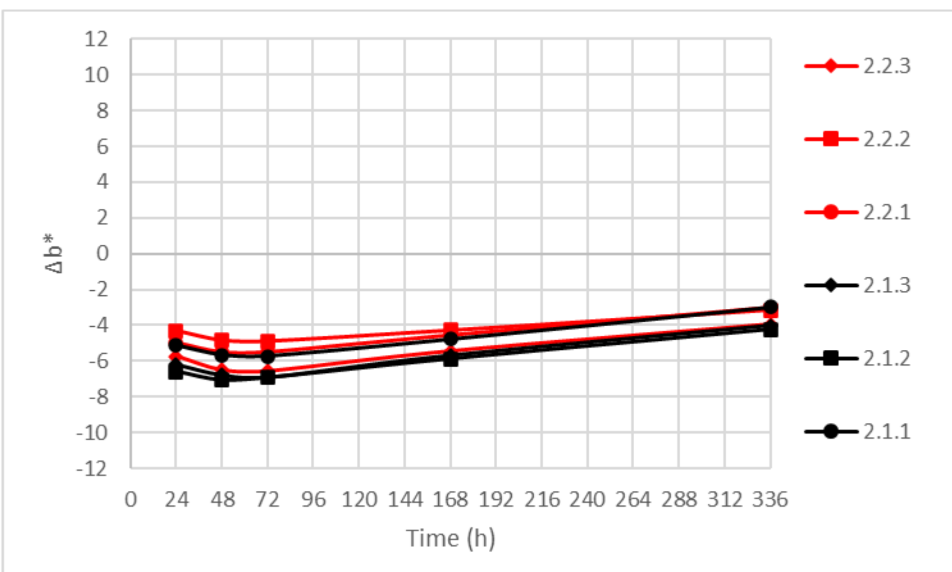


Figure 19. Δb* colour component of Mat #2 samples as a function of UV exposure time. A negative (-) Δb* means that the sample is bluer than the standard. A positive (+) Δb* means that the sample is yellower than the standard.

3.1.3 Rattan Design (Mat #3)

Key Points:

- **The overall colour change after 24 hours is the smallest observed across all the selected rattan mats.**
- **The overall colour change after 2 weeks is the largest observed across all the selected rattan mats.**
- **The colour change becomes significant after one week.**
- **The colour change and lightness haven't stabilized after 2 weeks.**
- **Mats become darker.**
- **Mats become redder.**
- **Mats turn yellower.**

The rattan mat design #3 offered the smallest colour change after 24 hours across all the selected rattan mats products tested in this study with average ΔE * of 1.53 (Figures 20 and 21). On the other end, design #3 returned the highest colour change difference after completion of the test (2 weeks) across all the rattan mats products tested with an average ΔE * of 11.23. The colour change became significant after one week for most samples with an average ΔE * of 5.94. As mentioned earlier in the report, a colour change above five (5) is perceived by the naked eye and depending on the application the change could be more or less significant. The colour change hasn't stabilized after 2 weeks.

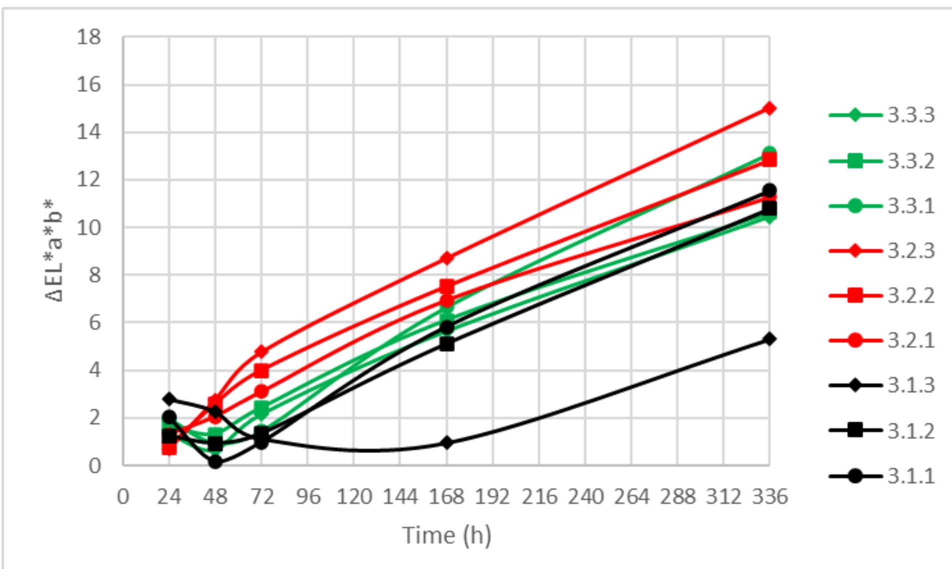


Figure 20. Colour change (ΔE_{L*a*b*}) of Mat #3 samples as a function of UV exposure time. A colour change above five (5) is perceived by the naked eye and depending on the application the change could be more or less significant.

Figure 21. Mats #3 (from left: 3.3.3, 3.3.2, and 3.3.1) after 24 hours (left) and 336 hours (right) of UV exposure.

All mat design #3 samples become darker as the test progress (Figure 22). Lightness change hasn't stabilized after 2 weeks.

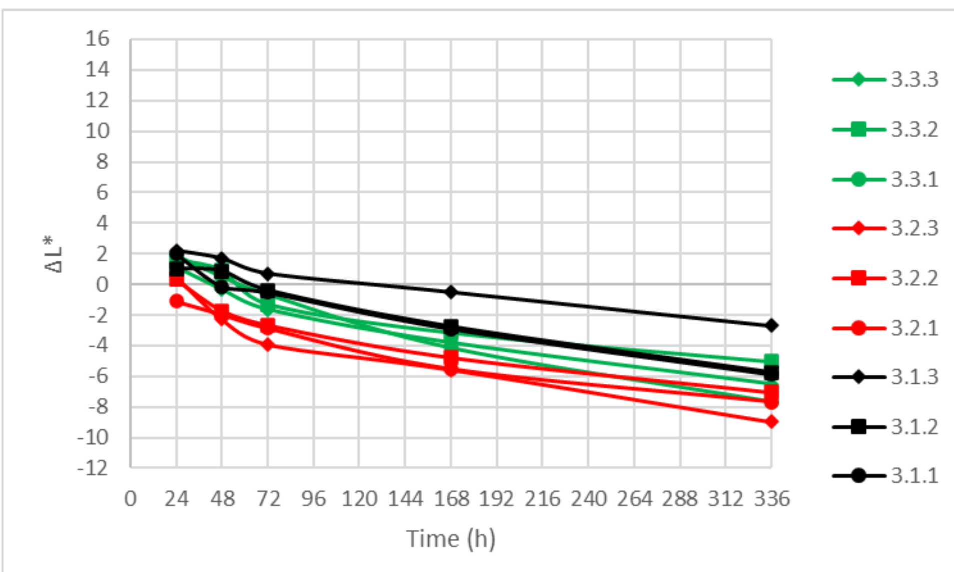


Figure 22. Lightness (ΔL*) colour component of Mat #3 samples as a function of UV exposure time. A positive (+) ΔL* means that the sample is lighter than the standard. A negative (-) ΔL* means that the sample is darker than the standard.

A few samples become slightly greener initially but eventually become redder as the test progress i.e., after 1 week of exposure (Figure 23). The Δa* colour component seems to have stabilized after two weeks. A few samples also become slightly bluer initially, but all samples eventually turn yellower as the test progress i.e., 72 hours week of exposure (Figure 24).

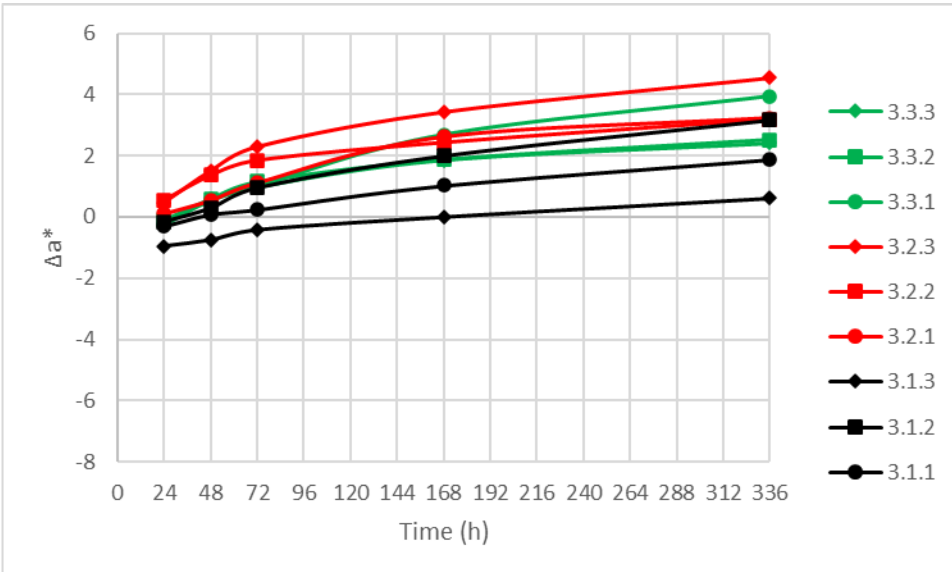


Figure 23. Δa* colour component of Mat #3 samples as a function of UV exposure time. A negative (-) Δa* means that the sample is greener than the standard. A positive (+) Δa* means that the sample is redder than the standard.

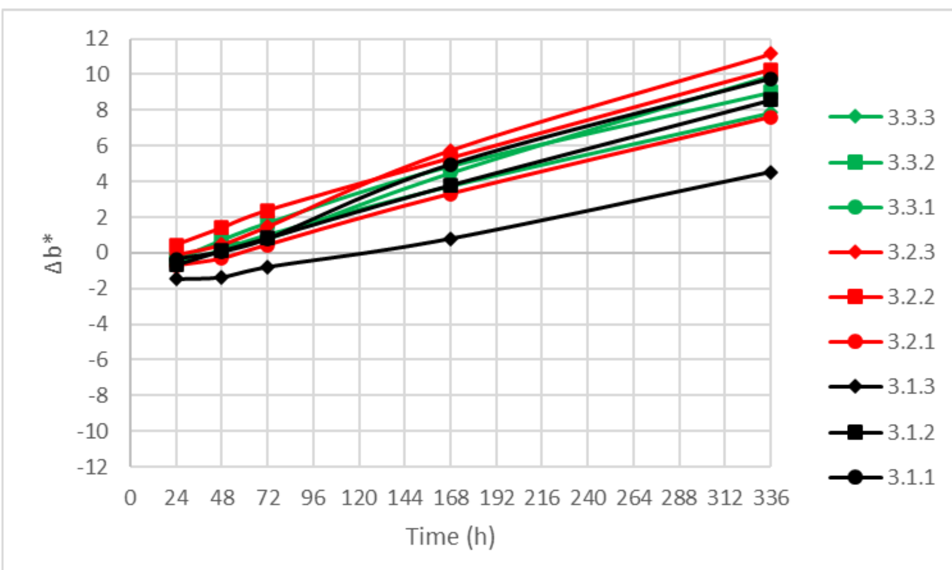


Figure 24. Δb* colour component of Mat #3 samples as a function of UV exposure time. A negative (-) Δb* means that the sample is bluer than the standard. A positive (+) Δb* means that the sample is yellower than the standard.

3.1.4 Rattan Design (Mat #4)

Key Points:

- **Very little and unsignificant overall colour change after 24 hours.**
- **The overall colour change after 2 weeks is the smallest observed across all the selected rattan mats.**
- **The colour change becomes significant after 1 to 2 weeks.**
- **The colour change and lightness haven't stabilized after 2 weeks.**
- **Mats become darker.**
- **Mats become redder.**
- **Mats become yellower.**

Like rattan mat design #3, rattan mat design #4 shows very little colour change after 24 hours with average ΔE * of 2.00 (Figures 25 and 26). The overall colour change becomes significant after 1 to 2 weeks of UV exposure for all tested samples with average ΔE * of 8.47 after 2 weeks which represents the smallest colour change difference after completion of the test (2 weeks) across all the rattan mats products tested in the present study (on par with mat #5). However, colour change hasn't stabilized after 2 weeks.

