Estimation of Compaction Parameters Based on Soil Classification

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Abstract. Factors that must be considered in compaction of the soil works were the type of soil material, field control, maintenance and availability of funds. Those problems then raised the idea of how to estimate the density of the soil with a proper implementation system, fast, and economical. This study aims to estimate the compaction parameter i.e. the maximum dry unit weight ($\gamma_{d,max}$) and optimum water content ($w_{opt}$) based on soil classification. Each of 30 samples were being tested for its properties index and compaction test. All of the data's from the laboratory test results, were used to estimate the compaction parameter values by using linear regression and Goswami Model. From the research result, the soil types were A4, A-6, and A-7 according to AASHTO and SC, SC-SM, and CL based on USCS. By linear regression, the equation for estimation of the maximum dry unit weight ($\gamma_{d,max}$)=$1,862-0,005*FINES-0,003*LL$ and estimation of the optimum water content ($w_{opt}$)=$-0,607+0,362*FINES+0,161*LL$. By Goswami Model (with equation $Y=m\log G+k$), for estimation of the maximum dry unit weight ($\gamma_{d,max}$) with $m=-0,376$ and $k=2,482$, for estimation of the optimum water content ($w_{opt}$) with $m=21,265$ and $k=-32,421$. For both of these equations a 95% confidence interval was obtained.

1. Introduction

Subgrade strength on the pavement construction is highly dependent on the value of the density of the subgrade. Field density is obtained by either Sand Cone Test or Dynamic Cone Penetrometer Test which yielded the Maximum Dry Maximum Content ($\gamma_{d,max}$) value in the field [1]. Whereas laboratory density is determined by performing Proctor Compaction Test on several soil samples with varying water content. Determining process for the Maximum Dry Unit Weight ($\gamma_{d,max}$) and Optimum Water Content ($w_{opt}$) in the laboratory required a quite considerable material, expert laboratory operators as well as time consuming. If the results of this classification can be used to estimate Maximum Dry Unit Weight ($\gamma_{d,max}$) and Optimum Water Content ($w_{opt}$) subgrade material then it would save time, effort and cost on the execution of this work. This is also a clarification (cross check) of the work that has been done by technicians in the laboratory [2].

Several studies in predicting the value of compaction parameters (maximum dry unit weight and optimum moisture content) have been widely developed. The first study to find out the relationship between compaction parameters was performed by Johnson and Sallberg, where the compaction values were related by means of linear regression based on the value of the index properties [3]. Then a study by Metacalf and Romanoschi [4], predicting the value of maximum dry unit weight and optimum water content also by using the linear regression equation method based on plastic limit, modulus plasticity, gradient coefficient and gradient ratio. A research by Blotz, et.al and then by Al-Khafaji were done and
formulated the relationship between the value of compaction with the Atterberg limit into an equation for several types of soils [5]. Another research by Ugbe proposed equations in predicting the maximum dry unit weight and optimum water content by using the value of index properties: fine grain percent, liquid limit, and specific gravity [6,7]. Isik F and Ozden G used artificial neural network (ANN) prediction models for estimating the compaction parameters of both coarse- and fine-grained soils [8]. Z A Muis determined the maximum dry unit weight of base material on a road project based on soil classification data [2] and estimated the compaction parameter values of pavement subgrade based on soil properties [3]. A S Lubis et al. estimated the compaction parameter values based on soil properties for pavement subgrade stabilized with portland cement [9] and for pavement subgrade stabilized with lime [10]. This study aims to estimate the compaction parameter i.e. the maximum dry unit weight ($\gamma_{d_{\text{max}}}$) and the optimum water content ($W_{\text{opt}}$) based on soil classification. Each of 30 samples were being tested for its properties index and compaction test. All of the data's from the laboratory test results, were used to estimate the compaction parameter values by using linear regression and Goswami Model.

2. Literature Review

Soil compaction is a process where air in the pores of the soil is removed by mechanical means. The mechanical way used to solidify the soil can be done in various ways. In field, grinding is widely used, whereas in the laboratory hitting with proctor is more common. There are two methods for Compaction testing in the laboratory, known as: Standardized Testing Test (Standard Proctor Test) and Modified Proctor Test (Modified Proctor Test) [1].

