EFFECTS OF NATURAL DEGRADATION ON THE MECHANICAL AND MORPHOLOGICAL PROPERTIES OF TROPICAL WOODS

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In this study, three Malaysian tropical woods, namely Balau, Maranti and Rubber wood, were used to investigate the effects of natural degradation using four natural stimuli (i.e. sun, water, air and earth) on their mechanical and morphological properties. The mechanical properties of wood in terms of tensile and impact strength were analyzed and found to be significantly changed after degradation. The surface morphology of the wood samples, before and after degradation, was observed through scanning electron microscopy (SEM). The SEM observation showed that the surface morphology of the wood samples was significantly altered after degradation. By visual observation, significant color changes were noted in the wood samples after thirty days of degradation. The tensile and impact strength of the wood samples was found to increase after water and earth degradation, however, after sun and air degradation, these properties decreased. In addition, the Balausample displayed lower water absorption compared to the Rubber and Meranti wood samples.

Keywords: tropical wood, degradation, natural degradation, mechanical strength, water absorption

INTRODUCTION

Wood is a versatile and most preferred building and construction material due to its high mechanical strength, low processing cost and many aesthetically pleasing characteristics. However, the essential properties of wood get readily deteriorated by various environmental factors, which is its main disadvantage and limits its applications.[1,2,3] The use of various types of wood in the construction and manufacture of ships, utensils or furniture greatly depends on its physical and mechanical properties. These properties are entirely dependent on the structure of its fibers, dimensions, weight, its tendency to absorb water and the angle at which force is applied to fiber. Generally, structural wood is exposed to water, earth, solar radiation, wind and dust during application. Wood is susceptible to natural degradation, which may result in physical deterioration, color change, surface roughening, cracking and damage of the wood microstructure.[4,5,6]

Wood is a biological material and hence, it degrades over time. The degree of degradation is directly proportional to the exposure to various detrimental or environmental elements.[7]The environmental elements can be water, moisture, excessive heat, salt, sunlight, temperature variation, mould and insects. If cured and protected properly, the life span of wood can be increased, even indefinitely in certain cases. Temperature variation, moisture or wetting and rapid drying are a major cause of wood decay, as they cause wood to swell and shrink, develop case hardening and lifting of the grain.[7] Sharp, rough and coarse sand and microscopic dirt travelling in the air, with sufficient momentum, will cause mechanical abrasive action over time, referred to as sand blasting. If left unchecked, sandblasting can severely damage any wood.

Air carries water, which aids in water degradation, when it gets absorbed into the wood surface. When dryer air blows, it removes moisture at a rapid rate, causing high fluctuation between expansion and contraction and leading to the rupture of wood faster than in a less dry environment. Moreover, fungus also uses air as a transport medium to travel from one place to another. Fungus spores travel from an infected area to wood that is located in an environment ideal for fungal growth. The fungi feed on wood for nutrition, degrading the wood and altering its mechanical properties.[8] Research indicates that the surface of wood can be degraded if the wood becomes repeatedly wet and dry, is exposed to high and low temperatures and to direct sunlight. The degradation causes roughening of the wood surface, checking, splitting and wood cell erosion. Erosion of cells results in the loss of wood cells from the lumber surface, and also it degrades the newer cells in a similar fashion.[9]

Earth degradation is a combination of effects caused to wood by air, water and sun. Under direct sunlight, the earth dries and, due to reverse osmosis, it causes the wood buried in it also to lose water. Under rainy conditions, earth will concentrate water around the wood and keep the wood wet for a much longer period of time than if it were outside of earth.[10,11] This phenomenon will allow water to get to the wood via osmosis and saturate it, leading to rupturing of wood fibers and causing the wood to crack and shear. Earth is also a breeding ground for countless insects, animals and vegetation, which feed on fibrous material. Wood is very prone to biodegradation. The buried wood is deprived of sunlight; fungal growth shows more attraction to the wood. Moreover, wood cells absorb water and swell, thus causing dimensional instability.[12,13] Water is one of the needs of microorganisms and decay fungi to breed. In an earth environment, wood is degraded by the combination of effects caused by air, water and sunlight. In addition, microorganisms and fungi will further degrade the wood.

