1. Fahrizal[1], 2. Muhidin Arifin[1], 3. Lukman Hakim Nasution[2], 4. Anuar Ahmad[3]

Faculty of Engineering and Life Sciences, University of Selangor, Shah Alam, Selangor-Malaysia (1)
Department of Technical Welding, State Vocational High School 1 Rambah, Rokan Hulu, Riau-Indonesia (2)
TATI University College (3)

doi:10.15199/48.2023.07.14

Experimental matrix palm oil empty fruit bunch composite concrete K300 (POEFB-cc K300) as a reinforcement of concrete road structures

***Abstract**: Experimental matrix Palm Oil Empty Fruit Bunch K300 Composite Concrete (POEFB-CC: K300) was carried out to reinforce the structure of concrete roads by maximizing the use of Empty Fruit Bunch (EFB) fibers in the concrete mixture. This study began with previous experiments, namely on K225 concrete, to determine the best percentage and size of EFB fibers added to the standard concrete mixture. It was found that the best addition is 1% and 5% with POEFB fiber sizes of 5 mm to 0.1 mm. The experimental and matrix analysis on the POEFB-CC: K300 matrix with the percentage and size of EFB fibers was the same as the experimental results on K225 concrete. The experimental and analysis presented in this study is the type of concrete K300 standard age of 28 days, using 72 experiments matrix POEFB-CC: K300 in the form of cubes, cylinders and beams according to the sample size of the Indonesian National Standard 03-2834-2000 (INS 03-2834-2000), and the main mixture of concrete according to INS 2847: 2013. Meanwhile, experimental analysis according to INS 03-1974-190, and INS 4331: 2011 had proven that the average compressive strength value of the POEFB-CC: K300 matrix in the addition of 1% and 5% of fibers measuring 5 mm to 0.1 mm is still within the standard K300 compressive strength value range; where the Compressive Strength value was 287.36kg/cm 2 at 1%, and 280.59kg/cm 2 at 5% for POEFB-CC: K300matrix: Medium K300 on standard K300 concrete was 240kg/cm 2 to 300kg/cm ^{2}. As for the average value of matrix bending strength exceeded the standard K300 concrete bending strength value, namely 34.82 MPa on the X (MX) array matrix, 32.95 MPa on MY and 36.29 MPa on MZ; while in K300 concrete the standard bending strength value was 29.4 MPa. The results of this analysis proved that the addition of 1% EFB fiber and 5% measuring 5 mm to 0.1 mm can increased the bending strength of standard K300 concrete with compressive strength still within the permissible limits of the standard. So it was recommended to use 1% and 5% EFB fibers measuring 5mm to 0.1 mm in standard K300 concrete mixtures, and other types of concrete to increase the structural strength of various types of concrete roads according to the POEFB-CC: K300 matrix: K300; and EFB is no longer considered waste.*