The index properties show soil properties that indicate the type (classification) and soil conditions which relate to the mechanical properties such as strength and compression or tendency to expand and permeability. The physical properties of the soil (index properties) are water content ($w$), specific gravity ($SG$), grain gradation (Fine=$F$), Atterberg consistency (LL, PL, PI), and many others.

The prediction for the value of maximum dry unit weight ($\gamma_{d_{\text{max}}}$) and optimum water content ($W_{\text{opt}}$) can also be calculated from the model suggested by Goswami with the following equation [2]:

$$Y = m \log G + k$$  \hspace{1cm} (1)

$Y$ = maximum dry unit weight ($\gamma_{d_{\text{max}}}$) and optimum water content ($W_{\text{opt}}$)

$m$ = the slope of the curve

$k$ = constant

$G$ = constant gradation $\left(1 + F\right) \left(A X_1 + B X_2 + C X_3\right)$

$X_1$ = % weight retained shieve 4.75 mm

$X_2$ = % weight retained between shieve 4.75 mm and 0.075 mm

$X_3$ = % weight through shieve 0.075 mm

$A, B, C =$ constants for shieve number

$F$ = % fine grain

The $m$ and $k$ constants are obtained from the graph between $\log G$ with the value of the maximum dry unit weight and the optimum water content from the experimental results in the laboratory. Whereas, F is fine grain percent that is determined based on percent through shieve 0.075 mm and Plasticity Index (IP) value (Table 1).

| % weight through shieve 0.075 mm | F value |
|---------------------------------|---------|
|                                 | IP < 10% | IP > 10% |
| 0 – 25                          | 0,0       | 0,0       |
| 26 – 40                         | 0,2       | 0,2       |
| 41 – 60                         | 1,0       | 1,0       |
| 61 – 85                         | 1,0       | 0,0       |
| 86 – 100                        | 1,0       | 1,0       |
3. Research Methods
Before testing, the 30 samples as subgrade material were dried to get dry air condition. Laboratory testing [1] consists of the index properties testing that were Water Content Test, Specific Gravity Test, Atterberg Limit Test, Shieve Analysis Test and Soil Classification Test (USCS and AASHTO). After that, the samples got The Compaction Test i.e. Standard Proctor Test.

All of the data’s from the laboratory test results, were used to estimate the compaction parameter values. The estimation of the relationship between parameter compaction values and index properties was done in two ways: firstly, by linear regression and secondly, by using Goswami model. In the estimation by using linear regression, the required data were value of index properties, while in the estimation by using Goswami model, the required data was only fine grain percentage.

From the estimation result by using linear regression and Goswami model, the relationship between compaction parameter values and index properties was analyzed. The compaction parameter values estimated by using the Goswami model then were compared with the compaction parameter values from the laboratory. The compaction parameter values estimated were also analyzed based on the soil classification. Afterward, the level of accountability was observed by the validation method, to get a positive correlation level of accountability.

