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Enhancement of Cement Sand Brick Incorporating Spent Catalyst and Copper Slag as Sustainable Partial Sand Replacements

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Abstract

The use of waste materials in the manufacturing of cement sand brick constitutes a big step forward in sustainable building approaches. The partial sand replacement with waste materials, especially residual materials that can be reused in the field of construction such as spent catalyst and copper slag, has the potential to minimize environmental pollution and lead to more sustainable buildings. This study used spent catalyst and copper slag as a partial sand replacement material ranging 10% to 90% and examines the effect on the properties of cement sand bricks. Apart from that, the study used the Design Expert software approach to systematically analyzed the effect of various materials on the compressive strength and hardened density of cement sand brick. It was used to optimize the mix proportions and analyzed the correlations between four factors variables: targeted density, cement to sand ratio, proportion of sand and spent catalyst to copper slag ratio and the two responses: compressive strength and hardened density. The results show that spent catalyst and copper slag has greatly increases the compressive strength of the brick up to 26.98 MPa while hardened density reached the highest 2009.09kg/m^3. Hence, the replacement of 10% spent catalyst has greatly enhance the compressive strength of cement sand brick while 90% replacement of copper slag has increased the hardened density.

1. Introduction

Cement sand brick is the most common form of brick used. The demands for sustainable construction materials are growing due to environmental and waste management concerns. The brick industry, well known for its huge environmental impacts and waste production, is looking into new eco-friendly options. It was frequently utilized in civil engineering structure and the majority of infrastructure requires brick, cement, and sand. Apart from that, cement sand brick is the main building worldwide material and concrete structures are mostly used in civil engineering. Due to the widespread use of bricks, the demand and manufacture of bricks will increase and at the same time the source of river sand will decrease where river sand is one of the natural resources to produce bricks.

Therefore, by replacing the spent catalyst and copper slag as sand replacement as one of the alternative materials is significant to encounter these issues.

The use of spent catalyst in construction industry are explored as a sustainable alternative material. According to estimations, the annual output of spent catalysts varies from 200,000 to 400,000 tons in a year [1]. This will cause the production rate of spent catalyst to increase. Spent catalyst was obtained from petroleum cracking in the oil-refinery sector which mostly composed of active silica and alumina [2]. Several researchers suggested other techniques for managing spent catalyst, such as metal reclamation, landfill disposal, and converting spent catalysts into valuable goods to replace sand [3]. Spent catalyst has a large specific surface area and a strong pozzolanic reaction [4]. Additionally, silicates and aluminates make up about 80% of its components. It may use to make bricks by partially or completely replacing traditional raw materials such as sand without affecting the compressive strength [5].

Copper slag is a kind of non-ferrous slag and by product which obtained during smelting and refining of copper [6]. These waste material produces one ton of refined copper which accompanied by the fabrication of 2-3 tons of copper slag and it shows that the production of copper slag produced is high in a year [7]. Apart from that, a sizable amount of copper slag builds up in open stockpiles as a result of its low comprehensive utilization rate, which causes a major resource waste and environmental contamination. Hence, this study intends to establish the performance, strength, and density of sand cement bricks including a mix of spent catalyst and copper slag as partial sand replacement materials to reduce the production of waste. To enhance the compressive strength and hardened density of cement sand brick, sand was replaced with spent catalyst and copper slag to produce sustainability alternatives.

2. Experimental Work

This subsection has been divided into three parts which is raw material preparation, preparation of brick mixing and mix design using design of expert v13 software.

2.1 Raw Material

Sand (fine aggregate), Ordinary Portland Cement (OPC), spent catalyst, copper slag and tap water are some of the substances utilized in cement sand brick production. Based on the Fig. 1 shows the copper slag and spent catalyst which are the main replacement materials were obtained from two different places which is spent catalyst from Qualitest Engineering Sdn Bhd (QESB) in Kemaman, Terengganu while copper slag from Malaysia Marine and Heavy Engineering (MMHE) in Pasir Gudang, Johor. Both of the waste materials were used as the main sand replacement component in cement sand brick production.

The spent catalyst was crushed using milling jaw crusher and was sieved using sieve pan. The sample of spent catalyst and copper slag that passing of 2mm sieves were used as sand replacement. By using the particle distribution test, Table 1 shows that sand having fines modulus of 2.78, spent catalyst is 3.70 and copper slag is 1.74 respectively. Hence, both waste materials are potentially suitable to be used as sand replacement based on the trend of line and fineness modulus in Fig. 2. For brick preparation and curing, tap water was used.

(a) **(b)**

Fig. 1 *(a) Copper slag; (b) Spent catalyst after grind*

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Table 1 *Physical properties of materials*

Properties	Sand	Spent Catalyst	Copper Slag
Physical State	Solid	Solid	Solid
Shape	Rounded	Rounded	Irregular
Colour	Light Yellow	Grey	Black
Fineness Modulus	2.78	3.40	1.74
Specific Gravity	2.60	2.28	3.38