Malaysia is one of the top producers of wood in the world. Several tropical wood species are abundantly available in Malaysia; however, they have not been exploited yet and studied sufficiently for appropriate application.[14] Three of the most commonly used Malaysian timbers are Balau (*Shorea spp.*), Meranti (*Shorea spp.*), and Rubber wood (*Heveabrasiliensis*). Many studies have been carried out to investigate the effect of natural degradation on the physical and mechanical properties of wood.[15,16] However, very little or no research work at all has been reported for Balau, Meranti and Rubber wood species, and their mechanical and morphological properties after natural degradation.[7]

In the present study, Balau (*Shorea spp*.), Meranti (*Shorea spp.*) and Rubber wood (*Hevea brasiliensis*) acquired from the same plantation were subjected to the influence of environmental factors, including water, sun, air and earth, and their mechanical and morphological properties were analyzed. The major objective of this study was to investigate the effect of natural degradation on the water absorption, mechanical and morphological properties of the tropical wood species mentioned above. In order to get accurate results, it was necessary to exclude the effects of other factors on the properties of the wood, such as the plantation area, and the climate in which they were grown, as well as the effect of locally occurring insects and fungi.

EXPERIMENTAL

Materials

In this study, three types of tropical wood species, namely Balau (*Shorea spp.*), Meranti (*Shorea spp.*) and Rubber wood (*Hevea brasiliensis*), were selected, as these are the most commonly used wood types in Malaysia and their features are significantly different as to fiber dimensions and arrangement. Thus, Balau wood has thin long fibers, which are tightly packed, Meranti wood has thick long fibers, which are loosely packed, while Rubber wood has thick, short and loosely packed fibers.

Wood planks were collected from various timber yards in a local town in Selangor, Malaysia. The planks were cut to 4 cm thickness. The planks were subsequently conditioned to air-dry in a room with relative humidity of 60% and ambient temperature of around 25 ^{o}C for 6 months before testing.

Specimen preparation

The clear, defect-free planks were ripped and sized to 100mm (L) x 20mm (T) x 10mm (R) samples for the tensile test, to 60mm (L) x 20mm (T) x 10mm (R) ones for the Charpy impact test, to 150mm (L) x 20mm (T) x 10mm (R) ones for the three point bending test, and to 60mm (L) x 20mm (T) x 10mm (R) ones for water absorption.

Degradation process

The wood samples were degraded in four media (i.e. water, sun, air and earth) under atmospheric conditions for 30 days. For the water medium degradation, the wood samples were placed in a box and a metal weight was put thereupon so as to keep the samples fully submerged for 30 days. All the samples were drawn every ten days. They were placed in sealed containers, allowing no water or air contact, on the roof and kept there for one month for sun degradation. For air degradation, all the samples were placed in the shade, with abundant flow of air and no possibility for the samples to come in contact with the sun or water. For the earth degradation, the wood samples were buried in 0.5 foot graves with partial shade from the sun and rain. The first set of tests/measurements (i.e. tensile, impact and water absorption tests) was carried out on the first day of the degradation cycle to obtain the control properties of all the wood samples. After ten days of degradation, the samples were extracted from their respective medium and exactly the same tests were performed on all of them.

Water absorption test

The dried and weighed specimens were immersed in distilled water according to ASTM D 570-99 for 2 hours. The specimens were periodically taken out of the water, wiped with tissue paper to remove water from the surface, reweighed, remeasured, and immediately put back into the water. Water absorption was calculated according to the given formula:

$$\text{Water absorption (\%)} = W_2\text{-}W_1/W_1 \times 100 \qquad (1)$$

where W_2 is the specimen weight after soaking and W_1 is the specimen weight before soaking. Five test specimens were measured in this test and the average was taken as the result.