4. Results and discussion
Tests results in the laboratory can be seen in Table 2.

| No. | Sample | w | SG    | LL   | PL | PI | FINES | $\gamma_{\text{max}}$ | $w_{\text{opt}}$ |
|-----|--------|---|-------|------|----|----|-------|----------------|---------------|
| 1.  | PTB-1  | 30.71 | 2.606 | 0.2967 | 17.21 | 12.46 | 45.28 | 1.519 | 20.79 |
| 2.  | PTB-2  | 36.95 | 2.604 | 0.3956 | 23.73 | 15.82 | 50.98 | 1.488 | 24.21 |
| 3.  | PTB-3  | 32.09 | 2.617 | 0.2983 | 17.37 | 12.46 | 50.11 | 1.533 | 21.67 |
| 4.  | PTB-4  | 30.40 | 2.632 | 0.2908 | 17.21 | 11.87 | 50.03 | 1.538 | 21.45 |
| 5.  | PTB-5  | 35.43 | 2.598 | 0.3264 | 21.10 | 11.54 | 50.15 | 1.506 | 22.15 |
| 6.  | PTB-6  | 32.25 | 2.603 | 0.3309 | 21.63 | 11.46 | 50.07 | 1.519 | 22.17 |
| 7.  | PTB-7  | 33.15 | 2.637 | 0.3278 | 20.97 | 11.82 | 43.37 | 1.521 | 20.66 |
| 8.  | PTB-8  | 33.24 | 2.603 | 0.2971 | 17.22 | 12.49 | 50.63 | 1.527 | 21.18 |
| 9.  | PTB-9  | 34.46 | 2.603 | 0.3911 | 24.65 | 14.46 | 50.59 | 1.466 | 24.01 |
| 10. | PTB-10 | 33.27 | 2.605 | 0.2908 | 17.33 | 11.75 | 50.67 | 1.522 | 21.58 |
| 11. | PTB-11 | 29.60 | 2.603 | 0.3805 | 25.00 | 13.05 | 51.87 | 1.481 | 24.08 |
| 12. | PTB-12 | 33.00 | 2.625 | 0.3317 | 20.81 | 12.36 | 48.84 | 1.522 | 22.16 |
| 13. | PTB-13 | 33.06 | 2.637 | 0.2977 | 17.39 | 12.38 | 44.43 | 1.556 | 20.34 |
| 14. | PTB-14 | 30.74 | 2.604 | 0.2975 | 17.52 | 12.23 | 42.03 | 1.566 | 19.81 |
| 15. | PTB-15 | 33.95 | 2.633 | 0.2978 | 16.56 | 13.22 | 50.93 | 1.530 | 21.75 |
| 16. | PTB-16 | 34.00 | 2.600 | 0.3229 | 20.48 | 11.81 | 56.94 | 1.454 | 25.51 |
| 17. | PTB-17 | 32.92 | 2.670 | 0.3826 | 20.11 | 18.15 | 57.03 | 1.457 | 26.62 |
| 18. | PTB-18 | 32.94 | 2.615 | 0.2395 | 15.96 | 7.99 | 53.76 | 1.490 | 25.14 |
| 19. | PTB-19 | 34.67 | 2.640 | 0.4190 | 22.06 | 19.84 | 57.86 | 1.427 | 26.66 |
| 20. | PTB-20 | 31.95 | 2.699 | 0.3900 | 18.87 | 20.13 | 57.22 | 1.456 | 25.08 |
| 21. | PTB-21 | 30.80 | 2.613 | 0.4028 | 24.44 | 15.84 | 55.91 | 1.442 | 26.22 |
| 22. | PTB-22 | 31.55 | 2.682 | 0.3698 | 19.30 | 17.68 | 56.34 | 1.489 | 25.55 |
| 23. | PTB-23 | 30.32 | 2.657 | 0.3106 | 19.20 | 15.51 | 55.91 | 1.471 | 25.94 |
| 24. | PTB-24 | 32.92 | 2.692 | 0.2039 | 15.97 | 4.42 | 52.95 | 1.502 | 21.58 |
| 25. | PTB-25 | 33.15 | 2.644 | 0.3096 | 16.35 | 14.61 | 53.09 | 1.498 | 23.34 |
| 26. | PTB-26 | 32.90 | 2.650 | 0.3984 | 22.23 | 17.61 | 49.17 | 1.447 | 25.78 |
| 27. | PTB-27 | 30.99 | 2.646 | 0.3667 | 21.18 | 15.49 | 55.03 | 1.453 | 25.86 |
| 28. | PTB-28 | 32.06 | 2.670 | 0.3400 | 20.81 | 13.19 | 56.37 | 1.464 | 25.46 |
| 29. | PTB-29 | 32.46 | 2.671 | 0.3023 | 12.37 | 17.26 | 48.19 | 1.512 | 20.18 |
| 30. | PTB-30 | 30.86 | 2.640 | 0.3126 | 15.89 | 15.37 | 50.19 | 1.472 | 25.20 |

Where: w = water content, SG = specific gravity, LL = liquid limit, PL = plastic limit, PI = plasticity index, FINES = grain gradation, $\gamma_{\text{max}}$ = maximum dry unit weight and $w_{\text{opt}}$ = optimum water content.
The compaction parameter values estimated by using the linear regression are the following equation:

\[ \gamma_{d_{\text{max}}} = 1.862 - 0.005 \times \text{FINES} - 0.003 \times \text{LL} \]  
(2)

\[ w_{\text{opt}} = -0.607 + 0.362 \times \text{FINES} + 0.161 \times \text{LL} \]  
(3)

From the equation (2) and (3), the maximum dry unit weight estimated (\(\gamma_{d_{\text{max}}}\)) and the optimum water content estimated (\(w_{\text{opt}}\)) were obtained as shown as Tabel 3. Equation (2) has \(R^2\) values = 0.75 and equation (3) has \(R^2\) values = 0.80; both have very good accuracy.