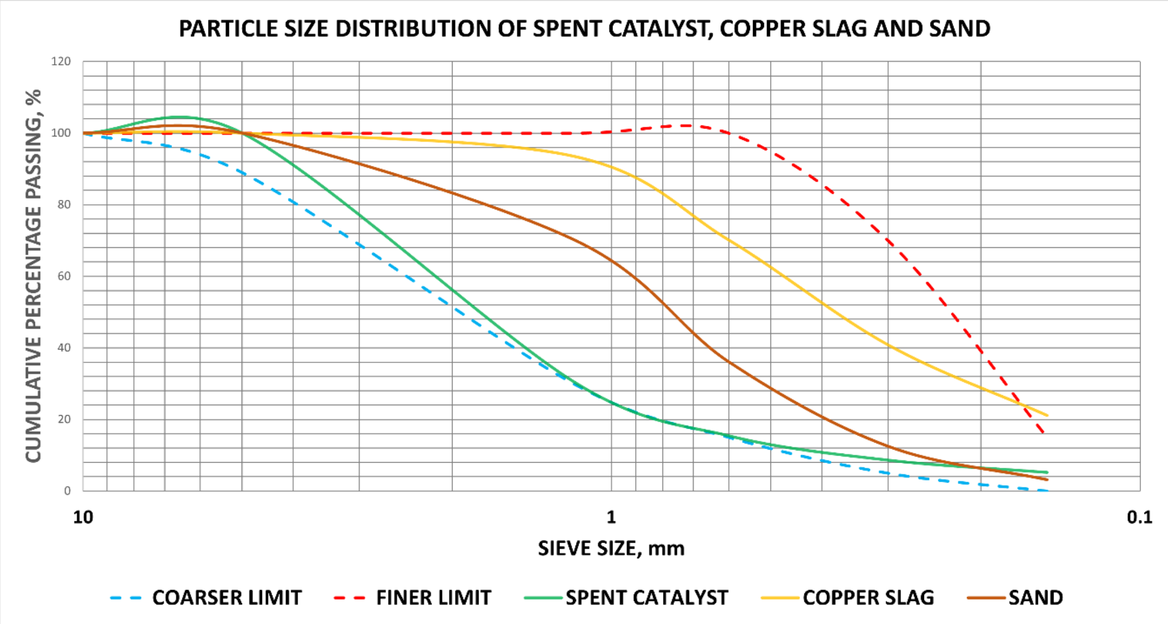

Fig. 2 *Particle distribution of spent catalyst, copper slag and sand*

2.2 Preparation of Brick Mixing

The 64 specimens were casted with each specimen's mix consists of four bricks of [100mm(l) x 220mm(w) x 65mm(h)] for compressive strength and hardened density. The cement sand brick with composition of cement to sand ratio as 1:8 was prepared with sand partially replaced by spent catalyst and copper slag ranging from 10% to 90% replacement. The water cement ratio of the cement sand brick was varying from 0.6 to 0.8. Table 2 shows the series of sand replacement mix proportion for cement sand brick. The cement sand brick was casted and air cured for 28 days as shown in Fig. 3 (a) and (b).

Table 2 *Series of sand replacement mix proportion*

Series	Percent of sand (%)	Waste Material Spent Catalyst + Coper Slag
A	10	90
B	30	70
C	50	50
D	70	30
E	90	10

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(a) **(b)**

Fig. 3 *(a) Cement sand brick casting; (b) Air curing*

2.3 Design of Expert Software

The design of expert software version 13 was created by using a statistical technique that provides substantial benefits in terms of time and cost effectiveness for creating materials with several components such as cement sand brick. This approach entails identifying variables that affect the brick's characteristics. It makes it possible to determine the main elements influencing brick variability, makes it easier to compare various variables, and it helps in the creation of a mathematical model that forecasts future outcomes.

In this study, the two-level factorial method was used is 2^4 which equivalent to 16 experimental runs by using the design of expert to achieve optimal production in bricks. Table 3 shows the design of mix ratio using design expert software in bricks and the responses for compressive strength and hardened density. The factors that have been selected are the main factors that may influenced the cement sand brick and it shows the high and low value for each factor.

Table 3 *Mix design factor in cement sand bricks*

Run.	Factor 1: Targeted Density	Factor 2: Cement-Sand ratio	Factor 3: Proportion of sand	Factor 4: Spent Catalyst and Copper Slag
1	1600	0.2	0.9	0.9
2	2100	0.2	0.1	0.1
3	2100	0.09	0.1	0.9
4	2100	0.09	0.9	0.9
5	2100	0.2	0.9	0.9
6	1600	0.2	0.9	0.1
7	1600	0.09	0.1	0.9
8	1600	0.09	0.1	0.1
9	2100	0.2	0.9	0.1
10	2100	0.09	0.9	0.1
11	1600	0.2	0.1	0.1
12	1600	0.2	0.1	0.9
13	1600	0.09	0.9	0.9
14	1600	0.09	0.9	0.1
15	2100	0.09	0.1	0.1
16	2100	0.2	0.1	0.9

3. Method of Testing

This subsection part concerned on physical behaviors of the cement sand brick samples for compressive strength and hardened density tests.

3.1 Compressive Strength Test

The purpose of compressive strength test is to determine a cement sand brick's compressive strength according to BS EN 12390-3:2009. Compressive strength will be carried out using universal testing machine as Fig. 4.

Fig. 4 *Universal testing machine*

3.2 Hardened Density Test

As according to BS 12390-7:2009, the density test is related with the physical behaviors of cement sand brick which contains with spent catalyst and copper slag. As it generally known, the density of cement sand brick is typically determined by the cement and sand with compound inside it. Hence, this study was conducted to investigate the influence of spent catalyst and copper slag on cement sand brick density. The brick density was identified and interpreted by using a formula in Eq. (1).

$$Density, \rho = \frac{mass\ (kg)}{volume\ (m^3)} \tag{1}$$

3.3 Main Factors Effect Analysis

The Pareto plot helps users to determine the factor and interaction effects that are most essential for the process or design optimization studies [8]. It shows the absolute values of the effects and creates a reference line on the graph. In this study, the impacts of these parameters and their interactions on compressive strength are investigated using the Pareto chart. In Fig. 5, partially colored bars indicate manually selected factors, whereas completely colored bars reflect those left unselected. Positive effects are depicted by orange bars, while negative effects are shown by blue bars. This research helps discover key parameters affecting compressive strength. The Pareto chart's bar arrangement and height indicate the order and degree of their impacts on compressive strength. The length of each bar is the t-value linked with the relevant estimated factors in software.

Based The Pareto chart includes two limit lines which is the Bonferroni limit line and the t-value limit line, with values of 17.2772 and 4.30265, respectively. Coefficients and t-values coefficients over the Bonferroni line tend to be very significant, while those between the Bonferroni line and the t-value limit line are possibly significant. In Fig. 5 shows the analysis of the Pareto chart that components D, CD, B, BC, ABCD and ABC have a considerable influence on compressive strength which above the t-value limit of 4.30265. Fig. 6 illustrates the analysis of the chart shows that components A, B, C, D, AD, ABCD, AC, ACD, BD, BC, ABC, and AB have considerable influence on hardened density which above the t-value limit of 4.30265.

