PAPER • **OPEN ACCESS**

Mechanical Performance of Mortar and Concrete Using Borneo Wood Sawdust as Replacement of Fine Aggregate

To cite this article: I Prasetia *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **999** 012001

Mechanical Performance of Mortar and Concrete Using Borneo Wood Sawdust as Replacement of Fine Aggregate

I Prasetia[1], D P PUTERA[1], and A Y Pratiwi[1]

Faculty of Engineering, Lambung Mangkurat University

Email: iprasetia@ulm.ac.id

Abstract. This study aims to analyze the utilization of wood sawdust from Borneo Island as a replacement for fine aggregate. For that purpose, two types of sawdust will be used, which are sawdust from ulin wood (Eusideroxylon Zwageri) and meranti wood (Shorea spp.). Subsequently, to test the effectiveness of replacing fine aggregate with sawdust, the compressive strength tests were carried out for mortar and concrete samples. Furthermore, the fine aggregate replacement ratio in all samples was set to 2.5% and 5% for both types of sawdust. Moreover, samples were also made by adding 0.5 kg/m^3 and 1 kg/m^3 of ulin and meranti sawdust to the concrete mixture. The compressive strength results of mortar samples show that sawdust from ulin wood has a better effect compared to meranti wood. In addition, the combination of sawdust from ulin and meranti gave a better effect in increasing the strength of the mortar samples. The same pattern could also be observed in the concrete samples, where ulin wood sawdust provides a good strength-enhancing effect, especially when used as an addition to the fine aggregate. Therefore, it is highly recommended to use sawdust, especially from ulin wood, as a material for making green concrete.

1. Introduction

Borneo is one of Indonesia's islands, which is famous for its beautiful scenery, primarily due to its tropical forests. Having abundant forests makes the people of Borneo use wood as construction material. However, this practice has a negative impact on the environment, especially on the accumulation of waste from wood processing, namely sawdust. Statistics Indonesia has mentioned that as much as 10,96 million m^3 logs (22.31% of Indonesia logs) were produced in Borneo island in 2017 [1]. Half of it was produced as chip and particle, plywood and sawn timber, and around 12% become sawdust [2]. Thus, approximately 600 thousand m^3 per year of sawdust is produced from the wood industry in Borneo. If not utilized, sawdust becomes a potential health problem, especially in the case of respiratory disease [3].

There are several common utilizations of sawdust, such as serving as a mulch, pellet fuel, and particleboard. Besides that, nowadays, researchers also got interested in the utilization of sawdust as a sustainable construction material [4]. One of them is sawdust as partial cement replacement [5], [6]. Sawdust is also being introduced as natural fibers in concrete [7]. In addition, recently, sawdust being studied as a substitute for fine or coarse natural aggregates [8]–[10].

The commencement of research on industrial by-products, such as sawdust, fly ash, and crushed stone waste, in concrete is based on the understanding of natural resources and other raw materials that have been exploited large enough for the production of concrete worldwide [11]. Hence, to minimize the negative environmental impact of the concrete industry and the environmental issues of industrial by-products, the use of industrial by-products as mortar or concrete material is considered as an effective, and sustainable solution [12]–[14].

Despite many studies regarding sawdust in mortar and concrete mixtures, some issues still occur such as cement does not bond well with all types of wood [15]. In addition, the difference in replacement ratio of fine aggregate with sawdust affected the strength of concrete [16]–[18]. Furthermore, based on previous studies, it can be concluded that different types of wood have different optimum sawdust substitution in terms of increasing the concrete compressive strength.

In this study, two types of sawdust will be used, which are sawdust from ulin wood (Eusideroxylon Zwageri) and from meranti wood (Shorea spp.). The experiments were carried out in the form of mortar and concrete samples to analyze the effect of both sawdust on the compressive strength. Samples with the sawdust replacement ratio of 2.5% and 5%, and sawdust as additional material as much as 0.5 kg/m^3 dan 1 kg/m^3 were analyzed at 28 days curing time. From this study, it is expected to determine the effectiveness of sawdust from Borneo wood as fine aggregate in mortar and concrete mixture.

2. Materials and methods

2.1. Materials

In this study, Portland pozzolanic cement (PPC) was used. Furthermore, two types of sawdust (S) from widely used wood in Borneo island were being used in the mortar (M) and concrete (C) mix, which are ulin wood (Eusideroxylon Zwageri) and meranti wood (Shorea spp.). Both sawdust were collected from the local wood industry in South Borneo and used in their raw form without any pre-treatment as can be seen on figure 1. As for the fine aggregate, natural river sand from the Barito River in South Borneo was used. Additionally, the coarse aggregate was obtained from the Katunun quarry in South Borneo.