**Table 3.** Compaction Parameter Values Estimated by Using the Linear Regression Model

| No. | Sample | AASHTO | USCS | LL | FINES | \(\gamma_{d_{\text{max}}}\) | \(\gamma_{d_{\text{max}}}^*\) | \(w_{\text{opt}}\) | \(w_{\text{opt}}^*\) |
|-----|--------|--------|------|----|-------|----------------|----------------|-------------|-------------|
| 1   | PTB-1  | A-6 (2)| SC   | 29.67 | 45.28 | 1.519         | 1.537          | 20.79       | 20.57       |
| 2   | PTB-2  | A-6 (4)| CL   | 39.56 | 50.98 | 1.488         | 1.477          | 24.21       | 24.23       |
| 3   | PTB-3  | A-6 (3)| CL   | 29.83 | 50.11 | 1.533         | 1.512          | 21.67       | 22.34       |
| 4   | PTB-4  | A-6 (2)| CL   | 29.08 | 50.03 | 1.538         | 1.515          | 21.45       | 22.19       |
| 5   | PTB-5  | A-6 (3)| CL   | 32.64 | 50.15 | 1.506         | 1.503          | 22.15       | 22.81       |
| 6   | PTB-6  | A-6(2)| CL   | 33.09 | 50.07 | 1.519         | 1.502          | 22.17       | 22.85       |
| 7   | PTB-7  | A-6(3)| CL   | 32.78 | 43.37 | 1.521         | 1.538          | 20.66       | 20.38       |
| 8   | PTB-8  | A-4(1)| CL   | 29.71 | 50.63 | 1.527         | 1.510          | 21.18       | 22.51       |
| 9   | PTB-9  | A-6(4)| CL   | 39.11 | 50.59 | 1.466         | 1.481          | 24.01       | 24.01       |
| 10  | PTB-10 | A-6(2)| CL   | 29.08 | 50.67 | 1.522         | 1.511          | 21.58       | 22.42       |
| 11  | PTB-11 | A-6(3)| ML   | 38.05 | 51.87 | 1.481         | 1.478          | 24.08       | 24.31       |
| 12  | PTB-12 | A-6(3)| SC   | 33.17 | 48.84 | 1.522         | 1.508          | 22.16       | 22.42       |
| 13  | PTB-13 | A-6(5)| SC   | 29.77 | 44.43 | 1.556         | 1.541          | 20.34       | 20.28       |
| 14  | PTB-14 | A-6(1)| SC   | 29.75 | 42.03 | 1.566         | 1.554          | 19.81       | 19.41       |
| 15  | PTB-15 | A-6(3)| CL   | 29.78 | 50.93 | 1.530         | 1.508          | 21.75       | 22.63       |
| 16  | PTB-16 | A-6(4)| CL   | 32.29 | 42.67 | 1.454         | 1.469          | 25.51       | 25.21       |
| 17  | PTB-17 | A-6(7)| CL   | 38.26 | 41.79 | 1.457         | 1.450          | 26.62       | 26.21       |
| 18  | PTB-18 | A-4(1)| CL   | 23.95 | 39.66 | 1.490         | 1.511          | 25.14       | 22.71       |
| 19  | PTB-19 | A-7(7)| CL   | 41.90 | 39.70 | 1.427         | 1.435          | 26.66       | 27.10       |
| 20  | PTB-20 | A-6(12)| CL   | 39.00 | 39.75 | 1.456         | 1.447          | 25.08       | 26.40       |
| 21  | PTB-21 | A-6(6)| CL   | 40.28 | 40.62 | 1.442         | 1.450          | 26.22       | 26.13       |
| 22  | PTB-22 | A-6(7)| CL   | 36.98 | 41.25 | 1.489         | 1.458          | 25.55       | 25.75       |
| 23  | PTB-23 | A-6(4)| CL   | 31.06 | 40.80 | 1.471         | 1.468          | 25.94       | 25.39       |
| 24  | PTB-24 | A-4(2)| CL   | 20.39 | 40.65 | 1.502         | 1.526          | 21.58       | 21.84       |
| 25  | PTB-25 | A-6(1)| CL   | 30.96 | 43.12 | 1.498         | 1.493          | 23.34       | 23.60       |
| 26  | PTB-26 | A-6(5)| SC   | 39.84 | 42.45 | 1.447         | 1.486          | 25.78       | 23.62       |
| 27  | PTB-27 | A-5(5)| CL   | 36.67 | 41.63 | 1.453         | 1.466          | 25.86       | 25.23       |
| 28  | PTB-28 | A-6(4)| CL   | 34.00 | 42.17 | 1.464         | 1.467          | 25.46       | 25.28       |
| 29  | PTB-29 | A-6(4)| SC   | 30.23 | 41.55 | 1.512         | 1.521          | 20.18       | 21.71       |
| 30  | PTB-30 | A-6(4)| CL   | 31.26 | 39.71 | 1.472         | 1.507          | 25.20       | 22.60       |