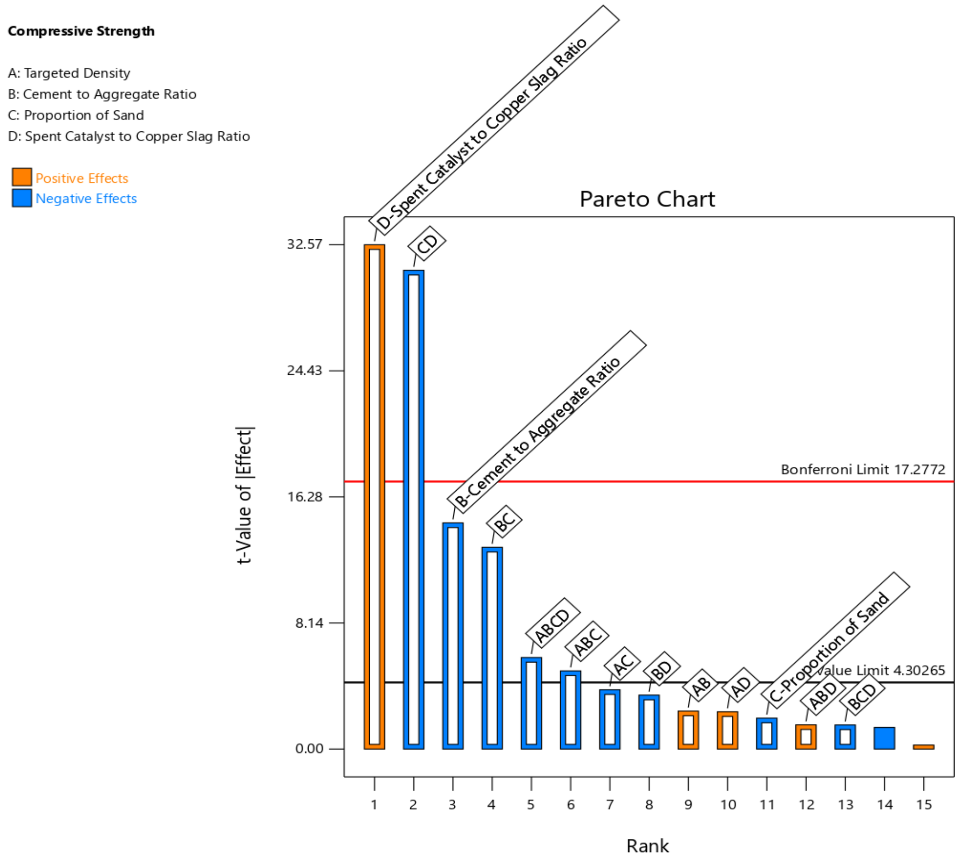

Fig. 5 *Pareto plot for compressive strength*

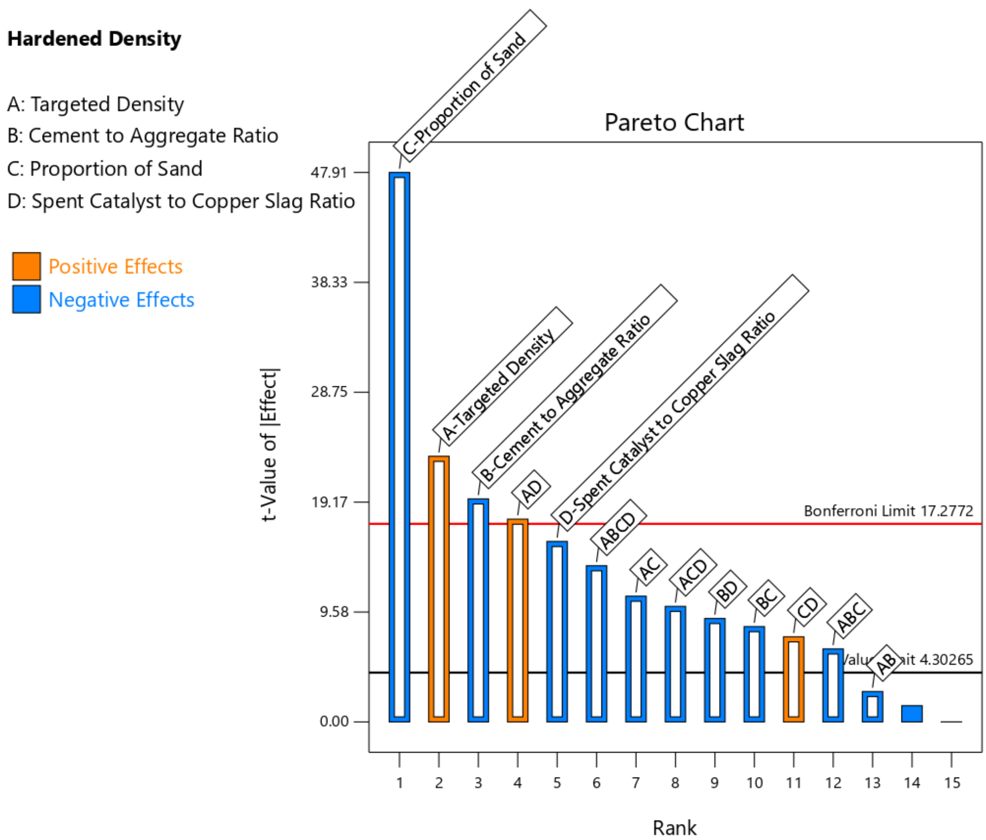

Fig. 6 *Pareto plot for hardened density*

4. Result and Discussion

4.1 Compressive Strength Model Analysis

The compressive strength run in a software shows a definite trend in cement sand brick performance when using spent catalyst and copper slag as partial replacement for sand. The statistical models created using the Design of Expert version 13 software framework shows a high correlation coefficient (R^2 = 0.9693), demonstrating the dependability of the experimental design, and considerable prediction accuracy at 28 days curing.

