Improvement of physical properties of jabon (*Anthocephalus cadamba*) through the impregnation of nano-SiO$_2$ and melamine formaldehyde furfuryl alcohol copolymer

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**Abstract.** Wood polymer nano composites (WPnC) based on nano-SiO$_2$ were prepared by the impregnation of nano-SiO$_2$ and melamine formaldehyde-furfuryl alcohol copolymer. The objectives of this research were to analyze the effect of impregnation of nano-SiO$_2$ and Melamine Formaldehyde Furfuryl Alcohol (MFFA) copolymers on the physical properties of jabon wood and to characterize treated jabon wood. Impregnation method improved the physical properties of jabon wood. Density of jabon become 0.56 g/cm$^3$, weight percent gain (WPG) is 68.34%, Anti-Swelling Efficiency (ASE) is 46.66%, bulking effect (BE) is 7.55%, water uptake (WU) is 75.49%. WPnC composites were characterized by Fourier Transform Infrared Spectroscopy (FTIR), XRD (X-ray Diffraction), SEM (Scanning Electron Microscopy), and SEM-EDX (Energy-dispersive X-ray Spectroscopy). FTIR results showed that the Si-O-Si asymmetric stretching vibration hand slightly shifts toward a higher wave number. It indicated a reaction between nano-SiO$_2$ and wood. XRD studies indicated a decrease in crystallinity of the composites. SEM images observed distribution of nano SiO$_2$ in the composites.

1. Introduction

Wood is a hygroscopic and anisotropic biopolymer composite which consists of cellulose, hemicellulose and lignin. Those main components are responsible for most of the physical, mechanical and chemical properties of wood. Wood is an important raw material for buildings and industries in terms of its strength, aesthetics, and low processing costs. However, wood has several disadvantages, such as high water absorption, low durability and changes in dimensions that vary with changes in environmental conditions [1]. Wood is a hygroscopic material because it has a hydroxyl group (-OH) that attracts water molecules through hydrogen bonds in the cell wall polymer [2]. This causes the dimensions of wood keep changing according to moisture content in the cell wall. Anisotropic is wood dimensions alteration due to alteration environmental moisture in three different orientations (longitudinal, radial and tangential). The largest shrinkage percentage is tangential followed by radial and longitudinal directions (the smallest shrinkage percentage). Differences in dimensional changes in these three orientation directions often cause problems in their utilizations.

Another property that can limit the utilization of wood is the presence of juvenile wood. Juvenile wood can experience a longitudinal shrinkage of 10 times that of mature wood. This tends to produce
defect such as warping and large checks [3]. Juvenile wood is a xylem mass that are formed in the first few years [4].

Fast-growing timber in Indonesia comes mostly from community forests and community plantations. Fast growing wood species that are widely planted, including sengon (Falcataria moluccana), jabon (Antocephalus cadamba), africa (Maesopsis eminii), mindi (Melia azedarach), fruit trees, and others. Fast growing wood has a short cutting cycle (around 6-7 years). At present, the area of community forests in West Java reaches 314.110 ha with a production of 1.3 million m$^3$ [5]. Based on [6], the total potential of forest stands in West Java with a diameter of wood above 20 cm is 27.3% of the overall potential on the island of Java. West Java has an area of production forest of 393 thousand ha or equal to 20% of the total production forest area of Java Island (1.97 million ha). This production area is a huge potential in supporting the supply of wood raw materials for the forestry industry in West Java Province.

Jabon is one of the fast-growing wood species that is widely planted in community forests. Jabon wood has the advantage of being fast growth, easy to adapt to various growing sites and relatively easy in silvicultural treatment. Jabon wood categorize as light wood with several benefits including: raw materials of plywood, lightweight construction, floors, pulp and paper, ceilings, boxes, crates, toys, and Melamine formaldehyde (MF) is one of the hardest and most rigid polymers that can improve the efficiency in poplar wood [16].

