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ORIGINAL ARTICLE

The Effect of Sand Replacement with Manganese Slag to Compressive Strength of Modified Brick

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ABSTRACT - The construction industry's overreliance on natural sand contributes to resource depletion and environmental degradation. This study aims to explore the feasibility of utilizing manganese slag, an industrial by-product, as a partial sand replacement in concrete brick production. This study also examines the impact of substituting sand with manganese slag on the compressive strength of concrete bricks. The study used a combination ratio of 1:2.5 (cement to sand) and substitutes manganese slag for sand at varying percentages of 0%, 20%, 40%, 60%, and 80%. The bricks underwent a curing process for durations of 3, 14, and 28 days and after that they were subjected to compressive strength testing. The results indicate that the MS40 sample exhibited strength improvement, over time reaching a strength of 9.27 MPa after 28 days which closely matched the controls 9.57 MPa. These results imply that manganese slag (MS) at a 40% replacement level is an acceptable approach to achieving almost similar compressive strength as traditional mortar mixes offering a promising alternative for construction applications.

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INTRODUCTION

The production of traditional bricks involves significant energy consumption and CO2 emissions, contributing to environmental degradation. The extraction of natural sand also leads to resource depletion and ecological imbalance [1]. Therefore, sustainable building materials are created and used in a manner that reduces harm to the environment, conserves resource and promotes ecological harmony from the beginning to the end of the [2-4]. Alternative materials such as fly ash, waste, recycled concrete aggregates, crushed glass and by-product like manganese slag and etc. These materials can replace a portion or all of the ingredients [4]. By selecting these options, the construction sector can make headway in reducing its environmental footprint and promoting a greener future.

Incorporating slag into concrete provides advantages improving its strength and eco friendliness. Slag serving as a supplementary cementitious material (SCM) can substitute some of the cement content thereby lessening the footprint of concrete manufacturing through decreased carbon emissions and preservation of natural resources [5; 6]. The addition of slag enhances the strength of concrete including its strength, flexural strength and elastic modulus resulting in a quality that can rival or surpass that of conventional concrete mixes [7; 8]. Moreover, slag improves the strength of concrete, by decreasing water penetration, chloride movement and sulfate corrosion all of which're essential, for the longevity of structures made of concrete [9; 10]. Using slag also helps improve the workability and lower the density of materials particularly when mixed with substances such as waste glass [11]. In self-compacting concrete (SCC), replacing fine aggregate with copper slag has shown to improve mechanical strengths and resistance to chloride penetration and voids, optimizing the quality of the concrete [12].

Manganese slag is the derivatives material from making silicomanganese alloys. Manganese slag consists of various elements such, as silicon dioxide, aluminium oxide, calcium oxide, manganese oxide, magnesium oxide, iron oxides and a mix of potassium oxide and sodium oxide. There are 2 forms of manganese slag which are air-cooled and water-quenched silico manganese slag. Air cooled silicon manganese slag is left to cool down on its own in the atmosphere that takes time. On the hand, water

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quenched silicon manganese slag is rapidly cooled with water resulting in solidification. Due the different duration of both types of manganese slag to be cooled of, this resulted in the size difference of both types of respective manganese slag [13]. In reactive powder concrete (RPC) the addition of slag powder and recycled concrete waste boosts strength characteristics. Lowers water absorption. However, it could result in a decrease, in workability due, to porosity levels [14]. The grounded slag can also serve as a colouring agent enhancing the appeal of decorative concrete projects while also fixing the porous structure and decreasing the amount of cement consumption [15].