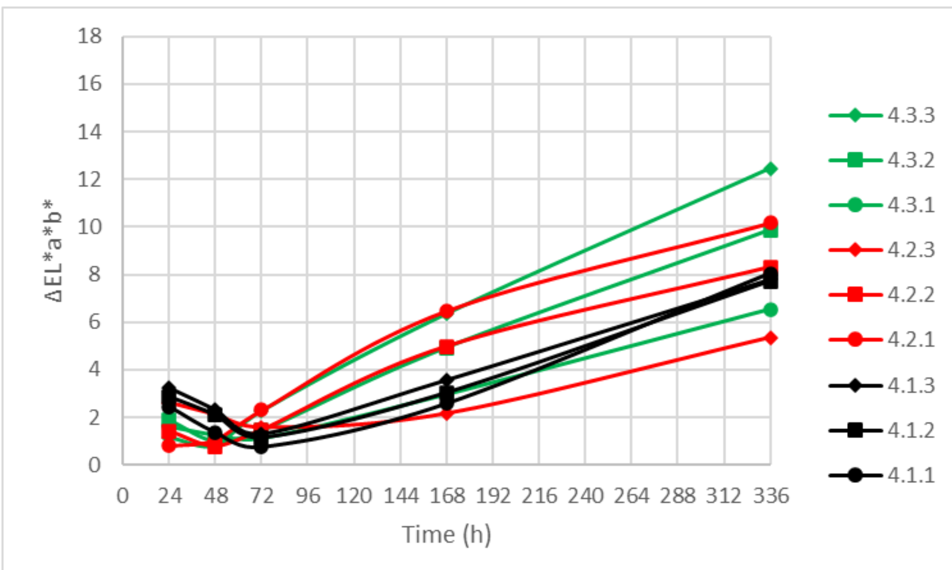


Figure 25. Colour change (ΔE_{L*a*b*}) of Mat #4 samples as a function of UV exposure time. A colour change above five (5) is perceived by the naked eye and depending on the application the change could be more or less significant.

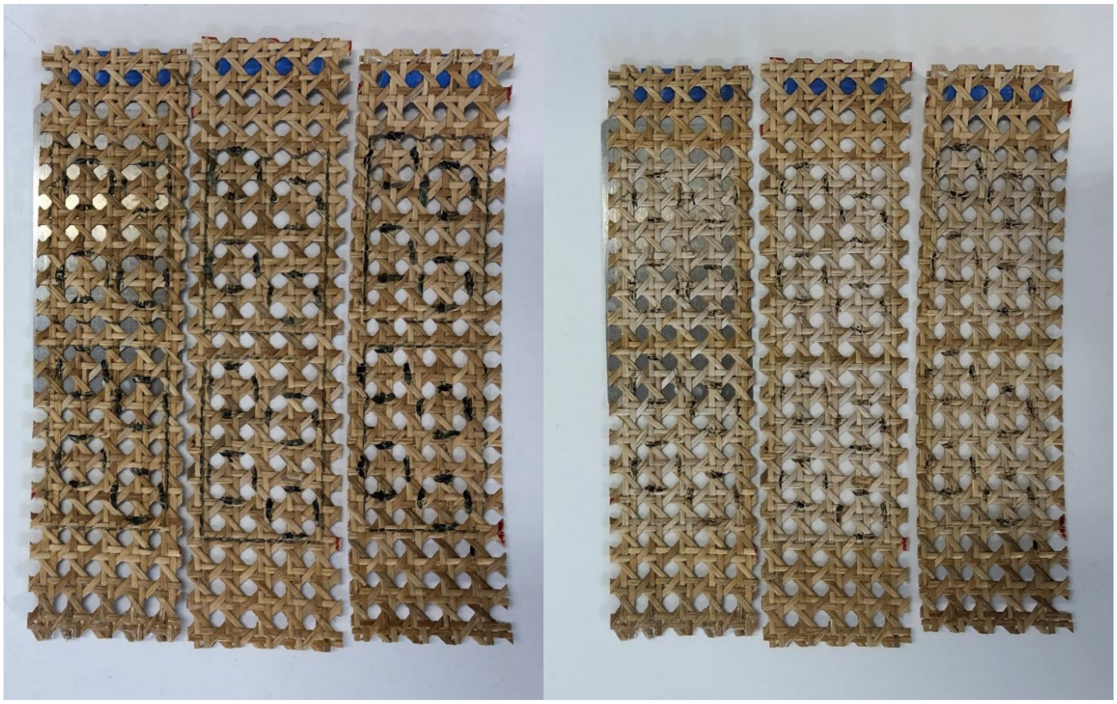


Figure 26. Mats #4 (from left: 4.3.3, 4.3.2, and 4.3.1) after 24 hours (left) and 336 hours (right) of UV exposure.

The rattan mat design #4 samples become darker as the test progress (Figure 27). Lightness change hasn't fully stabilized after 2 weeks.

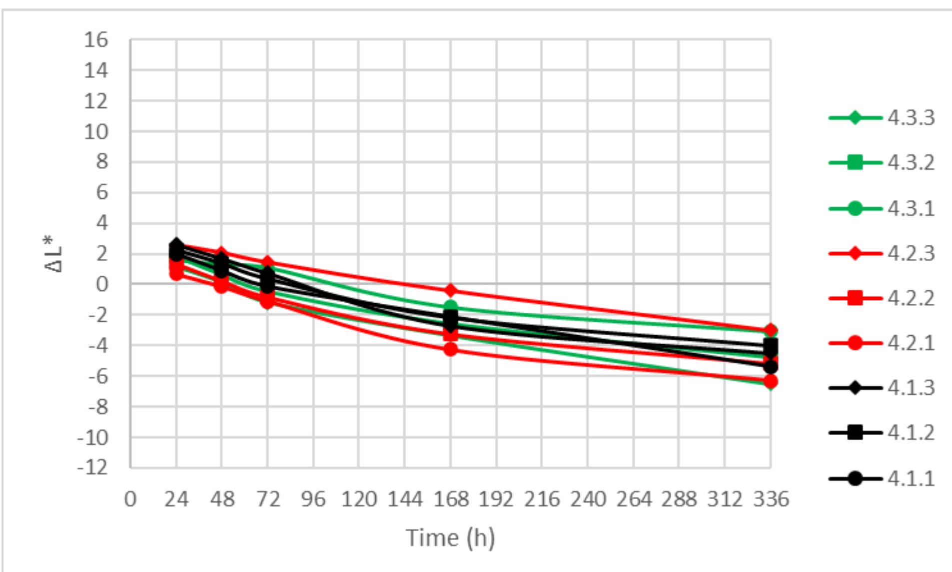


Figure 27. Lightness (ΔL*) colour component of Mat #4 samples as a function of UV exposure time. A positive (+) ΔL* means that the sample is lighter than the standard. A negative (-) ΔL* means that the sample is darker than the standard.

As observed with rattan mat design #3, a few samples become slightly greener initially but eventually become redder as the test progress i.e., after 1 week of exposure (Figure 28). The Δa* colour component stabilizes after one to two weeks. The Δa* colour component for mat #3 and mat #4 are within the same range. Variability between samples is also similar. Samples also become slightly bluer initially, but all samples eventually turn yellower as the test progress i.e., 72 hours week of exposure (Figure 29).

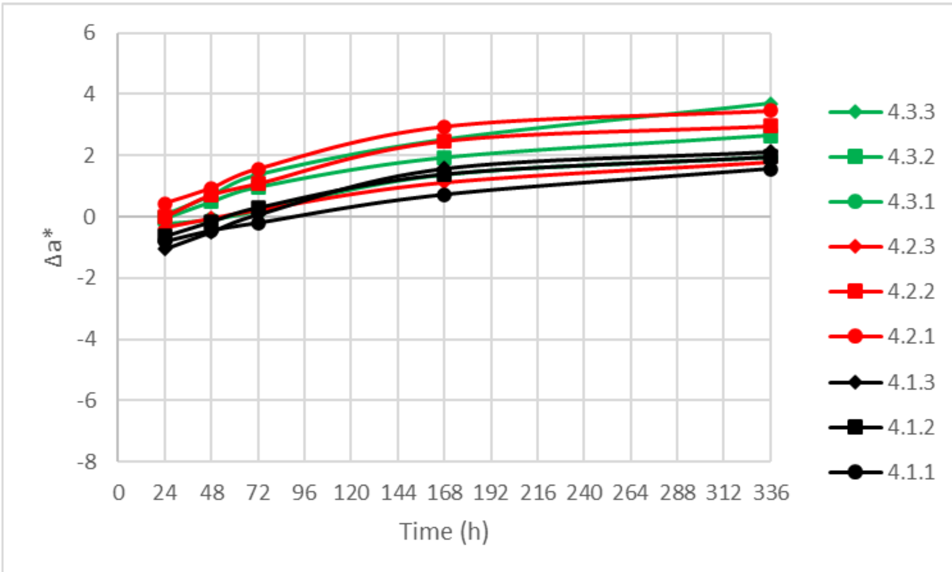


Figure 28. Δa* colour component of Mat #4 samples as a function of UV exposure time. A negative (-) Δa* means that the sample is greener than the standard. A positive (+) Δa* means that the sample is redder than the standard.

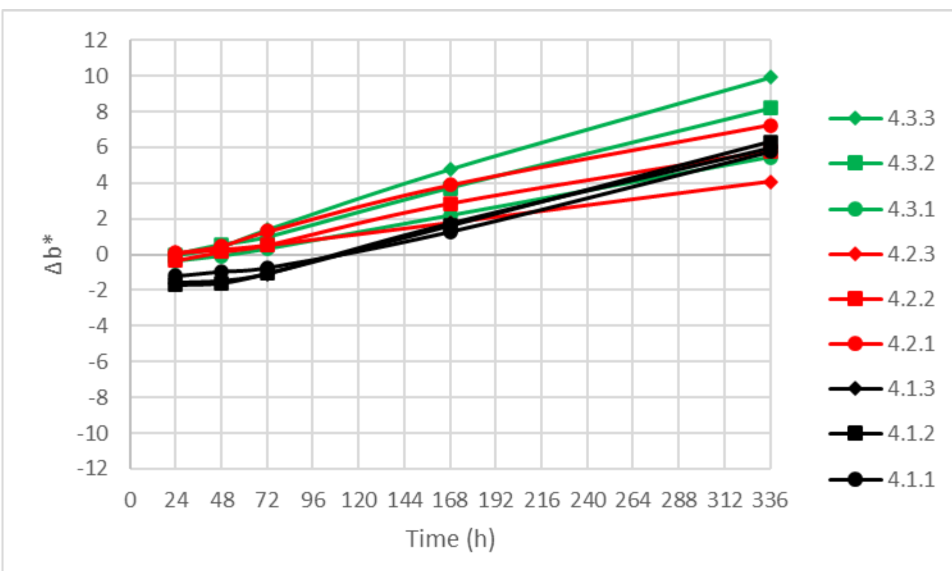


Figure 29. Δb* colour component of Mat #4 samples as a function of UV exposure time. A negative (-) Δb* means that the sample is bluer than the standard. A positive (+) Δb* means that the sample is yellower than the standard.

3.1.5 Rattan Design (Mat #5)

Key Points:

- **The overall colour change becomes significant after 24 hours.**
- **The overall colour change after 24 hours is the highest across all the rattan mats products tested.**
- **The overall colour change after 2 weeks is the smallest across all the rattan mats products tested.**
- **Smallest colour change variability between samples after 2 weeks across all the rattan products tested.**
- **Mats become lighter with lightness change stabilizing after 24 hours.**
- **Mats become greener with Δa* colour component stabilizing after 72 hours.**
- **Mats become bluer.**

The overall colour change becomes significant after 24 hours for all tested samples with an average ΔE * 11.93, reaching an average peak of 12.49 after 48 hours and then regressing to 8.46, unlike other rattan products tested in the present study (Figures 30 and 31). The colour change almost stabilized after 2 weeks. The overall colour change after 24 hours was the highest across all the rattan mats products tested. However, the overall colour change after completion of the test (2 weeks) was the smallest across all the rattan mats products tested. Smallest colour change variability between samples after completion of the test (2 weeks) across all the rattan mats products tested with a standard deviation of 1.11.