SiO$_2$-impregnated and melamine formaldehyde furfuryl alcohol (MFFA) copolymers on the physical properties of poplar wood, reduce water absorption and increase fire resistance [14]. A mixture of urea formaldehyde (UF) and nano-SiO$_2$ resins can improve the properties of poplar wood, reduce water absorption and increase fire resistance [15]. Addition of nano-SiO$_2$ to melamine formaldehyde-furfuryl alcohol (MFFA) showed that nano-SiO$_2$ can also reduce water absorption, improve mechanical properties, fire resistance, and thermal stability of Ficus hispida wood [16]. Nano-SiO$_2$ was treated with FA, experienced increased hardness, water uptake and anti-swelling efficiency in poplar wood [17]. Based on research Rahaya et al. [18], nano-SiO$_2$ can effectively increase the dimensional stability and density of sengon wood.

Rapid growth will trigger a low density of wood, low wood strength, lots of knots, and a large portion of juvenile wood. Juvenile wood has inferior properties when compared to mature wood [9]. One way to improve the quality of fast-growing wood is to modify wood.

Wood modification is a promising method for improving the quality of fast-growing wood. Efforts to strengthen solid wood with polymers have been carried out in the last few decades. Thermoplastic and thermosetting systems have been used and have succeeded in improving some of the properties of wood, but both show limitations [1,10,11]. Wood modification that has been performed a lot is impregnation with furfuryl alcohol. Furfurylation has succeeded in increasing dimensional stability of wood [12,13].

Nanotechnology-based treatment of wood modification provides new opportunities for improving the quality of fast-growing timber. Wood polymer nano composite (WPnC) that utilizes phenol formaldehyde (PF) and montmorillonite (MMT) impregnation can increase dimensional stability and fire resistance [14]. A mixture of urea formaldehyde (UF) and nano-SiO$_2$ resins can improve the properties of poplar wood, reduce water absorption and increase fire resistance [15]. Addition of nano-SiO$_2$ to melamine formaldehyde-furfuryl alcohol (MFFA) showed that nano-SiO$_2$ can also reduce water absorption, improve mechanical properties, fire resistance, and thermal stability of Ficus hispida wood [16]. Nano-SiO$_2$ was treated with FA, experienced increased hardness, water uptake and anti-swelling efficiency in poplar wood [17]. Based on research Rahaya et al. [18], nano-SiO$_2$ can effectively increase the dimensional stability and density of sengon wood.

Wood furfurilation can increase the dimensional stability of wood but does not bring changes to the flexural strength and Modulus of Elasticity (MOE) [16]. To fix it, melamine formaldehyde is then used. Melamine formaldehyde resin (MF) is one of the hardest and most rigid polymers that can improve the mechanical and thermal properties of wood [19]. Impregnation of solid wood with water-soluble MF resins has caused a significant increase in surface hardness and MOE [11]. In this research, wood impregnation will be carried out with a mixture of melamine formaldehyde furfuryl alcohol and nano-SiO$_2$.

The objectives of this research were to analyze the effect of impregnation of nano-SiO$_2$ and Melamine Formaldehyde Furfuryl Alcohol (MFFA) copolymers on the physical properties of jabon wood and to characterize treated jabon wood.
2. Materials and Methods

2.1 Materials
The sample used in this research was 6 years old jabon wood (Anithecephalus cadamba) originated from a community forest in Sukabumi, West Java. The tree used as research material has a 7 meter free branch height and diameters of 28 cm. The chemicals used are melamine, formaldehyde, furfuryl alcohol, NaOH, nano-SiO\(_2\) (particle diameter 15 ±5 nm), maleic anhydride, pH paper and distilled water.

The tools used are analytical balance, calipers, ovens, fans, sonicators, impregnation devices, moisture meters and aluminum foil. The characterization of the impregnated jabon wood was carried out with SEM (Scanning Electron Micrograph), SEM-EDX (Scanning Electron Micrograph - energy X-ray spectroscopy), XRD (X-ray diffraction), and FT-IR (Fourier Transform Infrared Spectrometry) tools.