Based on the Table 4, shows the run result of compressive strength for series A which is 10% replacement of sand and 90% replacement of waste materials. From the analysis, the highest compressive strength value is from sample 9A while the lowest from sample 1A which is 44.19 MPa and 1.51 MPa respectively. The results show for sample 3A until 9A increasing except only sample 1A and 2A shows the below control sample of value. In Fig. 4 illustrates the increasing trend of compressive strength series A.

Table 4 *Compressive strength with 10% of sand and 90% waste material*

Sample	Percent of Sand (%)	Percent of Waste Material (90%)		Compressive Strength (MPa)
		Spent Catalyst (%)	Copper Slag (%)	
Control	100	0	0	11.44
1A	10	10	90	1.51
2A		20	80	6.84
3A		30	70	12.18
4A		40	60	17.51
5A		50	50	22.85
6A		60	40	28.18
7A		70	30	33.52
8A		80	20	38.85
9A		90	10	44.19

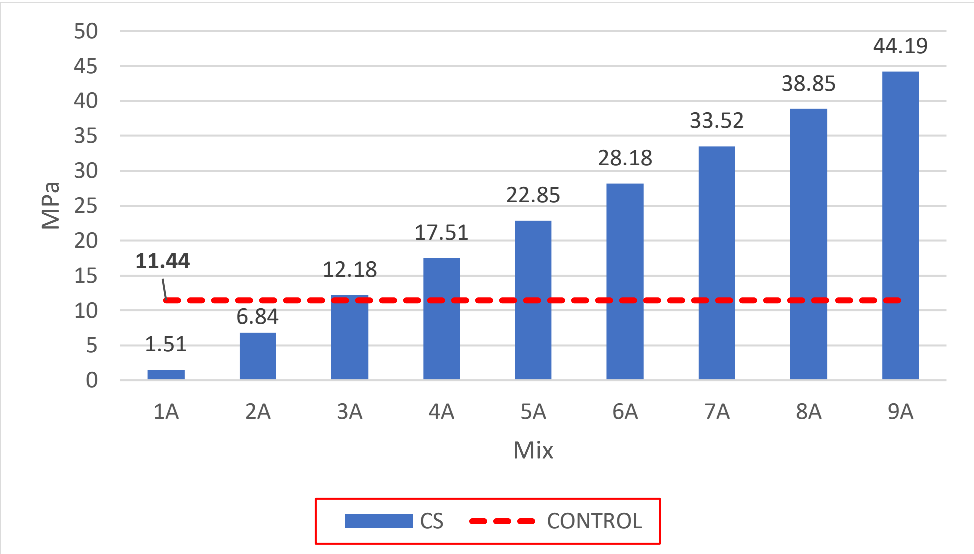

Fig. 7 *Compressive strength for series A*

Table 5 shows the result of compressive strength for series B which is 30% replacement of sand and 70% replacement of waste materials. From the analysis, the highest compressive strength value is from sample 9B while the lowest from sample 1B which is 40.31 MPa and 7.45 MPa respectively. The findings indicate for sample 2B until 9B increasing except only sample 1B shows the below control sample of value. In Fig. 8 illustrates the increasing trend of compressive strength series B.

Table 5 *Compressive strength with 30% of sand and 70% waste material*

Sample	Percent of Sand (%)	Percent of Waste Material (70%)		Compressive Strength (MPa)
		Spent Catalyst (%)	Copper Slag (%)	
Control	100	0	0	11.44
1B	30	10	90	7.45
2B		20	80	11.56
3B		30	70	15.67
4B		40	60	19.77
5B		50	50	23.88
6B		60	40	27.99
7B		70	30	32.09
8B		80	20	36.2
9B		90	10	40.31

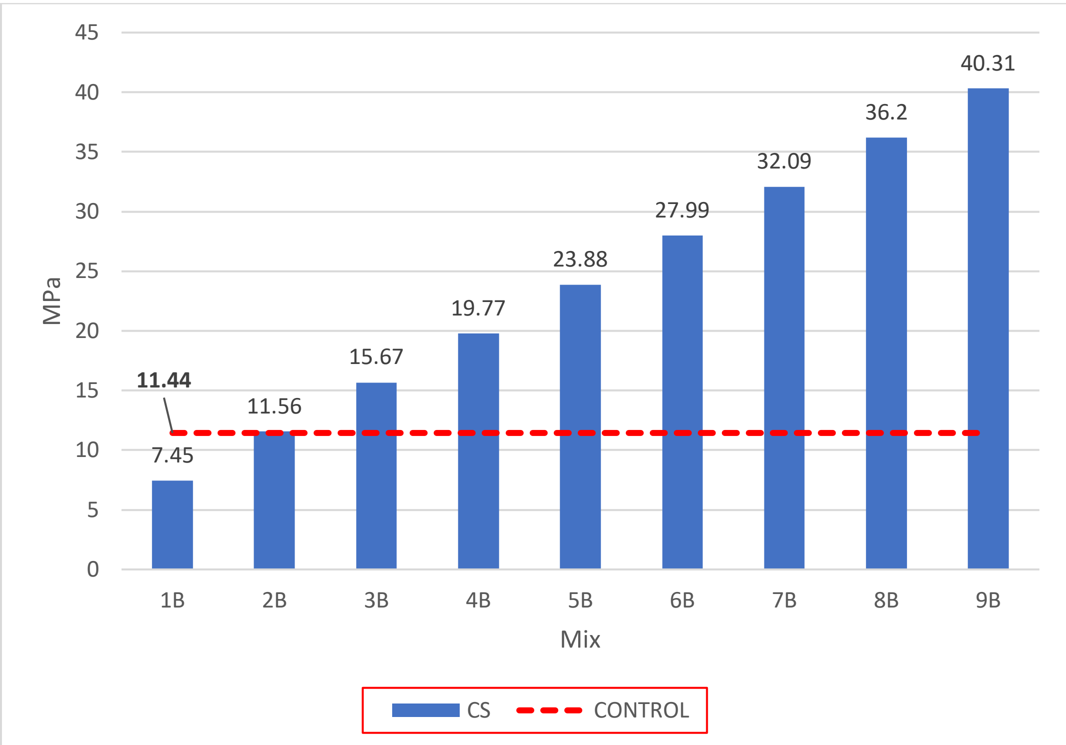

Fig. 8 *Compressive strength for series B*

Table 6 shows the result of compressive strength for series C which is 50% replacement of sand and 50% replacement of waste materials. From the analysis, the highest compressive strength value is from sample 9C while the lowest from sample 1C which is 36.43 MPa and 13.4 MPa respectively. The findings indicate for all sample 1C until 9C increasing significantly above the control sample of value. In Fig. 9 displays the increasing trend of compressive strength for series C. This increase is also influenced by the percentage of waste materials incorporated into the cement sand bricks.

