2019 Scienceline Publication

*Journal of Civil Engineering and Urbanism*

**Volume 9, Issue 5: 43-47; September 25, 2019** **ISSN-2252-0430**

DOI: https://dx.doi.org/10.29252/scil.2019.jceu6

# Study on Components of Straw Filler Concrete using Orthogonal Experiment

**Dang Van Thanh** and **Pham Van Tinh**

*Department of Civil Engineering, Vietnam National University of Forestry, Hanoi, Vietnam*

Corresponding author's Email: thanhdv@vnuf.edu.vn; thanh40e@yahoo.com

RESEARCH ARTICLE
PII: S225204301900006-9
Received: August 10, 2019
Revised: September 20, 2019

**ABSTRACT**

Study on the use of agricultural residues in the production of construction materials is important in reducing construction costs, while minimizing environmental impacts. By using the orthogonal experimental design method and the experimental method in laboratory for determining slump of the concrete mix, compressive strength and volumetric mass of concrete, this paper shows the designing method of concrete component using straw fillers (straw filler concrete - straw concrete). Also, this study analyzes and assesses the influence of three factors: cement content, water content and straw content on basic features of designed concrete such as slump, volume and compressive strength, thereby determines the reasonable content of the components. Experimental results showed that, straw padded concrete meets the basic performance criteria for lightweight concrete when designed with reasonable components and the effect of these three factors on the basic features of straw concrete is very pronounced. Reasonable values of cement content, water content and straw content used to produce straw concrete mixture are: 14.6%; 10% and 2.04% respectively.

**Keywords:** Light weight concrete; Straw filler concrete; Agricultural by-product; Orthogonal Experiments.

## INTRODUCTION

Reducing environmental impacts is an increasingly significant requirement in the agricultural production activities of people at present, especially after harvesting rice. There are six tons of straw per hectare remained on the environment after harvesting, and almost of them are removed by burning or left in the field. This destructing is not only waste but also affecting to our environment. This study aims to utilize rice straw - a source of local materials available in rural areas to make concrete materials and meets the practical requirements of the new rural program, while contributing to reducing the negative impact of agricultural waste on the environment.

In fact, there were rarely researches published on using straw for building materials, especially aggregate of concrete, up to now. Brojan et al. (2013) compared using brick and straw bale wall by environmental, economic and energy perspectives showed that straw wall can be replaced for brick wall. Brick is the most commonly used building material worldwide, whereas straw, though widely available and having many advantageous properties, is still rarely exploited. In terms of environmental, economic and energy values, the use of straw components is a good alternative to bricks.

Brojan and Clouston (2014) through analyzing the advantages and disadvantages of straw building material concluded that together with natural plaster, the "breathing" straw wall has good sound absorption and good fire resistance that will create the inner environment of a quieter, safer and healthier home. Furthermore, materials for fabricating components are easy to use, lightweight and do not require much equipment. The authors also suggested that more research is needed to further promote technology and to make efforts in propagating the value of straw construction works and to make straw become the main construction material.

Farooqi and Ali (2016) recommend the wheat straw reinforced concrete has the potential to be used for the concrete pavement applications due to its post cracking behavior as it can elongate the period from the first crack up to the complete deterioration. Liu et al. (2012) concentrated on the impact of rice straw as additive material on physical properties of hollow block. When the rice straw amount portion was 0 to 15% of aggregate of hollow block, the compressive, flexural strength of hollow block decreased gradually. However, it is more suitable for building material. Alcorn and Donn (2010); Hall (2012) and Sodagar et al. (2011) showed that using straw bale as a construction material reduces the $CO_2$ emissions. It is estimated that over fifteen tones of $CO_2$ may be stored in biotic materials of each of the semi-detached houses of which around six tones are sequestered by straw and the remaining by wood products. The analysis result indicates that the carbon lockup potential of renewable materials used in the construction of the house is the capable of reducing 61% $CO_2$ emissions in sixty year life compared with the house built with the common materials.

In Vietnam, almost there is no official study on the use of straw as a material generally and as a concrete filler in particular. Using orthogonal test methodology (Shaohua and Fenghua, 2003) and the laboratory test methods: slump test, volume weight test and compressive strength test, this paper introduction of mixed component design method and analysed the influences of three material composition factors, namely: cement content (X), water content (N) and straw content to basic properties of straw concrete; thereby determining the reasonable content of these three factors for straw padded concrete to meet the requirements of lightweight concrete.

