Analysis of Fly Ash and Sandblasting Waste Addition in Cementitious Composite Lawn Table Reinforced by Cocofiber and Wiremesh

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***Abstract*– Concrete technology has significantly advanced and remains an interesting research topic. The demand for cement usage rises significantly due to concrete usage in various sectors. Cement production leads to air pollution issues and causes a greenhouse effect, even in the modern filtration era. Fly ash is an industrial waste that has been identified as a viable substitute for cement due to its pozzolanic properties. Silica Sand is sandblasting waste, where added value is needed. This study investigates the effectiveness of fly ash substitution in the cement portion of cementitious composite materials as an effort to minimize cement usage. Using sandblasting waste is an effort to implement 3R activity (reduce, reuse, recycle) for maritime waste. Compressive and tensile tests were evaluated in the variation of fly ash substitution for cementitious composite reinforced by coco fiber and wiremesh model. The results show that a 40% fly ash substitution gives the highest compressive strength of 32.98 MPa and the tensile strength of 5.90 N/mm². The best model composition provides the increments of compressive and tensile strength compared to the control specimen at 43.60% and 12.60%, respectively. ANOVA tests confirmed the significance of the enhancing effect as the presence of fly ash, both for compressive and tensile strength. Additionally, static analysis simulations using Fusion360 software were performed and indicated that the cementitious composite lawn table prototype's design is safe and has good formability, as a safety factor performed 2.26, exceeding the required value of 2.00. This result explicates that fly ash and waste materials can be effectively used in cementitious composites for practical applications.**

Keywords—Cementitious Composite, Silica Sand, Cocofiber, Concrete, Static Analysis

I. INTRODUCTION

In the last three decades, concrete technology has significantly advanced [1]. Recent advancements in cementitious composites have been developed to minimize the imperfection of traditional concrete, such as low frost resistance, high open porosity that permits rapid penetration of water and aggressive agents, brittle fracture of the material, and microcracks in the cement matrix caused by shrinkage or excessive loading [1]. The primary ingredients of cementitious composites are cement, mineral admixtures, fine aggregates, water, superplasticizers, and up to 2% fibers. Utilizing substances like fly ash and silica fume enhances the permeability and durability of the composites [2].

The main ingredient applied in the production of cementitious composites is cement. Indonesia's capacity to produce cement has exceeded the demand over the last ten years, reaching an annual output of 115 million tons in 2020. According to Lokadata (2020), the current demand is expected to increase by 3% annually to 72 million tons. Harmful gasses and dust are released as a result of cement production. It is difficult to reduce the nitrogen oxides and sulfur oxides, even with recent filter technology. Globally, the cement sector is responsible for 3 billion tons of greenhouse gas emissions, or almost 9% of all carbon dioxide emissions [3].

Numerous research projects have been conducted to identify substitutes for cement additives as cementitious composite forming materials to address these issues. Fly ash is a substance with the same characteristics as cement. Fly ash, or industrial waste, is the byproduct of burning coal in steam power plants (PLTU) [4]. Fly ash's fine particles may lead to air pollution, especially when there is improper handling and processing.

Furthermore, fly ash is now handled sparingly and is typically piled in undeveloped areas. Because of its pozzolanic qualities, which are comparable to cement, fly ash is used as a matrix for cementitious composite material [5]. From an environmental perspective, using fly ash as a cementitious composite material is beneficial [6]. Fly ash is commonly found in industrial by-products such as sandblasting waste [7].

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The addition of fiber increases the compressive strength of cementitious composites. The effectiveness of fiber in increasing energy absorption capacity depends on bond-slip properties, which are influenced by factors such as volume fraction, orientation, shape, and fiber length [8]. Research conducted by Arham and Surianti (2017) showed that the strength of fiber cementitious composite increased with the addition of 0.25% coir fiber, with a compressive strength value of 205.2 kg/cm², an increase of 6.21% compared to regular concrete fiber without the addition of fiber [9].

Hermansyah and Reza found that adding coconut fiber to the cementitious composite mixture was unable to attain the planned compressive strength and resulted in a lower compressive strength value than regular cementitious composite[10]. Adding wiremesh to cementitious composite mixtures increases the structural strength of cementitious composites. Wiremesh, made of solid metal such as steel, is placed inside the cementitious composite layer to increase tensile resistance and resist cracks that may occur due to external pressure or force [11].