2.2 Methods
2.2.1 Test sample preparation
Jabon wood is sawn without distinguishing heart wood and sapwood. The test sample size used is 2 x 2 x 2 cm and density and dimensionoanal stability testing is carried out in form weight percent gain (WPG), bulking effect (BE), water uptake (WU), and anti-swelling efficiency (ASE), with 5 replication for each treatment.

2.2.2 Preparation of impregnant solutions
Preparation of MFFA copolymers. The method created refers to [16] and [20]. Melamine, formaldehyde, furfuryl alcohol (1:3:5 mole ratio) are placed into the flask. The first step in the reaction is the pre-reaction of melamine and formaldehyde to hydroxymethylated melamine. The pre-reaction starts when the pH of the medium is adjusted by dripping 10% NaOH solution until the pH ranges between 9.4-9.6 and the temperature is slowly raised to 98°C. When the solution is clear, furfuryl alcohol is added. After the reaction has been running for 10 minutes, anhydrous maleic catalyst 1.5% is added, and the reaction is continued for 5 minutes. For impregnation, this MFFA copolymer is made with a concentration of 50%.

Nano-SiO\(_2\) dispersion in MFFA copolymers. This method refers to [16] by making a sol-gel system. Nano-SiO\(_2\) was soaked in FA solution for 24 hours with mechanical stirring, then sonicated for 30 minutes. After that, MFFA copolymer solutions were slowly added to nano SiO\(_2\) suspensions under stirring conditions. Mixture of MFFA and nano-SiO\(_2\): FA using a volume ratio of 1: 1. Furthermore, this mixture was synchronized for 15 minutes. This mixture is made with three nano-SiO\(_2\) compositions (0.5, 1 and 1.5%), this is done to find the most optimal composition for wood impregnation.

2.2.3 Wood polymer nano-composite preparation (WPnC)
This process is a furfurilation process. The furfurilation process consists of three steps, that are impregnation, polymerization and drying. Impregnation is performed by adapting the [16] methods. In this research, wood samples were initially dried, measured and weighed. Wood samples consisting of untreated and treated were put and immersed in impregnation solutions in different containers and put in an impregnation tube. Impregnation was started with a vacuum of 0.5 bar for 1 hour, followed by a pressure of 2 bar for 2 hours. The polymerization process is carried out by cleaning the impregnant residual on wood samples surfaces, then wrapped in aluminum foil, and dried at a temperature of 90°C for 24 hours. For the drying process, after the aluminum foil is opened, the sample is re-dried with a temperature of 103 ± 2°C for 24 hours. After polymerization process completed, samples were measured and weighed to determine density, WPG, BE, WU [2] and ASE [21].

2.2.4 Analysis data
Data analysis was performed using an experimental design that is a simple randomized complete design (CRD) with 1 factor, that is the factor of treatment variation with 4 levels that is MFFA, MFFA nano-SiO\(_2\) 0.5%, MFFA nano-SiO\(_2\) 1% and MFFA nano-SiO\(_2\) 1.5%. The analysis was carried out by using the
IBM SPSS Statistics (Statistical Package for Service Solutions) version 25.0 calculation program and continued with the Duncan test at $\alpha = 5\%$ if there were significant differences.

2.2.5 Characterization of treated jabon

Determination of the presence of a mixture of MFFA and nano-SiO$_2$ particles in jabon wood was carried out using SEM (Scanning Electron Micrograph), SEM-EDX (Scanning Electron Micrograph - energy X-ray spectroscopy), XRD (X-ray diffraction), and FT-IR (Fourier Transform Infrared Spectrometry).