Streszczeenie.** Matryca eksperymentalna Palm Oil Empty Fruit Bunch K300 Composite Concrete (POEFB-CC: K300) została przeprowadzona w celu wzmocnienia konstrukcji dróg betonowych poprzez maksymalizację wykorzystania włókien Empty Fruit Bunch (EFB) w mieszance betonowej. Niniejsze badanie rozpoczęto od wcześniejszych eksperymentów, a mianowicie na betonie K225, w celu określenia najlepszego udziału procentowego i wielkości włókien EFB dodawanych do standardowej mieszanki betonowej. Stwierdzono, że najlepszym dodatkiem jest 1% i 5% przy wielkości włókien POEFB od 5 mm do 0,1 mm. Analiza eksperymentalna i matrycowa na osnowie POEFB-CC: K300 z procentem i rozmiarem włókien EFB była taka sama jak wyniki eksperymentalne na betonie K225. Eksperyment i analiza przedstawiona w tym opracowaniu dotyczy betonu typu K300 o standardowym wieku 28 dni, przy użyciu 72 eksperymentów macierzowych POEFB-CC: K300 w postaci kostek, walców i belek zgodnie z wielkością próbki Indonezyjskiej Normy Narodowej 03- 2834-2000 (INS 03-2834-2000), a mieszanka betonu głównego wg INS 2847:2013. Tymczasem analiza eksperymentalna wg INS 03-1974-190 oraz INS 4331:2011 wykazała, że średnia wytrzymałość na ściskanie wartość POEFB-CC: osnowa K300 z dodatkiem 1% i 5% włókien o średnicy od 5 mm do 0,1 mm mieści się nadal w standardowym zakresie wartości wytrzymałości na ściskanie K300; gdzie wartość wytrzymałości na ściskanie wynosiła 287,36 kg/cm 2 przy 1% i 280,59 kg/cm 2 przy 5% dla POEFB-CC: matryca K300: Średnia K300 na standardowym betonie K300 wynosiła od 240 kg/cm 2 do 300 kg/cm 2. średnia wartość wytrzymałości na zginanie osnowy przekroczyła normę wytrzymałości na zginanie betonu K300, tj. 34,82 MPa na matrycy X (MX), 32,95 MPa na MY i 36,29 MPa na MZ; natomiast w betonie K300 standardowa wartość wytrzymałości na zginanie wynosiła 29,4 MPa. Wyniki tej analizy wykazały, że dodatek 1% włókna EFB i 5% włókna o wymiarach 5 mm do 0,1 mm może zwiększyć wytrzymałość na zginanie standardowego betonu K300 przy wytrzymałości na ściskanie wciąż mieszczącej się w granicach dopuszczalnych przez normę. Zalecono więc stosowanie 1% i 5% włókien EFB o wymiarach od 5mm do 0,1mm w standardowych mieszankach betonowych K300 oraz innych rodzajach betonu w celu zwiększenia wytrzymałości strukturalnej różnego rodzaju dróg betonowych wg POEFB-CC: macierz K300: K300; a EFB nie jest już uważany za odpad.* (Doświadczalny beton kompozytowy K300 (POEFB-cc K300) z pustą wiązką owoców oleju palmowego jako zbrojenie betonowych konstrukcji drogowych***)

Keywords: Concrete K300 Standard, Compressive Strength, Bending Strength, Matrix POEFB-CC: K300.
Słowa kluczowe: Beton K300 Standard, wytrzymałość na ściskanie, wytrzymałość na zginanie, matryca POEFB-CC: K300

Introduction

The growth of oil palm plantations is expected to continue to grow until 2050 [1]; and many studies related to the use of Empty Fruit Bunches (EFB), because they are still considered waste in the form of residual solids from the crude palm oil processing industry [2, 3]. The remaining EFB was about 51.8 million tons in 2019, and i

t continues to increase until now [4, 5]. At every 1 kg of wet EFB can produce about 0.4 kg of dry fiber, where the fiber length is up to 20 cm [6]. EFB fibers can be grouped by branch type, namely single-branch, compound and dislocated-branch with a density of about 0.7 g/cm^3, and when chopped to be shorter by about 1.5 g/cm^3 [7]. The surface morphology is rough and has a pore hole that facilitates mechanical bonding with diameters between 150µm to 500µm, and potentially as a composite reinforcement mixture [8].

Concrete is a structural element with the content of aggregate particles bound by cement and water. Cement and water fill the empty cavities between the aggregate particles after the concrete is molded, and harden as a result of the chemical reaction between cement and water and form a solid structure [9]. Cement is an adhesive and solid material for mineral fragments to become a solid in reinforced concrete construction or not [10]; where it is use about 10% of the volume of concrete, and has its own type and characteristics based on the purpose of its usage [11]. The constituent materials of concrete are cement, coarse aggregate, fine aggregate, and water [12-14]; the strength depends largely on the type of material used [15]. Concrete can be formed according to the needs of construction, loading and resistance to temperature [16]. However, the disadvantage of concrete is that it is difficult to change its shape, and the implementation of work requires high accuracy [17].

In terms of weight, the type of lightweight concrete uses light aggregates such as clay, gravel and residual coal. The density of light aggregates is about 1900 kg/m^3 or based on the use of the structure is between 1440 kg/m^3 to 1850 kg/m^3 with a compressive strength of more than 17.2 MPa at the age of 28 days. Normal concrete medium weighs about 2200 kg/cm^3 to 2400 kg/m^3 with a mixture of natural aggregates broken down or not. While heavy concrete is produced from aggregates with a volume weight of more than normal concrete which is more than 2400 kg/m^3 [18]. Concrete is generally used for impact-resistant purposes [16], and it can be added to other types of materials such as palm empty bunch fibers [19].