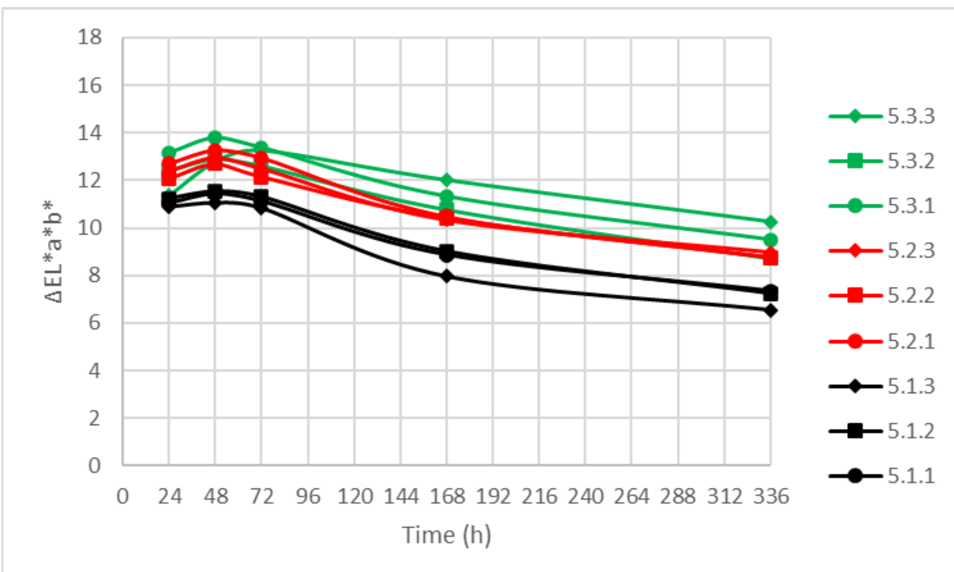


Figure 30. Colour change (ΔE_{L*a*b*}) of Mat #5 samples as a function of UV exposure time. A colour change above five (5) is perceived by the naked eye and depending on the application the change could be more or less significant.

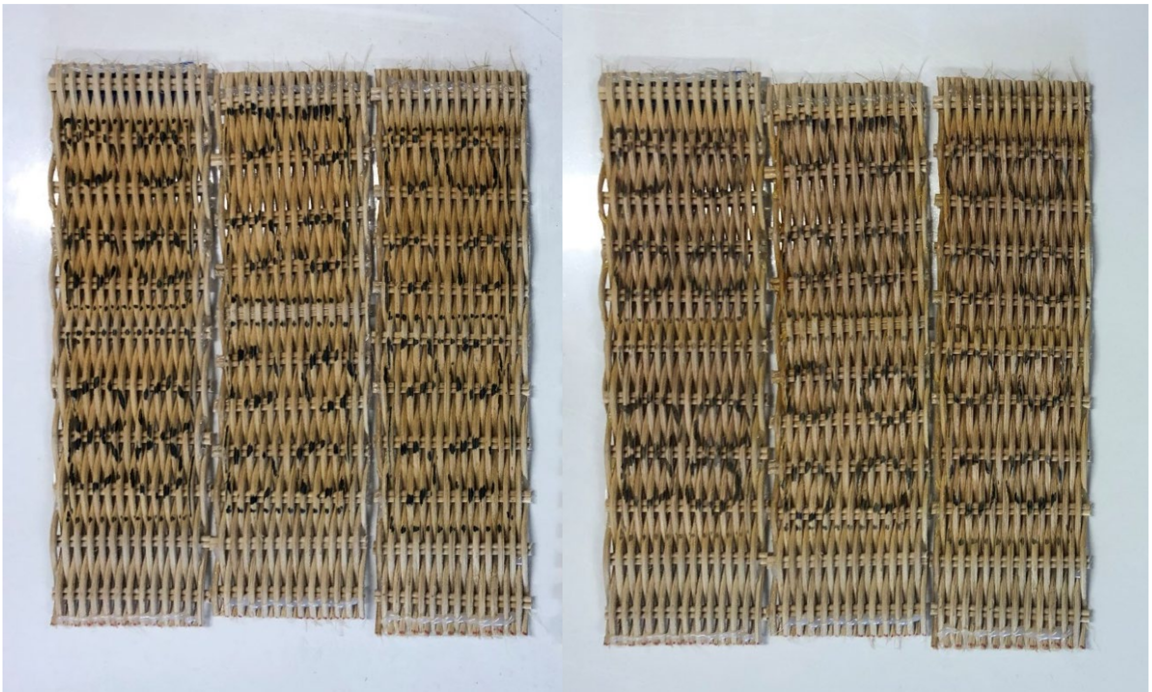


Figure 31. Mats #5 (from left: 5.1.3, 5.1.2, and 5.1.1) after 24 hours (left) and 336 hours (right) of UV exposure.

Figure 32 shows that all samples become lighter as the test progress. The lightness change stabilized after 24 hours, unlike the other two rattan products.

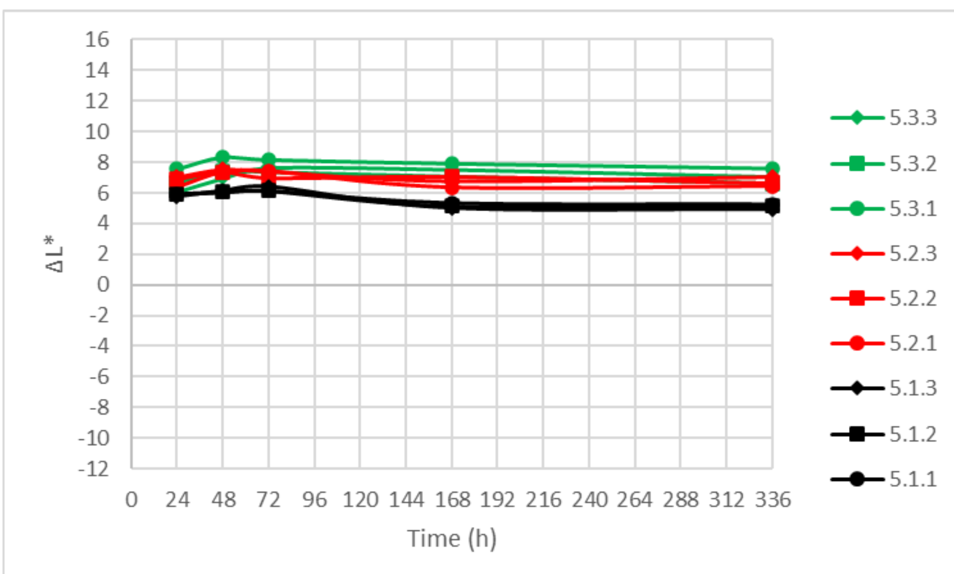


Figure 32. Lightness (ΔL*) colour component of Mat #5 samples as a function of UV exposure time. A positive (+) ΔL* means that the sample is lighter than the standard. A negative (-) ΔL* means that the sample is darker than the standard.

Unlike rattan mat designs #4 and #5, the samples become greener as the test progress. The Δa* colour component stabilizes after 72 hours. As with bamboo mat design #2, samples quickly become bluer after 24 hours but then tend to become yellower as the test progress.

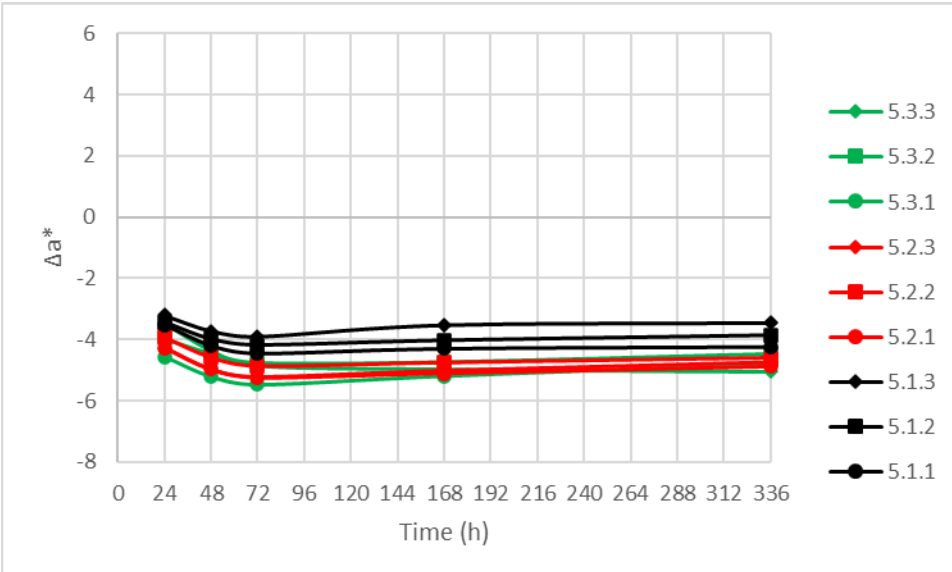


Figure 33. Δa* colour component of Mat #5 samples as a function of UV exposure time. A negative (-) Δa* means that the sample is greener than the standard. A positive (+) Δa* means that the sample is redder than the standard.

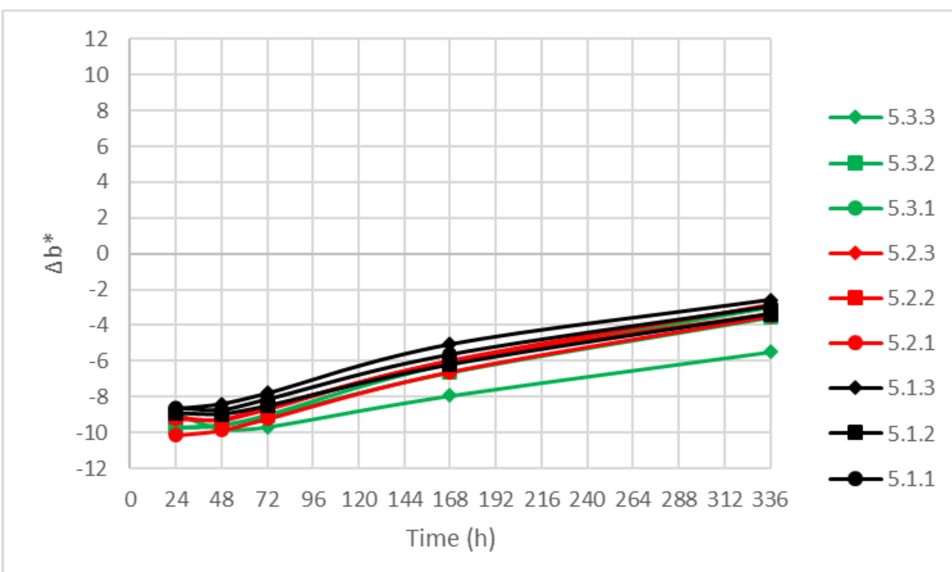


Figure 34. Δb* colour component of Mat #5 samples as a function of UV exposure time. A negative (-) Δb* means that the sample is bluer than the standard. A positive (+) Δb* means that the sample is yellower than the standard.

Summary after 2 weeks of UV exposure

Key Points Bamboo Mat #1

1. The **overall colour change** is significant after 24 hours for the yellow (pale) sections and after 48 to 72 hours for the green areas
2. Colour change is initially more pronounced for the yellow sections of the mats
3. Colour change for yellow areas stabilizes after 72 hours to 1 week
4. Colour change hasn't stabilized for the green areas after 2 weeks of UV exposure (see point #10)
5. There is more between mats colour change variability for the yellow sections (see point #8)
6. Green sections become **darker**
7. Yellow sections become **lighter**
8. Lightness change is more pronounced for yellow sections
9. Green and yellow sections both become **greener**
10. Green and yellow sections are both **bluer** - green sections haven't stabilized after 2 weeks of UV exposure.

Key Points Bamboo Mat #2

1. The overall colour change is significant after 24 hours of UV exposure
2. The overall colour change stabilizes after 72 hours to one week
3. The colour of bamboo mat design #2 is more stable than bamboo mat design #1
4. Mats become **lighter**
5. Mats become **greener**
6. Δa^* colour component for bamboo mat design #1 and #2 are within the same range but variability between samples is lower for mat design #2
7. Mats are **bluer** after 2 weeks

Key Points Rattan Mat #3

1. The **overall colour change** after 24 hours is the smallest observed across all the selected rattan mats
2. The overall colour change after 2 weeks is the largest observed across all the selected rattan mats
3. The colour change becomes significant after one week
4. The colour change and lightness hasn't stabilized after 2 weeks
5. Mats become **darker**
6. Mats become **redder**
7. Mats turn **yellower**

Key Points Rattan Mat #4

1. Very little and unsignificant **overall colour change** after 24 hours
2. The overall colour change after 2 weeks is the smallest observed across all the selected rattan mats
3. The colour change becomes significant after 1 to 2 weeks
4. The colour change and lightness haven't stabilized after 2 weeks
5. Mats become **darker**
6. Mats become **redder**
7. Mats become **yellower**

Key Points Rattan Mat #5

1. The **overall colour change** becomes significant after 24 hours
2. The overall colour change after 24 hours is the highest across all the rattan mats products
3. The overall colour change after 2 weeks is the smallest across all the rattan mats products
4. Smallest colour change variability between samples after 2 weeks across all the rattan products
5. Mats become **lighter** with lightness change stabilizing after 24 hours
6. Mats become **greener** with Δa* colour component stabilizing after 72 hours
7. Mats become **bluer**

The **overall trends in colour change for <u>rattan mats</u>**, based on the greatest colour difference changes, were:

- A shift towards negative ΔL *i.e.,* sample had become darker compared to unexposed reference sample, except for rattan mats design #5 which had become lighter.
- A shift towards positive Δa *i.e.,* sample had become redder, except for rattan mats design #5 which had become greener.
- A shift towards positive Δb *i.e.,* sample had become yellower, except for rattan mats design #5 which had become bluer.