3. Results and Discussion

3.1. Effects of MFFA nano-SiO$_2$ impregnation treatment on jabon wood

Impregnation using MFFA copolymers was proven in increasing jabon physical properties parameters including density, weight percent gain (WPG), bulking effect (BE), water uptake (WU), and anti-swelling efficiency (ASE) (Table 1). Jabon wood density values increase, this is in line with the increasing value of WPG. The higher the WPG value, the higher the density of jabon wood. The increase in WPG value is also directly proportional to the value of BE. But the increase in WPG value is inversely proportional to WU. This is presumably because the impregnant will reduce the ability of wood to absorb water. Hazarika and Maji [16] state that when wood is filled with MFFA, the polymer will fill lumens and empty pits resulting in increased density, WPG, ASE, BE, and decrease in WU. This is in line with the research of Yao et al. [20] which showed that impregnation with melamine formaldehyde modified with furfuryl alcohol succeeded in increasing density and WPG of Chinese fir. The addition of nano-SiO$_2$ in MFFA has also been proven to be able to improve its physical properties parameters (when compared to MFFA only). The higher the nano-SiO$_2$ concentration, the higher the physical parameter values [16]. Nano-SiO$_2$ will fill the empty lumens of the wood thereby reducing its water absorption capacity. Jabon wood with the addition of 0.5% and 1% nano-SiO$_2$, increase its physical properties parameters, but at a nano-SiO$_2$ concentration of 1.5% there was a decrease. The decrease in the value of physical properties parameters in the mixture is likely due to the change in the shape of the copolymer mixture into a gel so that it was difficult to penetrate into wood cells. Based on [22] with changes in pH and the distance between close particles due to solvent evaporation, the surface charge will decrease and gelation will take place.

Table 1. Density and dimensional stability of untreated and treated jabon wood

| Sample           | WPG          | BE          | Density  | WU         | ASE          |
|------------------|--------------|-------------|----------|------------|--------------|
| Untreated        | 0.56 (±0.46) | 2.22 (±0.71)| 0.32 (±0.01) | 215.79 (±5.37) |              |
| MFFA             | 45.83 (±5.17) | 5.63 (±2.11)| 0.50 (±0.04) | 85.60 (±5.84)  | 20.97 (±5.24) |
| MFFA nano-SiO$_2$ 0.5% | 68.34 (±5.07) | 7.55 (±1.00) | 0.56 (±0.04) | 75.14 (±5.09)  | 46.68 (±4.29) |
| MFFA nano-SiO$_2$ 1.0% | 69.97 (±6.02) | 8.15 (±0.61) | 0.57 (±0.45) | 72.87 (±5.92)  | 47.99 (±5.22) |
| MFFA nano-SiO$_2$ 1.5% | 67.33 (±5.74) | 7.31 (±1.47) | 0.56 (±0.03) | 77.69 (±6.75)  | 42.71 (±5.29) |

Note: The values in parentheses () indicate the standard deviation values. The letter after the value shows Duncan’s further test results.

The results of statistical analysis showed that the wood impregnated with MFFA copolymer and nano-SiO$_2$ was significantly different compared to MFFA treatment. Jabon wood which experienced the highest increase in physical property parameter values was impregnated with MFFA nano-SiO$_2$ 1%. However, based on the results of statistical analysis with Duncan’s further tests (Table 1) shows that there are no significant differences in the three nano-SiO$_2$ concentrations.
3.2. FTIR test

Figure 1 shows the FTIR spectrum of nano-SiO$_2$, a sample of untreated and treated wood. Untreated jabon wood (curve a) is marked with absorption bands at 3425 cm$^{-1}$ (–OH stretching), 2916 and 2843 cm$^{-1}$ (–CH$_2$ asymmetric stretching), 1744 cm$^{-1}$ (C = O stretching), 1666 cm$^{-1}$ for (–OH bending), 1026 cm$^{-1}$ (C – O stretching). The presence of nano-SiO$_2$ in composites causes a decrease in the intensity of hydroxyl groups and carbonyl groups. The peak intensity of the -CH group of treated wood is lower than untreated. The intensity of the carbonyl group also decreases due to the formation of hydrogen bonds with hydroxyl groups on the surface of silica [23]. For Si-O-Si groups, peak forms at different wave numbers. Nano-SiO$_2$ for impregnation has a peak at wave number 810 cm$^{-1}$ (symmetric stretching). This value is the same as the research of [24]. In wood, the Si-O-Si group has a peak at wave number 1018 cm$^{-1}$ (asymmetric stretching). Peak shifts to higher wave numbers indicate an interaction between nano-SiO$_2$ and wood. A shift towards larger numbers occurs when particle size increases [25]. Hydrogen bonding with the Si-O-Si group causes a reduction in the hydroxyl group. Shifting the wave number in a larger direction indicates the presence of a hydroxyl group replaced by the Si-O-Si group. This has reduced the ability of wood to absorb water. The entry of Si-O-Si also increases the weight of the wood so that WPG and its density will also increase.