Fibers are threads measuring 5μm to 500μm, about 25 mm long with their tensile strength value allowing as a reduction in the use of aggregates to increase the flexibility of concrete, but still resistant to impact [20]. Fiber can be added to the concrete mixture before or during the molding process. Its application exerts specific effects on concrete mixtures including improved workability [21]. Concrete with added fibers is known as composite concrete [22]; in theory, cement is brittle and has a higher compressive strength, while fibers such as EFB fibers have better flexibility [23]. The fiber added to the composite concrete mixture serves to change the properties of the concrete for the better [24]. The bond between cement and fiber affects strength by the ratio of cement and fiber according to physical and mechanical properties, and can be seen through laboratory testing [25]. Although the suitability of the bond between cement and EFB fibers has problems such as the presence of cellulose, lignin, and tannin elements as well as the regulation of mixtures and mortars. But still it can be done experimentally [25, 26].

Concrete with the addition of a mixture of EFB fibers can improve the contact properties of the interface [27-29], since the ratio of fibers to different cements has a direct influence on the rupture modulus and elasticity modulus. The strength of fibrous concrete depends entirely on the bond between the fibers and cement [25]. In any case the use of EFB fiber as an added material of concrete mixture can be done, since the compressive strength of concrete still allows meeting the requirements for structural types of concrete [30-32]. The influence of EFB fibers as an additive to concrete of various sizes and percentages can affect the compressive strength and bending strength of such concrete [33-37].

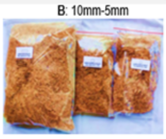
Table 3.1 Experimental POEFB-CC: K300 Matrix

72 Sample		
POEFB-CC:K300 Matrix		
Cube	Cylinder	Beam
28K$_3$1-B$_1$	28S$_3$1-B$_1$	28B$_3$1-B$_1$
28K$_3$1-B$_2$	28S$_3$1-B$_2$	28B$_3$1-B$_2$
28K$_3$1-B$_3$	28S$_3$1-B$_3$	28B$_3$1-B$_3$
28K$_3$5-B$_1$	28S$_3$5-B$_1$	28B$_3$5-B$_1$
28K$_3$5-B$_2$	28S$_3$5-B$_2$	28B$_3$5-B$_2$
28K$_3$5-B$_3$	28S$_3$5-B$_3$	28B$_3$5-B$_3$
28K$_3$1-C$_1$	28S$_3$1-C$_1$	28B$_3$1-C$_1$
28K$_3$1-C$_2$	28S$_3$1-C$_2$	28B$_3$1-C$_2$
28K$_3$1-C$_3$	28S$_3$1-C$_3$	28B$_3$1-C$_3$
28K$_3$5-C$_1$	28S$_3$5-C$_1$	28B$_3$5-C$_1$
28K$_3$5-C$_2$	28S$_3$5-C$_2$	28B$_3$5-C$_2$
28K$_3$5-C$_3$	28S$_3$5-C$_3$	28B$_3$5-C$_3$
Cube POEFB-CC:K300 Matrix		
28KXC1$_1$	28KYC1$_1$	28KZC1$_1$
28KXC1$_2$	28KYC1$_2$	28KZC1$_2$
28KXC1$_3$	28KYC1$_3$	28KZC1$_3$
28KXC5$_1$	28KYC5$_1$	28KZC5$_1$
28KXC5$_2$	28KYC5$_2$	28KZC5$_2$
28KXC5$_3$	28KYC5$_3$	28KZC5$_3$
Beam POEFB-CC:K300 Matrix		
28BXC1$_1$	28BYC1$_1$	28BZC1$_1$
28BXB1$_2$	28BYB1$_2$	28BZB1$_2$
28BXC1$_3$	28BYC1$_3$	28BZC1$_3$
28BXB5$_1$	28BYB5$_1$	28BZB5$_1$
28BXB5$_2$	28BYB5$_2$	28BZB5$_2$
28BXC5$_3$	28BYC5$_3$	28BZC5$_3$

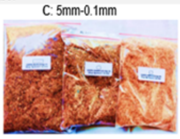
BC=fiber B 10mm-5mm- fiber C 5mm-0.1mm, 28=28Hari, $_{1,2,3}$ = Number sample, 1=S 1% fiber and 5=5% fiber

POEFB Fiber

B: 10mm-5mm



C: 5mm-0.1mm



Materials Matrix Arrangement

Material Arrangement	Code	Explanation
1. Mixture of cement, water and sand 2. Gravel 3. POEFB fiber 4. Sand	X	POEFB fibers are prepared on the road surface and aggregates are arranged after POEFB fibers, and then a mixture of cement, sand and water is stirred so poured over it.
1. Mixture of cement, water and sand 2. POEFB fiber 3. Gravel 4. Sand	Y	Gravel is laid out first on the road surface and the POEFB fiber is laid out after the gravel. Then a mixture of cement, sand and water that has been stirred evenly is poured over it.
1. Mixture of cement, water and sand 2. POEFB fiber 3. Gravel 4. Sand	Z	All ingredients mix and stir directly.