The **overall trends in colour change for <u>bamboo mats</u>**, based on the greatest colour difference changes, were:

- A shift towards positive ΔL *i.e.,* sample had become lighter compared to unexposed reference sample, except for the green areas of bamboo mat design #1 which had become darker.
- A shift towards negative Δa *i.e.,* sample had become greener.
- A shift towards negative Δb *i.e.,* sample had become bluer.

Overall, the test method using QUV weathering gave a fast method of assessing the discolouration of rattan and bamboo mats exposed to UV light. The study revealed that bamboo and rattans mats are similarly susceptible to UV discolouration but this discolouration tends to differ between the two materials and even within a specific group. The observed differences between the rattan groups can be explained by the fact that rattan, scientific name *Calameae*, is a general name for roughly 600 species of plant-climber from the palm family native to tropical regions especially in Asia. Ultimately, the discolouration could be retarded significantly through the appropriate choice of clear coating.

3.2 Preliminary prototype manufacturing trial

A key challenge identified was that the overlapping strands of the bamboo mats (mat designs 1 and 2) did not provide enough hold to guarantee the integrity of the sample section during separation with a circular saw. Individual strands moved easily or got pulled out of the assembly. This effect can be somewhat mitigated by application of a strong tape (quality masking or cloth tape) across the area where the cut is to be made. Smaller strands and a tighter weave of the rattan mats (mat designs 3, 4 and 5) resulted in significant less tear out or disintegration during cutting for these mat types.

Tape removal needs to be done in a cautious manner as the pulling motion can damage the position of the strands - the very issue trying to be avoided in the first place. The upwards pull of the saw blade is strong and can still lead to tear out despite securing the strands in place with the tape. When using a circular saw it is recommended to add a sacrificial sheet on top of the mat. In this way the mat is securely sandwiched between a bottom sheet where the blade enters and any potential tear out is mitigated towards the top sheets.

A similar principal applies when a table saw is used i.e., a sacrificial sheet should be secured to the top of the table to minimize the gap between the saw blade and table. In this way tear out is minimized and a clean edge could be achieved provided the mat is pressed downwards when passing the blade. The same principle applies when using a bandsaw. It should be noted that the lack of rigidity and size of the mats made the removal of the sample section in a safe manner directly from the original mat nearly impossible for by one person alone. It is recommended to initially remove an oversized section with the circular saw set and then process the sample further if a band saw or table saw was to be used by a single person. Alternatively, 2 people should handle the mats if the band saw or table saw was to be used only.

The guillotine provided the most efficient and safest way to produce clean sample edges with minimal disturbance to the bamboo strands. Intended for sheet metal cutting, the maximal material thickness to be cut was however limited to a few millimeters. Hence only mat designs 1, 2, 3 and 4 could be processed with the guillotine. Mat design 5 was the most rigid of all panels (round strands and rigid interlocking weave) which provided a beneficial prerequisite for sample machining with a saw blade.

The following photos illustrate some of the processing steps and equipment used to manufacture the prototypes. Additionally, individual photos of each prototype are presented at the end to illustrate the effect of glue spread rate.

Figure 35. Taping of sample edges with quality tape can help to stabilize the strands of bamboo mats to some extend when cutting with a circular saw. However, the edges appear rough and the loose weaving does not provide enough integrity to keep the strands aligned (especially when removing the tape)

Figure 36. A sacrificial cover sheet on top of the mat helps to stabilize individual strands in the mat and results is cleaner sample edges when a circular saw is used.

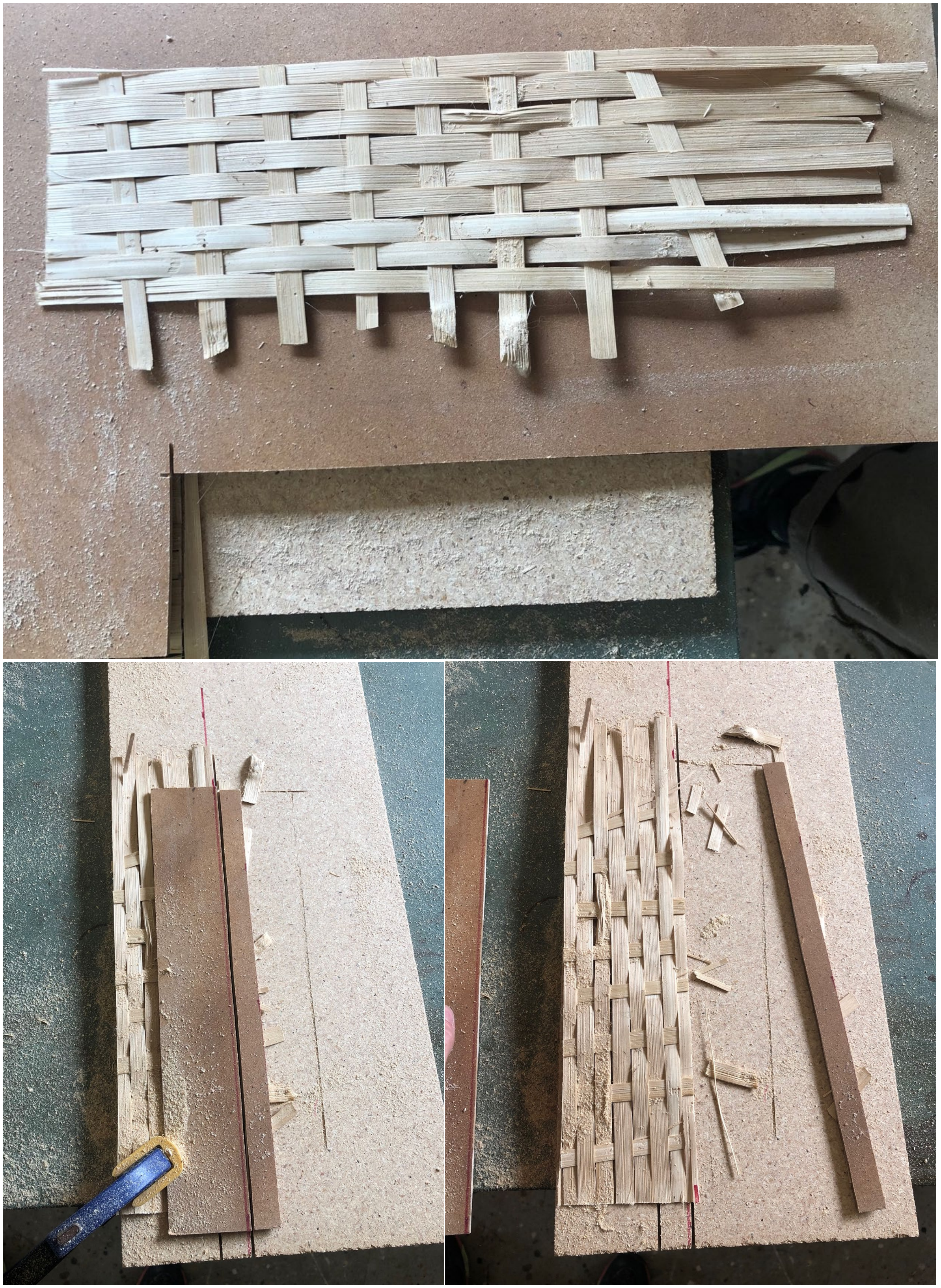


Figure 37. A sacrificial cover sheet on top of the mat design 2 (bamboo) helps to stabilize individual strands and results is cleaner sample edges when a circular saw is used.

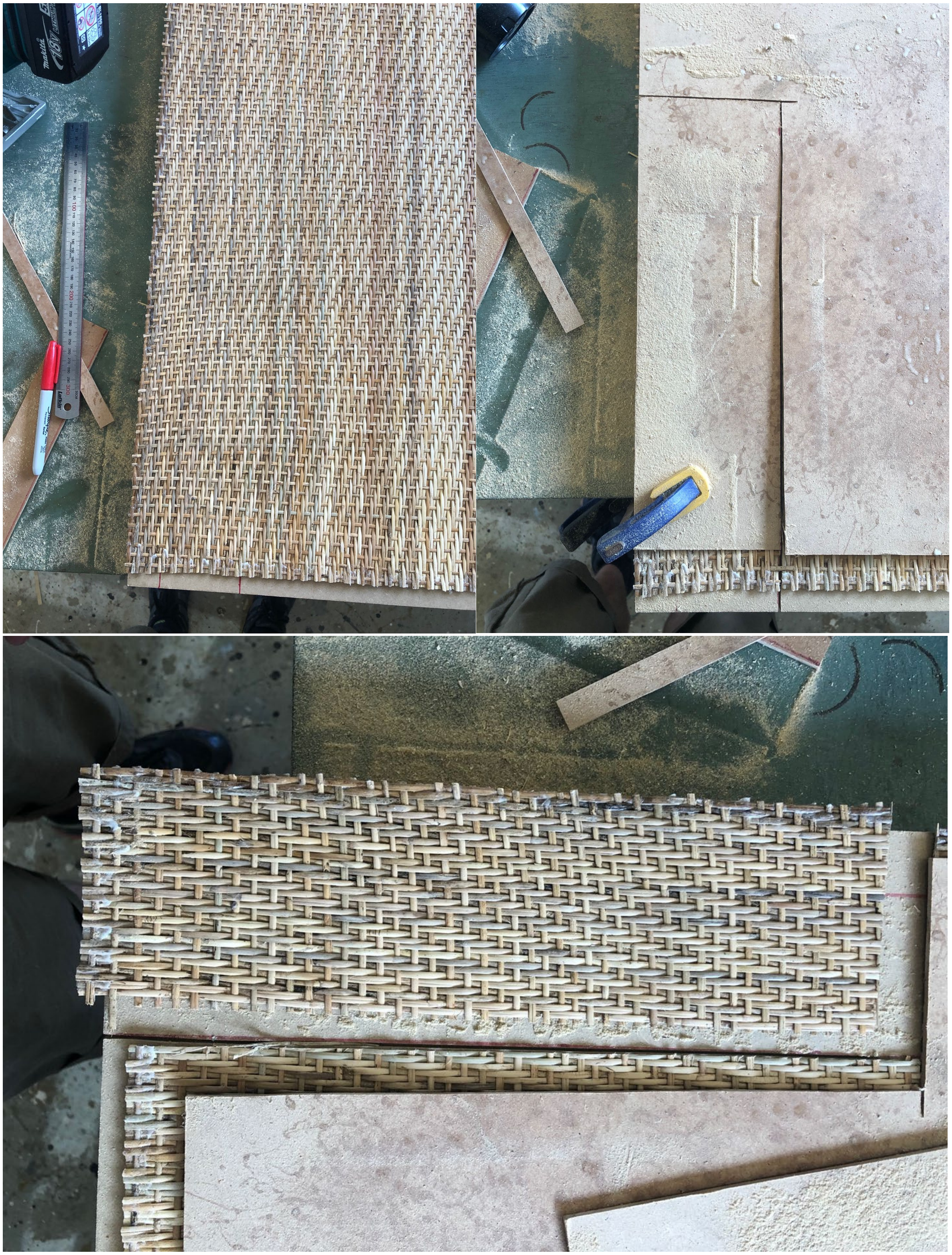


Figure 38. A sacrificial cover sheet on top of the mat design 3 (rattan) helps to stabilize individual strands and results is cleaner sample edges when a circular saw is used.