Table 6 *Compressive strength with 50% of sand and 50% of waste material*

Sample	Percent of Sand (%)	Percent of Waste Material (50%)		Compressive Strength (MPa)
		Spent Catalyst (%)	Copper Slag (%)	
Control	100	0	0	11.44
1C	50	10	90	13.4
2C		20	80	16.28
3C		30	70	19.16
4C		40	60	22.04
5C		50	50	22.04
6C		60	40	27.79
7C		70	30	30.67
8C		80	20	33.55
9C		90	10	36.43

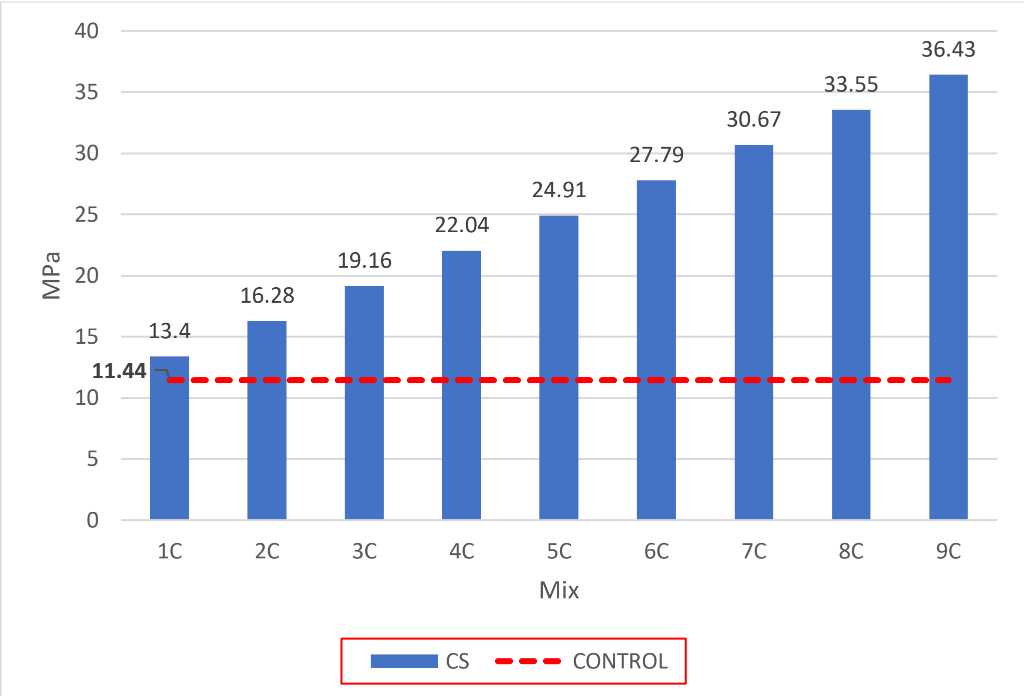

Fig. 9 *Compressive strength for series C*

Table 7 shows the result of compressive strength for series D which is 70% replacement of sand and 30% replacement of waste materials. Refer to analysis, the highest compressive strength value is from sample 9D while the lowest from sample 1D which is 32.55 MPa and 19.35 MPa respectively. The findings indicate for all sample 1D until 9D increasing significantly above the control sample of value. In Fig. 10 portrays the increasing trend of compressive strength for series D.

Table 7 *Compressive strength with 70% of sand and 30% of waste material*

Sample	Percent of Sand (%)	Percent of Waste Material (30%)		Compressive Strength (MPa)
		Spent Catalyst (%)	Copper Slag (%)	
Control	100	0	0	11.44
1D	70	10	90	19.35
2D		20	80	20.99
3D		30	70	22.65
4D		40	60	24.3
5D		50	50	25.95
6D		60	40	27.6
7D		70	30	29.25
8D		80	20	30.9
9D		90	10	32.55