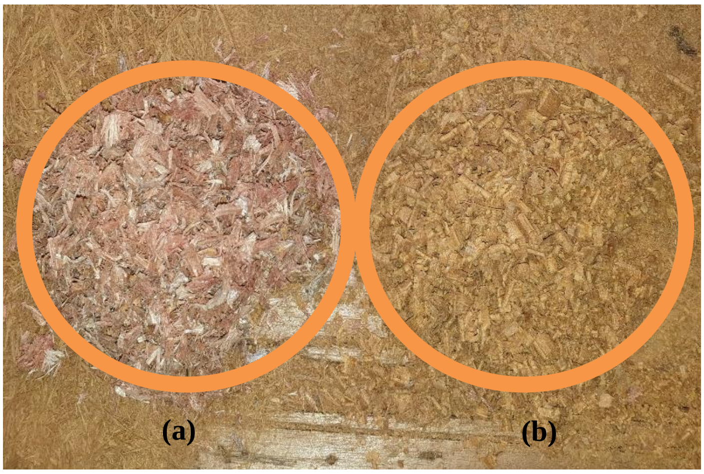

Figure 1. Sawdust material used in research (a) Meranti (b) Ulin

2.2. Methods

The mechanical properties of mortar (cubic shape with dimension of 5 x 5 x 5 cm) and concrete samples (cylinder shape with dimension of 15 x 30 cm) with two types of sawdust were studied through 42 mortar samples and 45 concrete samples. The variations are 2.5%, and 5% replacement ratio of fine aggregate with meranti sawdust (M) and ulin sawdust (U) by volume. Furthermore, regarding sawdust as an additional natural fiber in concrete, the addition was set at 0.5 kg/m^3 and 1 kg/m^3 for concrete samples. Moreover, the effect of mixing the two types of sawdust in one sample mortar and concrete was also investigated. For this purpose, the combination of meranti sawdust and ulin sawdust was set at 20:80 for a sand replacement ratio of 2.5% and 5% in the mortar and concrete samples. Ordinary mortar samples (NM) and ordinary concrete samples (NC) were also prepared as control samples.

The w/c ratio of 0.45 was set for mortar and concrete samples. In addition, the curing time for all samples (mortar and concrete sample) is set at 28 days curing time. The preparation of the mortar cube sample is based on SNI 03-6825-2002, whilst the concrete cylinder sample is based on SNI 03-2834-2000. Furthermore, concrete samples' workability and concrete samples' density (unit weight) was conducted based on SNI 1972:2008 and SNI 1973:2008, respectively. As for the compressive strength test of the mortar sample is based on SNI 03-6825-2002, whilst the compressive strength test of the concrete sample is based on SNI 1974:2011. table 1 and table 2 show the mixture proportions of samples used in this research.

Table 1. The mixture proportions of mortar samples

Denotation	Sawdust ratio	Material requirements for every 6 samples				
		Cement (gr)	Water (ml)	Fine Aggregate (gr)	Sawdust	
					Meranti (gr)	Ulin (gr)
NM	0%	537.78	242	1337.22	0	0
2.5SMM	2.5%	537.78	242	1303.79	3.02	0
5SMM	5%	537.78	242	1270.36	6.04	0
2.5SMU	2.5%	537.78	242	1303.79	0	3.02
5SMU	5%	537.78	242	1270.36	0	6.04
2.5SMMU	2.5%	537.78	242	1303.79	0.61	2.41
5SMMU	5%	537.78	242	1270.36	1.22	4.82

Table 2. The mixture proportions of concrete samples

Denotation	Sawdust ratio/addition	Material requirements for 1 m^3					
		Cement (kg)	Water (l)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Sawdust	
						Meranti (kg)	Ulin (kg)
NC	0%	455.55	205	601.42	1278.03	0	0
2.5SCM	2,5%	455.55	205	586.39	1278.03	1.31	0
5SCU	5%	455.55	205	571.35	1278.03	0	2.62
2.5SCMU	2,5%	455.55	205	586.39	1278.03	0.26	1.05
5SCMU	5%	455.55	205	571.35	1278.03	0.53	2.09
0.5SCM	+0.5 kg/m^3	455.55	205	601.42	1278.03	0.5	0
0.5SCU	+0.5 kg/m^3	455.55	205	601.42	1278.03	0	0.5
1SCM	+1 kg/m^3	455.55	205	601.42	1278.03	1	0
1SCU	+1 kg/m^3	455.55	205	601.42	1278.03	0	1

3. Results and discussion

3.1. Compressive Strength of Mortar Samples

Complete average compressive strength test results could be seen in figure 2.

