MECHANICAL PERFORMANCE OF ACETATE LACQUER FROM *ACACIA MANGIUM*

Melissa Sharmah Gilbert Jesuet, Ismawati Palle & Liew Kang Chiang

Wood Technology and Industry Program, Faculty of Science and Natural Resources (Forestry Complex), Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia

*Corresponding author ; melissa.gilbert@ums.edu.my

ABSTRACT. *Cellulose comprises about 40–50 % of the composition of wood, making it one of the most abundant organic polymers on earth. Cellulose is very versatile in terms of application, with a wide array of products fabricated, including the chemically modified cellulose derivatives. One of the more prominent and multifaceted derivatives is the cellulose acetate, in which have been used predominantly as cigarette filters, membrane filters, and coating. In this study, the intermediate product, Acacia mangium-produced cellulose acetate was modified into lacquer to produce a feasible wood coating product. The lacquer underwent a series of tests such as impact, abrasion, adhesion, and hardness to evaluate its mechanical performance. The results of the coating were compared to a similarly formulated acetate lacquer that was produced using commercial cellulose acetate instead as a control. Based on the result, it is shown that Acacia mangium-produced cellulose acetate lacquer shows a better impact resistance with a rating of 4 as opposed to the commercial cellulose acetate with a rating of 3 with moderate cracking, with an approximate 6% better abrasion resistance and higher hardness rating class. Meanwhile, the commercial cellulose acetate lacquer presents a better adhesion performance with only 5% flaking compared to the 15% flaking of Acacia mangium-produced cellulose acetate lacquer. The Acacia mangium-produced cellulose acetate lacquer indicates a novel benefit from the presence of impurities from the intermediate Acacia mangium-produced cellulose acetate product such as the plasticizing hemicellulose acetate, as well as the hydrophobic lignin.*

KEYWORDS. Cellulose acetate, lacquer, wood coating, mechanical properties

INTRODUCTION

Wood has long been utilized primarily as structural components in buildings and furniture. Due to the hygroscopic nature of wood, humidity is one of the conditions avoided for a prolonged utilization but to no avail other than with additional treatments or coating layers. One of the more decorated but functional type of coating is lacquer, a protective coating made out of cellulose esters or resin through the evaporation of solvent, or formerly as a resinous varnish obtained from *Rhus verniciflua* which originated in Japan (Ma *et al.*, 2014).

Lacquers are predominantly produced from nitrocellulose, a modified cellulose product where the free hydroxyl groups were substituted from nitro groups from the reagent. Similarly, cellulose esters such as cellulose acetate (CA) are also being developed into lacquers for wood coating. CA has a concomitant resemblance to the nitrocellulose, but with a low to none flammability hazard. CA and other cellulose derivatives are produced from renewable materials such as wood pulp and cotton, making them renewable materials and an environmentally friendly, material-wise, bio-based product (Egot & Alguno, 2018; Cheng *et al.*, 2010).

In this study, lacquer was produced from *Acacia mangium*-based cellulose acetate (AMCA) and evaluated based on the mechanical performance, which includes the impact, hardness, adhesion, and abrasion test. The properties of the AMCA lacquer will then be compared to the commercial cellulose acetate (CCA) lacquer based on the cellulose acetate coating compositions by Swain et al. (1940), to determine the differences of performance based on the purity of raw materials used in the production of the intermediate AMCA and CCA.

MATERIALS AND METHODS

2.1 Materials

The cellulose acetate produced from *Acacia mangium* pulp was produced from a previously developed acetylation process (Gilbert & Palle, 2013). The commercial cellulose acetate, ethyl acetate, and acetone were obtained from Sigma Aldrich, while the melamine formaldehyde was supplied from Norsechem (Sabah) Sdn. Bhd.

2.2 Lacquer Formulation and Application

The compound for the lacquer was loosely based on the Unites States Patent no. 2426379 by Swain *et al.* (1940). Both types of lacquer; the AMCA and CCA lacquer, followed the same mixture of cellulose acetate, ethyl acetate, acetone, and melamine formaldehyde. It follows a ratio of 1:9 between MF and the cellulose acetate stock solution. The stock solution meanwhile, follows a ratio of 1:5:1 that comprises of cellulose acetate, acetone, and ethyl acetate, respectively, still based on the aforementioned patent. The lacquer solution was then heated at 135˚ C oven for half an hour and left to cool. The lacquer was then applied on *Acacia mangium* blocks (30 x 10 x 1 cm) via brushing technique.

