# STRENGTH DEVELOPMENT OF HIGH STRENGTH CONCRETE MADE WITH RECLAIMED AGGREGATE

Md. Rakibul Hasan[1,*], Pornpen Limpaninlachat[2] and Thatchavee Leelawat[3]

[1] Student, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand.

[2] Lecturer, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand.

[3] Assistant professor, Faculty of Engineering, Mahidol University, Nakhon Pathom, Thailand.

[*]Corresponding author address: mdrakibul.has@student.mahidol.edu

*ABSTRACT*

This paper aims to evaluate the performance of concrete using the reclaimed aggregate in fresh properties and compressive strength compared to normal concrete using natural aggregate. Reclaimed aggregate was collected from the concrete waste obtained from ready mixed concrete at the construction site, Mahidol University, Kanchanaburi campus. The production process of the reclaimed aggregate was followed by two steps – crushing and screening process. The concrete mixes were designed to have equivalent strengths of 40 MPa, 50 MPa, and 60 MPa grade using Portland cement only and Portland cement replaced with 10% silica fume. The natural aggregates were replaced with different percentages of reclaimed aggregate such as 0%, 25%, 50%, 75%, and 100%. Wet aggregate pretreatment of reclaimed aggregate was initially conducted to minimize unstable slump property with respect to time. The results were found that no significant difference in slump loss of concrete using reclaimed aggregate and natural aggregate was observed. Concrete mixes using different percentages of reclaimed aggregate could exhibit strength development similar to those corresponding mixes using natural aggregate. No significant difference in the strength development of silica fume concrete mixes made with reclaimed aggregate and natural aggregate was also found. The results of this study will pave the way towards the better practice of using reclaimed aggregate in the concrete mix.

***Keywords:*** *Reclaimed Aggregate, Natural Coarse Aggregat, Recycled Concrete Aggregate, High Strength Concrete, Compressive Strength.*

## 1 INTRODUCTION

Due to the growing population and urbanization, the construction industry has dramatically developed. Many existing infrastructures are repaired or demolished due to their service life and poor workmanship. This process generates a massive amount of construction waste. For example, about 850 million tons of construction and demolition waste are generated in the E.U. per year, representing 31% of the total waste generation [1]. Among the waste materials, concrete waste was the majority and was disposed of in landfills, i.e., about 60% was the concrete waste, and the rest of 40% was other materials generated from a construction site [2].

Frequent use of natural resources in the construction work and concrete waste from the construction site causes a massive impact on the environment. Using the recycling of concrete waste in new concrete will reduce the environmental threat and offer more economic efficiency. Many authors studied and proposed reclaimed aggregate as the future construction aggregate, which could be used as an aggregate in standard grade concrete without any particular concern providing that the reclaimed aggregate has no significant contaminated particles.

When reclaimed aggregates are used to produce fresh concrete, known as recycled aggregate concrete, the suitability of reclaimed aggregate is one of the most requirements for use in standard grade concrete. Thus it has applied for various applications, such as foundations, paving, reinforced and prestressed concrete, examined by previous researchers [3],[4]. Limbachiya et al. (2000) suggested that coarse recycled or reclaimed aggregate may be extended to high strength concrete, thus offering additional material value.

Many previous researchers have studied aggregate properties, including physical, chemical and mechanical properties of recycled or reclaimed aggregate, fresh properties, strength development, and durability properties of concrete containing recycled or reclaimed aggregate and compared to the conventional concrete. The workability was found to be in the decreasing order for reclaimed concrete. It may be due to the absorption of water by the reclaimed aggregate. Furthermore, the compressive strength of concrete in which the coarse aggregate is replaced with reclaimed aggregate decreases when the percentages of reclaimed aggregate increases [5]. The replacement of 50% of natural aggregate by reclaimed aggregate reduces the compressive strength of concrete by approximately 10% [6]. However, no decrease in strength reported for concrete containing up to 20% fine or 30% coarse recycled aggregate [3].However, very limited studies about the use of reclaimed aggregate in high strength concrete were reported; especially use of silica fume as a cement replacement in high strength concrete.