![Figure 1. FTIR spectrum; (a) Untreated, (b) MFFA, (c) MFFA nano-SiO$_2$ 0.5%, (d) MFFA nano-SiO$_2$ 1%, (e) MFFA nano-SiO$_2$ 1.5% and (f) nano SiO$_2$ powder](image)

3.3. XRD test

From the XRD curve, untreated wood shows a sharper peak so that the crystallite value is high (a). Untreated wood exhibits broad diffraction peaks at 2Θ 22.84° with cellulose crystal fields 012. Two additional small peaks appear at 2Θ 16° and 44.54° with crystal fields 020 and 050 respectively. After being treated with MFFA and MFFA nano-SiO$_2$ decreased peak intensity (b,c,e). In jabon wood with MFFA nano-SiO$_2$ 0.5% treatment, at an angle of 2Θ of 16° the graph tends to be flat. This indicates a decrease in the crystallinity of wood cellulose. The graph shows nano SiO$_2$ and MFFA having broad diffraction peaks, this shows both amorph (f and g).

![Figure 1. FTIR spectrum; (a) Untreated, (b) MFFA, (c) MFFA nano-SiO$_2$ 0.5%, (d) MFFA nano-SiO$_2$ 1%, (e) MFFA nano-SiO$_2$ 1.5% and (f) nano SiO$_2$ powder](image)
The degree of crystallinity is shown in Table 2. Cellulose from untreated wood shows the highest degree of crystallinity. The lowest degree of crystallinity was shown by wood samples treated with MFFA nano-SiO$_2$ 0.5%. This is consistent with the results of the research of [16] which states that impregnation of nano silica with MFFA copolymers can reduce the degree of crystallinity of cellulose. Rabee et al. [24] also stated that coating surface fibers with nano silica reduced the degree of crystallinity by 15%. Tang et al. [26] show that the addition of SiO$_2$ increases the formation of hydrogen bonds with the fiber interface. Increased formation of hydrogen bonds with the Si-O-Si group causes the hydroxyl group to decrease. Shiraishi et al. [27] reported that chemical graft reactions occur in the amorphous regions of wood cellulose. The polymer reacts on the surface of the crystallite thereby opening several hydrogen-bound cellulose chains, so that more amorphous cellulose is produced. Decreasing the degree of crystallinity indicates the formation of hydrogen bonds between silica and wood, so that the hydroxyl group will decrease. This is in line with FTIR results. Decreasing the crystallinity degree will increase the physical parameter value of the wood. For wood that treated with MFFA nano-SiO$_2$ 1.5% showed a greater degree of crystallinity than those treated with MFFA and MFFA nano-SiO$_2$ (0.5 and 1%). This is probably due to the gelation process which makes it more difficult for the copolymers to penetrate into the wood. Nevertheless, the degree of crystallinity is still smaller when compared to untreated wood.