Methodology

EFB was taken from one of the palm oil processing plants in Rokan Hulu Regency, Riau, Indonesia. EFB is then chopped to obtain fibers measuring 10 mm to 5 mm long (type B), and 5 mm to 0.1 mm (type C). Then natural drying is carried out for ±9 hours, weighed according to the size and percentage of addition into the standard K300 concrete mixture. The percentage of POEFB fiber addition based on the weight of the K300 concrete sample according to the Indonesian National Standard (INS) was 7.5 kg for the cube shape, 12.5 kg for the cylindrical shape and 33 kg for the block shape.

Meanwhile, concrete materials are also taken from Rokan Hulu Regency, where the characteristics are based on SNI 2847:2013 [38], namely poured sand, gravel, cement and water. Then the experimental POEFB-CC: K300 was carried out based on the previous experimental results, namely on K225 concrete specifically to determine the addition of EFB fiber, and obtained the best addition of EFB fiber is 1% and 5% with a size of 10mm to 5mm (Type B) and 5mm to 0.1mm (Type C). The concrete mixture method for jenid K300 is in accordance with INS 03-2834-2000 [39], and the test method is carried out based on INS 03-1974-1990 [40] and INS 4431:2011 [41]. Then the experimental POEFB-CC: K300 as shown in Table 3.1.

Results and Disccusion

The test and analysis results of the compressive strength characteristics of the POEFB-CC MATRIX: K300 age 28 days cube sample shape 15cm x 15cm 15cm showed that the addition of 1% and 5% EFB fibers measuring 10 mm to 5 mm and 5 mm to 0.1 mm affects the compressive strength of standard K300 concrete; relating to the importance of influence on the strengthening of concrete road structures

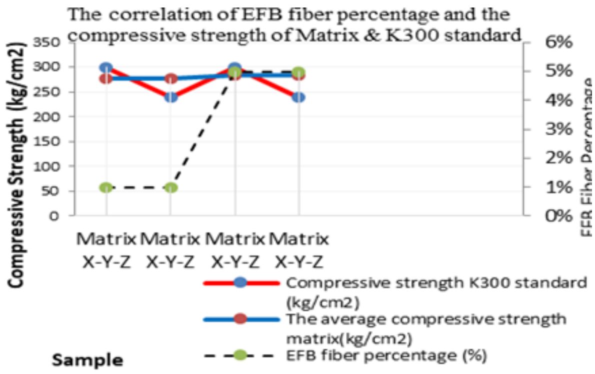


Fig 1. Graph of the correlation of EFB fiber percentage to the compressive strength of Matrix & K300 standard

Based on Figure 3.1 that the average compressive strength value of Matrix POEFB-CC: K300 is between the minimum and maximum compressive strength of standard K300 concrete. Where the minimum standard concrete compressive strength K300 is 240 kg/cm^2 and the maximum is 300 kg/cm^2. While the average compressive strength of Matrix POEFB-CC: K300 for X, Y and Z with the addition of 1% EFB fiber is 277.7 8 kg/cm^2 and at 5% is 284.3 kg/cm^2. The results proved that the compressive strength of Matrix POEFB-CC: K300 X, Y and Z life of 28 days is allowed, because it was still within the standard K300 concrete compressive strength range.

The highest K300 of the POEFB-CC Matrix Compressive Strength value at 1% additional EFB fiber is in the form of a 28KXC1$_3$ cube sample which is 287.36 kg/cm^2, and a sample 28KYC1$_1$ which is 289.07 kg/cm^2. The highest compressive strength value at the additional 5% of EFB fiber is the sample form of the 28KYC5 cube$_3$ is 280.59 kg/cm^2, and the sample 28KZC5 2 is 286.14 kg/cm^2. It also proved that 5 mm to 0.1 mm of POEFB type C fiber is the best size in 1% addition compared to the addition of 5% EFB fiber. The average difference in compressive strength values between the additions of 1% EFB fiber to 5% POEFB-CC: K300 type C measuring 5 mm to 0.1 mm is 4.85 kg/cm^2. This proved that the addition of the percentage of EFB fiber on 1% type C measuring 5 mm to 0.1 mm was the best for standard K300 concrete. Meanwhile, the relationship between the percentage of 1% and 5% EFB fibers to the bending strength of K300 and standard EFB is related to the importance of influence on the strengthening of concrete road structures.