Therefore, this paper was aimed at evaluating the fresh properties and strength development of high-strength concrete mixes using reclaimed aggregate, compared to corresponding equivalent design strength of high-strength concrete mixes using natural aggregate.

## 2 MATERIALS AND METHODS

### *2.1 MATERIALS*

Portland Cement Type-1 conforming to ASTM C-150 was used in this study to mix new concrete made with natural aggregate and reclaimed aggregate. The maximum nominal size of the natural coarse aggregates was 19.00 mm. Local river sand was used as natural fine aggregate. The maximum nominal size of the natural sands was 4.75 mm. The reclaimed aggregates were produced from ready-mix concrete delivered to the construction site, Mahidol University, Kanchanaburi Campus. Details of the production process for the reclaimed aggregate are mentioned in the following paragraph.

When the concrete pouring completed, some concrete wastes were rejected from the construction site. The rejected concrete was collected and poured into the cylinder specimens. After that, these concrete specimens were demoulded in the following day and then moist cured for 56 days to fulfil hydration and then air-dried in the laboratory until the age of 120 days. These concrete samples were transferred to the crushing factory. A jaw crusher was used to break the concrete samples. After that, the concrete specimens were crushed into small pieces within the range of 4.75 mm – 19.00 mm size. A sieving machine was used to separate the fine and coarse aggregates for producing reclaimed aggregates. The gradation of natural and reclaimed aggregates are shown in Figure 1. Only the coarse reclaimed aggregate was used in the study. The physical properties of natural sand, natural and reclaimed aggregate are given in Table 1.

The tap water was used in the processes of producing concrete and curing specimens. Silica fume was used for partial cement replacement. A high-range water-reducing admixture type A & F confoming to ASTM C-494- was used to produce high strength concrete. The dosage of high-range water-reducing admixture used for 40 MPa, 50 MPa and 60 MPa conecrete were 1.63 %, 1.94 % and 2.18 % respectively. High-range water-reducing admixture was used for the silica fume concrete mixes to reduced the w/c ratio upto 20 % and can improve the workability of the concrete.

### *2.2 PRODUCTION OF RECLAIMED AGGREGATE*

In order to minimize the problems due to unstable slump and loss of strength of concrete mixes using reclaimed aggregate, further processes have been conducted. Since high water absorption of reclaimed aggregate was found as given in Table 1, which affected to delay in water penetrating to aggregate particles during the concrete mixing, causing slump loss. Accordingly, this study was purposed to store reclaimed aggregates in a damped container for 24 hours prior to concrete mixing and placed in the controlled room condition to maintain the aggregate’s damped condition. The moisture content of reclaimed aggregate was conducted and used in the batch proportion.

Many previous researchers have found a reduction in compressive strength with increasing reclaimed aggregate content. However, very limited research on high-strength concrete using silica fume and reclaimed aggregate were found. Accordingly, this study's assumption has been made to follow the same trends as the previous study. Therefore, binder content was linearly added to minimize loss of strength with increasing content of reclaimed aggregate. These were to exhibit similar design strength of concrete made with reclaimed and natural aggregates as shown in Figures 2 and 3 respectively for concrete proportioned using Portland cement only and Portland cement replaced with 10% silica fume.

The concrete mixes were designed following ACI 211.4R - 93 standard. Natural aggregate was replaced with 0%, 25%, 50%, 75%, and 100% reclaimed aggregate in the concrete mix. Details of concrete mixes are given in Table 2.

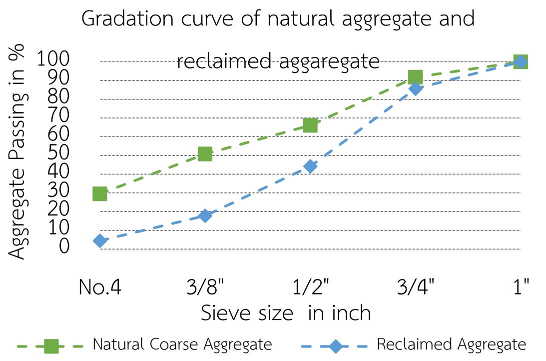


Figure 1 Gradation curve of natural and reclaimed aggregate.