### Table 2. Crystallinity degree results of untreated and treated jabon wood

| Treatment           | Degree of crystallinity (%) |
|---------------------|----------------------------|
| Untreated           | 28.99                      |
| MFFA                | 23.42                      |
| MFFA nano-SiO$_2$ 0.5% | 19.79                  |
| MFFA nano-SiO$_2$ 1% | 19.99                    |
| MFFA nano-SiO$_2$ 1.5% | 23.56               |
| Nano Silica         | 21.17                      |
3.5. SEM test results
Figure 3 shows SEM images of untreated and treated jabon wood samples. From the picture it can be observed that there are empty lumens and pits on cell walls (Figure 3a and 3b). The impregnation method causes the impregnant material to deposit on the wood cell walls. The presence of polymer deposits in cell walls and pits can be seen in treated wood samples with MFFA (Figure 3c) and MFFA nano-SiO2 (Figure 3d-3f). The pits which previously had empty space, after being treated with MFFA, became evenly closed. Indications for the presence of nano-SiO2 can be detected by several white deposits located in the cell walls and pits of treated jabon wood by MFFA nano-SiO2 (Figure 3d-3f). Nano-SiO2 can enter the pits and cover almost evenly on cell walls. Figure 3d-3f, showed the increase of white deposits as the increase nano-SiO2 concentration.

Additional information obtained from the analysis with SEM is EDX data, which is explained in Table 3. The EDX analysis results from untreated and MFFA treated jabon wood showed no silica content. Jabon wood that was impregnated with MFFA nano-SiO2 showed the presence of silica content. Silica levels in wood impregnated by MFFA nano-SiO2, increased with the increase in the concentration of nano-SiO2.

![Figure 3](image_url)

**Figure 3.** Scanning Electron Micrograph images of jabon vessel wall (magnification 1000x) of (a, b) Untreated (c) MFFA, (d) MFFA nano-SiO2 0.5%, (e) MFFA nano-SiO2 1%, and (f) MFFA nano-SiO2 1.5%

| Treatment               | Silica content (mass %) |
|-------------------------|-------------------------|
| Untreated               | 0                       |
| MFFA                    | 0                       |
| MFFA nano-SiO2 0.5%     | 0.30                    |
| MFFA nano-SiO2 1%       | 0.42                    |
| MFFA nano-SiO2 1.5%     | 0.60                    |

4. Conclusion
Wood samples were impregnated with MFFA and nano-SiO2 copolymers in vacuum and pressure conditions. Impregnation of wood with MFFA and nano-SiO2 copolymers can improve physical
properties of the jabon wood parameter, namely increase density, WPG, BE, ASE, and an decrease in WU.

Characterization of MFFA and nano-SiO₂ treated samples were carried out by FTIR, XRD, SEM and SEM-EDX. FTIR analysis results shifting wave number in nano-SiO₂ peak as an indication of bond between nano-SiO₂ and wood. The results of XRD analysis prove the decrease in crystallinity degree of wood cellulose in MFFA nano-SiO₂ treated wood. The presence of MFFA and nano-SiO₂ polymers in wood cell walls and cell lumen was seen by SEM images. Based on the physical properties parameters and characterization with FTIR, XRD and SEM, MFFA nano-SiO₂ 0.5% is an optimum treatment for 6 years old jabon wood.