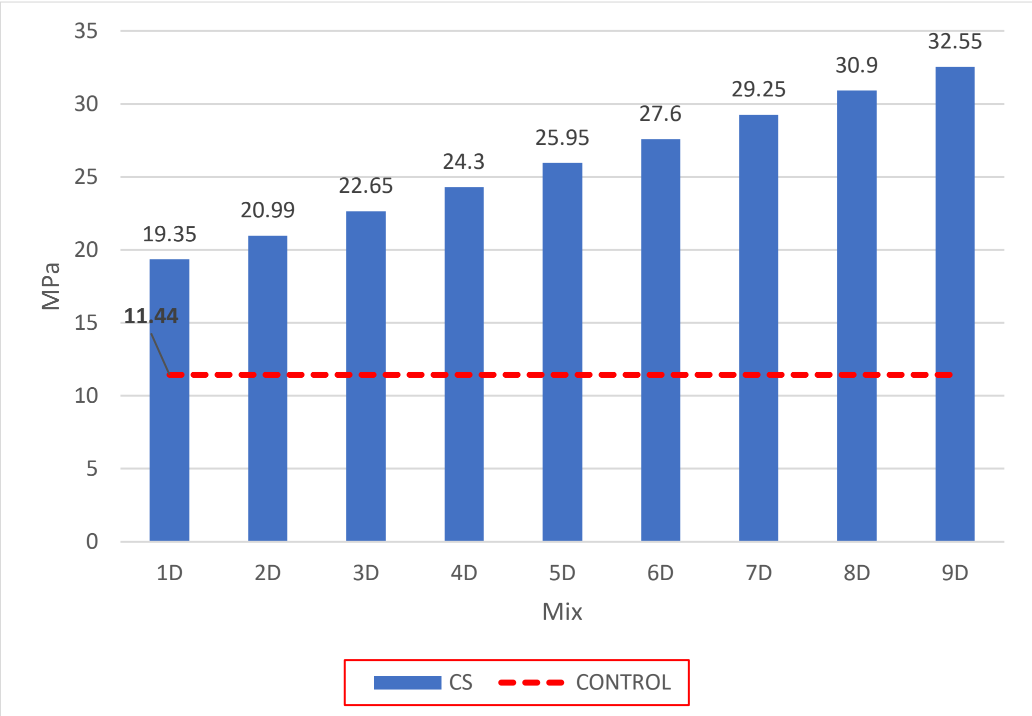

Fig. 10 *Compressive strength for series D*

According to the Table 8, the result of compressive strength for series E which is 90% replacement of sand and 10% replacement of waste materials. From the analysis, the highest compressive strength value is from sample 9E while the lowest from sample 1E which is 28.67 MPa and 25.29 MPa respectively. The findings indicate for all sample 1E until 9E increasing significantly above the control sample of value. In Fig. 11 displays the increasing trend of compressive strength for series E. The results show that the maximum compressive strength increased by up to 150% compared to the control value, demonstrating the effectiveness of the replacement materials.

Table 8 *Compressive strength with 90% of sand and 10% of waste material*

Sample	Percent of Sand (%)	Percent of Waste Material (10%)		Compressive Strength (MPa)
		Spent Catalyst (%)	Copper Slag (%)	
Control	100	0	0	11.44
1E	90	10	90	25.29
2E		20	80	25.72
3E		30	70	26.14
4E		40	60	26.56
5E		50	50	26.98
6E		60	40	27.4
7E		70	30	27.82
8E		80	20	28.25
9E		90	10	28.67

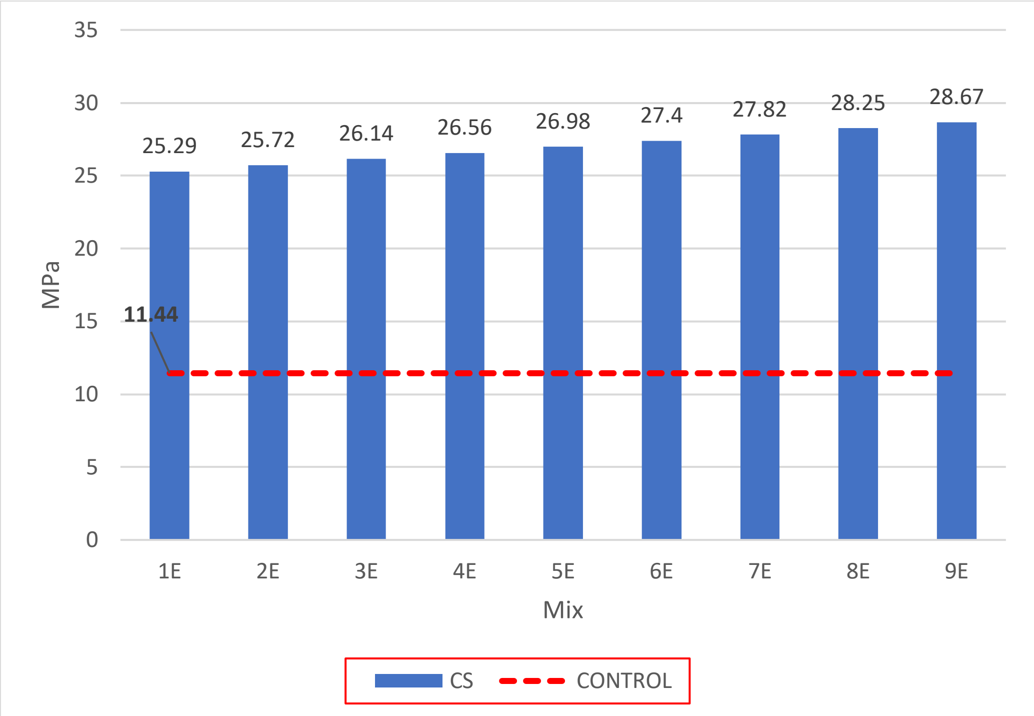

Fig. 11 *Compressive strength for series E*

4.2 Hardened Density Model Analysis

Hardened density is defined as the mass per unit volume of a hardened cement sand brick, which includes both the solid material and any voids present. All figure below shows how different quantities of spent catalyst and copper slag as part of the 10% to 90% waste material replacing sand affect the hardened density of cement sand bricks. The overall results display all series of hardened density was passed the mix control which is 1900 kg/m^3. Fig. 10 shows the decreasing trend of hardened density at 10% of sand and 90% of waste materials. The highest density is in series 1A is 2178.05 kg/m^3 while the lowest at 9A which 2130.24 kg/m^3. The trend of graph Fig. 10, Fig. 11, Fig. 12 and Fig. 13 shows the hardened density is decreasing where all the series was passed mix control while only Fig 14 depicts the increasing trend of hardened density at 90% sand and 10% of waste materials. It is clearly shows when the higher percentage of copper slag, the density will increase significantly.