## MATERIAL AND METHODS

### Materials

Binder: Portland cement PCB-40 manufactured in Vietnam was used. The technical properties of the cement are in accordance with Vietnam standard TCVN 2682:2009 and are shown in Table 1. Fine aggregate and Coarse aggregate used for this study was produced from local sources in Hanoi city of Vietnam. Technical properites of fine and coarse aggergates were in accordance with Vietnam Standard (2006). Straw fillers used new straw (straw immediately after harvesting rice); the straw is dried, then cut into small pieces about 3 ÷ 5cm long. Before mixing, the straw is soaked in 20 ÷ 30 minutes in clean water, then picked out and drained. The images and processing of straw fillers are shown in Figure 1.

**Table 1.** Typical properties of cement PCB-40

| N° | Typical properties | Request |
|---|---|---|
| 1 | Compressive strength | |
| | 3 days (± 45 minutes) | ≥ 21 $N/mm^2$ |
| | 28 days ( ± 8 hours) | ≥ 40 $N/mm^2$ |
| 2 | Setting time | |
| | Initial | ≥ 45 min |
| | Final | ≤ 375 min |
| 3 | Fineness: | |
| | The amount of 0,09mm sieve | ≤ 10 % |
| | Blain rate | ≥ 2800 $cm^2/g$ |

**Figure 1.** Specification and process of straw fillers

### Study plan

Using theoretical calculation method combined with experiments to design basic components of straw concrete: by calculating for determination of the base concrete composition with the required average compressive strength is 20MPa (concrete B15); then, use the experimental method gradually (mixing, intuitive and test slump) to replace a part of coarse aggregate by straw and determine the initial material composition. Based on the initial material composition, cement content, water content and straw content are changed. Using the method of orthogonal experimental design the sample groups are manufacture. Afterwards, the indicators included slump of mix, volume weight and compressive strength of samples at 28 days of age are determined with reasonable contents for the material components through experiments.

### Orthogonal experimental design method

To evaluate the influence of these factors to performances of straw concrete, we use the orthogonal experimental design method (Brojan et al., 2013). The method studies the influence of many factors in experiments. Based on methods of scientific experiment, orthogonal method has advantages in minimizing numbers of experiments, thereby to reduce time and cost for doing experiments. In fact, this method is very efficient, fast and economical. The order for the design and analysis of experimental results according to the orthogonal experiment method can be divided into three steps: experimental plans design, experiment performance and analysis of experimental results.

### Basic testing methods

The basic property tests of aggregates, of concrete and concrete mixtures are done according to current Vietnamese standards:

TCVN 7572 - 1-18: 2006 - aggregate tests;

TCVN 3106: 1993 - method for slump test;

TCVN 3118: 1993 - method for determination of compressive strength;

TCVN 3115: 1993 - method for determination of density.

## RESULTS AND DISCUSSION

### Calculation and basic component selection results

**Determining the amount of mixing water.** The amount of water (N) was determined based on the conditions of the materials and designing requirements. Chosen concrete grade was B15 with average compressive strength $R_b$ = 20MPa; the coarse aggregate used had the largest diameter $D_{max}$ = 20mm. The slump of concrete mixture and the amount of mixing water was selected by the method used in common constructions (Shaohua and Fenghua, 2003): For coarse aggregate, crushed stones with $D_{max}$ = 20mm were used, and the slump of mixture

To cite this paper: Thanh DV and Tinh PV (2019). Study on Components of Straw Filler Concrete using Orthogonal Experiment. *J. Civil Eng. Urban.*, 9 (5): 43-47. www.ojceu.ir

was about 2 ÷ 4cm. The amount of water determined for $1m^3$ of the concrete was 200 liters.

**Determining the ratio of cement to water.** The ratio of cement to water (X/N) was based on the Bolomey – Skramtaev fomula (Huy et al., 2011):

Regular concrete (X/N = 1.4 ÷ 2.5):

$$\frac{X}{N} = \frac{R_{yc}}{AR_x} + 0.5$$

In which, $R_x$ – the strength of cement ($R_x$ = 40MPa); $R_{yc}$ – the strength of concrete at 28 days; A – the factors of raw materials, choose A = 0.6 (with good quality materials) (Huy et al., 2011). The cement –water ratio was finally calculated to be 1.42.

**Determining the amount of cement.** Determining the amount of cement (X) was based on X/N ratio which was determined in the above step. From the amount of water (N) = 200 litres and the X/N ratio = 1.42 determined above, the amount of cement for $1m^3$ of concrete was calculated to be 292 kg. The amount of cement should be compared to the amount of minimum and maximum cement ($X_{min}$ and $X_{max}$) which are based on the design standard. The determined cement amount was within the range for the minimum and maximum cement in Vietnam standard.