Based on the description above, it is necessary to study the addition of fly ash and sandblasting waste sand to cementitious composite materials reinforced with coconut fiber and wire mesh. This research identifies the effectiveness of fly ash substitution as an additional material to replace cement in cementitious composites. This research aimed to determine the optimum value of fly ash content in the cementitious composite and also evaluates the effect of sandblasting waste sand addition as aggregate, the effect of coir fiber on the compressive strength of cement composites, and the effect of wire mesh addition on the flexural strength of cement composites. The formulation design of this research is implemented at the material level and influences the design of the finished product. A garden table was chosen as an example of a product that reflects the practicality of this material in everyday life.

II. Method

A. *Material Preparation*

Several examinations were carried out to identify the characteristics of the materials. XRF (X-Ray Fluorescence) and XRD (X-Ray Diffraction) analysis were conducted on the fly ash and cement. XRD was performed to determine the crystallinity of the materials, while XRF was carried out to identify the chemical composition [12]. An XRF examination was performed in the R&D Laboratory of Semen Indonesia Gresik to analyze the potential and efficacy of fly ash as a cement substitute.

TABLE 1.
MIX DESIGN OF CEMENTITIOUS COMPOSITE

Code	Fly Ash	Cement	Sandblasting Waste	Superplasticizer	Water	Cocofiber
A1	0%	97%	100%	2%	0,3	0,5%
A2	20%	77%	100%	2%	0,3	0,5%
A3	30%	67%	100%	2%	0,3	0,5%
A4	40%	57%	100%	2%	0,3	0,5%

TABLE 2.
XRF AND XRD FLY ASH

XRF			XRD		
Silicon Dioxide (SiO_2)	%	47,51	Lime	CaO	0,02
Aluminium Oxide ($Al2O_3$)	%	19,27	Periclase	MgO	2,51
Ferric Oxide (Fe_2O_3)	%	18,46	Quartz	Ca(OH)2	26,96
Calcium Oxide (CaO)	%	8,89	Aphthitalite	$NaKSO_4$	1,25
Magnesium Oxide (MgO)	%	3,77	Anhydrite	$CaSO_4$	2,64

TABLE 3.
XRF AND XRD CEMENT

XRF			XRD		
Calcium Oxide (CaO)	%	56,24	Dolomite	$CaMg(CO_3)_2$	26,46
Silicon Dioxide (SiO_2)	%	17,33	C3S <M1>	Ca_3SiO_5	16,41
Aluminium Oxide (Al_2O_3)	%	4,73	C2S_beta	Ca_2SiO_4	12,74
Ferric Oxide (Fe_2O_3)	%	3,31	C3S <M3>	Ca_3SiO_5	6,99
Magnesium Oxide (MgO)	%	1,98	Quartz	SiO2	0,97

As XRF results presented in Table 2, the composition of the fly ash used in this study was 85.24% of SiO_2 + Al_2O_3 + Fe_2O_3. The Cao level of 8.89% contained in the fly ash was lower compared to ASTM C618 requirements of 18%. According to Suraneni et al., this composition was in compliance with the ASTM C618 requirements for the type F fly ash [13]. On the other hand, the XRF result of PCC cement were displayed in Table 4. The result shows the predominant chemical composition was 56.24% of CaO, 17.33% of SiO_2, and 4.73% of Al_2O_3. Meanwhile, the SO_3 value of 1.74% statisfies the standard for the characteristic of PCC cement with the SO_3 level less than 4% [14].

B. *Compression Test*

The compression test was carried out at the Laboratory of Building Materials and Structures (LMSG), Institut Teknologi Sepuluh Nopember to evaluate the compressive strength of the cementitious composites. The specimens with seventy-five mm in diameter and one hundred and fifty mm in height were used for testing, following the ASTM C39/C39M standard. Compression test was done with a time constraint of ± 20 hours after curing for a total of 28 days [15]

C. Tensile Test

The direct tensile test was performed according to ASTM C-307 to determine the tensile strength of the cementitious composites. The specimens were prepared by shaping the composites to the form of a dog bone (Dog Bone Specimen), as shown in Figure 1. The tensile strength value obtained is calculated from the maximum tensile load (N) divided by the smallest cross-sectional area (mm²).