Various potential uses are being considered for Manganese Slag in various industries. Among them are adding Manganese Slag to soil for farming to help cut down on greenhouse gas emissions and utilizing it as a stabilizer for highway construction materials [16-18]. Research also has shown that manganese slag can help decrease methane emissions in rice paddies highlighting its effectiveness for environmental value [19]. In farming it plays a role, in cutting down greenhouse gas emissions, methane by around 55% and decreasing the global warming impact of paddy fields by 63% compared to controlled fields. This positive impact is due to the properties of oxide minerals that act as electron acceptors and support photocatalysis aiding in carbon fixation and reducing greenhouse gas levels [16]. Moreover, the presence of slag has the potential to enhance soil quality and crop productivity by immobilizing heavy metals in polluted soils due to the positive interactions between slag and microorganisms [17]. In concrete, the addition of manganese slag can reduce the shrinkage of bricks, leading to better dimensional stability. It also helps in minimizing efflorescence, thereby improving the aesthetic and structural quality of the bricks [21]. The objective of this study is to evaluate the suitability of using manganese slag as a partial replacement for cement in large quantities, while also considering its potential to reduce waste and environmental pollution.

MATERIALS AND METHODOLOGY

Materials

Ordinary Portland Cement (OPC), natural river sand passing through a 4.75 mm sieve, Manganese Slag obtained from Pertama Ferra Alloy Bintulu, water.

Methodology

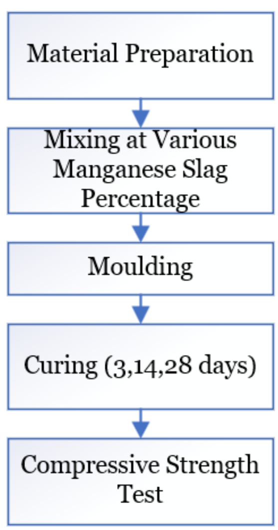

Figure 1. Flowchart of Methodology

The ratio of the cement to sand was fixed at 1:2.5. The sand was partially replaced with manganese slag at 0%, 20%, 40%, 60% and 80%. Each batch of mix were labelled as Control, M20, MS40, MS60 and MS80 respectively.

The cement, sand and manganese slag were measured and mixed according to the specified proportions. The water was added gradually to the dry mix until the uniform consistency was achieved.
The paste then was placed in the brick mould in 3 layers. Each layer was compacted with the tamper for 30 blows each. After 24 hours, the bricks were demoulded and were immersed in curing tanks for specified durations (3, 14 and 28 days).

After 3,14 and 28 days, each variation of bricks will be tested using compression testing machine. The setting for brick testing was adjusted at the machine setting. Each brick was placed one at a time in the testing machine and the uniform rate of load was applied until the brick fails. The maximum load at failure then was recorded. This experiment was conducted following ASTM C140.

RESULTS AND DISCUSSION

Compressive Strength

Figure 2 depicts the comparison of compressive strength of five different types of bricks MS20 (20% of sand replacement by manganese slag), MS40 (40% of sand replacement by manganese slag), MS60 (60% of sand replacement by manganese slag), MS80 (80% of sand replacement by manganese slag) and Control that have been tested over a duration of 28 days.