Where: LL = liquid limit, FINES = grain gradation, \(\gamma_{d_{\text{max}}}\) = maximum dry unit weight, \(\gamma_{d_{\text{max}}}^*\) = estimated maximum dry unit weight with linear regression, \(w_{\text{opt}}\) = optimum water content, and \(w_{\text{opt}}^*\) = estimated optimum water content with linear regression.

According to Goswami model (eq. 1), the correlation between maximum dry unit weight (\(\gamma_{d_{\text{max}}}^*\)) and Log G was shown as figure 1, with \(m=0.376\) dan \(k=2.482\). While the correlation between optimum water content (\(w_{\text{opt}}^*\)) and Log G was shown as figure 2, with \(m=21.265\) dan \(k=-32.421\). Using the \(m\) and \(k\) constants, maximum dry unit weight estimated (\(\gamma_{d_{\text{max}}}^*\)) and optimum water content estimated (\(w_{\text{opt}}^*\)) were obtained as shown as Tabel 4.
Figure 1. Correlation maximum dry unit weight ($\gamma_{d_{\max}}$) with Log G

Figure 2. Correlation optimum water content ($w_{\text{opt}}$) with Log G

Table 4. Compaction Parameter Values Estimated by Using the Goswami Model

| No | Sample | AASHTO | USCS | FINES | $\gamma_{d_{\max}}$ | $\gamma_{d_{\max}^g}$ | $w_{\text{opt}}$ | $w_{\text{opt}^g}$ |
|----|--------|--------|------|-------|----------------------|----------------------|----------------|----------------|
| 1  | PTB-1  | A-6 (2) | SC   | 45.28 | 1.519                | 1.494                | 20.79          | 23.452         |
| 2  | PTB-2  | A-6 (4) | CL   | 50.98 | 1.488                | 1.518                | 24.21          | 22.085         |
| 3  | PTB-3  | A-6 (3) | CL   | 50.11 | 1.533                | 1.524                | 21.67          | 21.743         |
| 4  | PTB-4  | A-6 (2) | CL   | 50.03 | 1.538                | 1.514                | 21.45          | 22.286         |
| 5  | PTB-5  | A-6 (3) | CL   | 50.15 | 1.506                | 1.514                | 22.15          | 22.283         |
| 6  | PTB-6  | A-6(2)  | CL   | 50.07 | 1.519                | 1.509                | 22.17          | 22.589         |
| 7  | PTB-7  | A-6(3)  | CL   | 43.37 | 1.521                | 1.479                | 20.66          | 24.252         |
| 8  | PTB-8  | A-4(1)  | CL   | 50.63 | 1.527                | 1.516                | 21.18          | 22.155         |
| 9  | PTB-9  | A6-(4)  | CL   | 50.59 | 1.466                | 1.518                | 24.01          | 22.092         |
Table 4. Cont.