D. ANOVA

For the statistical evaluation, a One Way ANOVA analysis was conducted to determine the effect of fly ash addition to the composite.[16]

E. Finite Element Method

In this research, the strength analysis uses the help of Fusion 360 software. The static stress of cementitious composites must be analyzed by adding or customizing the material's properties. Strength analysis was performed using the values from various test results. Some of the values included basic thermal, mechanical properties, and strength properties. The basic thermal properties in this study referred to Lin et al., who had a thermal conductivity value in fly ash concrete of 1.694 W/m.K, assuming a similar temperature and conditions [17]. The tensile strength value was obtained from the tensile test. Meanwhile, the yield strength value was taken from the previous study [10].

The determination of the design stress was based on the Von Mises criterion, which was obtained through the Finite Element Method. To simplify the determination of design stresses, an engineer often specifies the desire load globally [18]. The selection of the allowable stress was decisive for calculating and rechecking the size of the garden table. Therefore, the design structure should determine the amount of allowable stress before the construction fails (breakdown) depending on the safety factor (SF) number.

III. RESULTS AND DISCUSSION

The value of compressive strength is presented in Table 4. The cementitious composite with the lowest compressive strength value of 19.700.45 MPa was tested at 28 days with 0% fly ash substitution. The compressive strength was increased by 8.09% with an average of 23.10 MPa by adding the fly ash up to 20%. The compressive strength was an increment of 17.18% after 30% fly ash addition compared to no fly ash substitution. Furthermore, the 40% fly ash addition resulted in the maximum compressive strength.

The impact of substituting fly ash on cementitious composite's compressive strength is demonstrated in Figure 4. At higher substitution percentages (30% and 40%), the increment of compressive strength is particularly noticeable. The compressive strength increases as higher fly ash percentage. The strength has significantly improved 43.60% by adding 40% of fly ash.

The compressive strength of 0% fly ash substitution value satisfies the minimum fc value specified in the SNI 2847:2019 standard, which is 17 MPa for generic concrete. At 40% fly ash substitution, the strength value has surpassed the minimal value of fc of regular concrete, which is 21 MPa. This cementitious composite can be applied as a unique structural wall and moment-bearing frame system (SNI, 2847:2019).

Table 4 presents the results of the tensile tests. The control specimens (0% fly ash substitution) exhibited an average stress of 5.24 N/mm², with a standard deviation of 0.28. The average stress increased to 5.34 N/mm^2 at 20% fly ash substitution, representing a 1.91% increase. The average stress value was 5.29 for 30% fly ash substitution. With a modest deviation value of 0.03 with 40% fly ash substitution, the stress value rose to 5.90 N/mm2. Compared to 0% fly ash, the tensile strength value tends to rise with fly ash substitutions of 20%, 30%, and 40%. Figure 4 shows that the rise resulting from adding fly ash grows linearly.

TABLE 4.
RESULTS COMPRESSION AND TENSILE TEST

Code	A1	A2	A3	A4
Compression Test (MPa)	19,70	21,29	23,10	28,29
Tensile Test (MPa)	5,237	5,337	5,291	5,901

TABLE 5.
RESULTS ONE WAY ANOVA OF COMPRESSION STRENGTH

Source	*DF*	*Adj SS*	*Adj MS*	*P-Value*
Fly ash (%)	3	108,813	36,2709	0,000
Error	8	5,923	0,7404	
Total	11	114,736		

Figure. 1. Speciment Dogbone Tensile Strength

Figure. 2. Speciment Tensile Test

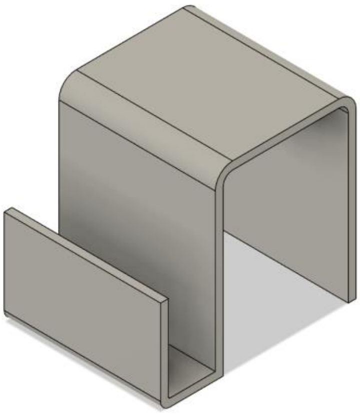
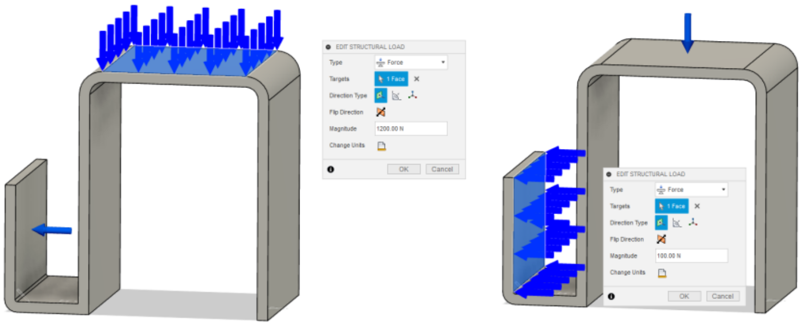


Figure. 3. Design of Lawn Table

Statistical tests were conducted using the tensile test results to assess whether the fly ash substitution significantly affected the cementitious composite's tensile strength. The One-Way ANOVA approach was chosen because it focuses on the effect of a single variable on compressive strength. For the One-Way ANOVA statistical test to be valid, two conditions must be met: homogeneity of variance and normality of the data.

