Design of experiment of material level settings on the factors affecting the quality of calcium silicate board by using the Taguchi method

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Abstract: The main purpose of this paper is to identify and determine the level of regulation on factors that influence the type and characteristics of the pulp so that it can produce optimal quality Calcium Silicate Boards. The experiments were carried out using the Taguchi method and using quality characteristics: strength, deflection, density, and water absorption. Then, the factors that influence product quality are the use of pulp percentage, pulp type, and pulp composition. Data processing uses two analyzes to determine the optimal level setting, which consists of mean analysis and signal to noise ratio analysis, then an experiment is carried out to confirm the predictive value of the level setting factor under optimal conditions. The results showed that the type and composition of the pulp affected the strength and density of the product, the use of the percentage of the pulp affected the deflection of the product, and all factors did not affect the absorption of product water, with an optimal level of regulation: 9.8% percentage of pulp, Y type of pulp, and 100% pulp composition. Confirmation results obtained an average value of the strength test was 154.5 kg / cm², 13 mm for the deflection test, 1.3275 g / cm³ for the density test and 36.35% for the water absorption test.

Keyword: Calsium Silicate Board, pulp, level setting, strength, density, deflection

1. Introduction
Current construction development is supported by the latest discoveries in building materials. The use of building materials began to shift from the Flat Board, Flat Sheet Gypsum Board, GRC Board to the last one is the Calcium Silicate Board. Calcium Silicate Board is made of calcium silicate panels and uses cellulose fibers as reinforcement. In plain view Calcium Silicate Board Material Pulp is a very important raw material because it functions as a framework of reinforcement, providing flexibility and ease when nailed, so that
it can affect product quality. Therefore, determining the appropriate type of pulp becomes very important.

This paper conducts experiments to determine the type of pulp and the characteristics of the pulp that is most suitable for the manufacture of quality Calcium Silicate Board products.

This experiment differs from previous papers which deal more with the chemical elements forming Calcium Silicate. In this paper, the setting level on the factors that determine the types and characteristics of the pulp so that calcium silicate board products can be produced with strong strength, deflection, density and optimal water absorption.

2. Methods and Materials

2.1. The Calcium Silicate Board Experiment

Calcium silicate boards mainly consist of inorganic materials such as silica sand, portland, cement, cellulose and water. This is widely used as an alternative to gypsum and asbestos cement boards which have some disadvantages where asbestos cement boards give a bad influence on the health of building occupants, while gypsum boards will dissolve in water so that it cannot be used on building exteriors [1].

There have been a number of experiments carried out previously to improve the quality of calcium silicate boards such as the one conducted by [2], testing calcium silicate boards by observing microstructure characteristics and thermal conductivity for their density levels. In line with (Tsui), the observed thermal increase in conductivity with an increase in temperature is better explained by Russell's theory and freer than with Bruggeman. Measurement at 400 °C using Hot Disk equipment is complicated by the slow approach to thermal/hygral balance of these materials and the resistance of higher temperature nickel/mica sensors.

Tennis and Jennings [3] used methods to predict density, porosity of nitrogen-accessible gels and the associated surface area of Calcium silicate in Portland cement paste. The basis for this model is that calcium silicate Hydrate is formed as one of two types of calcium silicate with high or low density.

In investigations on the formation of tobermorite on calcium silicate boards and their influencing factors under autoclaving, the optimal cement content is hydration and only has an improvement in the structure of the specimen, because of the transformation of hydration production, the autoclaved curing time and the curing temperature must be controlled respectively within a specific range between 4-8 hours and 190-195 °C, so this is very promising to be applied in calcium silicate boards [4].

The strength of calcium silicate boards is derived from fibers that press and strengthen ie when the mold pressure is 10 MPa, the flexural strength of the sample, bulk density and thermal conductivity are 5 MPa, 0.7 g/cm3 and 0.12 W/m.K respectively. When the mold pressure is 20MPa, the flexural strength is 9.04 MPa, and the thermal conductivity is less than 0.2 W/m.k [5].

On the other hand [6] evaluates the effect of ultrasonic and manual placement techniques on the strength of the Biodentine and MTA push-out bonds with and without calcium chloride, the results suggest that ultrasonic activation significantly increases the bond strength of the material values. Biodentine shows a higher bond strength value than the MTA group. Addition of CaCl2 to MTA does not increase the strength of the material bonding.