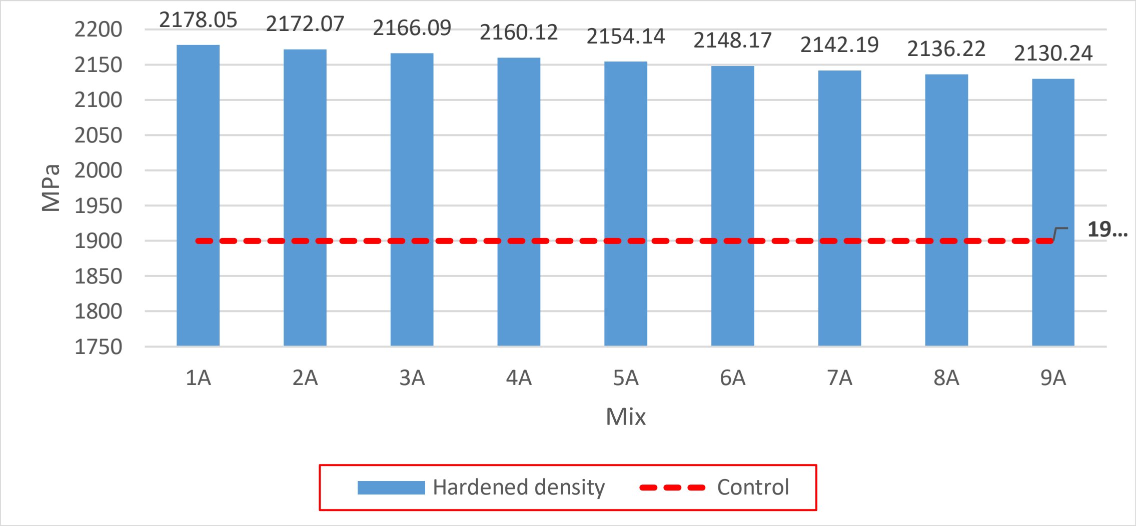

Fig. 12 *Hardened density for series A*

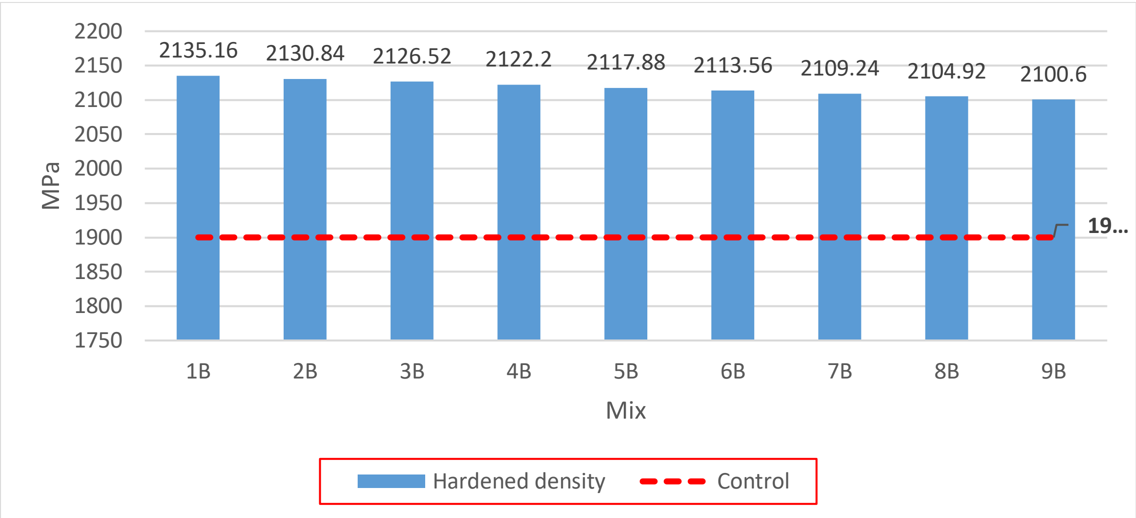

Fig. 13 *Hardened density for series B*

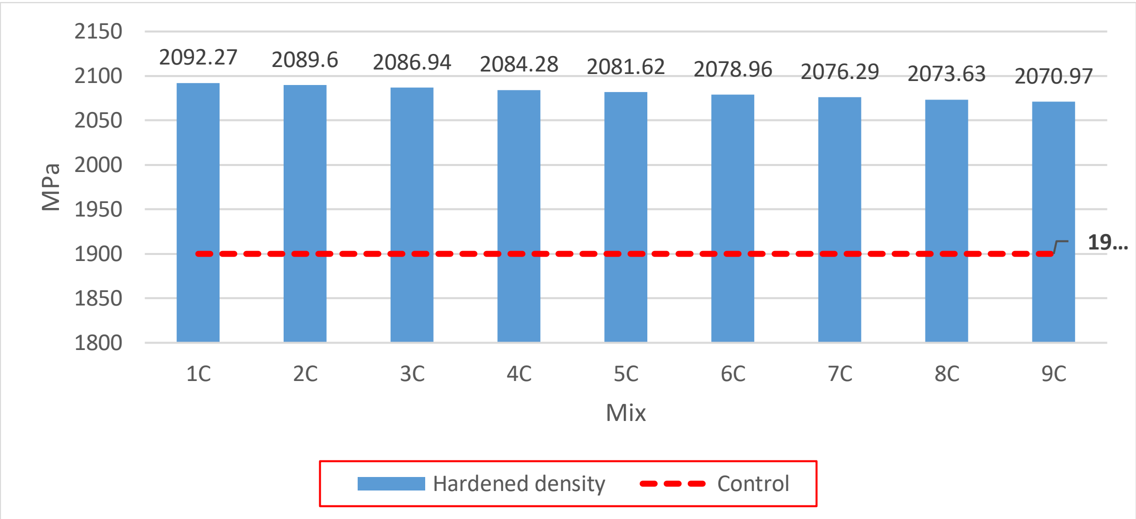

Fig. 14 *Hardened density for series C*

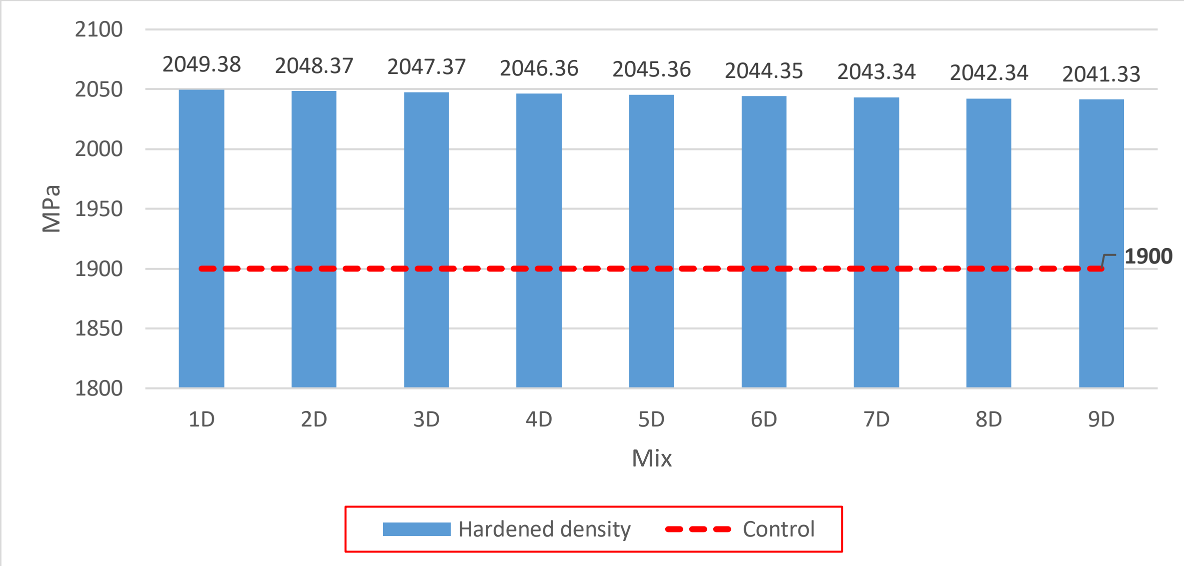

Fig. 15 *Hardened density for series D*

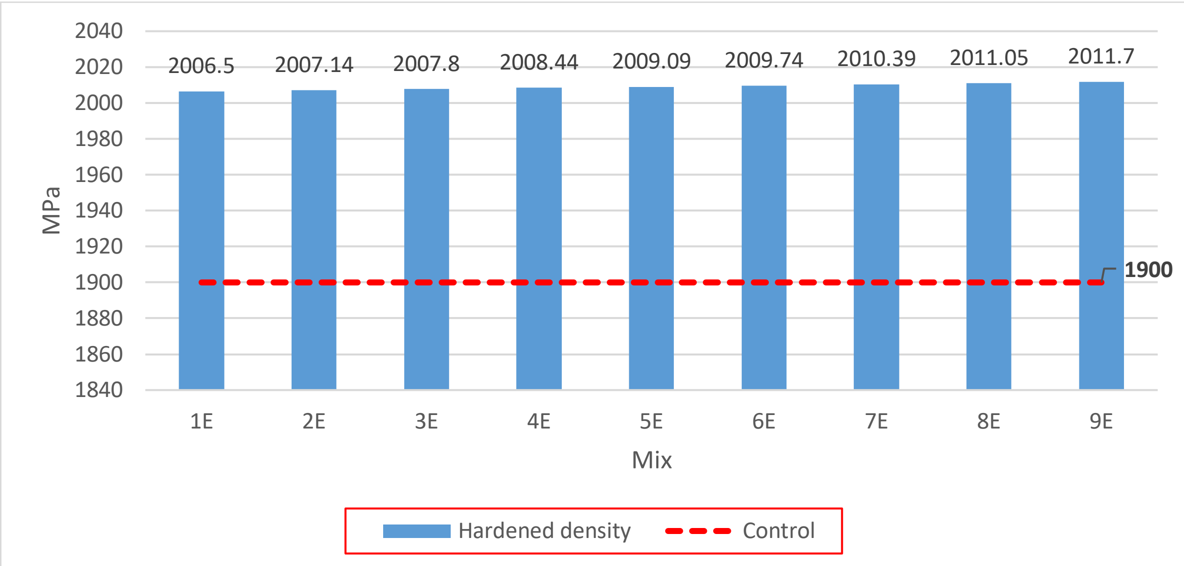

Fig. 16 *Hardened density for series E*

5. Conclusion

In this study, utilization of spent catalyst and copper slag as sand partial replacement in cement sand brick production has been observed. Material testing includes specific gravity and sieve analysis. Hardened samples are examined by their physical and mechanical characteristics. Spent catalyst was compatible used as a partial replacement for fine aggregates due to the physical properties of spent catalyst almost similar with sand.

- The specific gravity and fines modulus values for these materials varied within a limited range and it has been demonstrated that spent catalyst are suitable for usage as fine aggregates replacement compared to copper slag.
- From the result, the highest compressive strength is series A where 10% of sand, 90% of spent catalyst and 10% of copper slag is 44.19 MPa.
- Apart from that, the findings highlight the spent catalyst and copper slag significantly enhanced the compressive strength of cement sand brick by 10% of spent catalyst and 90% of copper slag, respectively. These advancements make cement sand brick incorporating spent catalyst and copper slag a material for structural applications for more sustainable and efficient construction work.