**Determining the amount of coarse and fine aggregates.** ***Determining the amount of coarse aggregate (D):*** The amount of coarse aggregate for $1m^3$ of concrete was determined as follows (Shaohua Z and Fenghua ed J - 2003).

$$D = \frac{1000}{\frac{k_d . r_D}{\gamma_{oD}} + \frac{1}{\gamma_{aD}}}; kg$$

Where: $\gamma_{0D}$ – volumetric weight of coarse aggregate; $\gamma_{aD}$ - density of solid particles of coarse aggregate; $r_D$ – porosity of coarse aggregate; $k_d$ – mortar residue coefficent. From the experimental results: $\gamma_{0D}$ = 1.48g/cm$^3$, $\gamma_{aD}$ = 2.8g/cm$^3$ và $r_D$ = 0.47; with the amount of cement is 292kg, mortar residue coefficient $k_d$ = 1.36.

Substituting all the paramaters into the formula, the amount of coarse aggregate in $1m^3$ of concrete was calculated: D = 1197kg.

***Determining the amount of fine aggregate (C):***

After the amount of the mixing water (N), cement (X) and coarse aggregate (D) were determined, the fine aggregate (C) for $1m^3$ of concrete was calculated using the following formula (Huy et al., 2011):

$$C = \left[1000 - \left(\frac{X}{\gamma_{aX}} + \frac{D}{\gamma_{aD}} + N\right)\right] . \gamma_{aC}; kg$$

Where: $\gamma_{aX}$ – weight of solid particles of cement ($\gamma_{aX}$ = 3.05g/cm$^3$); $\gamma_{aD}$ – weight of solid particles of coarse aggregate ($\gamma_{aD}$ = 2.8g/cm$^3$); $\gamma_{aC}$ – weight of solid particles of fine aggregate ($\gamma_{aC}$ = 2.75g/cm$^3$). Substituting all these paramaters into the above formula gives the amount of fine aggregate: C = 747kg.

**Determine the amount of straw to replace a part of coarse aggregate.** From the calculation results of concrete base components, try gradually by mixing, visual observation and slump measurement, the finally amount of large aggregate is determined by reducing 40% (compared to the volume of initial coarse aggregate) and replacing this amount with straw with a content of 1.46% (percentage between dry weight of straw and the total volume of the mixture). Specifically, the calculation results and selected initial materials of straw concrete production are shown in Table 2.

**Results of determining orthogonal experimental plans**

Based on the calculation results and selection of initial material components (Table 2), we selected 4 experimental levels for each influencing factor, shown in Table 3. From the data in Table 3, using the orthogonal experimental design method in Alcorn, A. and Donn, M. (2010) to design, obtained 16 experimental groups, specifically as shown in Table 4.

**Table 2**. The original material composition

| Materials | **D** | **C** | **X** | **N** | **R** | **Total** |
|---|---|---|---|---|---|---|
| Mass, kg | 718 | 761 | 292 | 200 | 29,2 | 2000 |
| Content, % | 35,90 | 38,05 | 14,60 | 10,00 | 1,46 | 100 |

**Table 3.** The influence factors, experimental levels and composition of manufactured materials

| **Exp levels** | **Influence factors** | | | **D, % (kg)** | **C, % (kg)** |
|---|---|---|---|---|---|
| | **X, % (kg)** | **N, % (kg)** | **R, % (kg)** | | |
| 1 | 12.60 (252) | 9.50 (190) | 1.46 (29.20) | 35.90 (718) | 38.05 (761) |
| 2 | 14.60 (292) | 10.00 (200) | 1.75 (35.04) | 35.90 (718) | 38.05 (761) |
| 3 | 16.60 (332) | 10.50 (210) | 2.04 (40.88) | 35.90 (718) | 38.05 (761) |
| 4 | 18.60 (272) | 11.00 (220) | 2.34 (46.72) | 35.90 (718) | 38.05 (761) |