One-way ANOVA can be performed after confirming that the sample data are normally distributed and the variances across groups are homogeneous. Having conducted normality and homogeneity tests, the necessary assumptions for the analysis have been met. Therefore, a one-way ANOVA can be conducted. The following is the initial hypothesis for the compressive strength value: H0: There is no effect of fly ash substitution on compressive strength H1: There is an effect of fly ash substitution on compressive strength. Hypothesis acceptance criteria: Accept H0 if P-value> 0.05. Reject H1, if P-Value < 0.05



(a). 1000N (b) 100N

Figure. 4. Loads

TABLE 6.
RESULTS ONE WAY ANOVA OF TENSILE STRENGTH

Source	DF	Adj SS	Adj MS	P-Value
Fly ash (%)	3	0,8606	0,28687	0,007
Error	8	0,2672	0,03341	
Total	11	1,1278		

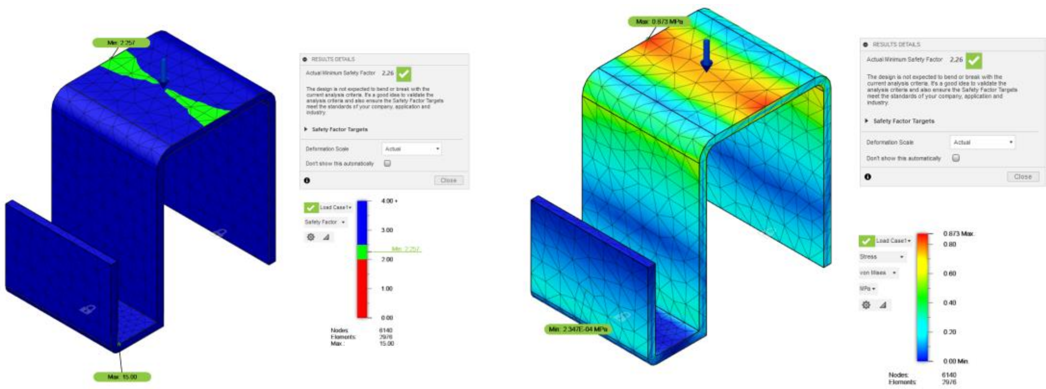


Figure. 5. Results

Based on the one-way ANOVA test results in Table 5, the P-value of 0.000 is significantly less than the significance level of 0.05. Therefore, the result obtained is to reject H0 and accept H1. It can be concluded that the addition of fly ash statistically affects the compressive strength of the cementitious composite.

Based on the one-way ANOVA test results presented in Table 6, the P-value of 0.007 is significantly less than the significance level of 0.05. Therefore, the results obtained are reject H0 and accept H1. It can be concluded that the addition of fly ash statistically affects the tensile strength of the cementitious composite.

Following the ANOVA analysis of the material, the next step involves designing a garden table using a cementitious composite with a 40% fly ash substitution. The design incorporates various ergonomic and functional considerations. The table features an open side panel that can store books, plants, or other items. Figure 3 illustrates the specific dimensions of the cementitious composite garden table.

The 55 cm table height in Figure 3 was thoroughly tested using CATIA V5R28 software to ensure ergonomic compliance for average Asian users. The test results indicate that this height is optimal for comfort and efficiency. Users can interact with the table without excessive bending while seated on a chair with a leg height of approximately 43 cm. This posture minimizes strain on the waist and back, promoting a healthier working position.

The lawn table's seating position is designed for user comfort and health. The table height is adjusted to accommodate the average height of an Asian person, ensuring it is not lower than a comfortable sitting distance. Following the creation of the 3D garden table design, the next step involved calculating material requirements for strength analysis. A strength analysis was conducted using Fusion 360 software to ensure the table's aesthetic appeal, solidity, and durability.