2.3 Mechanical Testing

Standardized double layer of lacquer was applied on the *A. mangium* blocks. A series of performance-intensive mechanical testing was measured on both AMCA and CCA applied lacquer that includes impact resistance, adhesion, abrasion, and hardness test.

2.3.1 Impact Resistance

For this test, the ball drop test was executed. A 1.0 kg ball of steel was dropped onto the surface of the coating from a height of 1.0 meter. Impacts from the ball were evaluated based on the Indian Standard 5807 Part 6 (2002) as in Table 1.

Table 1: Impact Test Rating Code Description

Rating (Code)	Description
1	More than 25% of finish removed from the area of indentation
2	Cracking extending outside the area of the indentation and/or slightly flaking of the finish
3	Moderate or severe cracking confined of the area of indentation
4	Slight cracking e.g: One or two circular around the edge of indentation
5	No surface cracking

(Source: Indian Standard (IS) 5807 Part 6: 1980)

2.3.2 Adhesion

For the adhesion test, the crosscut method based on ASTM D3359 (1997) was used where a lattice pattern is cut into the coating, penetrating fully into the film and substrate. Each line of six (6) must be 1–2 mm apart, where the outcome of the cross-cut test is evaluated based on the principal classifying paint film adhesion in Figure 1.

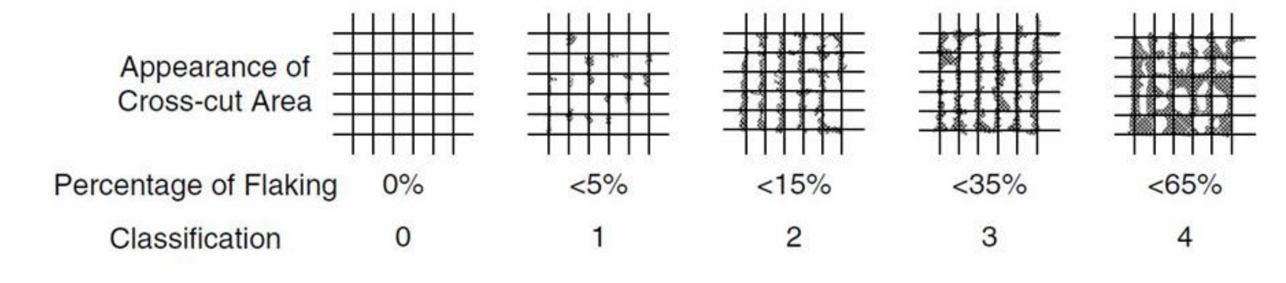


Figure 1: Principle of classifying paint film adhesion in the cross-cut test based on the percentage of flaking.(Source: Zorll 2007)

2.3.3 Abrasion

The abrasion resistance test following Koleske (2006) is a scrub resistance test for the coating (ASTM D2486). Basically, it shows the resistance to changes of its original appearance and structure due to the influence of ablating actions such as rubbing, erosion, and scrapping. For this test, the number of brushing cycles over the same area were accounted until the coating was damaged and surface was exposed.

2.3.4 Hardness

The final test is based on the hardness of the coating (ASTM D3363) where a number of different pencil grade (6B to 6H) was used to try to cut the coat. The eventual result is based on the grade of pencil that could not scratch the surface, just before the pencil grade that could, stipulating the grade of the surface hardness based on the pencil grading.

RESULTS AND DISCUSSION

Raw material plays an important role in the production of any products, especially in the lignocellulosic segment. Abundant and renewable resources such as raw *Acacia mangium* pulp are rarely being prioritized as the primary cellulosic material due to the presence of other impurities such as lignin and hemicellulose, despite undergoing the mechanical and chemical alteration from the pulping processes, compared to cotton. Certain application that ignores the presence of impurities is proven to be at a disadvantage, such as the production of paper that shows a drawback in appearance and strength. However, the hidden novel usage of these impurities may contribute positively to the properties of certain products such as shown in the AMCA lacquer production.

The effectuation of the mechanical performance of both CCA and AMCA lacquer was observed based on the impact, adhesion, abrasion, and hardness quality. Based on Figure 2, AMCA lacquer block sample that underwent the impact test has shown a slightly superior resistance towards impact compared to the CCA lacquer, as circular indentation and moderate cracking appeared on the CCA lacquer blocks, rather than just circular indentation appearing on the former. The presence of lignin may be the main contributor to the better performance in impact resistance as lignin is known to provide physical support on most lignocellulosic materials and serves as a retainer for the structure (Kakroodi & Sain, 2016).