**Table 4.** Tested results of sample groups

| **TT** | **X** | **N** | **R** | **$S_1$, cm** | **$\gamma_0$, g/cm$^3$** | **$R_b$, MPa** |
|---|---|---|---|---|---|---|
| 01 | 1(12.6) | 1(9.5) | 1(1.46) | 4.0 | 1.98 | 4.50 |
| 02 | 1 | 2(10) | 2(1.75) | 5.5 | 1.86 | 3.30 |
| 03 | 1 | 3(10.5) | 3(2.04) | 6.5 | 1.74 | 2.70 |
| 04 | 1 | 4(11) | 4(2.34) | 7.0 | 1.65 | 2.30 |
| 05 | 2(14.6) | 1 | 2 | 1.0 | 1.76 | 3.60 |
| 06 | 2 | 2 | 3 | 2.0 | 1.70 | 4.78 |
| 07 | 2 | 3 | 4 | 3.0 | 1.66 | 2.80 |
| 08 | 2 | 4 | 1 | 9.0 | 1.83 | 5.50 |
| 09 | 3(16.6) | 1 | 3 | 0 | 1.76 | 2.70 |
| 10 | 3 | 2 | 4 | 0 | 1.71 | 2.50 |
| 11 | 3 | 3 | 1 | 8.0 | 1.89 | 5.30 |
| 12 | 3 | 4 | 2 | 7.0 | 1.82 | 3.95 |
| 13 | 4(18.6) | 1 | 4 | 0 | 1.68 | 3.20 |
| 14 | 4 | 2 | 1 | 6.5 | 2.04 | 6.90 |
| 15 | 4 | 3 | 2 | 4.0 | 1.90 | 5.50 |
| 16 | 4 | 4 | 3 | 3.0 | 1.77 | 3.55 |
| Request | | | | 2 - 4[14] | ≤ 1.8[16] | ≥ 1.0[16] |

**Orthogonal experiment results**

Based on the orthogonal experimental plan designed and experimental procedures, experiments are carried out to determine the initial slump ($S_1$), compressive strength at 28 days in natural dry state ($R_b$) and the volumetric weight of 28-day-old in the natural dry state ($\gamma_0$) of the concrete sample groups. From Table 4 shows, the sample group were satisfactory on the minimum compressive strength with lightweight concrete regulations. The maximum compressive strength reaches the highest value when the contents of X, N and R are 18.6%, 10% and 1.46%, respectively; the compressive strength reaches the smallest value when the contents of X, N and R are: 12.6%, 11% and 2.34%, respectively. Therefore, the selection of reasonable values of X, N and R content is mainly based on the consideration of two criteria: Slump and Volumetric weight.

**Analysis of optimal options**

From the results of experiments conducted orthogonal analysis of factors affecting the criteria to select the optimal concentrations, respectively; analysis results are shown in Table 5. Results of the general equilibrium analysis in Table 5, shows that the slump of the mixture will be greatest when the contents of X, N and R are 12.6%, 11% and 1.46%, respectively; the volumetric weight will be greatest when the contents of X, N and R are 12.6%, 11% and 2.34% respectively; the compressive strength will be greatest when the contents of X, N and R are 18.6%, 10% and 1.46%, respectively. Also, it can be preliminary assessment that as the cement content increases, the compressive strength increases; the water content increases, the slump increases; the straw content increases, the volumetric weight decreases. This is completely consistent with the structural principle of concrete.

Combined with the experimental results in Table 4, it is very clearly that there are 3 sample groups can satisfy all 3 criteria simultaneously (Slump, Volumetric weight and Compressive strength), that are the sample groups in order: 06, 07 and 16. In which, sample group No. 06 has the advantage of small cement content, high straw content, but the highest compressive strength and reasonable volumetric weight.

Finally, we choose reasonable values for the cement content, water content and straw content, respectively: 14.6%, 10% and 2.04%. For component materials with selected content, the designed straw type has the slump, the volumetric weight and the compressive strength respectively: 2cm, 1.7g / cm$^3$ and 4.78 MPa.

To assess the degree of influence and reliability, we conducted variance analysis. Analysis results are shown in Table 6. From Table 6, it can be seen that the F values correspond to the influence of cement content, water content and straw content on slump, volumetric weight and compressive strength are greater than values of $F_{0.05}$ and $F_{0.09}$. This shows that the effect of all three factors on the performance characteristics of straw concrete is very clear.

**Table 5.** Results of general equilibrium analysis

| Indicator | Parametric analysis | X (%) | N (%) | R (%) |
|---|---|---|---|---|
| Slump - $S_1$ | $K_1$ | 23.000 | 5.000 | 27.500 |
| | $K_2$ | 15.000 | 14.000 | 17.500 |
| | $K_3$ | 15.000 | 21.500 | 11.500 |
| | $K_4$ | 13.500 | 26.000 | 10.000 |
| | The variance | 13.92188 | 63.42188 | 47.29688 |
| | Optimal scheme | | $X_1N_4R_1$ | |
| Volumetric weight - $\gamma_0$ | $K_1$ | 7.230 | 7.180 | 7.740 |
| | $K_2$ | 6.950 | 7.310 | 7.340 |
| | $K_3$ | 7.180 | 7.190 | 6.970 |
| | $K_4$ | 7.390 | 7.070 | 6.700 |
| | The variance | 0.02482 | 0.00722 | 0.15337 |
| | Optimal scheme | | $X_1N_4R_4$ | |
| Compressive strength - $R_b$ | $K_1$ | 12.800 | 14.000 | 22.200 |
| | $K_2$ | 16.680 | 17.480 | 16.350 |
| | $K_3$ | 14.450 | 16.300 | 13.730 |
| | $K_4$ | 19.150 | 15.300 | 10.800 |
| | The variance | 5.70395 | 1.63970 | 17.63595 |
| | Optimal scheme | | $X_4N_2R_1$ | |