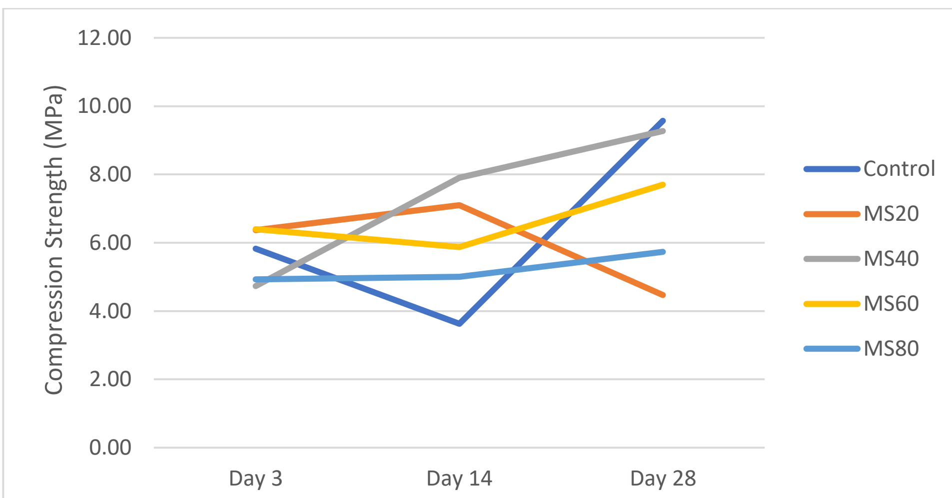

Figure 2. Compressive Strength of all Samples

Compressive Strength of Control and MS20

On day 3, the MS20 brick had a strength of 6.37 MPa and on Day 14, the strength of MS20 rises to 7.10 MPa. This could be as a result of the hydration process in the sample is still ongoing [22] and the formation of calcium silicate hydrate [23].

However, on Day 28, there is a noticeable change in the patterns: the strength of the MS20 declines to 4.47 MPa. This could be attributed to internal structure may undergo changes like increasing porosity [24; 25] and this process may be due to the reactions of elements present in manganese slag. The chemical composition of the manganese slag may impact the later hydration process [26]. If there is unreactive slag included during the process, this could be a reason for the decline in strength at day 28.

Compressive Strength of Control and MS40

By day 3, the MS40 sample measured 4.73 MPa. Moving to day 14, the MS40 samples strength increased to 7.90 MPa indicating there was a hydration process and pozzolonic reaction occur in MS40 sample.

By Day 28, both samples demonstrated improvements in their strengths with the MS40 sample reaching 9.57 MPa and the Control sample at 9.27 MPa. The rate is still increasing however the rate is diminished compared to previous early age. As hydration process continues, the availability of unhydrated cement particles decreases, leading to a slower rate of strength gain. The hydration products begin to fill the capillary pores, reducing the rate at which water can penetrate and continue the hydration process [27]. It is also may be due to secondary pozzolonic reaction. In this process, the reactive materials might have already undergone reactions, resulting in a slower rate rise of compressive strength [28] compared to the rate rise from day 3 to day 14.

Compressive Strength of Control and MS60

On day 3, the MS60 specimen displays a strength of 6.40 MPa, which surpasses the Control specimen strength of 5.83 MPa. By day 14, the strength of the MS60 specimen slightly reduces to 5.87 MPa while the Control specimen experiences a decline to 3.63 MPa. This indicates that the early-stage strength retention is better in the MS60 specimen compared to the Control one. However, by day 28 there is an increase in strength, for both specimens. The MS60 sample reaches 7.70 MPa while the Control sample demonstrates a recovery and attains a strength of 9.57 MPa.

The MS60 sample shows greater performance than the Control sample in terms of early strength suggesting that the MS60 formula may contain elements that boost early strength development. Although there is a decrease in the strength of MS60 by day 14 it still maintains better strength compared to the Control sample which experiences a notable decline in strength at this point. The early drop of both samples might due to incomplete curing process [29; 30].

Compressive Strength of Control and MS80

On day 3 the Control brick displays a compressive strength at 5.83 MPa compared to the MS80 brick at 4.93 MPa. By Day 14 the compressive strength of the MS80 brick slightly rises to 5.00 MPa while the Control bricks strength notably decreases to 3.63 MPa. This suggests that the MS80 brick demonstrates performance in its early stages compared to the Control brick, which shows a significant decline in strength during this period. Moving towards day 28, both types exhibit an increase in strength. The MS80 brick reaches 5.73 MPa while the Control brick experiences a rise to 9.57 MPa.

Initial curing times and the materials used are factors affecting both early and long-term strength in concrete samples [31]. The observed decrease in strength in the Control sample may be due to initial curing stresses or the inclusion of additives that might result in delayed strength development. On the other hand, the MS80 sample's constant increase in strength corresponds to research indicating that materials with pozzolanic characteristics or other materials tend to have more reliable early strength growth [32] The significant rise in the strength of the Control sample by day 28 could be due to hydration and the gradual formation of additional calcium silicate hydrate (C-S-H) enhancing the lasting durability of concrete [33].