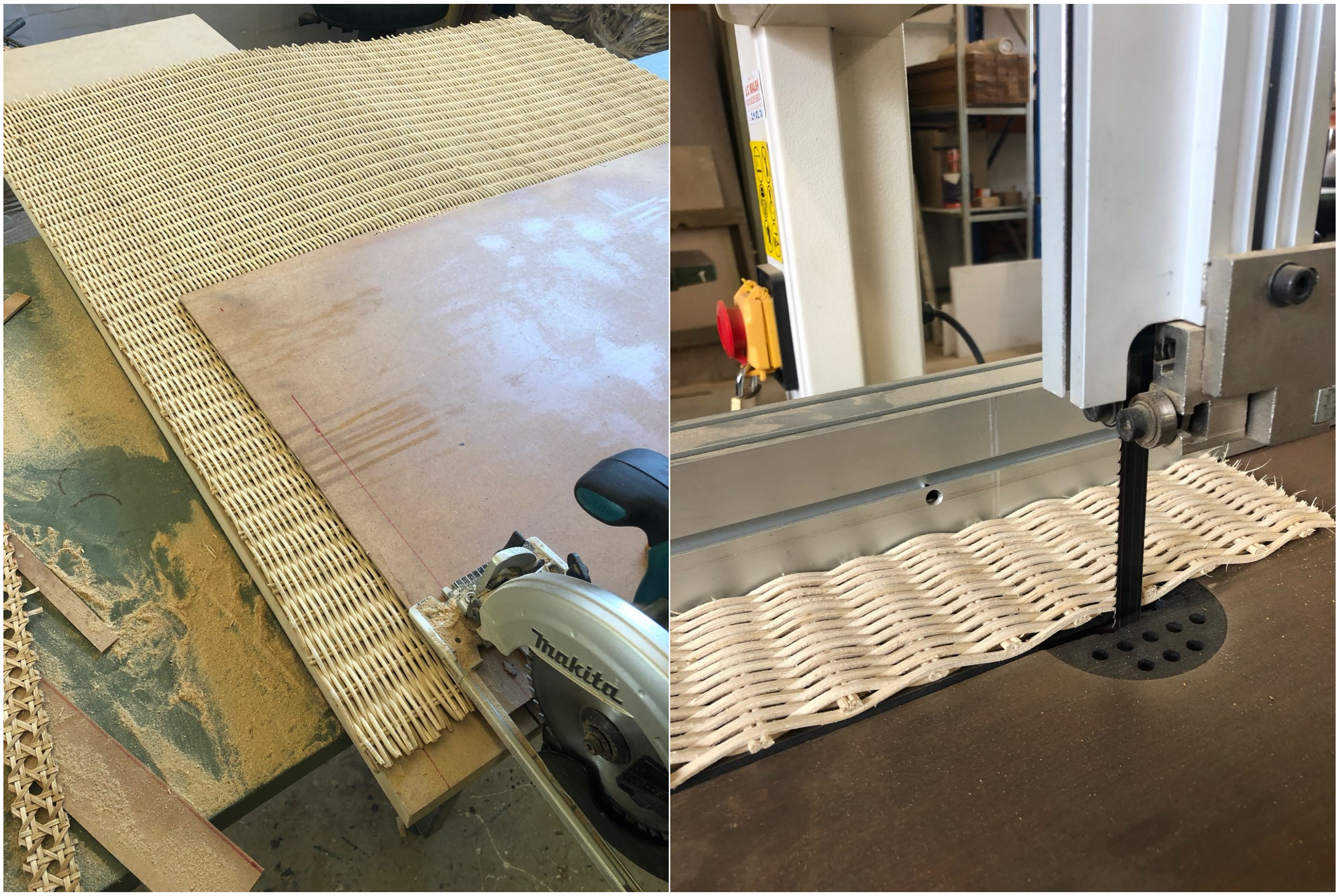


Figure 39. Mat design 5 has a tighter weave and thicker individual strands that machine well with either the sawing equipment (band, circular or table saw)

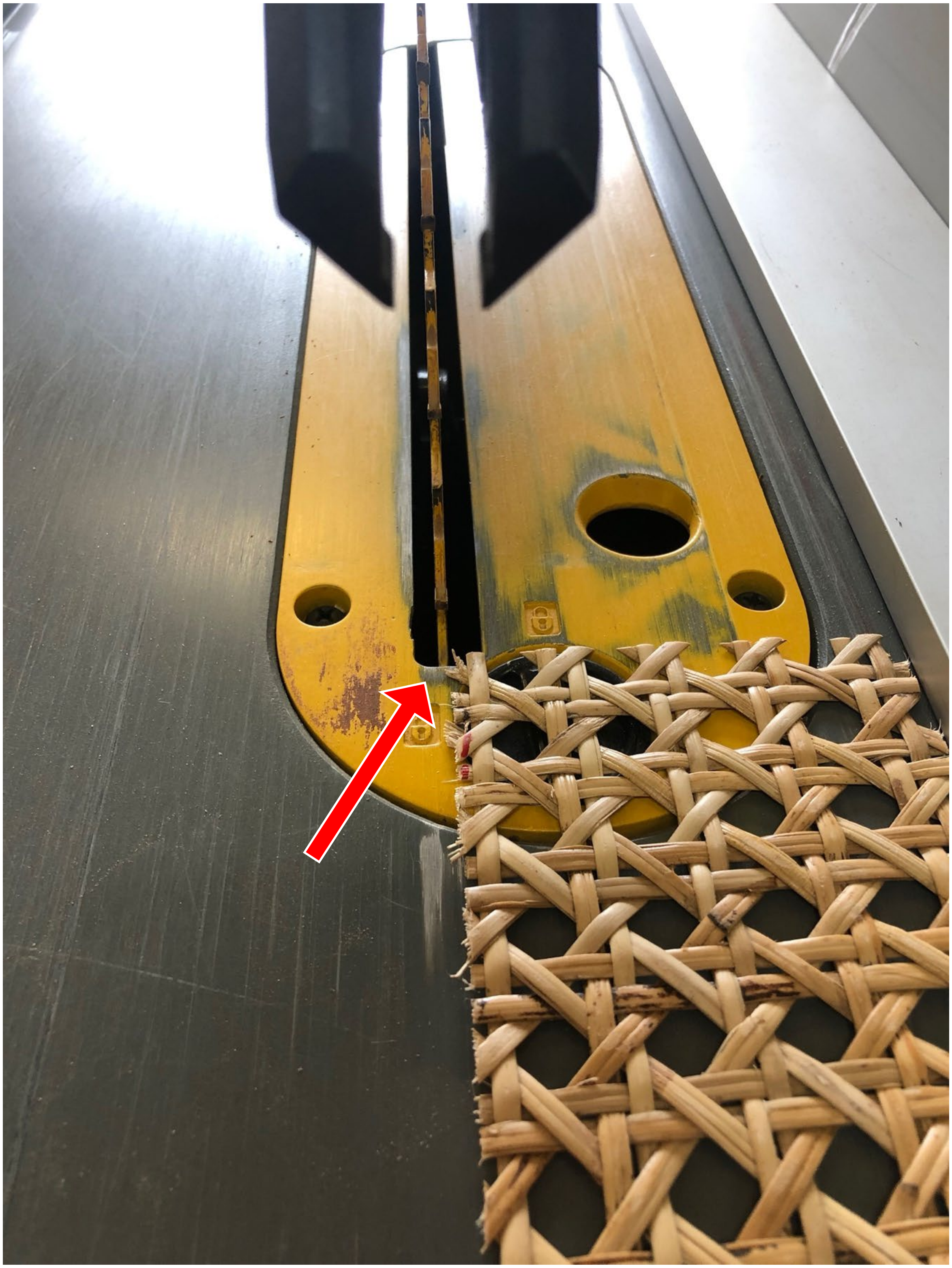


Figure 40. A large gap in the infeed table of the table saw can cause rough edges and disintegration of mats especially with loose weaving.

Figure 41. A sacrificial cover sheet (width of the saw blade) on top of the infeed table reduces the gap in the table. This guarantees a safer work process and higher quality of sample edges

Machining and Guillotine

Figure 42. In some cases the width of the mat did not exceed the capacity of the guillotine and the entire sample could be generated using the guillotine alone.

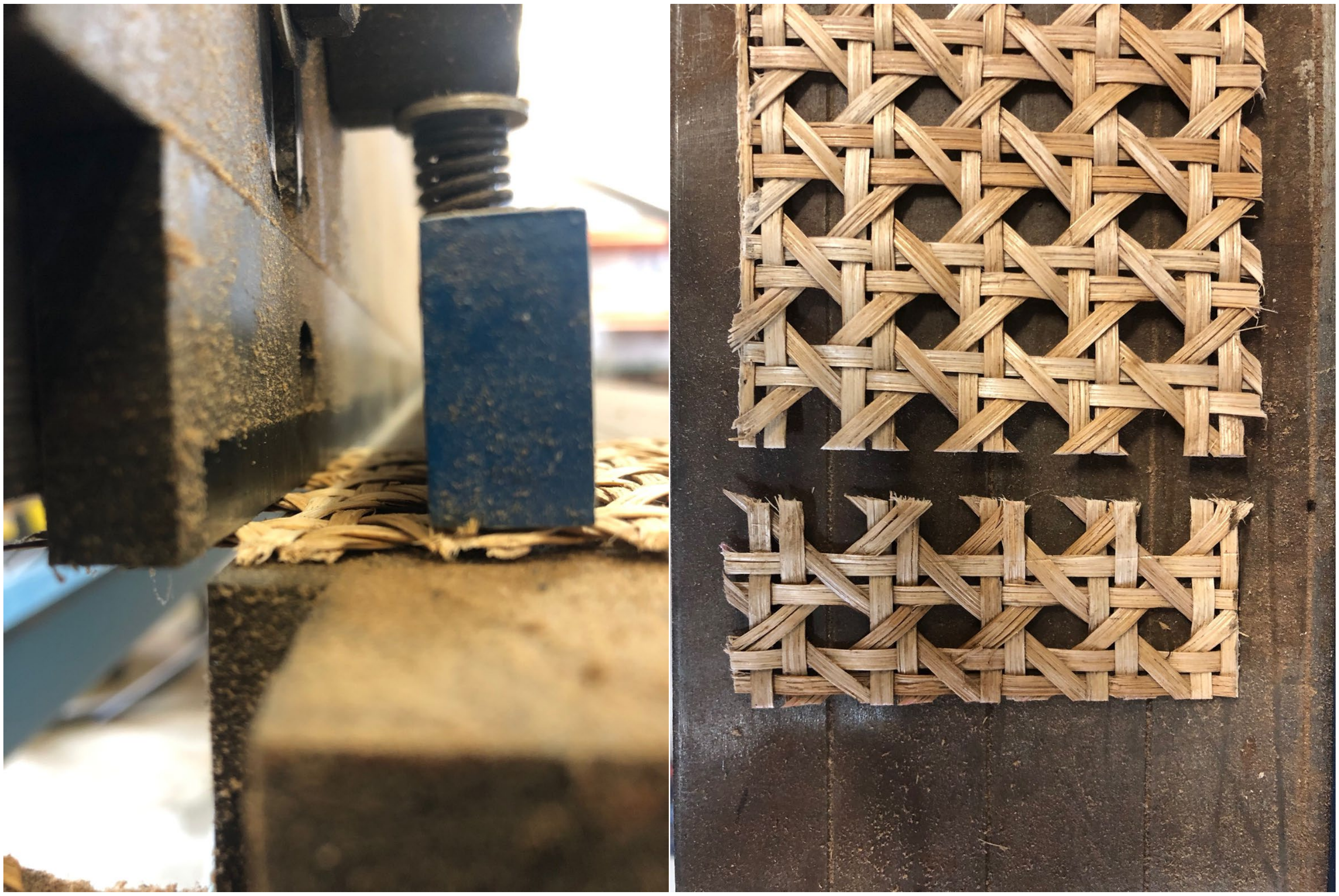


Figure 43. The shearing bars separate the rattan strands (left). Accurate and clean sample edges generated with the guillotine (right).