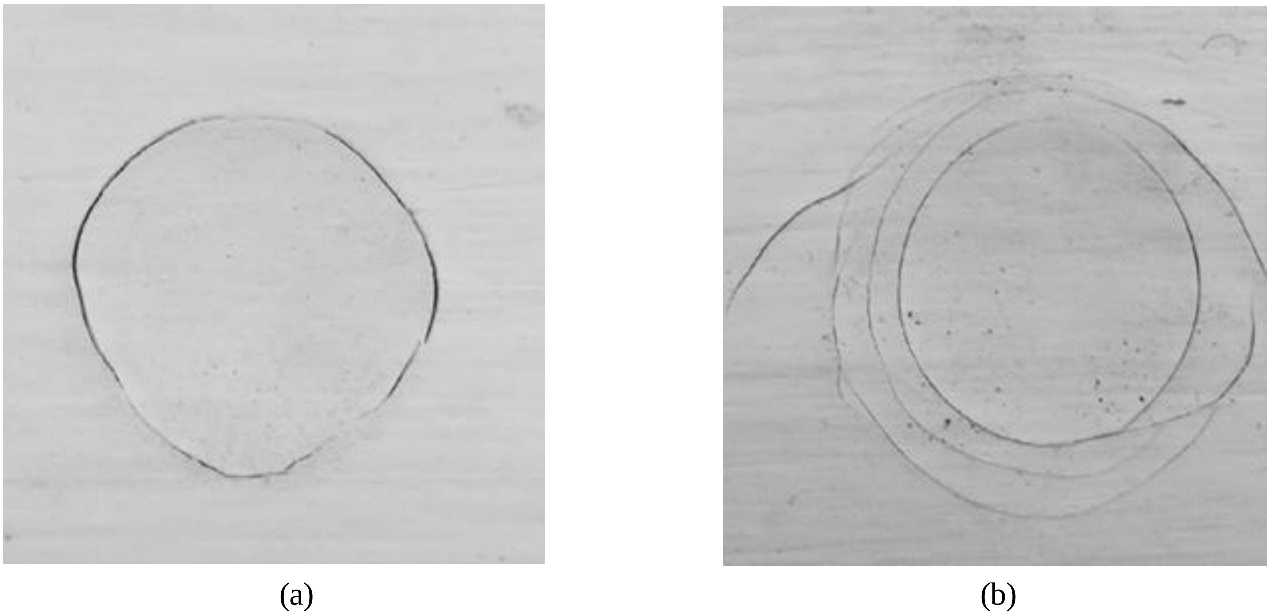


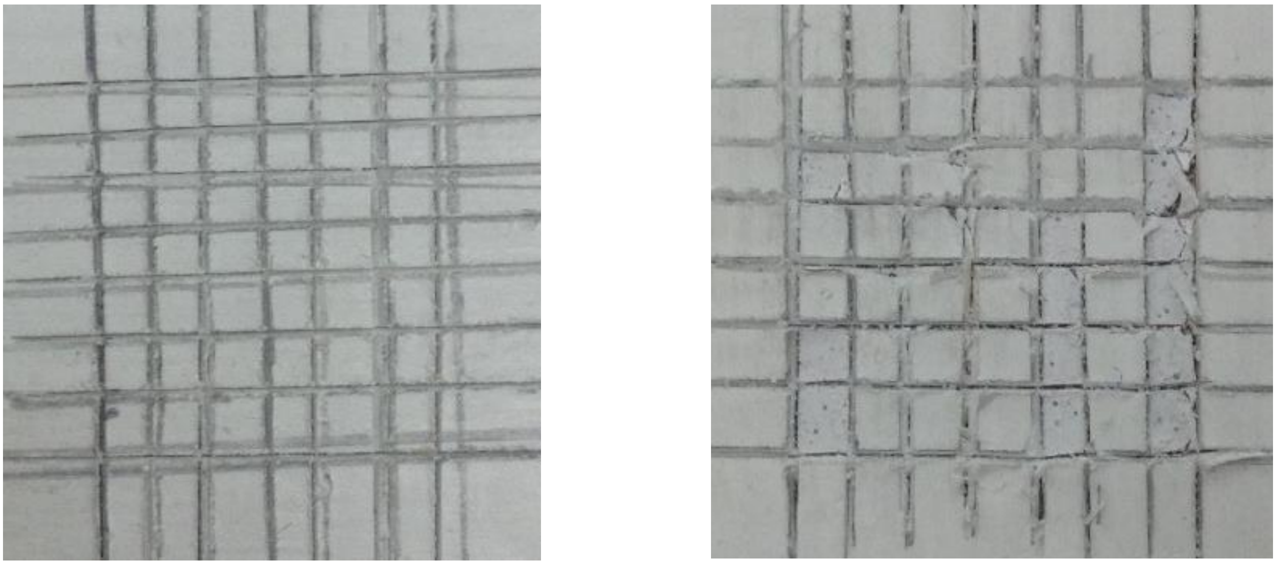
Figure 2: Circular indentation (a) AMCA lacquer blocks; (b) CCA lacquer