Tensile test

The tensile strengths of the samples were measured according to ASTM D7205/D7205M - 06(2011), using a Universal Testing machine (model LLOYD-LR50KPlus Series) at a cross head speed of 10 mm/min. The test dimensions were 148mm x 10mm x 4.1mm. The test was conducted in a laboratory environment at an average temperature of 23°C and relative humidity of 50%.

Charpyimpact test

Charpy impact tests were conducted on specimens according to ASTM D 6110-97, using a Charpy Impact Tester MH-358model.

Scanning Electron Microscopy (SEM)

The surface morphology of the samples was examined using Scanning Electron Microscopy (Quanta 400 FE-SEM by FEI) under vacuum-pressure conditions at the temperature of 23°C. The specimens were first fixed with Karnovsky's fixative and then subjected to a graded alcohol dehydration series. Once dehydrated, the specimens were coated with a thin layer of gold before examination under SEM.

RESULTS AND DISCUSSION

Visual observation

Fig. 1 shows typical optical microscopy images of rubber wood samples with visible effects of earth degradation. After ten days of degradation, all the wood samples exhibited a lighter color and were shinier. All the samples subjected to degradation in the sun had shrunk and lost weight. The samples that had been buried in the earth experienced the effects of both sun and rain, and seemed to be slightly increased in size. The Rubber wood also had bite marks, as insects attacked the sample. The samples that had been kept in the water swelled, and all the samples exhibited discoloration, but the Meranti sample presented the most significant discoloration, having turned from bright red to dark brown. After twenty days of degradation, all the wood samples that had been kept in the air and sun showed no significant changes. The samples subjected to earth degradation experienced heavy rain and swelled as they absorbed some water; besides, more deterioration caused by insects was also noticed. The samples that underwent water degradation swelled slightly more. The Meranti samples showed the highest degree of swelling, followed by the Rubber and Balau wood samples.

No significant changes were observed in the wood samples after thirty days of degradation in the air, sun and water. However, the samples that had been buried in the earth exhibited visible changes in their geometry caused by insects. This is especially obvious in the case of the rubber wood, as seen in Fig. 1. The wood was damp most of the time and thus could be readily damaged by termites, which feed on wet wood as it is easier to disintegrate.[13]

Figure 1: Typical Rubber wood degradation caused by insects under earth degradation