Before initiating the strength analysis, it was necessary to input the physical properties of the selected material, a cementitious composite with a 40% fly ash substitution reinforced with four layers of wire mesh. The input data included fundamental properties such as thermal, mechanical, and material strength.

The elastic modulus Ec value for cementitious composite can be calculated through equation 2.5. Then the elastic modulus value of the cementitious composite is obtained as follows

$$Ec = 4700\sqrt{f'_c}$$
$$Ec = 4700\sqrt{28{,}99\ \text{MPa}}$$
$$Ec = 25305{,}91\ \text{MPa}$$
$$Ec = 25{,}305\ \text{GPa}$$

The density value of the cementitious can be obtained from the average total weight of the specimen at 40% substitution divided by the volume of the specimen. Then the density value is obtained as follows

$$\rho = \frac{m}{v}$$
$$\rho = \frac{1344{,}67\ \text{g}}{662{,}34\ \text{cm}^2}$$
$$\rho = 2{,}030\ \text{g/cm}^2$$

The yield strength and tensile strength values were taken from the tensile testing of cementitious composite with 40% fly ash substitution. The tensile strength value obtained is 5.901 MPa. Then, the yield strength value is as follows

$$\sigma_{yield} = \frac{1{,}550\ MPa + 2{,}671\ MPa + 1{,}704\ MPa}{3}$$
$$\sigma_{yield} = \frac{5{,}925\ MPa}{3}$$
$$\sigma_{yield} = 1{,}975$$

The designed structure must determine the amount of stress that can be accepted (permit stress) before the construction fails (breakdown), depending on the safety factor (SF) number. The safety factor in this study was determined to be 1.5

$$\sigma_{allowable} = \frac{\sigma_{yield}}{SF}$$
$$\sigma_{allowable} = \frac{1{,}975\ MPa}{1{,}5}$$
$$\sigma_{allowable} = 1{,}31\ MPa$$

After the two stages are completed, the next step is to perform a strength analysis of the load pressure that the garden table will receive. This analysis uses Fusion 360 software to see the maximum load value the garden table can support. This analysis will consider the distribution of loads evenly, and point loads that the table may receive.

In this garden table design, two different magnitudes of loads were applied to two different places, for 100 kg of weight (1000 N) on the top of the table and 10 kg (100 N) on the side of the table. The given load was evenly distributed, as shown in Figure 4.

The static stress analysis can be seen in Figure 5. The results show that the structure has a minimum safety factor of 2.26, greater than the specified safety factor value. This indicates that the structure is safe and able to withstand the given load without risk of failure.

The stress values show that the structure experienced a maximum stress of 0.872 MPa, less than the allowable stress of 1.31 MPa. The stress distribution, which varies from low (blue) to high (red) values, shows how the load is distributed across the structure, with the critical area receiving the highest stress marked in red. The analysis results for the garden table design indicate that it is safe and can proceed to the prototyping process.

The prototype garden table construction commenced with determining the material specifications based on a mix design composed of 40% fly ash. The materials used included cement, fly ash, CaCO3, sandblasting waste sand, superplasticizer, water, and fibers, with total amounts listed in the table. Afterward, a mold made of 8 mm plywood was prepared, with the table's thickness set at 2.5 cm, reinforced by four layers of wire mesh shaped to follow the mold. The casting process was conducted by mixing the cementitious composite according to the specified scales and then pouring it evenly into the mold. The curing process was carried out over several days to ensure the cementitious composite reached its maximum strength.

After 28 days of curing, the garden table achieved sufficient structural strength and complied with the desired design standards. Despite encountering technical challenges, such as incomplete mortar filling due to its moderate viscosity, the issue was resolved by patching the unfilled areas with additional mortar. The prototype construction was successfully completed according to the initial design, providing valuable insights for future production and improving manufacturing techniques for further research.

IV. CONCLUSION

Based on the research results, the conclusions are 40% fly ash substitution gives the highest compressive strength of 32.98 MPa, as well as the tensile strength of 5.90 N/mm². The best model composition provides the increments of compressive and tensile strength compared to the control specimen at 43.60% and 12.60% respectively. ANOVA tests confirmed the significance of enhancing effect as the presence of fly ash both for compressive and tensile strength. Additionally, static analysis simulations using Fusion360 software were performed and indicated that the cementitious composite lawn table prototype's design is safe and has good formability, as a safety factor performed 2.26, exceeding the required value of 2.00. This result explicates that fly ash and waste materials can be effectively used in cementitious composites for practical applications.

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