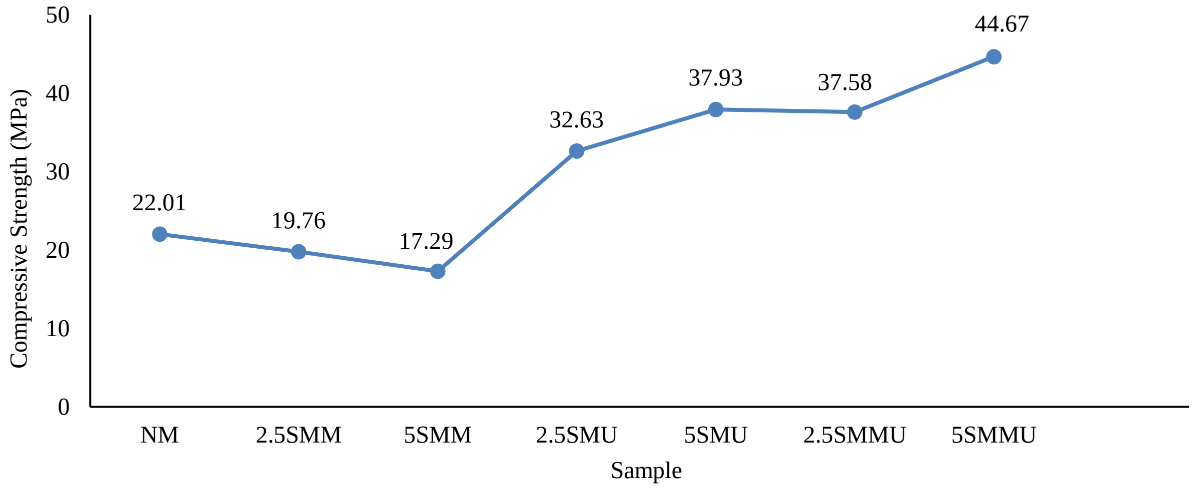

Figure 2. Average compressive strength test results for mortar samples at 28 days curing time

Figure 2 shows the effectiveness of using sawdust as a replacement for sand in increasing mortar strength. This finding is in line with the findings of Narayanan et al. and Shafigh et al. [17], [19]. However, the contrary result could be found on the sample with meranti sawdust (2.5SMM and 5 SMM samples). Compared to the ordinary mortar sample (NM), SMM samples show a decrease in compressive strength, which is similar to Ahmed et al. findings [16]. A conclusion that could be drawn from this result is that, for mortar samples, the use of sawdust from ulin wood shows a superior effect in increasing mortar compressive strength.

Furthermore, samples with 20% combination of meranti sawdust and 80% ulin sawdust (SMMU) even showed a higher compressive strength. From these results, it is recommended to use sawdust from ulin wood or a combination of both ulin and meranti sawdust in making mortar. Furthermore, in terms of sustainable development, the replacement of sand with sawdust will help conserve natural resources.

3.2. Workability of Fresh Concrete Samples

The slump test according to SNI 1972:2008 was carried out to assess the workability of concrete samples. The composition of the concrete sample mixture is based on the mixture of the samples with high compressive strength test results from the mortar samples on each type of sawdust. Thus, the concrete samples were only made with 0% (NC), 2.5% of meranti sawdust (2.5SCM), 5% of ulin sawdust (5SCU), 2.5%, and 5% combination of meranti and ulin sawdust (2.5SCMU and 5SCMU). In addition, based on Siswandi et al. studies [20], concrete samples with the addition of 0.5 kg/m^3 and 1 kg/m^3 sawdust were also prepared. The targeted slump of the concrete's job mix formula is 7 ± 2 cm. table 3 shows the results of the concrete slump test.