**Table 6.** Values of the variance analysis (Note: $F_{0.05}$ - significant at 95% probability; $F_{0.01}$ - significant at 99% probability)

| Element | $F_{S1}$ | $F_{\gamma 0}$ | $F_{Rb}$ | $F_{0.05}$ | $F_{0.01}$ |
|---|---|---|---|---|---|
| Cement content - X | 0.69 | 0.59 | 1.05 | 4.76 | 9.78 |
| Water content - N | 3.12 | 0.17 | 0.30 | 4.76 | 9.78 |
| Straw content - R | 2.33 | 3.66 | 3.26 | 4.76 | 9.78 |

## CONCLUSION

Taken the B15 mixture as a basic concrete, straw padded concrete components are designed and analyzed to assess the effect of cement content, water content and straw content on the performance of this mixture. The study results showed that the effect of all three factors on the performance characteristics of straw concrete is very clear. Through a general analysis of the effect of orthogonal experimental results, reasonable values for cement content, water content and straw content were selected: 14.6%, 10% and 2.04%. With the selected component contents, the type of straw concrete is designed to ensure the slump, volumetric weight and compressive strength of lightweight concrete. Thereby, it can be determined that the type of straw concrete as well as the design of straw concrete components according to the orthogonal testing method is feasible.

### Competing interests

The author declare that it has no competing interests.

## REFERENCES


Alcorn A and Donn M (2010). Life Cycle Potential of Strawbale and Timber for Carbon Sequestration in House Construction. Coventry University and the University of Wisconsin Milwaukee Centre for By-products Utilization, Second International Conference on Sustainable Construction Materials and Technologies, June 28–30, 2010. Google Scholar

Brojan L and Clouston PL (2014). Prednosti in Slabosti Uporabe Bal Slame Pri Gradnji/ Advantages and Disadvantages of Straw-Bale Building. Arhitektura, Raziskave/ Architecture Research, 2014(1), 21. Google Scholar

Brojan LPA and Clouston PL (2013). A comparative study of brick and straw bale wall systems from environmental, economical and energy perspectives. ARPN Journal of Engineering and Applied Science, 8: 920-926. Google Scholar

Farooqi MU and Ali M (2016). Compressive Behavior of Wheat Straw Reinforced Concrete for Pavement Applications. Fourth International Conference on Sustainable Construction Materials and Technologies, Las Vegas, USA, August 7-11. Google Scholar

Hall M (2012). Earth and Straw Bale: An investigation of their performance and potential as building materials in New Zealand. Victoria University of Wellington, Master thesis of Architecture 2012. Google Scholar

Huu P D, Quang N T, Loc M D (2011). Building materials. Communication and Transport Press, Hanoi,

Liu J, Zhou H H and Zhang B (2012). Effect of Rice Straw Amount Portion on Physical Properties of Adding Admixtures Hollow Block. In *Advanced Materials Research* (Vol. 450, pp. 727-732). Trans Tech Publications. Google Scholar

Shaohua Z and Fenghua ed J (2003). Experimental design and data processing. Beijing: Chinese Building Materials Industry Press.

Sodagar B, Rai D, Jones B, Wihan J, and Fieldson R (2011). The carbon-reduction potential of straw-bale housing. Building Research & Information, 39(1): 51-65. Google Scholar

Vietnam Standard TCVN 2682:2009 - Portland cements – Specifications. Hanoi, 2009.

Vietnam Standard TCVN 3106:1993 – Heavyweight concrete – Method for slump test. Hanoi, 1993.

Vietnam Standard TCVN 3115: 1993 – Heavyweight concrete - Method for determination of density.

Vietnam Standard TCVN 3118:1993 – Heavyweight concrete – Method for determination of compressive strength. Hanoi, 1993.

Vietnam Standard TCVN 7570:2006 – Aggregates for concrete and mortar – Specifications. Hanoi, 2006.

Vietnam Standard TCVN 7572 - 1-18: 2006 – aggregate tests.

Vietnam Standard TCVN 9029: 2017 – Lightweight concrete – Foam concrete and non-autoclaved aerated concrete products - Specifications.