Other materials that can be used to produce calcium silicate boards are using egg shells and ash rice husk (RHA) through mixing heat-treated RHA (~93% SiO2) and calcined eggshells (~99% CaO) at 1050 °C. CSB specimens were prepared at room temperature with a simple drying process followed by mixing proportions of different CS powder, ordinary portland cement (OPC) and unground rice husk ash (URHA), this experiment produced a low density (<1000 kg/m3), flexural proportional strength (~6 MPa) and low thermal conductivity (<0.153W/m.K) [7]. Calcium silicate boards from waste can be recommended for use in the internal layer of buildings for insulation.

The effect of the proportion of molybdenum or diatomite tailings on hydration characteristics, thermal conductivity, water absorption, flexural strength and moisture adsorption properties of calcium silicate board adsorption also became an investigative material which revealed that molybdenum tailings are environmentally friendly for preparing building materials. The main hydration product in calcium silicate boards under autoclave conditions is C-S-H with low crystallinity and tobermorite. Molybdenum tail is beneficial for the formation of tobermorite. The flexural strength and bulk density of calcium silicate
boards gradually increase as the molybdenum tailing content increases. The optimal content of molybdenum tailing is 20%, furthermore, the flexural strength and thermal conductivity of calcium silicate boards in this content meet the JC / T564.1-2008 standard of China [4, 8, 9].

Tests conducted specifically for calcium silicate board products and only cover the types of pulp X and Y. Before conducting the experiment, measurements of the actual conditions are first carried out in order to compare them with the optimal conditions of the experimental results.

2.2. Design of Experiment

This experiment was conduct using the Taguchi technique. This technique consists of the stages of the process of identifying influence factors, determining the level factor setting, determining the orthogonal array and determining the number of specimens to conduct matrix balance that indicates assignment experimental factor [10, 11].

In this paper the preparation stage of the experiment will identify the quality characteristics and determination of the measurement system for each quality characteristic so that it can be calculated on the results of the experiment. The characteristics used in this paper refer to the quality characteristics of the Taguchi method, namely; Smaller the Better (STB), Larger The Better (LTB) and Nominal is The Best (NTB). The characteristics that will be used in measuring Calcium silicate board quality are STB for water absorption and LTB measurement for strength, deflection and density testing.

The materials used in this experiment were Hascheck cement Portland, pulp silica, chemical water and other additives. The independent variable is silica pulp, while other materials are of the same type, component and process. To ensure the accuracy of the results, each experiment is only done once a day, so that the pulp to be tested does not mix with the others.

In this Taguchi experiment, there are 3 influencing factors where each factor have 2 level and there is no interaction factor. From the number of levels and factors, the number of rows of the matrix of orthogonal array can be determined that is L4 (2^4), because this orthogonal array can accommodate the number of factors and the existing level. Experiments carried out four times with three times replication for each experiment to reduce the level of errors and improve the accuracy of the experimental data. So that the number of specimens required for Taguchi experiment as much as 12.

3. Result and Discussion

This experiments using two setting levels of factors that indicate a high level (high) and low (low). In figure 1 setting levels for the factors which involved in this experiment are described as follows percentage of pulp, types of pulp and Composition of the pulp types.

| Influences factors          | Level 1 | Level 2 |
|-----------------------------|---------|---------|
| Percentage of Pulp          | 9.0%    | 9.8%    |
| Types of Pulp               | X       | Y       |
| Composition the pulp types  | 50%     | 100%    |

In this method using means analysis to find the optimal level of adjustment that minimizes the average deviation value. The calculation is done with the Minitab software 17. Table and figure 1 responses are made by calculating the difference in mean values between factor level responses and then sorting various factor levels from the largest to the smallest.

| Level | Strength | Deflection | Density | Water Absorption |
|-------|----------|------------|---------|------------------|
|       | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| 1     | 137.6 | 130.6 | 128.8 | 13.63 | 15.63 | 16.8 | 1.256 | 1.221 | 1.223 | 36.42 | 38.07 | 36.84 |
| 2     | 137.9 | 144.9 | 146.8 | 17.75 | 15.75 | 14.50 | 1.259 | 1.294 | 1.293 | 36.10 | 34.45 | 35.67 |
| Delta | 0.3 | 14.3 | 18.0 | 4.13 | 0.13 | 2.38 | 0.002 | 0.073 | 0.070 | 0.33 | 1.63 | 1.17 |
| Rank  | 3 | 2 | 1 | 1 | 3 | 2 | 3 | 1 | 2 | 3 | 1 | 2 |
The hypothesis for all quality tests based on the above data are:

- $H_0$ = there is no influence factor (A/B/C) on the quality of the product deflection/density/water absorption
- $H_1$ = there is the influence of factor (A/B/C) on the quality of the product (strength/deflection/density/water absorption)
- If the $P_{value} > \alpha = 0.05$ then $H_0$ is accepted (not significant), otherwise $P_{value} \leq \alpha = 0.05$ then $H_0$ is rejected (significant). $P_{value}$ calculated using Minitab 17 software whose results are shown in table 3 and table 4.