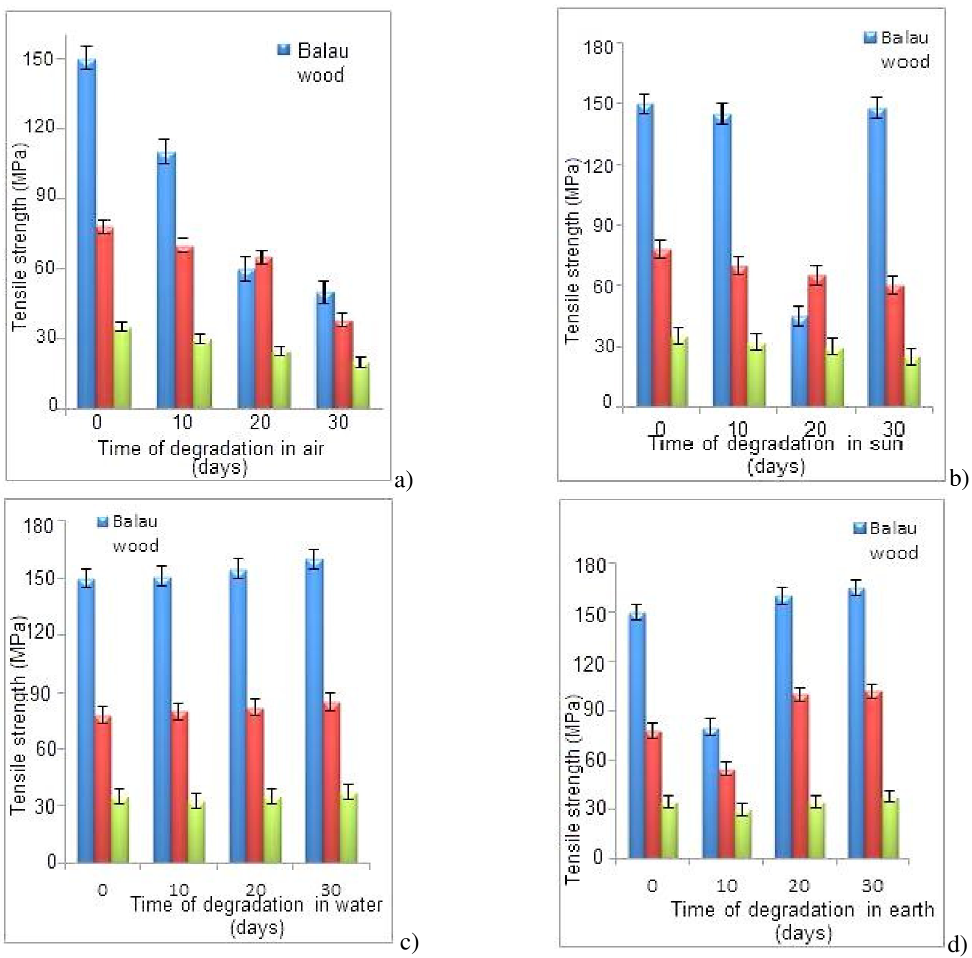

Figure 2: Tensile strength of wood samples after (a) air degradation, (b) sun degradation, (c) water degradation and (d) earth degradation

Tensile test

The effects of degradation due to air, water, sun and earth on the tensile property of the wood samples were measured and the results are shown in Figs. 2(a), 2(b), 2(c) and 2(d), respectively. Fig. 2(a) shows the effect of a 30-day degradation period on the tensile strength of all the wood samples. Thus, it can be noted that the tensile strength of all the wood samples decreased dramatically under air degradation. It can also be observed that the tensile strength decreased over time. This could be due to the weight loss of the wood fibers after air degradation,[18] which increased over time. Thus, the wood samples became dry and hence brittle and easy to break. Furthermore, the samples had been attacked by fungi and insects, which also reduced their weight. Fig. 2(a) clearly shows the decrement of tensile strength for Meranti wood. It was found to be lower compared with the tensile strength values for the Rubber and Balau wood types, due to the larger fiber size of Meranti wood, thus taking a much longer time to lose the stored moisture from the wood fibers. This indicates that water was lost at a slow rate and the observed high impact strength leads to the conclusion that at a certain ratio of water the strength of moist fibers is high.

Fig. 2(b) indicates that the tensile strength of wood was increased slightly due to water degradation. The observed results can be explained by the absorption of carbonate and calcium carbonate impurities inside the wood in concert with water, which provides high weight, as compared to that of raw wood. Similar results were also observed by other researchers.[19,20]

From Fig. 2(c), it is evident that the effect of sun degradation on the tensile strength of wood was almost similar to that of air degradation. It was observed that the tensile strength decreased after sun degradation and the trend of decrement increased with the increase in the degradation time. As the sun degradation continued, the values of tensile strength dropped similarly to those of the impact strength. This can be explained by the fact that as the fibers lose moisture, they also lose their elastic properties and become too brittle to withstand high impact or tensile forces. The highest decrement of the tensile strength was found for Rubber wood, which is explained by its shorter fiber size.

Fig. 2(d) indicates that the tensile strength of the wood samples decreased by the tenth day of the degradation period, mainly due to wood weight loss, as explained earlier. However, this value started increasing in the case of earth degradation continuing up to 30 days. This result was expected and could be explained by the presence of clay particles incorporated in the wood surfaces, acting as reinforcement and thus improving the mechanical strength of the wood samples.[19]

Impact test

Fig. 3(a-d) displays the impact strength of the raw wood sample and of the wood samples degraded due to air, sun, water and earth. As Fig. 3(a) illustrates, the impact strength of the Balau and Rubber wood samples increased after air degradation. In contrast, air degradation decreased the impact strength of the Meranti wood sample. This result indicates that the water absorbing capacity varies from wood species to wood species, and has an impact on the strength-to-weight ratio of wood. After degradation, the Balau and Rubber wood samples were able to absorb more energy at the time of impact before failure.[21] On the contrary, Meranti wood specimens showed brittle fracture characteristics as the fiber size and structure were different from those of the former.