Table 3. The slump test results

Denotation	Sawdust ratio/addition	Slump test results (cm)
NC	0%	8
2.5SCM	2.5%	5
5SCU	5%	5
2.5SCMU	2.5%	6
5SCMU	5%	5
0.5SCM	+0.5 kg/m^3	8
0.5SCU	+0.5 kg/m^3	7
1SCM	+1 kg/m^3	8
1SCU	+1 kg/m^3	7,5

The results showed that samples with additional sawdust had better workability compared to samples with sawdust as a replacement of natural fine aggregate. This result could become evidence of higher water absorption of sawdust. As could be seen in Tabel 2, the sawdust content of samples with sawdust addition is smaller compared to the sample with sawdust substitution. Higher water absorption will result in lower concrete workability. This finding follows the findings of Shafigh et al. and Siswandi et al. studies [19], [20]. Nonetheless, all samples met the targeted slump values designed in the job mix formula. The targeted slump value of 7 ± 2 cm can make the concrete casting process run easily. As an alternative, the addition of a superplasticizer can be used for concrete with sawdust, although it could increase production costs.

3.3. Workability of Fresh Concrete Samples

Complete average concrete samples density results could be seen in figure 3.

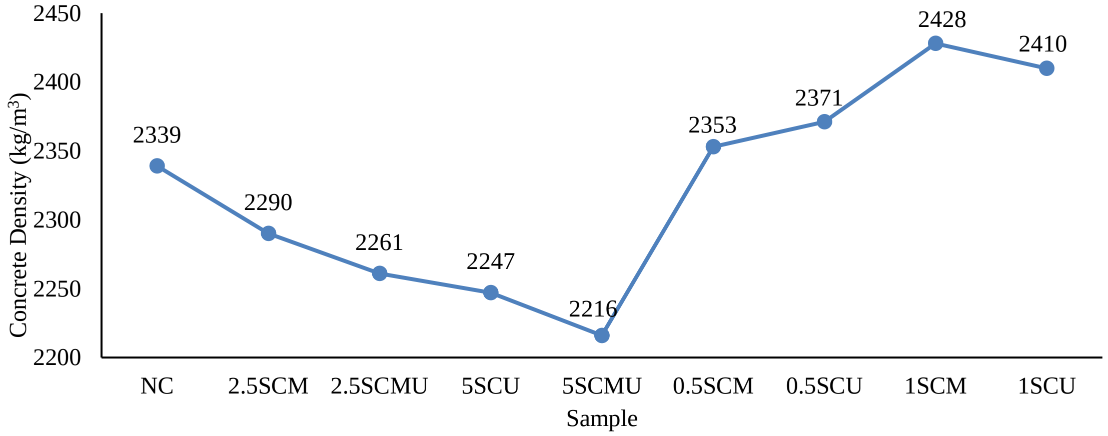

Figure 3. The concrete samples density results

Figure 3 shows that the replacement of natural fine aggregate with sawdust decreases the density of concrete, especially for samples with ulin sawdust. This finding is in line with other studies [6], [19]. Obviously, this is attributed to the lower specific gravity of sawdust compared to fine aggregate. As for the samples with sawdust as an addition, the density is undoubtedly increased. However, the difference is not significant compared to ordinary concrete. In addition, the positive effect is that based on Aigbomian and Fan findings, sawdust concrete has lower thermal conductivity due to its lightweight and porous structure [21].

3.4. Workability of Fresh Concrete Samples

Complete test results could be seen in figure 4.