Gluing & pressing

Figure 44. Spatula with serrated and flat edge used for glue application

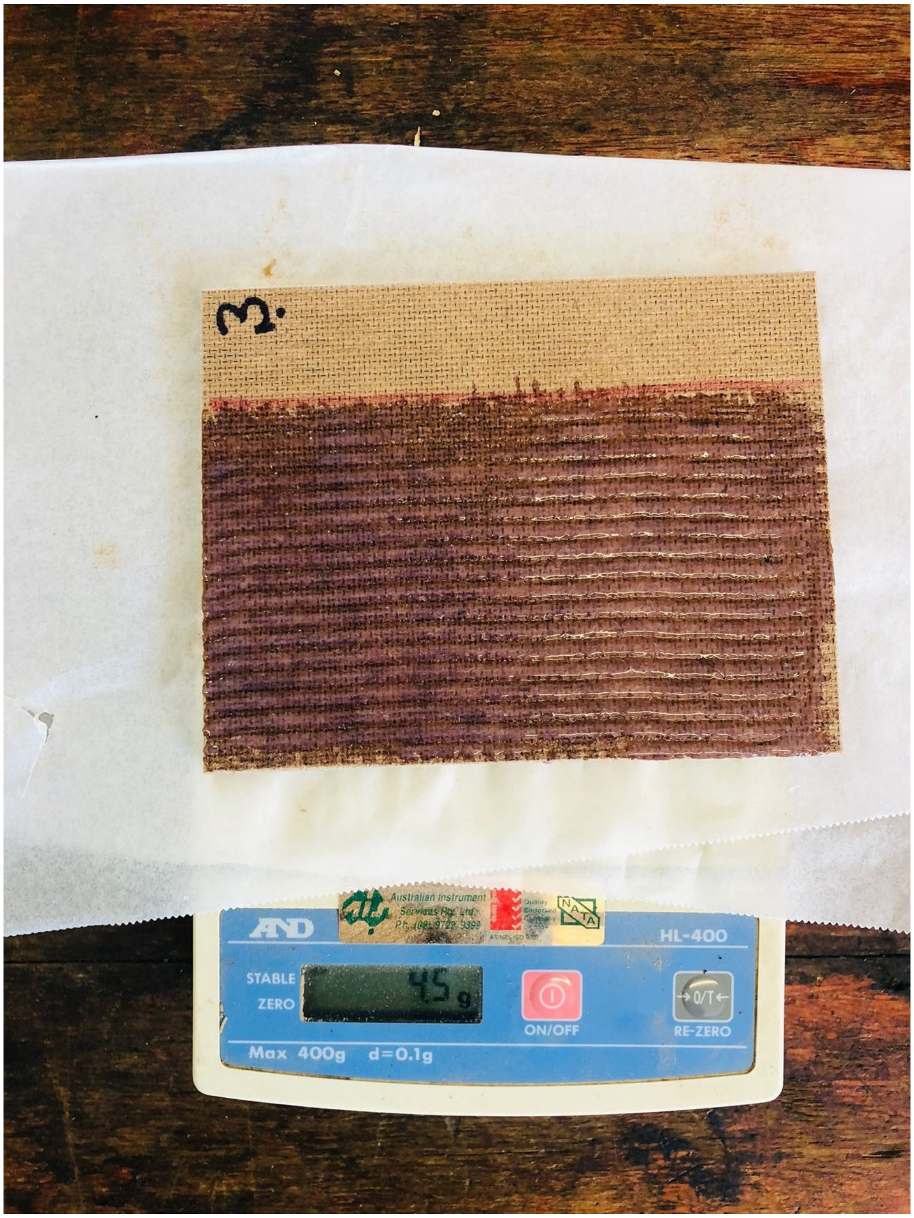


Figure 45. Application of PUR adhesive with serrated spatula.

Figure 46. Mixing of 2-component EPI adhesive.

Figure 47. Application of EPI adhesive with flat edge of the spatula.

Figure 48. EPI samples assembly prior to pressing.

Figure 49. Application of PVA adhesive with flat edge of the spatula.

Figure 50. Sample assembly in the laboratory press (Dake model 944226, USA).

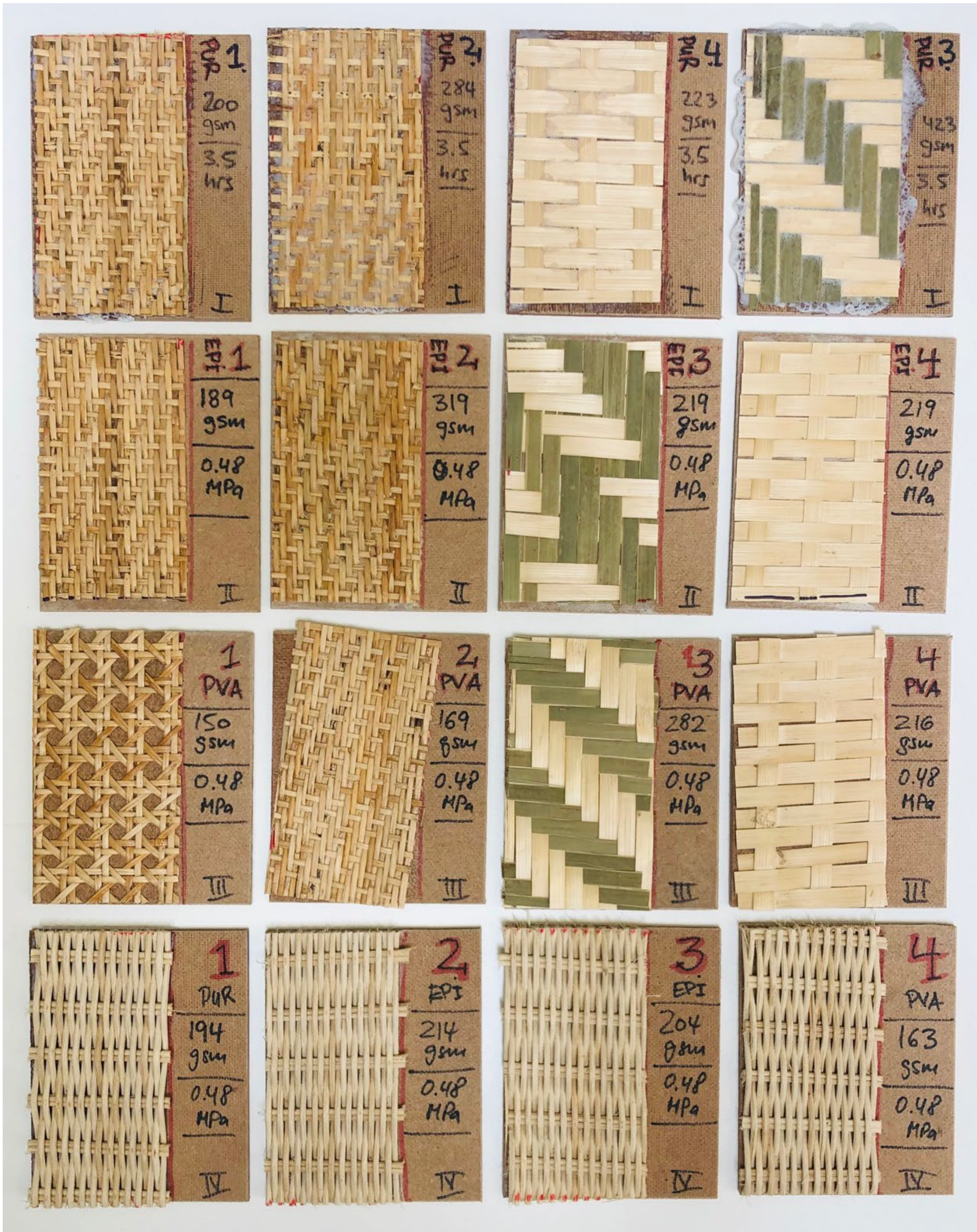


Figure 51. Overview of manufactured prototypes. Initial glue spread (gsm) of PUR and EPI needed to be reduced as excess adhesive caused foaming (PUR) and squeeze out (EPI) (first and second row). PVA showed good adhesion throughout, dried translucent and no squeeze out was observed even at slightly higher gsm (row three). Reduced glue spreads resulted in no observable adhesive excess whilst producing good bonding with mat design 5 (row 4).

3.3 Decorative paneling prototype manufacturing

Prototypes were manufactured by laminating sections of mat designs 1 to 5 to one side of selected plywood and laminated veneer (LVL) panels manufactured as part of objective 2 activities (e.g., rubberwood and eucalyptus K7 panel manufacturing, testing trials for PML Easbeam). Favourable adhesives, glue spreads and pressing parameters were established in previous preliminary gluing and pressing trials. Manufacturing details of the prototypes to be used as demonstration samples for future promotional activities are shown in Table 4.

The plywood and LVL panels were received pre-cut to final dimensions and stored in a controlled environment at 23 °C and 65% relative humidity prior to assembly. Mat overlays were cut as oversized section from the larger originals stored in the laboratory. A guillotine was used for cutting mat designs 1 to 4 were mat design 5 was prepared on the bandsaw.

The prototype fabrication was carried out following the protocol established in the preliminary trials. A reduction of glue spread to approximately 150 g/m^2 was considered since the veneers faces of the plywood panels were smoother and less absorptive compared to material used in the pre-trials.

After the adhesive had cured the oversized mats were trimmed back to the plywood panel size using a table saw. A sacrificial MDF sheet was used to narrow the gap between table and saw blade, preventing excessive tear out of fibres. The edges of the laminated panels were then smoothed and bevelled using a belt sander (120 grit). Any remaining torn out or loose fibres were removed with the flame of a lighter. The charred off areas were then carefully hand sanded (120 grit).

The following photos illustrate the processing steps and equipment used to manufacture the prototypes. Additionally, the back and front of individual prototype are presented at the end of the document.

Table 4. Manufacturing details of decorative paneling prototypes.

Mat Design #	Backing Layer	Backing Layer Size (mm)	Adhesive	Glue spread (g/m^2)	Pressing parameters
5	LVL - Plantation-Grown Rubberwood (*Hevea brasiliensis*) and Eucalyptus Hybrid (*Euc. camaldulensis* x *Euc. deglupta*)	150 x 150	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	150	40 min at 45 °C
3	Plywood - Plantation-Grown Rubberwood (*Hevea brasiliensis*) from Luang Namtha, Lao PDR	150 x 150	One-component polyurethane (PUR) Jowapur ® 686.70	150	40 min at 45 °C
4	LVL - Plantation-Grown Rubberwood (*Hevea brasiliensis*) from Luang Namtha, Lao PDR	150 x 150	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	Spot Gluing	40 min at ambient temperature
3	LVL - Plantation-Grown Rubberwood (*Hevea brasiliensis*) from Luang Namtha, Lao PDR	150 x 150	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	120	40 min at ambient temperature
1	Plywood - Eucalyptus Hybrid K7 (*Euc. camaldulensis* x *Euc. deglupta*)	150 x 150	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	150	40 min at ambient temperature
5	Plywood - Eucalyptus Hybrid K7 (*Euc. camaldulensis* x *Euc. deglupta*)	150 x 150	One-component polyurethane (PUR) Jowapur ® 686.70	150	40 min at 45 °C
2	Plywood - Eucalyptus Hybrid K7 (*Euc. camaldulensis* x *Euc. deglupta*)	150 x 150	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	150	40 min at ambient temperature
3	Eucalyptus Hybrid K7 (*Euc. camaldulensis* x *Euc. deglupta*)	275 x 200	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	150	40 min at 45 °C
2	Eucalyptus Hybrid K7 (*Euc. camaldulensis* x *Euc. deglupta*)	275 x 200	Emulsion polymer isocyanate (EPI) Jowacoll ® 102.49	150	40 min at 45 °C

Figure 52. Array of panels to be used as backing layer for the decorative paneling products.

Figure 53. Weighing and preparation for emulsion polymer isocyanate (EPI) application.

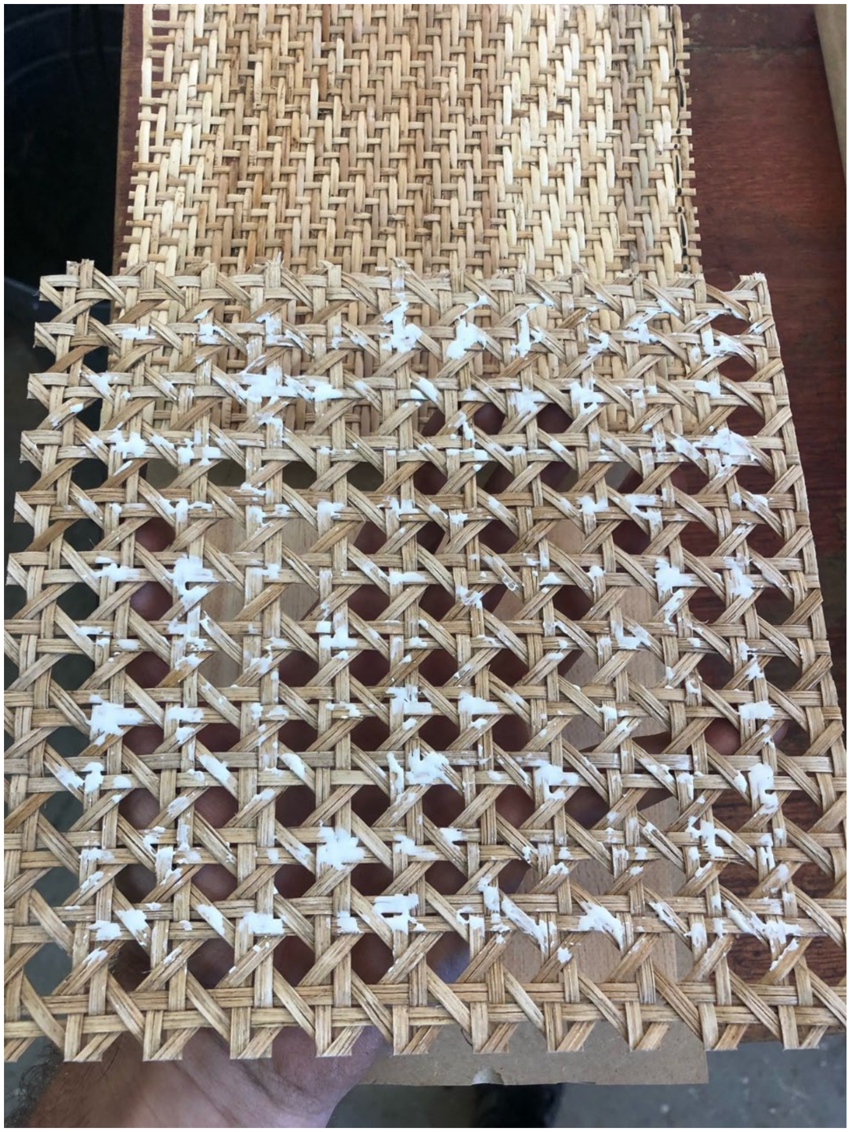


Figure 54. Emulsion polymer isocyanate (EPI) application in "spot" fashion to mat design 4 to prevent squeeze through into visible (uncovered) areas.