After sun degradation, the impact strength of Balau wood increased significantly compared to that of Meranti and Rubber wood, as may be noted in Fig. 3(b). It was also found that the impact strength of Rubber wood increased slightly after ten days of sun degradation. However, this value started decreasing upon increasing degradation time from 10 to 20 and 30 days. A small decrement of impact strength was observed for Meranti wood after 30 days of degradation. The increasing or decreasing trends of the impact strength are solely due to the structural changes within the wood species.[22]

Fig. 3(c) shows that the impact strength of wood increased slightly due to water degradation. The reason is that the overall weight increased due to water sorption. Additionally, some impurities, such as sodium carbonate and calcium carbonate, could have been absorbed together with water.[23] After 30 days of degradation, Meranti wood showed the lowest impact strength. This may be due to the loss of fiber strength by water degradation.[16] Fig. 3(d) shows that the impact strength of all wood samples increased after 30 days of earth degradation. The observed results are due to the deposition of some clay particles on the wood surfaces, acting as reinforcement filler. Wood weight loss explained the initial decrement of impact strength. The clay medium was dissolved during rainy days and filled the wood pores through water absorption, thus affecting the wood specimens during earth degradation. Another point worth noting is that most of the clay impurities get deposited near the surface of the specimens as it is harder for them to diffuse further into the wood, owing to their large particle size, as well as the low pressure conditions. In the case of earth degradation, the wood samples had a very good strength-to-weight ratio, resulting in improved impact strength of the wood samples.[24]

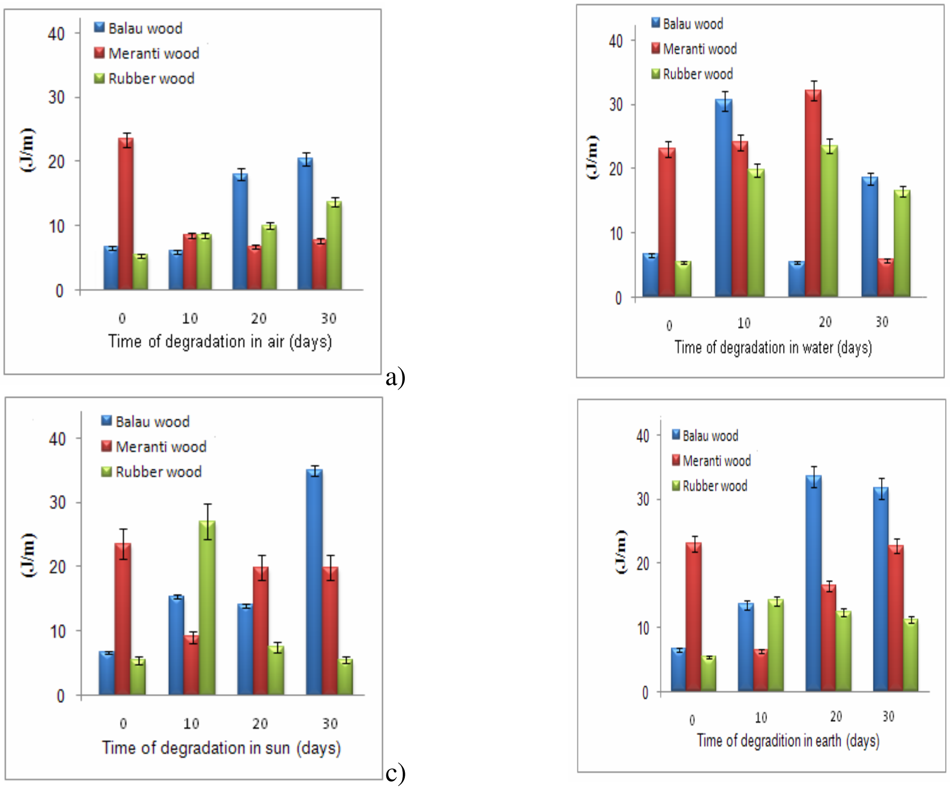

Figure 3: Impact strength of wood samples after (a) air degradation, (b) water degradation, (c) sun degradation and (d) earth degradation