|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 10| PTB-10| A6-(2)| CL| 50.67| 1.522| 1.521| 21.58| 21.905 |
| 11| PTB-11| A6-(3)| ML| 51.87| 1.481| 1.529| 24.08| 21.453 |
| 12| PTB-12| A6-(3)| SC| 48.84| 1.522| 1.505| 22.16| 22.821 |
| 13| PTB-13| A6-(5)| SC| 44.43| 1.556| 1.518| 20.34| 22.087 |
| 14| PTB-14| A6-(1)| SC| 42.03| 1.566| 1.499| 19.81| 23.160 |
| 15| PTB-15| A6-(3)| CL| 50.93| 1.530| 1.515| 21.75| 22.221 |
| 16| PTB-16| A6-(4)| CL| 42.67| 1.454| 1.487| 25.51| 23.807 |
| 17| PTB-17| A6-(7)| CL| 41.79| 1.457| 1.484| 26.62| 23.989 |
| 18| PTB-18| A4-(1)| CL| 39.66| 1.490| 1.475| 25.14| 24.506 |
| 19| PTB-19| A7-(7)| CL| 39.70| 1.427| 1.474| 26.66| 24.578 |
| 20| PTB-20| A6-(12)| CL| 39.75| 1.456| 1.474| 25.08| 24.556 |
| 21| PTB-21| A6-(6)| CL| 40.62| 1.442| 1.476| 26.22| 24.459 |
| 22| PTB-22| A6-(7)| CL| 41.25| 1.489| 1.479| 25.55| 24.298 |
| 23| PTB-23| A6-(4)| CL| 40.80| 1.471| 1.476| 25.94| 24.415 |
| 24| PTB-24| A4-(2)| CL| 40.65| 1.502| 1.475| 21.58| 24.492 |
| 25| PTB-25| A6-(1)| CL| 43.12| 1.498| 1.469| 23.34| 24.836 |
| 26| PTB-26| A6-(5)| SC| 42.45| 1.447| 1.480| 25.78| 24.224 |
| 27| PTB-27| A6-(5)| CL| 41.63| 1.453| 1.478| 25.86| 24.315 |
| 28| PTB-28| A6-(4)| CL| 42.17| 1.464| 1.480| 25.46| 24.192 |
| 29| PTB-29| A6-(4)| SC| 41.55| 1.512| 1.480| 20.18| 24.211 |
| 30| PTB-30| A6-(4)| CL| 39.71| 1.472| 1.473| 25.20| 24.640 |

Where: FINES = grain gradation, $\gamma_{\text{max}}$ = maximum dry unit weight, $\gamma_{\text{dmax}*}$ = estimated maximum dry unit weight with Goswami Model, $w_{\text{opt}}$ = optimum water content, and $w_{\text{opt}}^\#$ = estimated optimum water content with Goswami Model.

By Using linear regression and Goswami model, the relationship between compaction parameter values Estimated and index properties were obtained, included the soil classification. So, the purpose of this research has been achieved.

For both estimation models, correlation between the compaction parameter values estimated with the compaction parameter values laboratory, then were calculated for their level of confidence intervals, as in Table 5.

Table 5. Level of Confidence Intervals

|                     | Linear Regression Model | Goswami Model |
|---------------------|-------------------------|---------------|
|                     | Maximum dry unit weight ($\gamma_{\text{dmax}*}$) | Optimum water content ($w_{\text{opt}*}$) | Maximum dry unit weight ($\gamma_{\text{dmax}*}$) | Optimum water content ($w_{\text{opt}*}$) |
| Correlation Coefficient | 1,000                  | 1,000         | 0.988           | 1,000         |
| T value             | 3,268                   | 3,674         | 3,453           | 3,068         |
| T table (95% of Confidence Intervals) | 2.055                   | 2.055         | 2.052           | 2.052         |

5. Conclusion

By linear regression, the equation for estimation of the maximum dry unit weight ($\gamma_{\text{dmax}*}$) = 1,862-0,005*FINES-0,003*LL and estimation of the optimum water content ($w_{\text{opt}*}$) = -0,607+0,362*FINES+0,161*LL. By Goswami Model (with equation $Y=m\log G+k$), for estimation of the maximum dry unit weight ($\gamma_{\text{dmax}*}$) with $m$=-0,376 and $k$=2,482, for estimation of the optimum water
content (w_{opt}^*) with m=21,265 and k=-32,421. For both of these equations a 95% confidence interval was obtained. Estimation by using Goswami Model is easier and more effective than Linier Regression Model because it only require fine grains (Fines) value. Based on the classification value, the types of soil were A4, A6 and A7 (AASHTO) or SC and CL (USCS).

Acknowledgements
The authors also would like to thank to Sustainable Energy and Biomaterial Center of Excellence (SEBCOE), Universitas Sumatera Utara for the financial aids.

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