Table 1 Properties of natural aggregate, reclaimed aggregate and natural sand.

| Property | Coarse aggregate: Natural aggregate | Coarse aggregate: Reclaimed aggregate | Natural sand |
|---|---|---|---|
| Max. size of aggregate in (mm) | 19.00 | 19.00 | 4.75 |
| Fineness Modulus (F.M.) | - | - | 2.89 |
| Material finer than 75 µm (No.200) sieve in (%) | 0.33 | 1.05 | 1.64 |
| Clay lumps and friable particles in (%) | 0.25 | 2.69 | 0.37 |
| Specific gravity | 2.67 | 2.32 | 2.51 |
| Water absorption in(%) | 0.59 | 4.01 | 1.19 |
| Organic impurities | - | - | Plate 3 |
| Unit weight in (kg/m$^3$) | 1577 | 1040 | 1655 |
| Voids in (%) | 38 | 58 | 33 |
| Los Angeles abrasion value in (%) | 16.87 | 35.16 | - |

For each concrete mix, six cylindrical samples were prepared for the compressive strength test at 7 days and 28 days. The concrete specimens were cured in the moist-curing room controlling the relative humidity beyond 95%.

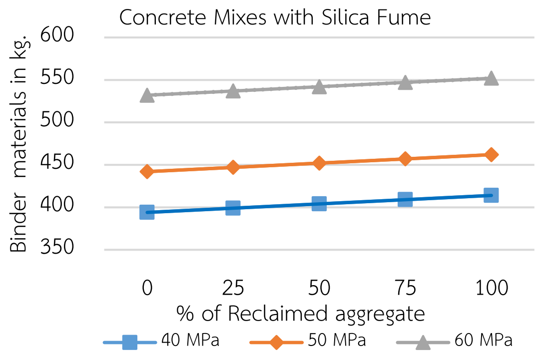


Figure 2 Binder content of silica fume concrete mixes made with reclaimed and natural aggregates.

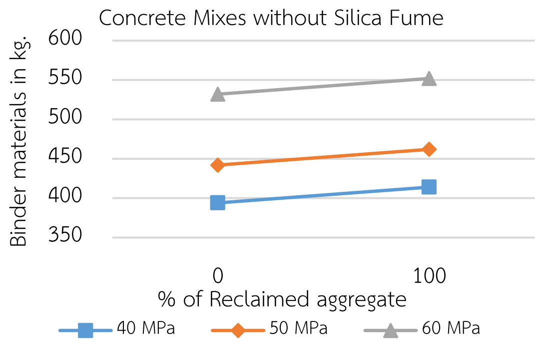


Figure 3 Binder content of Portland cement concrete mixes made with reclaimed and natural aggregates.

### *2.3 TESTING METHODS*

The slump test was used to check the consistency of freshly mixed concrete. Adjustments have been made to use a high-range water-reducing admixture to maintain the slump values for all the mixes to be within 75-100 mm. In addition, the slump retention period for the 50 MPa concrete series was conducted at a 15-minute interval until a zero slump value was observed. The cylindrical specimens having 100-mm diameter and 200-mm height were tested using ASTM C 39 to determine the compressive strength at 7 days and 28 days. The crack pattern also checked after testing the concrete specimens.

## 3 RESULTS AND DISCUSSION

### *3.1 SLUMP TEST*

The slump retention results of 50 MPa concrete mixes are shown in Figure 4. It was found that similar trends of slump loss were found for the silica fume concrete mixes made with reclaimed and natural aggregates. The slump retention time of silica fume concrete mixes with reclaimed and natural aggregate was longest than the portland cement concrete mixes with reclaimed and natural aggregate. The Trends of slump loss for Portland concrete mixes made with reclaimed and natural aggregates were higher than those silica fume concrete mixes. This may imply that storing reclaimed aggregate in the damped containers could minimize the slump loss characteristics of reclaimed aggregate. This is due to small pores of aggregate being saturated prior to mixing the concrete.