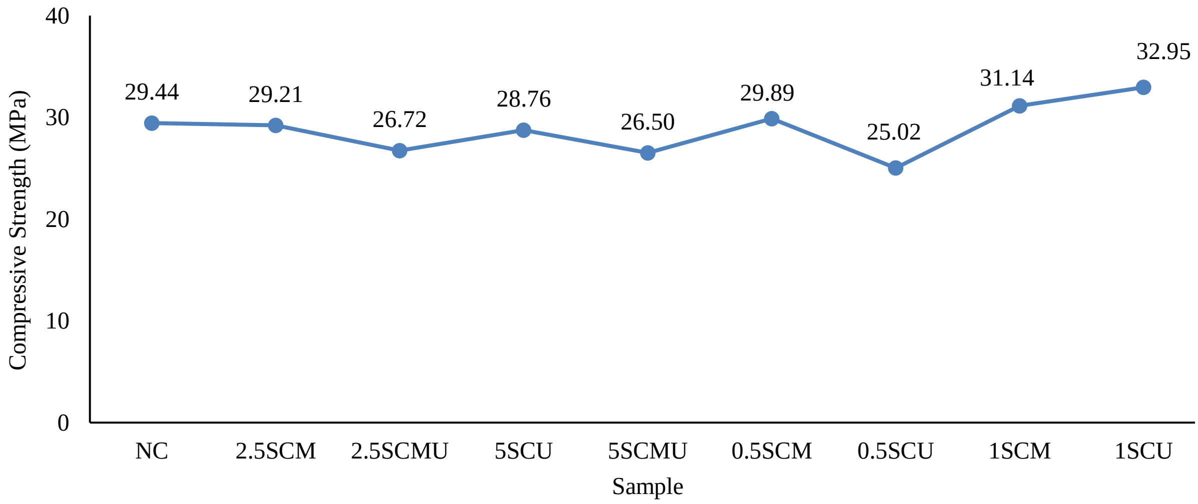

Figure 4. Average compressive strength test results for concrete samples at 28 days curing time

The pattern of average compressive strength test results for samples with sawdust as a replacement of natural fine aggregate and with sawdust as an additional natural fiber material is slightly different. Samples with sawdust as a replacement of natural fine aggregate have decreased in terms of compressive strength when compared to ordinary concrete. Ahmed et al. and Shafigh et al. mention that due to the agricultural wastes, such as sawdust, are more porous and weaker than natural fine aggregate, the strength and stiffness of aggregates are less than natural fine aggregate, which leads to a decrease in concrete's compressive strength [16], [19]. In addition, based on the concrete sample density results, it can be seen that there is a high correlation between concrete density and compressive strength. A decrease in density will be followed by a reduction in strength.

Furthermore, for samples with sawdust as an additional natural fibers material, the concrete's compressive strength tends to increase compared to ordinary concrete. As also reported by Siswandi et al., the addition of 1 kg/m^3 sawdust gave the highest compressive strength compared to other samples [20]. Therefore, among all variations of sawdust concrete, the addition of 1 kg/m^3 ulin sawdust as natural fibers material is the optimum concrete mixture. Moreover, in the case of lightweight concrete and lower thermal conductivity, 2.5% replacement ratio of sand with meranti sawdust and a 5% replacement ratio of sand with ulin sawdust can be the best alternative for concrete mixture with compressive strength up to 28 MPa.

4. Conclusions

This latest research study aims to analyze the use of Borneo sawdust as a replacement of natural fine aggregate in terms of mortar dan concrete compressive strength. As for the compressive strength of mortar samples, a superior effect in increasing mortar compressive strength could be seen in samples with sawdust from ulin wood. Therefore, it is recommended to use ulin wood sawdust or a combination of ulin and meranti wood sawdust for making mortar in construction works.

However, as for the workability of fresh concrete, the results show that samples with additional sawdust have better workability compared to samples with sawdust substitution. In general speaking, the workability of concrete with sawdust still meets the slump value specified in the job mix formula.

Furthermore, the replacement of fine aggregate with sawdust decreases the density of concrete, especially for samples with ulin sawdust. The aftermath is that compressive strength will also decrease. Nevertheless, lower density leads to lower thermal conductivity in concrete.

In addition, the results showed that the addition of 1 kg/m^3 sawdust gave the highest compressive strength compared to other samples. Still, in the case of lightweight concrete and lower thermal conductivity, 2.5% replacement ratio of sand with meranti sawdust and a 5% replacement ratio of sand with ulin sawdust can be the best alternative for concrete mixture with compressive strength up to 28 MPa.

Concerning future works, this study lacks an in-depth analysis regarding the mechanism by which sawdust affects the compressive strength of mortar and concrete. Therefore, in future studies, the substitution ratio or addition of sawdust could be modified based on these research findings. Analysis such as SEM and XRD could also be introduced in the next research.

5. References

[1] Statistics Indonesia, *Statistik Produksi Kehutanan 2017*. Badan Pusat Statistik, 2018.

[2] D. Purwanto, "Analisa Jenis Limbah Kayu pada Industri Pengolahan Kayu di Kalimantan Selatan (the Analysis of Variety of Wood Waste Material From Wood Industry in South Borneo)," *J. Ris. Ind. Has. Hutan*, vol. 1, no. 1, pp. 14–20, 2009.

[3] S. Baran and I. Teul, "Wood dust: An occupational hazard which increases the risk of respiratory disease," *J. Physiol. Pharmacol.*, vol. 58, no. SUPPL. 5, pp. 43–50, 2007.