Figure 55. Oversized mats prior to glue application.

Figure 56. Trimming the mat back to the plywood edge. Notice the reduced gap between table and saw blade using a sacrificial MDF sheet.

Figure 57. Panel with torn out fibres ready for smoothing on the belt sander.

Figure 58. Finished decorative paneling prototype - FSC certified rattan on plantation-grown rubberwood.

Figure 59. Finished decorative paneling prototype - FSC certified rattan on rubberwood and eucalyptus K7.

Figure 60. Finished decorative paneling prototype - FSC certified rattan on plantation-grown rubberwood.

Figure 61. Finished decorative paneling prototype – Bamboo on eucalyptus Hybrid K7.

Figure 62. Finished decorative paneling prototype – Bamboo on eucalyptus Hybrid K7.

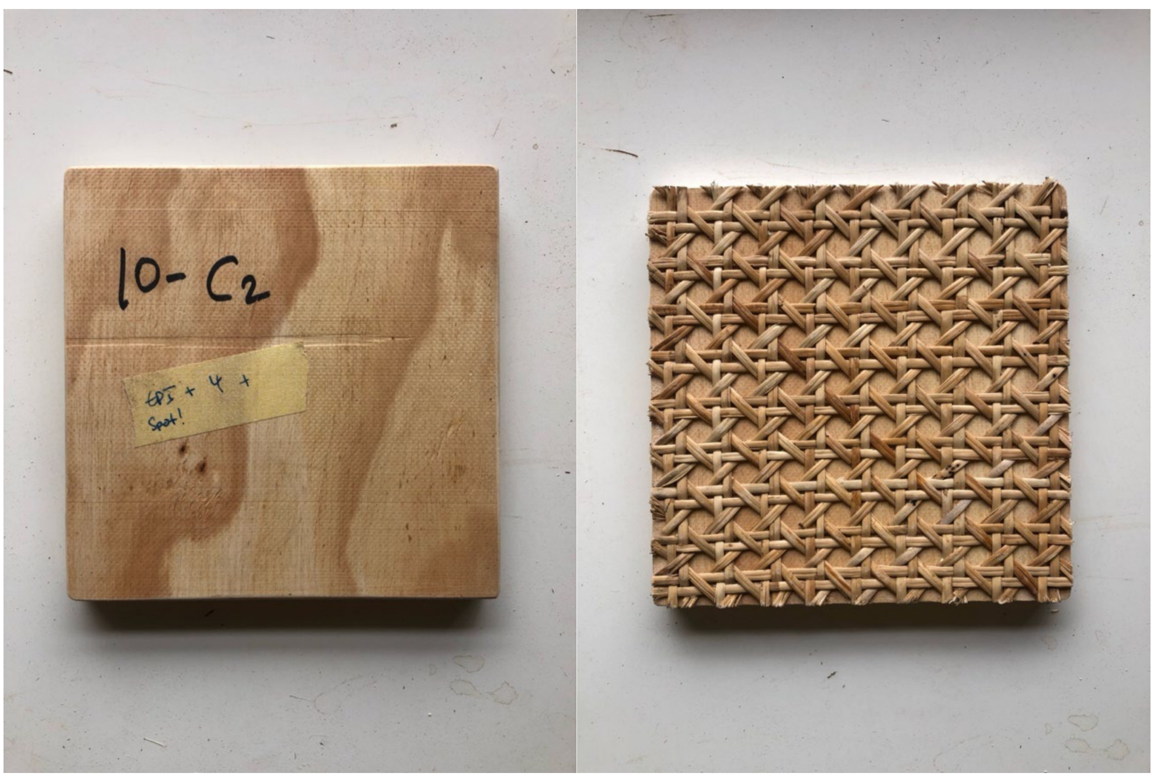


Figure 63. Finished decorative paneling prototype - FSC certified rattan on plantation-grown rubberwood.

Figure 64. Finished decorative paneling prototype - FSC certified rattan on eucalyptus hybrid K7.

Figure 65. Finished decorative paneling prototype - FSC certified rattan on eucalyptus hybrid K7.

Figure 66. Finished decorative paneling prototype – Bamboo on eucalyptus hybrid K7.

Conclusions

This milestone report aimed to (i) present the technical findings from the UV weathering testing program and (ii) presents recommended processing steps for the manufacturing of decorative paneling using rattan and bamboo mats as cover for non-structural constructions.

Key points:

UV Weathering

The study revealed that bamboo and rattans mats are similarly susceptible to UV discolouration but this discolouration tends to differ between the two materials and even within a specific group. The observed differences between the rattan groups can be explained by the fact that rattan, scientific name *Calameae*, is a general name for roughly 600 species of plant-climber from the palm family native to tropical regions especially in Asia.

The overall trends in colour change for rattan mats, based on the greatest colour difference changes, were:

- Samples have become darker compared to unexposed reference sample, except for rattan mats design #5 which had become lighter.
- Samples have become redder, except for rattan mats design #5 which had become greener.
- Samples have become yellower, except for rattan mats design #5 which had become bluer.

The overall trends in colour change for bamboo mats, based on the greatest colour difference changes, were:

- Samples have become lighter compared to unexposed reference sample, except for the green areas of bamboo mat design #1 which had become darker.
- Samples have become greener.
- Samples have become bluer.

Ultimately, the discolouration could be retarded significantly through the appropriate choice of clear coating.

Decorative paneling prototype manufacturing

A key challenge identified was the overlapping strands of the bamboo mats which did not provide enough hold to guarantee its integrity during machining. Individual strands moved easily or got pulled out of the assembly. This effect can be mitigated by application of a strong tape (quality masking or cloth tape) across the area where the cut is to be made. Smaller strands and a tighter weave of the rattan mats resulted in significant less tear out or disintegration. When using a circular saw it is recommended to add a sacrificial sheet on top of the mat to mitigate any potential tear out. A similar principal applies when a table saw is used to minimize the gap between the saw blade and table. In this way tear out is minimized and a clean edge could be achieved provided the mat is pressed downwards when passing the blade. Where the material thickness allowed for it, a guillotine proved to be the most efficient and safest way to produce clean sample edges with minimal disturbance to the bamboo strands.

Foaming is always going to be a problem with polyurethane (PUR) adhesives in areas that no pressure is applied such as the voids present in the rattan panels. There really is no way around this - especially with the EMC, temperatures and humidities in Laos. Consequently, an emulsion polymer isocyanate (EPI) which is suitable for bonding hard wood species and other materials with high resin content and moisture content is recommended for decorative paneling products.

Edging or trimming laminated decorative panels also proved difficult because of excessive tear out of fibres. Bamboo mats basically frizzles away when holding sandpaper against it. The weaving also doesn’t help as individual strand around the edges are still prone to being pulled out. Tear out of fibres seems to be the nature of the material and therefore, having bamboo mats weaved to desired dimensions would be desirable. A similar conclusion can be made for the rattan mats although tear out was not as problematic as bamboo, especially when using a guillotine.

On a different note, the research team identified an example of combination between rattan and wood, here identified as the Kovax foldable chair (Figure 74). Such EWP could easily combine certified rattan and other products covered as part of the different VALTIP projects such as LVL.

Figure 67. Kovac rattan chair – An example of the combination between rattan and wood (Kovac 2022).

References

ASTM. 2016. Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials. ASTM G154-16. ASTM International, West Conshohocken, PA, 2016

ASTM. 2019. Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources, ASTM G151-19. ASTM International, West Conshohocken, PA

ASTM. 2014. Standard Test Methods for Small Clear Specimens of Timber, ASTM D143-14. ASTM International, West Conshohocken, PA

Bolza E, Kloot NH. 1963. The mechanical properties of 174 Australian timbers. Division of Forest Products technological paper #25. CSIRO. Australia

Forest Products Laboratory (FPL). 2010. Wood handbook—Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 508 p.

Kingston RST, Risdon CJE. 1961. Shrinkage and density of Australian and other South-West Pacific woods. Division of Forest Products technological paper #13. CSIRO. Australia

Kovac. 2022. www.kovacfamily.com. [Website accessed January 2022].

WoodSolutions. 2021. www.woodsolutions.com.au. [Website accessed February 2021].

Appendix 1. Photos of UV weathering samples as a function of time

Figure 68. Mat design 1 - Replicate 2- Sample strip 3 (Day 1, Day 2, Day 3, Day 7, Day 14)

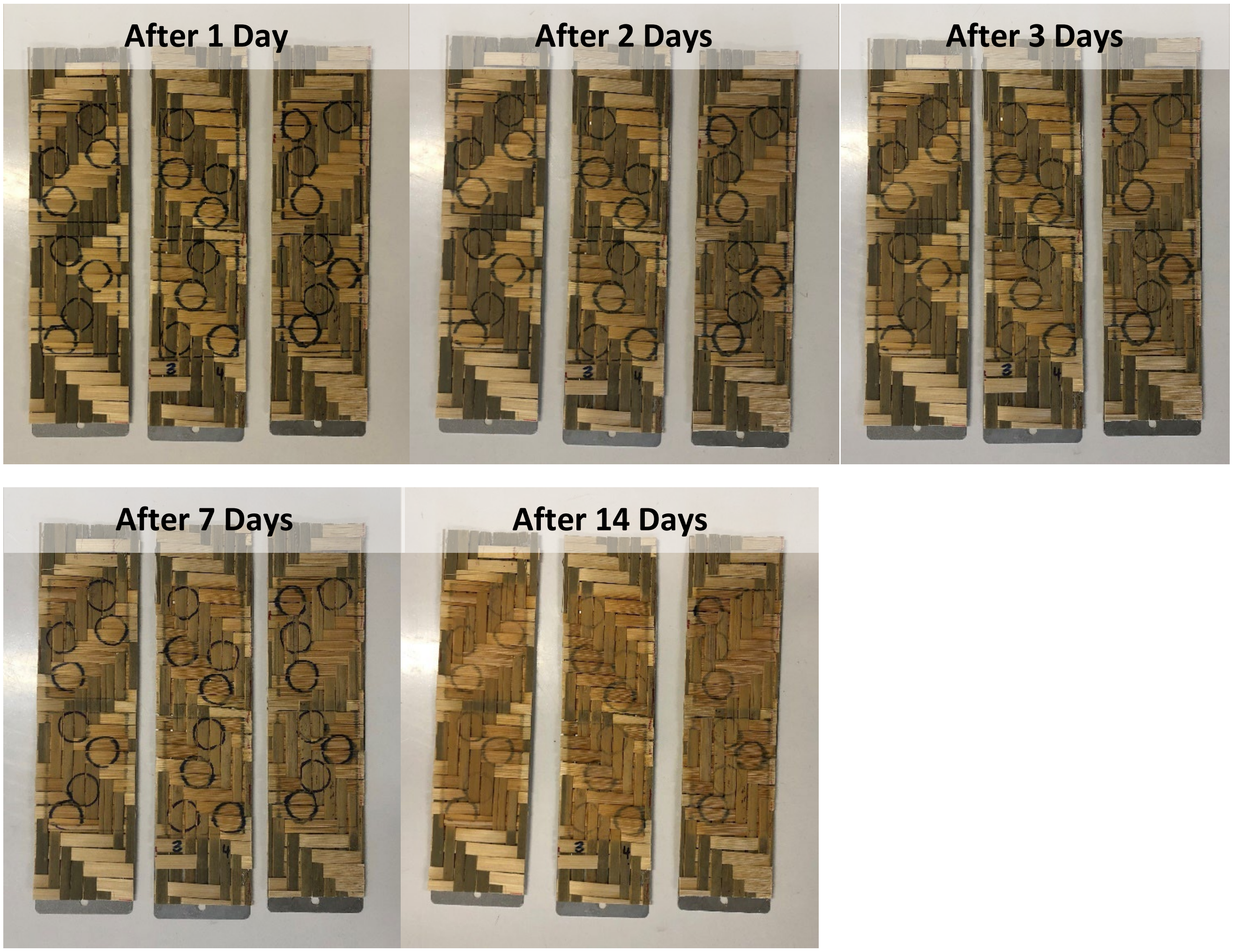


Figure 69. 2-1-3 (Day 1, Day 2, Day 3, Day 7, Day 14)