Reference
[1] Kumar S 1994 Chemical modification of wood Wood and Fib. Sci. 26(2)270-80
[2] Hill C 2006 Wood modification: chemical, thermal and other processes (London: John Wiley & Sons)
[3] Senft J, Quanci M, and Bendtsen B 1986 Property profile of 60-year-old douglas-fir proc. of Cooperative Technical Workshop of Juvenile Wood pp. 17-28
[4] Clark A, Daniels RF, and Jordan L 2006 Juvenile/mature wood transition in loblolly pine as defined by annual ring specific gravity, proportion of latewood and microfibril angle Wood and Fib. Sci. 38(2) 292-299
[5] [Forest Service of West Java Province] 2019 West Java Forestry Statistics 2018 (Bandung: West Java Provincial Forestry Service)
[6] [KLHK] 2019 Environmental and Forestry Statistics 2018 (Jakarta: Ministry of Environment and Forestry)
[7] Martawijaya A, Kartasujana I, Mandang YI, Prawira SA, and Kadir K 2005 Atlas Kayu Indonesia Volume II (Bogor: Forestry Research and Development Agency, Ministry of Forestry)
[8] Darmawan W, Nandika D, Rahayu I, Fourier M, and Marchal R 2013 Determination of juvenile and mature transition ring for fast growing sengon and jabon wood J. of Indian Aca. of Wood Sci. 10(1)
[9] Zhang S, Qibin Y, and Beaulieu J 2004 Genetic variation in veneer quality and its correlation to growth in white spruce J. Can. J. For. Res. 34(6) 1311-8
[10] Schneider MH, Brebner KI and Hartley ID 1991 Swelling of a cell lumen filled and a cell wall bulked wood polymer composite in water Wood and Fib. Sci. 23(2) 165-72
[11] Deka M and Saikia C 2000 Chemical modification of wood with thermosetting resin :Effect on dimensional stability and strength property Bioresource Tech. 73(2)179-81
[12] Lande S, Westin M, and Schneider M 2004 Properties of furfurylated wood. Scand J. For Res. 19(5) 22-30
[13] Esteves B, Nunies L and Pereira H 2011 Properties of furfurilated wood (Pinus pinaster) Euro. J. Wood Prod. 69(4) 521-5
[14] Xue F and Zhao G 2008 Optimum preparation technology for Chinese fir wood/Ca montmorillonite (Ca-MMT) composite board For. Stud. China 10(3)199-204
[15] Shi J, Li J, Zhou W, and Zhang D 2007 Improvement of wood properties by urea formaldehyde and nano-SiO₂ Frontiers of For. in China 2(1)104-9
[16] Hazarika and Maji TK 2013 Properties of softwood polymer composites impregnated with nanoparticles and melamine formaldehyde furfuryl alcohol copolymer J. of Poly. Engine. and Sci. 54(5)1019-29
[17] Dong Y, Yan Y, Zhang S, and Li J 2014 Wood/polymer nanocomposites prepared by impregnation with furfuryl alcohol and nano SiO₂ BioResources 9(4) 6028-40
[18] Rahayu I, Darmawan W, Zaini LH, and Prihatini E 2019 Characteristic of fast growing wood impregnated with nano particles J. For. Res. 31(2) 677-85
[19] Gindl W, Hansmann C, Gierlinger N, Schwanninger M, Hinterstoisser B, and Jeronimidis G 2004 Using a water-soluble melamine-formaldehyde resin to improve the hardness of Norway spruce wood J. of Appl. Poly. Sci. 93(4) 1900-07

[20] Yao M, Yang Y, Song J, and Yu Y 2017 Melamine formaldehyde modified furfurylation to improve Chinese fir’s dimensional stability and mechanical properties Bioresources 12(2) 3057-66

[21] Rowell R and Ellis W. 1978. Determination of dimensional stabilization of wood by water soak method. Wood Fib. Sci. 10 104-11

[22] Milea C, Bogatu C, and Dut A 2011 The influence of parameters in silica sol-gel process Engine. Sci. 4(1) 59-66

[23] Motaung T and Luyt A 2010 Effect of maleic anhydride grafting and the presence of oxidized wax on the thermal and mechanical behaviour of LDPE/silica nanocomposites Materials Sci. and Engineer. 527(3) 761-8

[24] Rabee J, Santos LP, Menezzi CH, and Tonoli GH. 2018. Effect of nano-silica deposition on cellulose fibers on the initial hydration of the Portland Cement Bioresources 3525-44

[25] Li M. Yu Y. Li J, Chen B, Wu X, Tian Y, and Chen P 2015 Nanosilica/carbon composite sphere as anodesin li-ion batteries with excellent cycle stability J. of Materials Chem. 3(4)1476-82

[26] Tang C, Li X, Li Z, and Hao J 2017 Interfacial hydrogen bonds and their influence mechanism on increasing the thermal stability of nano-SiO₂-modified meta-aramid fibres Polymers 9(10) 504

[27] Shiraishi N, Matsunaga T, and Yokota T 1979 Preparation of higher aliphatic acid esters of wood in an N204-DMF cellulose solvent medium. J. of App. Poly. Sci. 24(12) 2347-59