These results align closely with previous research that explores the utilization of industrial by-products such as copper slag, steel slag, fly ash and Ground Granulated Blast Surface (GGBS) in concrete and brick manufacturing. Copper slag has been effectively used as a partial replacement for fine aggregates in concrete. Research indicates that replacing up to 40% of fine aggregates with copper slag can enhance the compressive strength of concrete, achieving a maximum strength of 59.29 MPa with optimal mix proportions [34]. Steel slag can replace coarse aggregates in concrete, with a 30% replacement level yielding significant improvements in compressive and flexural strengths [35]. Fly ash, a by-product of coal combustion, is used to partially replace cement, reducing CO2 emissions and improving the mechanical properties of concrete. A 40% fly ash replacement can lead to a 60.22% increase in compressive strength over 56 days [36]. GGBS is another industrial by-product used to replace cement in concrete production. It improves the mechanical strength and durability of concrete, although it may reduce flowability. Optimal replacement levels vary but generally range from 10% to 20% [37].

Scanning Electron Microscopy (SEM) Test

The SEM images shown in this research exhibit the microstructural change of modified bricks as the amount of slag substitution rises. The SEM images were presented in Figure 3 to 7.

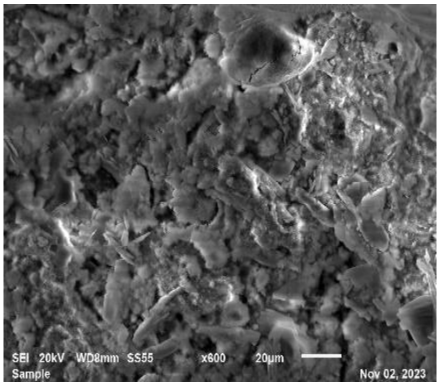

Figure 3. SEM Image of Control

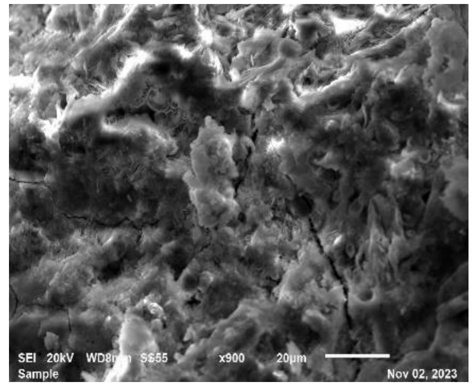

Figure 4. SEM Image of MS20

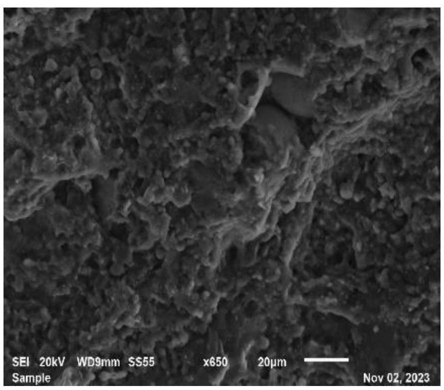

Figure 5. SEM Image of MS40

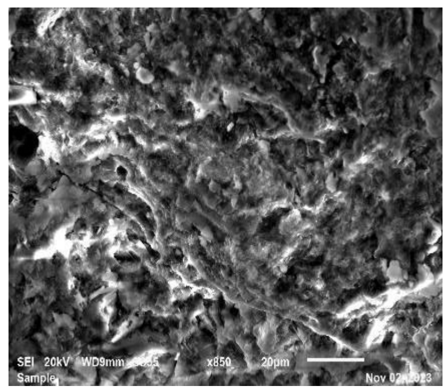

Figure 6. SEM Image of MS60

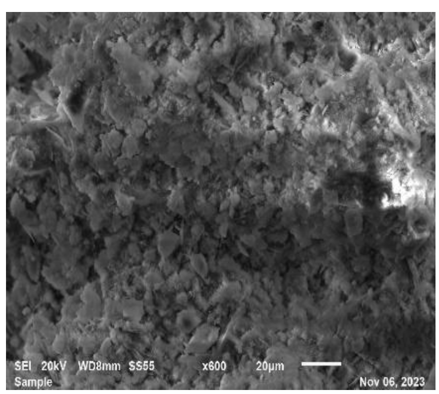

Figure 7. SEM Image of MS80

From Figure 3, the SEM image of the control sample shows a packed structure, with very few holes. This consistency suggests a connection between the cement materials and sand creating the better compressive strength than other percentage of replacement as can be seen in compressive strength results.

From Figure 4, when 20% of slag is used as a replacement the structure starts showing pores. The appearance of spaces implies a decrease in density and a possible weakening of the brick. However, with this alteration, the matrix seems to be fairly stable suggesting that substituting 20% of the material could still be considered acceptable for preserving brick durability.

From Figure 5, with 40% replacement of cement by manganese slag, there is an increase in porosity and a uniform structure. The presence of slag particles is more evident leading to empty spaces and an uneven distribution.

From Figure 6 and Figure 7, the SEM image shows a porosity and fragmentation with noticeable gap in the matrix due to the high presence of manganese slag particles. The abundance of voids indicates a weakening of the bricks strength, at a 60% and 80% replacement rate. This extent of replacement implies that the bricks might have difficulty to bear loads [38] and could experience higher water absorption and decreased durability [39].