### Table 3. Calculation of $P_{value}$ with Minitab 17 software

| Testing          | Percentage of pulp | Types of pulp | Composition of pulp types |
|------------------|--------------------|---------------|---------------------------|
| Strength         | 0.938              | 0.001         | 0.000                     |
| Deflection       | 0.054              | 0.949         | 0.242                     |
| Density          | 0.928              | 0.020         | 0.024                     |
| Water Absorption | 0.886              | 0.130         | 0.610                     |

### Table 4. The result of hypothesis test for mean value

| Testing               | A       | B       | C       |
|-----------------------|---------|---------|---------|
| Strength              | Accepted| Rejected| Rejected|
| Deflection            | Rejected| Accepted|         |
| Density               | Accepted| Rejected| Rejected|
| Water Absorption      | Accepted| Accepted|         |

Based on the results of hypothesis test, the factors that have an influence on the quality of the test as follows:

a. There is the influence of A factor (percentage of pulp) to the flexibility of the product (percent contribution: 58.63%).

b. There is influence of B factor (types of pulp) to the strength of the product (percent contribution: 36.64%).

![Figure1. Response graph for taguchi experiment mean value](image)
c. There is influence B factor (types of pulp) to the product density (percent contribution: 44.93%).

d. There is the influence of C factor (composition of the pulp types) to the strength of the product (percent contribution: 59.58%).

e. There is the influence of C factor (composition of the pulp types) to the product density (percent contribution: 40.74%).

For analysis of signal to noise ratio to find the factors that have contributed to the reduction of the quality characteristic variance (the response variable). Table 5 dan figure 2 shows the results for SNR value is calculated with Minitab 17 software.

**Table 5.** Response table for taguchi experiment SNR value

| Level | A    | B    | C    | A    | B    | C    | A    | B    | C    | A    | B    | C    |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1     | 42.71| 42.29| 42.15| 22.55| 23.47| 23.97| 1.952| 1.708| 1.715| -31.26| -31.62| -31.37|
| 2     | 42.75| 43.17| 43.31| 24.26| 23.34| 22.84| 1.926| 2.221| 2.213| -31.19| -30.84| -31.09|
| Delta | 0.05 | 0.89 | 1.15 | 1.71 | 0.13 | 1.14 | 0.024| 0.512| 0.498| 0.07  | 0.79  | 0.29 |
| Rank  | 3    | 2    | 1    | 1    | 3    | 2    | 3    | 1    | 2    | 3    | 1    | 2    |

**Figure 2.** Response graph for taguchi experiment SNR value

Based on the data processing, the optimum level is the largest SNR value of each factor. To reduce variance and set a target according to the specifications, then used optimization process in two-stage based on the average value (mean) and SNR of Taguchi experiment which has an influence on the quality of the test; with Table 6 and Table 7:

**Table 6.** Optimum level based SNR

| Testing       | (A) Percentage of pulp | (B) Types of pulp | (C) Composition of pulp types |
|---------------|-------------------------|-------------------|-------------------------------|
| Strength      | 9.80 %                  | Y                 | 100%                          |
| Deflection    | 9.80 %                  | X                 | 50%                           |
| Density       | 9.80 %                  | Y                 | 100%                          |
| Water Absorbtion | 9.00 %              | X                 | 50%                           |
Table 7. Optimal setting level

| Testing | (A) Percentage of pulp | (B) Types of pulp | (C) Composition of pulp types |
|---------|------------------------|-------------------|-----------------------------|
| Strength | Not Influenced | Influenced Level 2; Y | Influenced Level 2; 100 |
| Deflection | Influenced Level 2; 100 | Not Influenced | Not Influenced |
| Density | Not Influenced | Influenced Level 2; Y | Influenced Level 2; 100 |
| Water Absorption | Not Influenced | Not Influenced | Not Influenced |

The results of an optimal level factor combination based on the table above are: A2, B2 and C2. After determining the optimal setting level factor, it is necessary to predict an expected optimum condition of average value and SNR to compare with experimental confirmation. If the response prediction and experimental confirmation fairly close to each other, it can be concluded that the design meets the requirements of Taguchi experiments. Whereas the use of confidence interval is to make an estimate of the factor levels and average prediction process in optimal conditions.