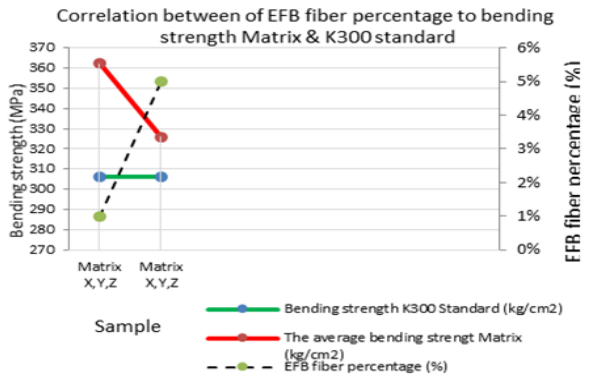


Fig 2. Graph of the correlation of EFB fiber percentage to bending strength Matrix & K300 standard

Based on figure 3.2 that the average bending strength value of Matrix POEFB-CC: K300 is greater than the standard K300 bending strength value. In the addition of 1% EFB fiber, the bending strength value of Matrix POEFB-CC: K300 is 35,501 MPa; while the K300 standard concrete is 29.4 MPa. POEFB-CC bending strength value: K300 of 5% addition EFB fiber is 31.95 MPa; while the K300 standard concrete is 29.4 MPa. This proved that the bending strength of Matrix POEFB-CC K300 was better than standard K300 concrete; where the value gain of bending strength was 2.55 MPa to 6.10 MPa.

The greatest bending strength value of the POEFB-CC Matrix: K300 is in the 28BXC1 1 sample (39.04 Mpa) and the $28BXC1_2$ sample is 38.97 MPa, and the $28BXC1_3$ sample is 38.76 MPa. This proved that the best EFB fiber size was 5mm to 0.1 mm with the percentage addition being 1%; related to the strengthening of concrete road structures. So that it can be analyzed the comparison of fiber size to bending strength in the POEFB-CC Matrix: K300.

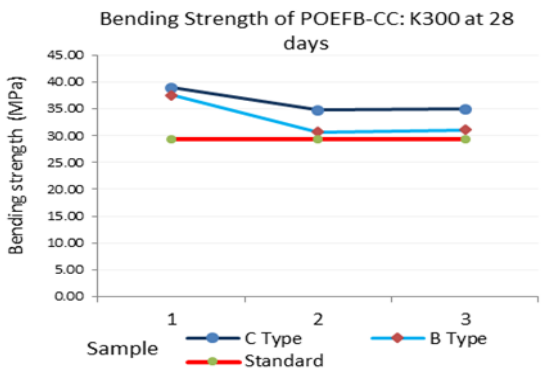


Fig 3. Comparison chart of EFB fiber size to standard bending strength

The comparison of POEFB fiber size to standard bending strength in Figure 3.3 shows that the type of fiber size added to the POEFB-BB Matrix concrete mixture: K300 has a bending strength greater than the bending strength of standard K300 concrete. This means that POEFB fiber size fibers of 5 mm to 0.1 mm are the best to add in a standard K300 concrete mixture, as well as 10mm to 5mm sizes for purposes as reinforcement of concrete road structures. The best fiber percentage addition is at 1%, then 5% of the planned concrete volume. So, the comparison of Matrix POEFB-BB: K300 related to the matrix arrangement of materials X, Y, and Z can be analyzed.