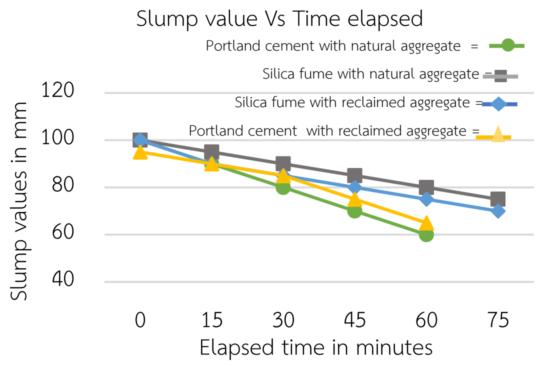


Figure 4 Slump retention period of four mixes from 50 MPa concrete.

### *3.2 STRENGTH DEVELOPMENT OF RECLAIMED CONCRETE MIXES WITH SILICA FUME*

After adjusting binder content to obtain equivalent design strength for 40MPa, 50MPa, and 60 MPa mixes as mentioned in Figure 2, the 7-day and 28-day compressive strength results of 40MPa concrete mixes made with reclaimed and natural aggregates and using silica fume are shown in Figures 5 and 6 respectively. It was found that strength development results of 40 MPa concrete made with reclaimed aggregate were no significant difference when compared to corresponding mixes with natural aggregate. Similar results were observed for equivalent design strength of 50 MPa and 60MPa concrete mixes, as shown in Figure 7 and 8. The reclaimed aggregate concrete mix's targeted strength was achieved because of the replacement of binder content with 10 % silica fume and added high-range water-reducing admixture. Silica fume and high-range water-reducing admixture both together increase the bonding strength of concrete mixes with reclaimed aggregate. The relationship between 28-day compressive strength and water-to binder ratio of reclaimed and natural aggregate concrete mixes with silica fume is shown in Figure 9.

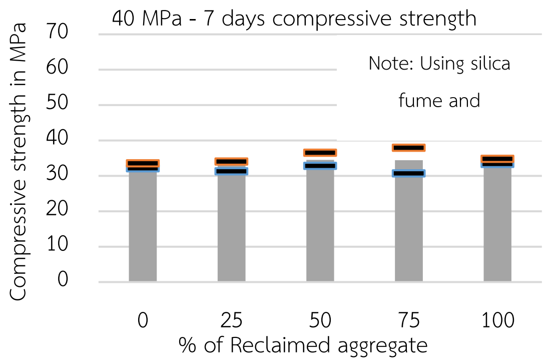


Figure 5 7-day compressive strength test results of 40 MPa concrete using silica fume.

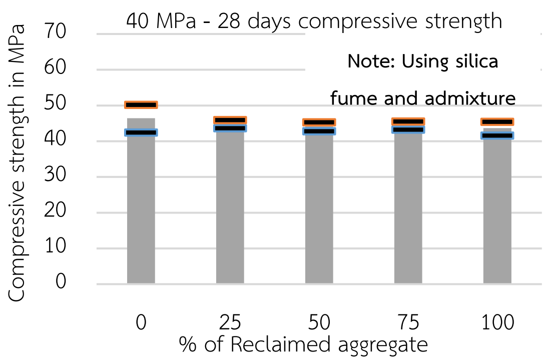


Figure 6 28-day compressive strength test results of 40 MPa concrete using silica fume.

Table 2 Summary of concrete mix.