Experiment confirmation was conducted to test the predictive setting level factor value in optimal conditions. If the confirmation experiment could verify the prediction result, then the optimum conditions of setting level have fulfilled the experiment requirements. Confirmation experiment was conducted by taking a sample of 4 specimens based on the optimal level which has been obtained previously, that is: percentage of pulp: 9.8%, pulp types: Y, and composition of the pulp types: 50%. The comparison of confidence interval on optimal and confirmation conditions shown at figure 3.

Figure 3. The comparison of confidence interval on optimal and confirmation conditions

Furthermore, the simulation of quality loss function is based on the actual and optimal conditions which has an influence on the value factor, that is: strength test, deflection test, and density test. Based on the table 9, QLF optimization is smaller than before the optimization. This means that the function of losses in corporate responsibility is reduced after optimization.

Table 8. Comparison of QLF in Actual and Optimal Conditions

| Testing | QLF |
|---------|-----|
| Actual  | Optimal |
| Strength | 3.18 | 0.38 |
| Deflaction | 783.63 | 51.86 |
| Density | 54.22 | 48.57 |
Factors levels that have a major impact in raising the average and reduce the variance of quality characteristics can be determined based on the results of analysis of mean and analysis of the signal to noise ratio. By using a 95% confidence level, the confidence interval can be predicted for each test quality that shown at table below.

| Testing | Factor Code | Level | Factor of Influence                  | Value      |
|---------|-------------|-------|--------------------------------------|------------|
|         | B           | 2     | Types of pulp                        | Y          |
| Strength| C           | 2     | Composition of the pulp types         | 100%       |
|         | A           | 2     | Percentage of pulp                   | 9,8%       |
| Deflection| C         | 2     | Types of pulp                        | Y          |
| Density | B           | 2     | Composition of the pulp types         | 100%       |

Experiment confirmation is an experiment being run on a combination of the best factor levels were chosen based on the results obtained from the Taguchi experiments. The experimental results show that the optimal setting level is acceptable. It can be seen from the comparison of the confidence interval between the experimental confirmation with optimal conditions (prediction) that uses 95% confidence level.

A quantitative calculation of quality loss caused by the variance of the product can be done by calculate the quality loss function. From the calculation of average and standard deviation of the actual and optimal conditions, then the quality loss function for the actual and optimal conditions can be calculated. Although the costs incurred in optimal conditions is higher than the actual conditions, but the quality loss functions is less in optimal conditions. This is because the value of means in optimal conditions relatively higher than the actual conditions. QLF value is directly proportional to the cost and the variance, but inversely proportional to the amount of means.

To obtain a valid results, experimental using the optimal level factors is needs to be done . This can be seen in the experiment confirmation that although the confidence intervals of confirmation mostly located on the limits of the optimal interval, but the range of the experiment confirmation is still larger than the optimal confidence interval. That is because the number of experiment confirmation is inversely proportional to the value of F table, where the fewer number of experiments carried out, then the value of F table is greater. If the value of F table is larger, then the range of the confidence interval will be greater as well.

4. Conclusion
The results of experiments that have been carried out show that the strength and density of the Calcium Silicate board are influenced by the pulp type and the composition of the pulp type. Whereas product flexibility is influenced by pulp percentage. However, these factors do not affect the ability of the product to absorb water.

Optimal setting levels for the quality characteristics of the Calcium Silicate Board are setting level 2 for pulp percentage (9.8%), setting level 2 for pulp type (Y type pulp), and setting level 2 for pulp type composition (100%). For optimal conditions of product strength (strength test) at an interval of 147.32 ≤ prediction ≤ 160.68 (kg / cm²), the optimal conditions of product flexibility (deflection test) are at intervals : 14.91 ≤ μ_prediction ≤ 23.09 (mm) and the optimal conditions of product density (density test) are at intervals: 1,274 ≤ μ_predictions ≤ 1,388 (g / cm³) and the optimum conditions of product water...
absorption (water absorption test) are at intervals: 34.09 ≤ μ prediction ≤ 43.55%. Therefore from these results it can be stated H1 is accepted that there is the influence of factor (A/B/C) on the quality of the product (strength/deflection/density/water absorption).

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