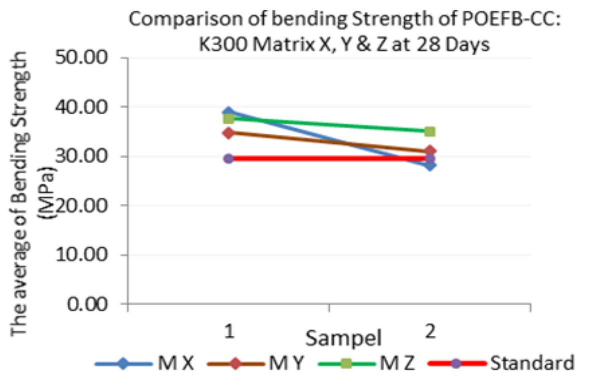


Fig 4. Comparison chart of bending strength of POEFB-CC: K300 Matrix X, Y and Z against standard

Comparison of bending strength of Matrix POEFB-CC: K300 in figure 3.4 shows that matrix material arrangement X (MX), Matrix material arrangement Y (MY) and matrix material arrangement Z (MZ) the bending strength value exceeds the bending strength of standard K300 concrete. This means that the arrangement of MX, MY and MZ materials is allowed in standard K300 concrete molding for concrete road structure reinforcement. Physical and mechanical properties that have been demonstrated by the BB-TKKS Matrix: K300 with an average bending strength of 34.82 MPa on MX, 32.95 MPa on MY and 36.29 MPa on MZ; where the bending strength of K300 standard concrete is 29.4 MPa. Thus, POEFB-CC: K300 matrix was able to increase the ability of standard K300 concrete, and other types of concrete as reinforcement of concrete road structures according to the type of concrete road planned.

Conclusion

Experimental results and analysis of Matrix POEFB-CC: K300 has been successfully carried out for the use of EFB fiber as a mixed material as a reinforcement of concrete road structures. This is evidenced from the results of the analysis of the Compressive Strength value on the addition of 1% EFB fiber is 287.36 kg/cm^2. While the addition of 5% EFB fiber is 280.59kg / cm^2; where it is still in the standard range allowed for the Compressive Strength of K300 standard concrete. POEFB fiber sizes of 5 mm to 0.1 mm and 10 mm to 5 mm with the addition of 1% POEFB fiber can be applied because it has a bending strength exceeding that of the standard K300 bending strength. This is evidenced by the average bending strength values of 34.82 MPa on MX, 32.95 MPa on MY and 36.29 MPa on MZ; where the bending strength of K300 standard is only 29.4 MPa. So that the addition of 1% and 5% EFB fibers measuring 5 mm to 0.1 mm was recommended as a structural reinforcement of various types of concrete roads according to the experimental results and analysis of the POEFB-CC Matrix: K300; where EFB is no longer considered waste.

Acknowledgment

The author would like to thank the government of Rokan Hulu Regency for the support of this research financing, University of Selangor and the Riau-Indonesia Province Concrete Testing Engineering Laboratory for providing support in this research. The author also thank the Supervisor and Co-Supervisor for their guidance and direction during this research.

REFERENCES

[1] *T. J. Killeen, N. L. Harris, K. Brown, M. Netzer and P. Gunarso, "Projections of Oil Palm Expansion in Indonesia, Malaysia and Papua New Guinea from 2010 to 2050," Rspo.Org, September 2013, pp. 89–112, 2013.*

[2] *F. B. Ahmad, Z. Zhang, W. O. S. Doherty, and I. M. O'Hara, "The prospect of Microbial Oil Production and Applications from Oil Palm Biomass," Biochem. Eng. J., Vol. 143, pp. 9–23, 2019, doi: 10.1016/j.bej.2018.12.003.*

[3] *E. Hambali and M. Rivai, "The Potential of Palm Oil Waste Biomass in Indonesia in 2020 and 2030," IOP Conf. Ser. Earth Environ. Sci., Vol. 65, no. 1, 2017, doi: 10.1088/1755-1315/65/1/012050.*

[4] *L. Indriati, N. Elyani, and S. F. Dina, "Empty Fruit Bunches, Potential Fiber Source for Indonesian Pulp and Paper Industry," IOP Conf. Ser. Mater. Sci. Eng., Vol. 980, no. 1, 2020, doi: 10.1088/1757-899X/980/1/012045.*

[5] *Erwinsyah, Atika Afriani, and Teddy Kardiansyah. "Potensi dan Peluang Tandan Kosong Sawit Sebagai Bahan Baku Pulp Dan Kertas: Studi Kasus Di Indonesia," Jurnal Selulosa, Vol. 5, No. 2: 2015, 79-88.*

[6] *Siu Hua Chang. "An Overview of Empty Fruit Bunch from Oil Palm as Feedstock for Bio-Oil Production," Biomas and bioenergy. 2014, 174-179.*

[7] *K. K. Mahato, K. Dutta, and B. C. Ray, "Emerging Advancement of Fiber- Reinforced Polymer Composites in Structural Applications," INC, 2020.*