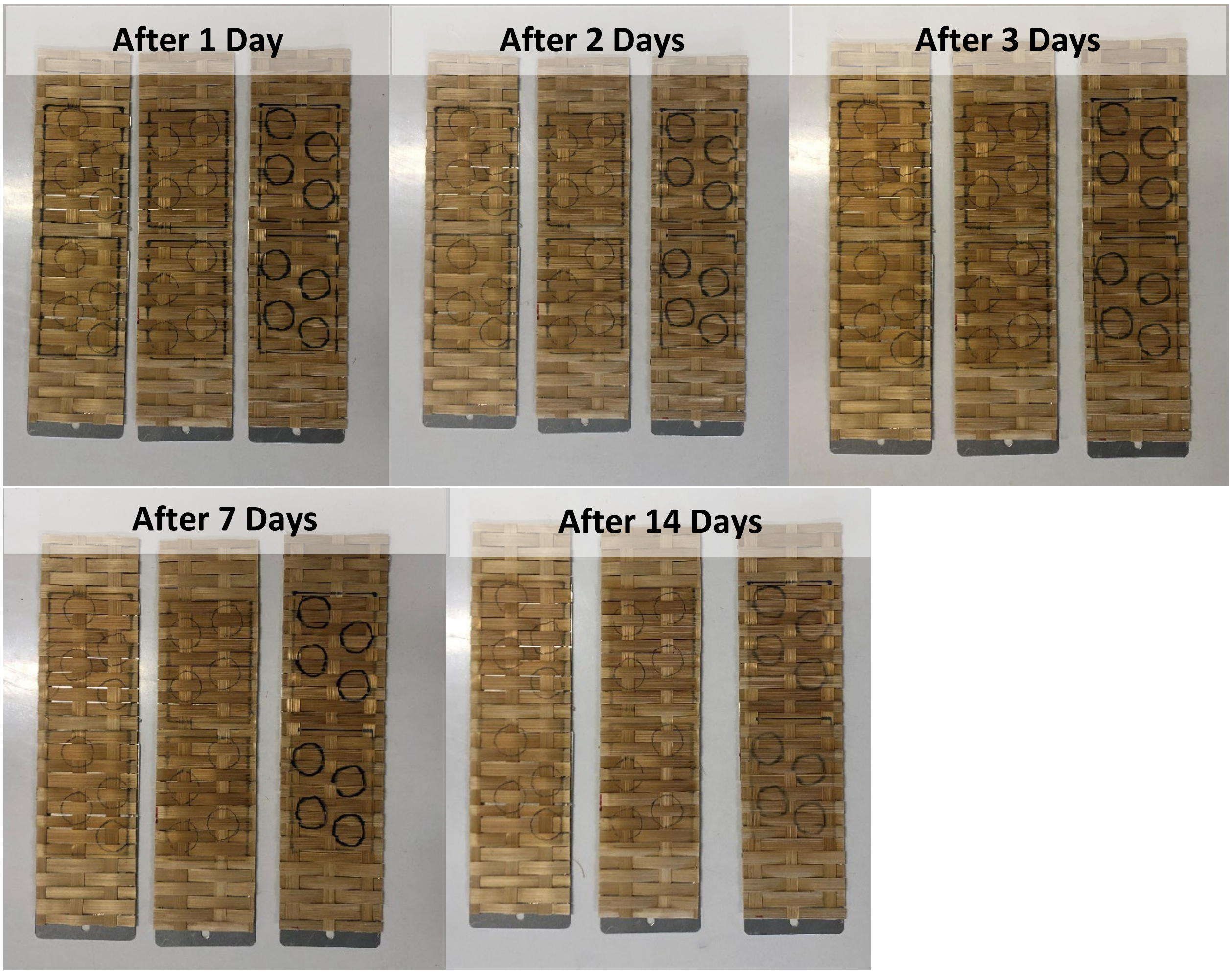


Figure 70. 3-3-3 (Day 1, Day 2, Day 3, Day 7, Day 14)

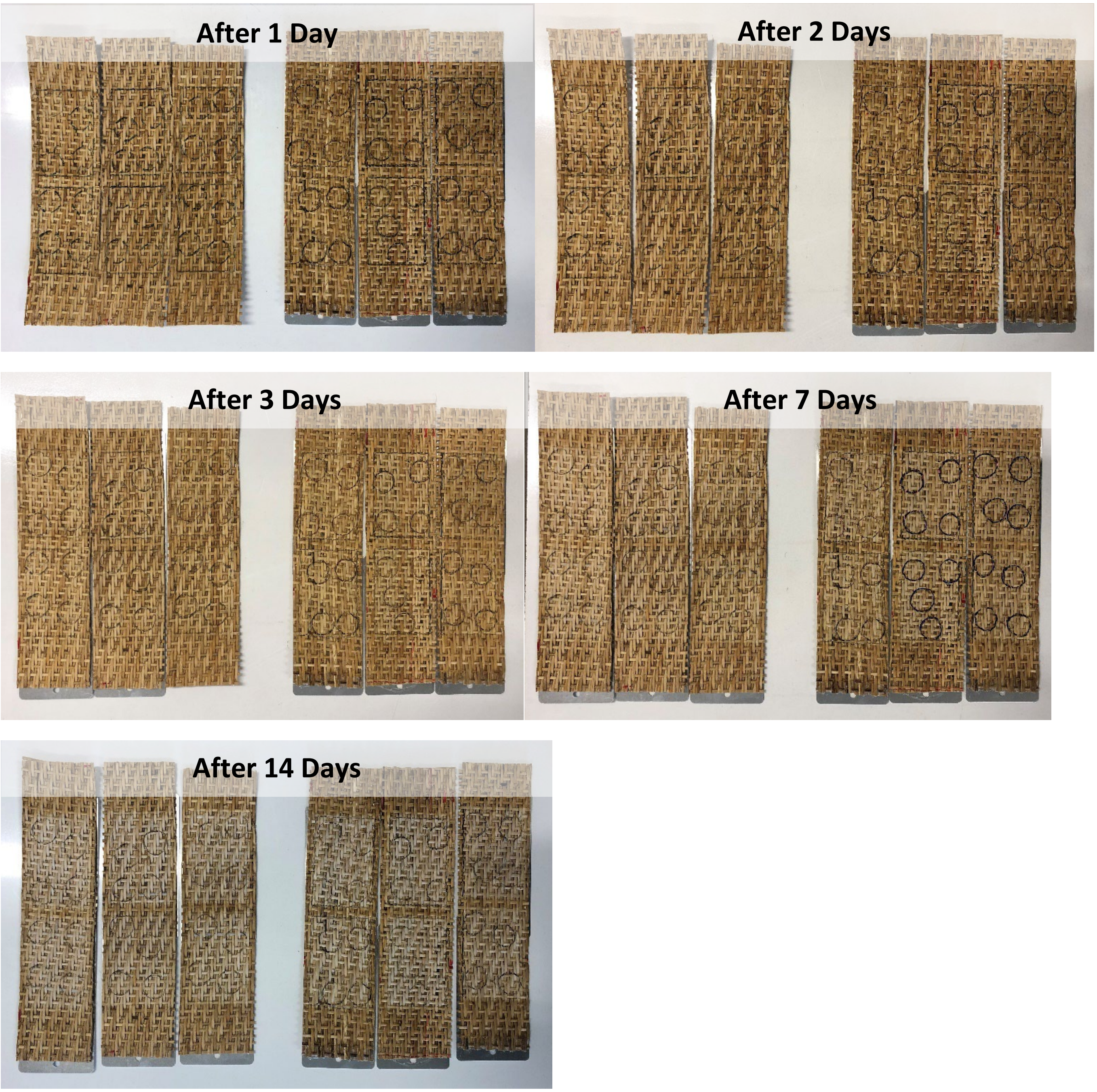


Figure 71. 4-2-3 (Day 1, Day 2, Day 3, Day 7, Day 14)

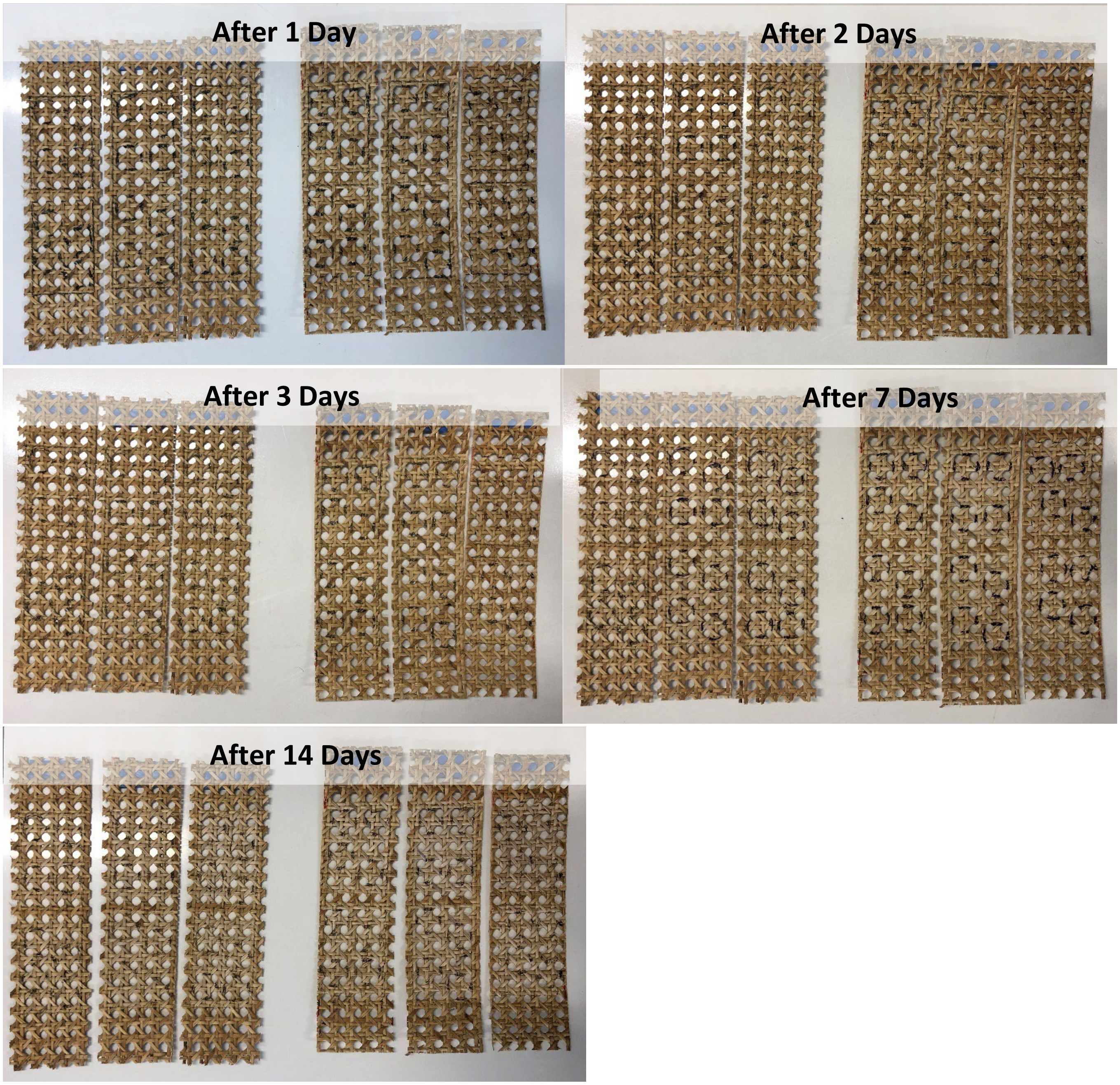


Figure 72. 5-3-3 (Day 1, Day 2, Day 3, Day 7, Day 14)