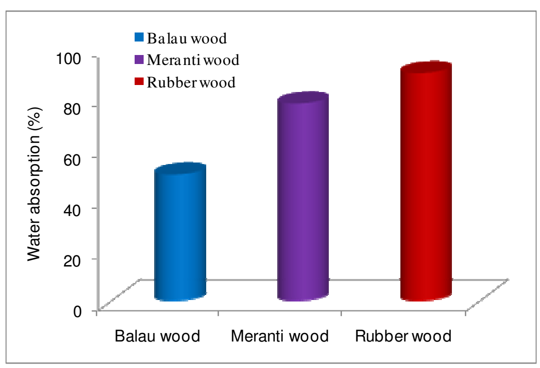

Figure 4:Absorption behaviour of wood subjected to degradation in water for seven days

Water absorption

The differences in water absorption among the different types of wood before and seven days after the water absorption test are illustrated in Fig. 4. It can be observed from Fig. 4 that the Rubber wood exhibited the highest water absorption rate (97.6%), followed by Meranti wood (85.7%) and Balau wood (55.3%). The difference in water absorption among the wood species can be attributed to factors such as the concentration of wood fibers within the sample volume. Thus, in short fiber wood species, there are more fibers per unit of volume and more water can be potentially absorbed and thus they have a higher water absorbing potential compared to long fiber species. The existence of moisture even after prior oven drying affects the rate of absorption. If the fibers are too closely packed, then the water will have difficulty in reaching inner fibers, whereas in wood with loosely packed fibers, there is significant space among the fibers, and thus water can easily penetrate and reach inner fibers.[16]