| Concrete grade (MPa) | Percentage of reclaimed aggregate (%) | Cement (kg/m$^3$) | W/C ratio | Water (kg/m$^3$) | Cement replacing with silica fume (kg/m$^3$) | Silica fume (10 % of cement) (kg/m$^3$) | High-range water-reducing admixture (%) | Fine aggregate (kg/m$^3$) | Natural Aggregate (kg/m$^3$) | Reclaimed aggregate (kg/m$^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 0 | 394 | 0.45 | 177 | - | - | - | 716 | 1135 | - |
| | 0 | 394 | 0.45 | 177 | 354.6 | 39.4 | 1.63 | 716 | 1135 | - |
| | 25 | 399 | 0.44 | 177 | 359.1 | 39.9 | 1.63 | 780 | 851 | 187 |
| | 50 | 404 | 0.44 | 177 | 363.6 | 40.4 | 1.63 | 844 | 568 | 374 |
| | 75 | 409 | 0.43 | 177 | 368.1 | 40.9 | 1.63 | 909 | 284 | 561 |
| | 100 | 414 | 0.43 | 177 | 372.6 | 41.4 | 1.63 | 973 | - | 749 |
| | 100 | 414 | 0.43 | 177 | - | - | - | 973 | - | 749 |
| 50 | 0 | 442 | 0.40 | 177 | - | - | - | 677 | 1135 | - |
| | 0 | 442 | 0.40 | 177 | 397.8 | 44.2 | 1.94 | 677 | 1135 | - |
| | 25 | 447 | 0.40 | 177 | 402.3 | 44.7 | 1.94 | 741 | 851 | 187 |
| | 50 | 452 | 0.39 | 177 | 406.8 | 45.2 | 1.94 | 805 | 568 | 374 |
| | 75 | 457 | 0.39 | 177 | 411.3 | 45.7 | 1.94 | 870 | 284 | 561 |
| | 100 | 462 | 0.38 | 177 | 415.8 | 46.2 | 1.94 | 934 | - | 749 |
| | 100 | 462 | 0.38 | 177 | - | - | - | 934 | - | 749 |
| 60 | 0 | 532 | 0.33 | 177 | - | - | - | 606 | 1135 | - |
| | 0 | 532 | 0.33 | 177 | 478.8 | 53.2 | 2.18 | 606 | 1135 | - |
| | 25 | 537 | 0.33 | 177 | 483.3 | 53.7 | 2.18 | 670 | 851 | 187 |
| | 50 | 542 | 0.32 | 177 | 487.8 | 54.2 | 2.18 | 734 | 568 | 374 |
| | 75 | 547 | 0.32 | 177 | 492.3 | 54.7 | 2.18 | 799 | 284 | 561 |
| | 100 | 552 | 0.32 | 177 | 496.8 | 55.2 | 2.18 | 863 | - | 749 |
| | 100 | 552 | 0.32 | 177 | - | - | - | 863 | - | 749 |

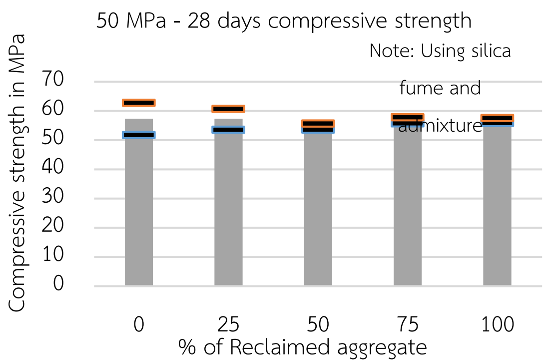


Figure 7 28-day compressive strength test results of 50 MPa concrete using silica fume.

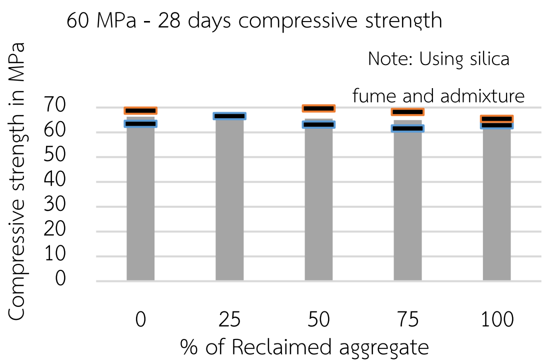


Figure 8 28-day compressive strength test results of 60 MPa concrete using silica fume.