[4] M. V. Madurwar, R. V. Ralegaonkar, and S. A. Mandavgane, "Application of agro-waste for sustainable construction materials: A review," *Constr. Build. Mater.*, vol. 38, pp. 872–878, 2013.

[5] J. Torkaman, A. Ashori, and A. Sadr Momtazi, “Using wood fiber waste, rice husk ash, and limestone powder waste as cement replacement materials for lightweight concrete blocks,” *Constr. Build. Mater.*, vol. 50, pp. 432–436, Jan. 2014.

[6] S. Chowdhury, M. Mishra, and O. Suganya, “The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview,” *Ain Shams Eng. J.*, vol. 6, no. 2, pp. 429–437, 2015.

[7] S. Vajje and N. R. Krishna, “Study on Addition of the Natural Fibers into Concrete,” *Int. J. Sci. Technol. Res.*, vol. 2, no. 11, pp. 213–218, 2013.

[8] P. Shafigh, H. Bin Mahmud, M. Z. Jumaat, and M. Zargar, “Agricultural wastes as aggregate in concrete mixtures - A review,” *Constr. Build. Mater.*, vol. 53, pp. 110–117, 2014.

[9] A. Kanojia and S. K. Jain, “Performance of coconut shell as coarse aggregate in concrete,” *Constr. Build. Mater.*, vol. 140, pp. 150–156, 2017.

[10] M. Li, M. Khelifa, and M. El Ganaoui, “Mechanical characterization of concrete containing wood shavings as aggregates,” *Int. J. Sustain. Built Environ.*, vol. 6, no. 2, pp. 587–596, 2017.

[11] A. Rashad, “Cementitious materials and agricultural wastes as natural fine aggregate replacement in conventional mortar and concrete,” *J. Build. Eng.*, vol. 5, pp. 119–141, 2016.

[12] I. Prasetia and M. F. Rizani, “Analysis of fly ash from PLTU Asam-Asam as a construction material in terms of its physical and mechanical properties,” *MATEC Web Conf.*, vol. 280, p. 04013, 2019.

[13] I. Prasetia and A. Maulana, “Effects of Crushed Stone Waste as Fine Aggregate on Mortar and Concrete Properties,” in *The 2nd Sriwijaya International Conference on Science, Engineering, and Technology*, 2018.

[14] I. Prasetia, S. Yoshida, T. Itasaka, and K. Torii, “The Mitigating Effect of ASR Expansion in PC Girder and PCa Product by Using High-Quality Fly Ash,” in *The Third International Conference on Sustainable Construction Materials and Technologies*, 2013.

[15] A. A. Moslemi and S. C. Pfister, “The influence of cement/wood ratio and cement type on bending strength and dimensional stability of wood-cement composite panels,” *Wood fiber Sci.*, vol. 19, no. 2, pp. 165–175, 1987.

[16] W. Ahmed, R. A. Khushnood, S. A. Memon, S. Ahmad, W. L. Baloch, and M. Usman, “Effective use of sawdust for the production of eco-friendly and thermal-energy efficient normal weight and lightweight concretes with tailored fracture properties,” *J. Clean. Prod.*, vol. 184, pp. 1016–1027, 2018.

[17] A. Narayanan, A. Mary, G. Hemnath, and K. Sampaul, “Replacement of Fine Aggregate with Sawdust,” *Int. J. Adv. Res. Basic Eng. Sci. Technol.*, vol. 3, no. 35, pp. 206–210, 2017.

[18] M. Mageswari and B. Vidivelli, “the Use of Sawdust Ash As Fine Aggregate Replacement in Concrete,” *J. Environ. Res. Dev.*, vol. 3, no. 3, pp. 720–726, 2009.

[19] P. Shafigh, H. Bin Mahmud, M. Z. Bin Jumaat, R. Ahmmad, and S. Bahri, “Structural lightweight aggregate concrete using two types of waste from the palm oil industry as aggregate,” *J. Clean. Prod.*, vol. 80, pp. 187–196, 2014.

[20] Siswandi, A. Rapa, and D. Puspitasari, “Pengaruh Penambahan Serbuk Kayu Sisa Penggergajian Terhadap Kuat Desak Beton,” *J. Tek. Sipil*, vol. 7, no. 2, pp. 144–151, 2007.

[21] E. P. Aigbomian and M. Fan, “Development of Wood-Crete Building Materials from Sawdust and Waste Paper,” *Constr. Build. Mater.*, vol. 40, pp. 361–366, 2013.