Based on the chemical composition of *Acacia mangium* pulp by Gilbert *et al.* (2013), a near-absolute 95% of its content is cellulose, where the remaining 5% of its content consists of hemicellulose, lignin, and extractives. Due to the difference in raw material used, the AMCA which was developed from raw *Acacia mangium* pulp contains a lot more impurities as compared to the CCA, which has the content of an absolute cellulose purity. These impurities may contribute to the more advantageous performance on all three properties such as for the impact resistance, as shown in the overall results in Table 2.

Table 2: Mechanical performance of commercial cellulose acetate (CCA) lacquer compared to the *Acacia mangium* cellulose acetate (AMCA) lacquer

Lacquer	CCA	AMCA
Impact (Rate)	3 Moderate cracking	4 Two circulars around the edge of indentation
Adhesion (Percentage of flaking)	1 < 5%	2 < 15%
Abrasion (cycle)	271	288
Hardness (Pencil grade)	2H	3H

The adhesion performance for the AMCA lacquer was the only one lower than the CCA lacquer, with the CCA lacquer only obtaining less than 5% flaking covered to opposed of the 15% for the AMCA's in Figure 3. The adhesion or inter-crosslink between the coating and the surface or substrate is presumed lower than that of the CCA, in which the optimal layer thickness determination plays a great role in providing the higher strength of the bonded substrate, where the film thickness of the CCA lacquer is proven to be thicker and adhere more than that of the AMCA lacquer. Higher thickness provides better adhesion performance in coatings and adhesives (Müller *et al.*, 2006.



(a) (b)

Figure 3: Flaking percentage (a) AMCA lacquer; (b) CCA lacquer

However, despite the disadvantage of a lower adhesion property for the AMCA lacquer, the abrasion resistance is showed in Figure 4 to be higher than the CCA lacquer with 288 cycles compared to 271, respectively. The intra-crosslink or cohesion between the AMCA in its molecular level is higher compared to the CCA, resulting in a higher abrasion resistance. This could be contributed by the presence of hemicellulose acetate, which increases the tensile strength of the product as demonstrated from the production of hemicellulose plasticizers in films, where in the sugarcane bagasse-cellulose acetate production study, increases the tensile strength up to three to four times from 14 MPa to 61 MPa (Shaikh *et al.*, 2009). The tensile strength includes the ability of the materials to resist permanent deformation such as breaks or ruptures.

This is also evident based on the pencil hardness test, where the AMCA lacquer is shown to have a higher level of tolerance towards scratching compared to the CCA lacquer, where only the pencil grade of 3H or higher was able to scratch the surface of the AMCA coating, with the latter showing a slightly lower hardness with 2H. The AMCA lacquer has a higher resistance towards permanent change in shape compared to the CCA lacquer due to the very same reason of the abrasion, which is the higher tensile strength provided by the hemicellulose and lignin presence. In the production of printable hemicellulose-based films, cellulose alongside hemicellulose are proven to complement each other by enhancing the tensile sand contributes to the strength of the coatings (Ma *et al.*, 2017). The resistance of the coat breaking may also be due to the plasticizing effect of hemicellulose, which is commonly absence in industrial grade cellulose acetate, compared to the homemade AMCA that contains traces of hemicellulose and lignin from its pulp source (Shaikh *et al.*, 2009). Apart from that, a higher cohesion force may as well contribute to the resistance.

(a)

(b)

Figure 4: Abrasion resistance on the (a) AMCA lacquer is higher than the (b) CCA lacquer, with 288 and 271 cycles, respectively.

CONCLUSION

The impact and abrasion resistance for the AMCA lacquer is higher than the commercial CCA lacquer, which strictly underwent gruesome formulation uniformity to avoid bias. The hardness test result also shows a higher deforming resistance for the AMCA lacquer, with hemicellulose, lignin, and other impurities surprisingly bestowing an upper hand in the properties of the lacquer.

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