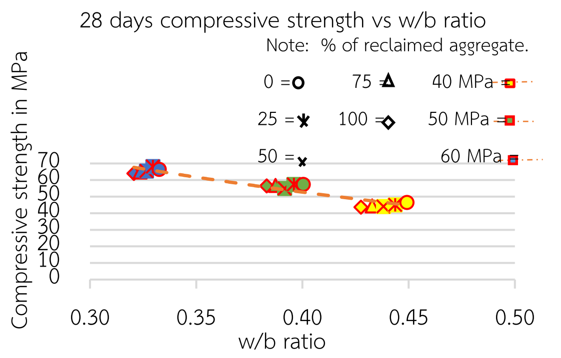


Figure 9 28-day compressive strength vs w/b ratio of 40 MPa, 50 MPa and 60 MPa concrete.

### *3.3 STRENGTH DEVELOPMENT OF RECLAIMED CONCRETE MIXES WITHOUT SILICA FUME*

After adding cement content of reclaimed aggregate concrete mixes to achieve equivalent design strength with natural aggregate concrete mixes, the 7-day and 28-days compressive is shown in Figures 10 and 11, respectively.

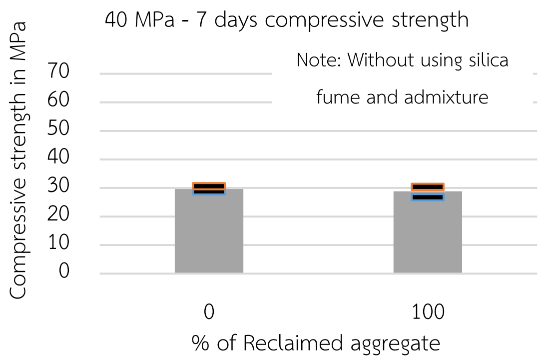


Figure 10 7-day compressive strength test results of 40 MPa concrete without using silica fume.

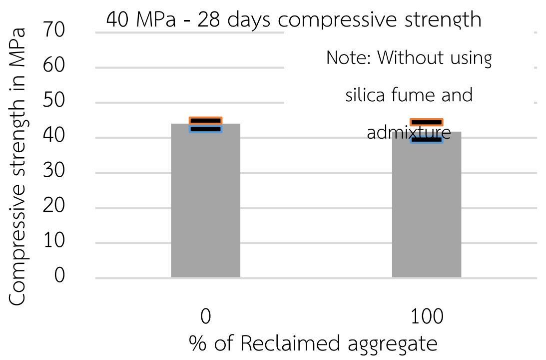


Figure 11 28-day compressive strength test results of 40 MPa concrete without silica fume.

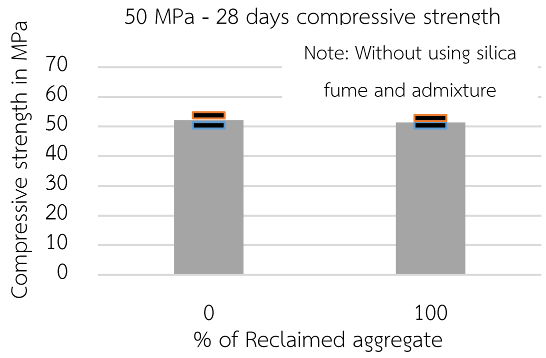


Figure 12 28-day compressive strength test results of 50 MPa concrete without using silica fume.

It was also found that using the purposed cement content, as mentioned in Figure 3, reclaimed aggregate concrete could exhibit the 28-day compressive strength slightly lower than natural aggregate concrete. Similar results were observed for equivalent design strength of 50 MPa and 60 MPa concrete mixes, as shown in Figures 12 and 13. The relationships between 28-days compressive strength and water-to binder ratio of reclaimed and natural aggregate concrete mixes without silica fume are shown in Figure 14. Therefore, it may imply that slightly extra cement content needed to be added in the mixes with reclaimed aggregate to achieve a similar compressive strength of concrete.