[8] *Muthia Egi Rahmasita. "Analisa Morfologi Serat Tandan Kosong Kelapa SawitSebagai BahanPenguat Komposit Absorpsi Suara," Jurnal Teknik ITS Vol. 6, No. 2, 2017, 2337-3520.*

[9] *Samuel Adu-Amankwah. "Relationship between Cement Composition and the Freeze-Thaw Resistance of Concretes," ICE Publishing. Duke University, 2018.*

[10] *Chu-Kia Wang, and Salmon Charles G. "Disain Beton Bertulang," Erlangga, Jakarta, 1993.*

[11] *R. R. Irawan. "Semen Portland Di Indonesia Untuk Aplikasi Beton Kinerja Tinggi," 2013.*

[12] *Laurynas Zarauskasa, Gintautas Skripkiūnas, and Giedrius Girskas. "Influence of Aggregate Granulometry on Air Content in Concrete Mixture and Freezing-Thawing Resistance of Concrete," Science Direct. Procedia Engineering 172: 1278-1285, 2017.*

[13] *Devid Falliano. "Experimental Investigation on the Compressive Strength of Foamed Concrete: Effect of Curing Conditions, Cement Type, Foaming Agent and Dry Density. Construction and Building Materials," 165: 735-749, 2018.*

[14] *Ilker Bekir Topcu, and Tayfun Uygunoglu. "Construction and Building Materials," 24: 1286-1295, 2010.*

[15] *Vinh Duy Cao. "Microencapsulated Phase Change Materials for Enhancing the Thermal Performance of Portland cement Concrete and Geopolymer Concrete for Passive Building Applications," Energy Conversion and Management 133: 56-66, 2017.*

[16] *Sherif Yehia. "Strength and Durability Evaluation of Recycled Aggregate Concrete. International Journal of Concrete Structures and Materials,"* DOI 10.1007/s40069-015-0100-0, 2015.

[17] T. Mulyono. *"Teknologi Beton: Dari Teori Ke Praktek,"* No. October 2018, p. 574, 2006.

[18] Mulyati, and Herman. ***"**Komposisi Dan Kuat Tekan Beton Pada Campuran Portland Composite Cement, Pasir Dan Kerikil Sungai Dari Beberapa Quarry Di Kota Padang,"* Jurnal Momentum. Vol.17 No.2, 2015.

[19] Siswadi, Alfeatra Rapa, and Dhian Puspitasari. *"Pengaruh Penambahan Serbuk Kayu Sisa Penggergajian Terhadap Kuat Desak Beton,"* Jurnal Teknik Sipil. Volume 7 No. 2: 144-151, 2007.

[20] Sri Hidayati, Sapta Zuidar, and Ahmad Fahreza. *"Optimasi Produksi Pulp Formacell dari Tandan Kosong Kelapa Sawit (TKKS) dengan Metode Permukaan Respon,"* Reaktor, Vol. 16 No. 4: 161-171, 2016.

[21] M. Ahmadi, S. Farzin, A. Hassani, and M. Motamedi. *"Mechanical properties of the concrete containing recycled fibers and aggregates,"* Constr. Build. Mater, Vol. 144, pp. 392–398, 2017, doi: 10.1016/j.conbuildmat.2017.03.215.

[22] M. K. A and R. S. *"A Review on Natural Fiber and Its Characteristics,"* Ind. Eng. J., Vol. 13, no. 3, 2020, doi: 10.26488/iej.13.3.1224.

[23] A. M. Brandt. *"Fibre Reinforced Cement-Based (FRC) Composites after Over 40 Years of Development in Building and Civil Engineering,"* Compos. Struct., Vol. 86, no. 1–3, pp. 3–9, 2008, doi: 10.1016/j.compstruct.2008.03.006.

[24] Standar Nasional Indonesia. *"Spesifikasi Bahan Tambahan Untuk Konkrit,"* SNI 03-2495. Badan Standardisasi Nasional, Jakarta, 1991.

[25] W. Maynet, E. M. Samsudin, and N. M. Z. N. Soh. *"Physical and Mechanical Properties of Cement Board Made From Oil Palm Empty Fruit Bunch Fiber: A Review,"* IOP Conf. Ser. Mater. Sci. Eng., Vol. 1144, no. 1, p. 012008, 2021, doi: 10.1088/1757-899x/1144/1/012008.