- For the hardened density result, the highest is series A gives the value 2178.09 kg/m^3 where 10% of sand, 10% of spent catalyst and 90% of copper slag. Overall, by increasing the percentage of copper slag, it can improve the density of cement sand bricks, indicating that these are the ideal ratios to employ in cement sand brick design.
- The Pareto plot for compressive strength reveals that the most significant and positive effect is attributed to the spent catalyst-to-copper slag ratio, while the negative effects are associated with the combination of the sand proportion and the spent catalyst-to-copper slag ratio. Other than that, the Pareto plot for hardened density reveals that the most significant factors contributing to the targeted density exhibit a positive effect, enhancing the material's properties. Conversely, factors with negative effects deviate from the targeted density, highlighting areas for optimization.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publications of the paper.

Author Contribution

The author confirm contribution to the paper as follows: ***study conception and design:*** *Alfian Noor Firdaus Mohd Azwan Abdullah, Masni A.Majid, Khairol Kamaruddin;* ***data collection:*** *Alfian Noor Firdaus Mohd Azwan Abdullah;* ***analysis and interpretation of results:*** *Alfian Noor Firdaus Mohd Azwan Abdullah, Masni A.Majid, Khairol Kamaruddin;* ***draft manuscript preparation:*** *Alfian Noor Firdaus Mohd Azwan Abdullah.*

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