Manganese slag contains oxides like SiO_2, CaO, Al_2O_3, and Fe_2O_3 that can engage in pozzolanic reactions with calcium hydroxide produced during cement hydration. This interaction results in the formation of additional calcium silicate hydrate (C–S–H) gel, which enhances the strength of the concrete over time. However, similar as the past research encounter, while the initial incorporation of ground manganese slag improves workability, higher replacement rates can lead to reductions in compressive and flexural strengths [40].

CONCLUSION

Each sample shows unique strength development patterns. By Day 28 the Control sample stands out with an increase in strength reaching the highest value of 9.57 MPa among all comparisons. On the hand the MS samples ; MS40, MS60 and MS80 demonstrate more consistent strength improvements throughout the curing period but fall short of matching the final high strength of the Control sample. These results indicate that while traditional Control mixes excel in long term strength development MS based samples provide intermediate strength gains – offering a viable option for certain applications where early strength is crucial. The data highlights the significance of considering both long term performance when choosing construction materials. Further enhancements to optimize the performance of MS samples could make them competitive in terms of long-term durability.

The data for the MS40 sample shows a steady enhancement throughout the 28 days curing period eventually reaching a strength level very similar to Control sample. By Day 28 the compressive strength of MS40 stands at 9.27 MPa while the Controls strength is at 9.57 MPa. This suggests that MS40 with its robust strength progression serves as an alternative to traditional materials providing nearly equivalent long term compressive strength. Consequently, MS40 displays promise as a replacement in construction scenarios, where both early and long-term strength are crucial factors to consider.

LIMITATIONS AND SUGGESTIONS FOR FUTURE STUDIES

For limitation, this study is limited by several factors that should be considered when interpreting the results. The most notable limitation is the time constraint, as the study was only conducted for a period of 28 days, which does not allow for the evaluation of long-term material behaviour or performance under sustained conditions.

In order to address the limitations of the current study and gain a more comprehensive understanding of the material's potential, future research should focus on long-term performance studies. These studies would help evaluate the material's stability, durability, and effectiveness over extended periods, providing insights into its longevity and resistance to environmental factors. Furthermore, conducting lifecycle assessment would be invaluable in determining the material's cost-effectiveness, sustainability, and overall environmental impact throughout its entire lifespan.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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