[26] R. da R. Azambuja, V. G. de Castro, B. T. V. Bôas, C. F. A. Parchen, and S. Iwakiri. *"Particle Size and Lime Addiction on Properties of Wood-Cement Composites Produced By the Method of Densification by Vibro Compaction,"* Ciência Rural, Vol. 47, no. 7, pp. 2–6, 2017, doi: 10.1590/0103-8478cr20140250.

[27] P. A. Bonnet-Masimbert, F. Gauvin, H. J. H. Brouwers, and S. Amziane. *"Study of Modifications on the Chemical and Mechanical Compatibility between Cement Matrix and Oil Palm Fibres,"* Results Eng., Vol. 7, p. 100150, 2020, doi: 10.1016/j.rineng.2020.100150.

[28] T. S. Cheng, D. N. Uy LAN, S. Phillips, and L. Q. N. Tran. *"Characteristics of Oil Palm Empty Fruit Bunch Fiber and Mechanical Properties of Its Unidirectional Composites,"* Polym. Composite, Vol. 40, no. 3, pp. 1158–1164, 2019, doi: 10.1002/pc.24824.

[29] J. Wang, Z. Xiao, C. Zhu, C. Feng, and J. Liu. *"Experiment on the Bonding Performance of the Lightweight Aggregate and Normal Weight Concrete Composite Beams,"* Case Stud. Construction Material, Vol. 15, no. May, p. e00565, 2021, doi: 10.1016/j.cscm.2021.e00565.

[30] Khairul Amna, Wesli, and Hamzani. *"Pengaruh Penambahan Serat Tandan Sawit Terhadap Kuat Tekan Dan Kuat Kelenturan Konkrit,"* Teras Jurnal. Vol.4, No.2: 11-20, 2014.

[31] Siswadi, Alfeatra Rapa, and Dhian Puspitasari. *"Pengaruh Penambahan Serbuk Kayu Sisa Penggergajian Terhadap Kuat Desak Konkrit,"* Jurnal Teknik Sipil. Volume 7 No. 2: 144-151, 2017.

[32] Sri Hidayati, Sapta Zuidar, and Ahmad Fahreza. *"Optimasi Produksi Pulp Formacell dari Tandan Kosong Kelapa Sawit (TKKS) dengan Metode Permukaan Respon,"* Reaktor, Vol. 16 No. 4: 161-171, 2016.

[33] L. Indriati, N. Elyani, and S. F. Dina. *"Empty Fruit Bunches, Potential Fiber Source for Indonesian Pulp and Paper Industry,"* IOP Conf. Ser. Material, Sci. Eng., Vol. 980, no. 1, 2020, doi: 10.1088/1757-899X/980/1/012045.

[34] Maya Jacoba, Sabu Thomasa, and K.T. Varugheseb. *"Mechanical Properties Of Sisal/Oil Palm Hybrid Fiber Reinforced Natural Rubber Composites,"* Composites Science and Technology 64: 955-965, 2004.

[35] Reza Mahjoub. *"Tensile Properties of Kenaf Fiber Due to Various Conditions of Chemical Fiber Surface Modifications,"* Construction and Building Materials. 55: 103-113, 2014.

[36] M.S. Sreekalaa. *"The Mechanical Performance of Hybrid Phenol-Formaldehyde-Based Composites Reinforced With Glass and Oil Palm Fibres,"* Composites Science and Technology 62: 339-353, 2002.

[37] Hamid Essabir. *"Mechanical and Thermal Properties of Hybrid Composites: Oil-PalmFiber/Clay Reinforced High Density Polyethylene,"* Mechanics of Materials. MECMAT 2581, 2016.

[38] Kepala Badan and Standar Nasional. *"Penetapan Standar Nasional Indonesia 2847 : 2019 Persyaratan Beton Struktural Untuk Bangunan Gedung dan Penjelasan Sebagai Revisi dari Standar Nasional Indonesia 2847 : 2013,"* No. 8, 2019.

[39] Standar Nasional Indonesia and B. S. Nasional. *"Tata Cara Pembuatan Rencana Campuran Beton Normal,"* 2000.

[40] Standar Nasional Indonesia and B. S. Nasional. *"Metode Pengujian Kuat Tekan Beton,"* 1990.

[41] Standar Nasional Indonesia 4431-2011. *"Cara Uji Kuat Lentur Beton Normal Dengan Dua Titik Pembebanan,"* Badan Standar Nasional Indonesia, p. 16, 2011.