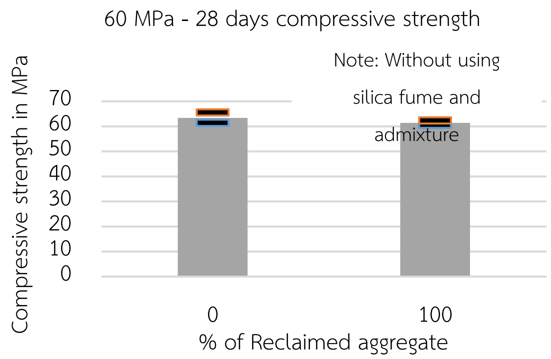


Figure 13 28-day compressive strength test results of 60 MPa concrete without using silica fume.

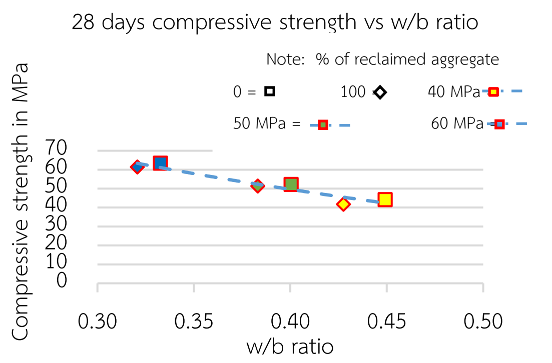


Figure 14 28-day compressive strength vs w/b ratio of concrete without using silica fume.

Based on the results obtained, it is found that

1) Workability of silica fume concrete mixes with reclaimed and natural aggregate longer than Portland cement concrete mixes.
2) The compressive strength of 40 MPa, 50 MPa, and 60 MPa concrete was considered equivalent compared with natural and reclaimed aggregate and natural aggregate replaced with different percentages of reclaimed aggregate.
3) The compressive strength for concrete with different percentages of reclaimed aggregate was comparatively the same when 10% silica fume replaced Portland cement.
4) Portland cement concrete mixes with reclaimed and natural aggregate achieve the targeted compressive strength because of the extra cement added to the concrete mix.

## 4 CONCLUSIONS

1) Slump loss problems of reclaimed aggregate concrete could be solved by storing reclaimed aggregate in the damped containers.
2) Trends of slump loss for reclaimed aggregate concrete with and without silica fume were similar to those corresponding concrete mixes made with natural aggregate.
3) By using 10% silica fume and high-range water-reducing admixture in the concrete mixes with reclaimed aggregate, the targeted strength can be obtained, even in the concrete mixes of high strength concrete 50 MPa and 60 MPa.
4) Without using silica fume, the compressive strength of concrete mixes with reclaimed aggregate and natural aggregate could be achieved by increasing the Portland cement content in the mix.
5) All replacement levels of natural coarse aggregate with reclaimed coarse aggregate were found to exhibit the strength development of concrete similar to natural aggregate concrete providing that adjustment of binder content with silica fume to achieve equivalent design strength as purposed in the study had been made for reclaimed aggregate concrete.

## 5 REFERENCES

[1] Fischer, C., Werge, M., & Reichel, A. (2009). EU as a Recycling Society.

[2] Islam, R., Nazifa, T. H., Yuniarto, A., Uddin, A. S., Salmiati, S., & Shahid, S. (2019). An empirical study of construction and demolition waste generation and implication of recycling. Waste management, 95, 10-21.

[3] Dhir, R., Limbachiya, M., & Leelawat, T. (1998). recycled concrete aggregate for use in BS 5328

[4] Dhir, R., Limbachiya, M., Leelawat, T., BS, & 882, B. (1999). SUITABILITY OF RECYCLED CONCRETE AGGREGATE FOR USE IN BS 5328 DESIGNATED MIXES. Proceedings of the Institution of Civil Engineers-Structures and buildings, 134(3), 257-274.

[5] Arul, R., Vidhya, A., Karthikeyan, K., & Uthayakumar, P. (2016). Study on strength of concrete by using recycled aggregate from demolition waste in concrete. Int. J. Res. Eng. Technol, 5(6), 176-181.

[6] Ghosn, S., Cherkawi, N., & Hamad, B. (2020). Studies on Hemp and Recycled Aggregates Concrete. International Journal of Concrete Structures and Materials, 14.