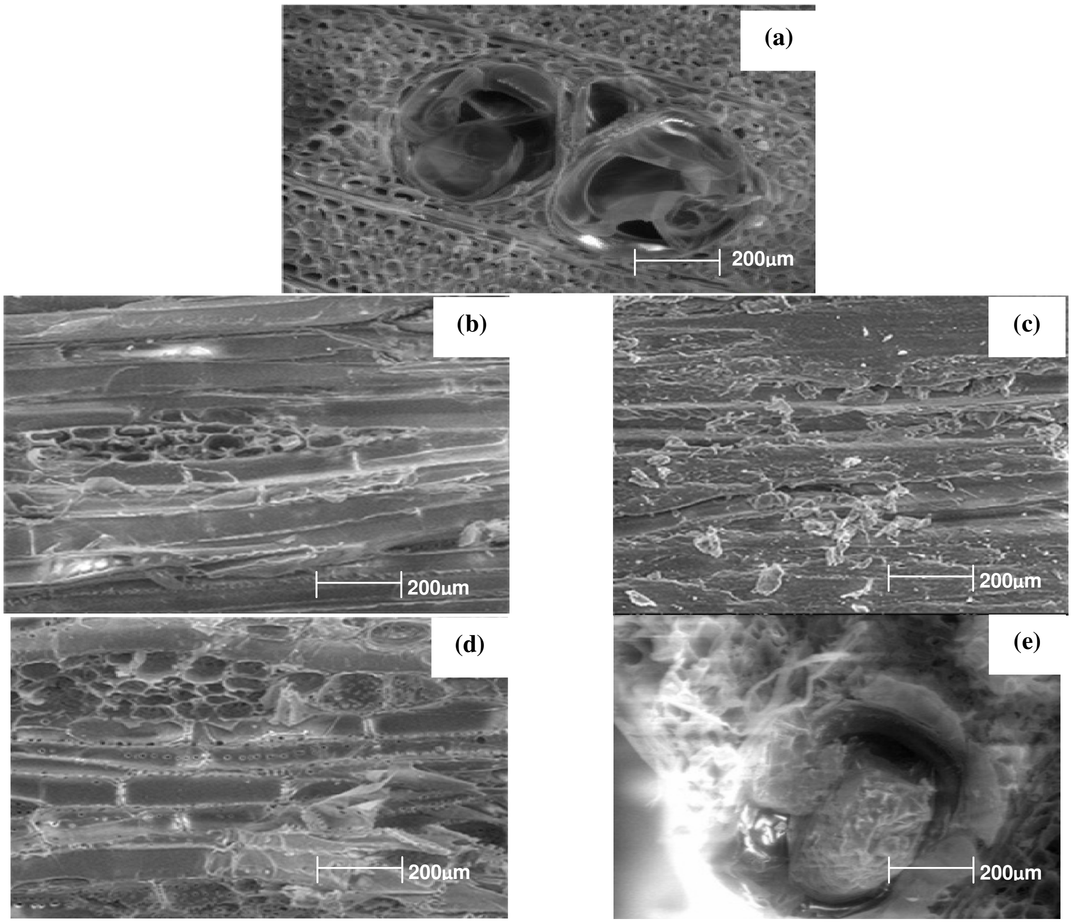

Figure 5: Typical SEM microscopy of Meranti wood: (a) raw wood; (b) air degraded; (c) water degraded; (d) sun degraded and (e) earth degraded

Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) was carried out to observe the degradation effect on the surface morphology of the wood samples. SEM images of raw wood and wood samples degraded in air, sun, water and earth media are presented in Fig. 5(a-e). Fig. 5(a) shows that the raw wood surfaces are covered with an uneven layer and a number of voids are present in the lumen, vessels and tracheids, as also reported previously.[25] On the other hand, it can be seen from Fig. 5(b-e) that the cell walls, vessels and tracheids of wood were significantly altered after degradation. Fig. 5(b and d) reveals higher swelling of the cell walls due to air and sun degradation. This indicates that air and sun degradation greatly affects the whole wood structure. Similar results were also observed by other researchers.[26] Fig. 5(b and d) displays the micrographs of wood samples after air and sun degradation, illustrating degraded and distorted cell lumen and cell wall. Furthermore, Fig. 5(c and e) shows some clay particles found inside the wood pores, especially in the vessel, after water and earth degradation, and, interestingly, the structures are indicative of the category of smectite clay.[27,28] Although only a small amount of such particles were deposited inside the wood samples, their presence has the tendency to improve the mechanical and thermal properties of some materials, especially wood-related materials.[29] In the case of earth degradation, due to the Malaysian climate, the clay medium dissolved during rainy days and then dried (or cured) during sunny days, thus some of the clay impurities filled the wood pores. For water degradation, impurities such as sodium carbonate and calcium carbonate could be absorbed together with water.[24] Moreover, the SEM images of all the wood samples degraded by the air and the sun present the same common trend as to the effect of degradation on surface morphology. Similarly, the earth degradation followed the pattern of water degradation, as evident in Fig. 5 (c and d).

CONCLUSION

From the present study, it can be concluded that natural degradation produces significant changes in the mechanical and morphological properties of tropical wood samples. It was observed that these effects varied by wood species. The tensile and impact strength of the wood samples was slightly improved after water and earth degradation. Conversely, the tensile and impact strength of the wood samples was slightly decreased after air and sun degradation. The improved mechanical properties could be ascribed to the good strength-to-weight ratio achieved after degradation. SEM results confirmed that some clay particles and impurities, such as sodium carbonate and calcium carbonate, were deposited on the wood surfaces due to earth and water degradation. Significant color changes were also obtained in the wood samples after all the types of degradation. Furthermore, Balau wood exhibited lower water absorption (58%), compared to Meranti wood (98%) and Rubber wood (85%) samples.

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