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Properties of Mortar Incorporating Spent Garnet as Fine Aggregates Replacement

Nor Hasanah Abdul Shukor Lim[1*], Noor Fazura Najihah Alladin[1], Hossein Mohammadhosseini[1], Nur Farhayu Ariffin[2], Ain Naadia Mazlan[1]

[1]Construction Research Centre, School of Civil Engineering,
Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA

[2]Faculty of Civil Engineering Technology,
Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Kuantan, Pahang, MALAYSIA

*Corresponding Author

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Abstract: The rapid growth in the construction industry has increased the consumption of fine aggregates whereby it depletes the natural resources. Also, garnet is a material that can be reused for several times in the ship cleaning process. However, when this garnet can no longer be used, it is then disposed in landfill, oceans and rivers, thus increase the volume of landfill waste and causing environmental problems. Therefore, this research is aimed to study the effect of spent garnet as a fine aggregates replacement in terms of physical, fresh and hardened properties of mortar. In this study, several specimens are prepared by using different percentage of spent garnet range from 0%, 25%, 50%, 75% and 100% as a fine aggregates replacement in mortar. The specimens are cast using 50 mm x 50 mm x 50 mm mould and the materials used in preparing the mortar sample are cement, fine aggregates, water and spent garnet. The samples are then cured in the water before tested at the age of 7, 14, and 28 days. The characteristic of the materials, fresh and hardened properties of mortar were investigated. It was found that the workability of mortar increases with the increasing amount of spent garnet. Overall, it is found out that the spent garnet can be used as fine aggregates replacement in mortar up to 50% since it has a comparable strength (40 MPa at 28 days) with a conventional mortar with 16% improvement in water absorption test. In addition, the environmental impact can also be reduced through the use of spent abrasive waste by preserving the use of natural resources.

Keywords: Spent garnet, mortar, spent abrasive waste, fine aggregates replacement

1. Introduction

Nowadays, concrete has become predominant building material in the construction industry due to its excellent mechanical and physical properties when properly designed and manufactured. More than 10 billion tonnes of concrete produced annually. As it has been estimated that by the year 2050, the rate of world's population will increase from 1.5 to 9 billions, thus, this will increase the demand for housing as well as the concrete materials which are estimated to be 18 billions tonnes by 2050 [1]. However, as the construction industry begin to rise, the usage of river sand in the construction industries have been increased and cause certain issues such as excessive use of river bed. This situation will also interrupt the ecosystem of living organism in the river. Other than that, there are certain matters such as the increase of river bed depth, reduce of the water table, increase of salinity and elimination of river embankments have been triggered due to this situation. The over exploitation of river sand can deplete the natural resources as it is non-

*Corresponding author: norhasanah@utm.my

renewable. In addition, the effect of continuous digging sand can also disrupt the river embankment and the stability of the ecosystem. Based on the previous research, it stated that the use of waste material can lead to product development [2]. The need towards sustainability and sustainable environment has made the use of waste material in construction become popular. Within these few years, natural and industrial wastes have been used as construction materials namely, ceramic tile waste, pumice aggregates, oil palm kernel shell (OPKS), waste glass and laterite aggregates [3]-[7].

Besides, Malaysia imports huge amount of garnet to be used as abrasive material for ship cleaning and repairing, and resulting in spent garnet as waste material. There is a need to recycle or reuse this waste as it polluted the land and water resources. It has been estimated that the total production of garnet for global industrial is estimated to be 440,000 tonnes. There are 2000 tons' garnet imported from Australia to Malaysia in the year of 2013 by Malaysia Marine and Heavy Industry (MMHE) for use in a sandblasting ship [8]. The materials used for this sandblasting is replaced with garnet to remove paint, rust and to prepare surfaces for painting. This secondary waste can be used as a raw material for fine aggregates replacement in concrete industry without loss of quality [9,10].

Garnet is the general name for a group of complex silicate minerals with similar crystalline structures and diverse chemical compositions [11]. It mostly obtained from metamorphic rocks and precious metals are deposited inside such rocks [12]. When the recycled garnet degrades to a point at which it can no longer be reused in the abrasive blasting process, it is removed from the shipyards and named "spent garnet" [8]. Garnets have major industrial uses such as water jet cutting, abrasive blasting media, water filtration granules and abrasive powders [8]. However, different types of garnet, even when chemically and physically similar, perform quite differently [12]. It is recommended the outcomes of mechanical properties (compressive, split and flexure) had indicated significant performance for spent garnet series. However, the increase in sand replacement levels by garnet has caused a decrease in strength that spent garnet should be used in concrete as a sand replacement up to 25% to reduce environmental problems, costs and the depletion of natural resources [13].

The study focuses on the use of spent garnet as a waste material to partially replace river sand in mortar mixes. The main materials that used for mortar mixing are cement, fine aggregates and water. There are several tests that are conducted to study the characteristic of the materials (spent garnet and river sand) besides fresh and hardened properties of mortar. For the characteristic tests, sieve analysis, bulk density and water absorption are conducted while the fresh test, the flow test is done. For the hardened test, density, Ultrasonic Pulse Velocity (UPV), compressive strength and water absorption are performed. Finding new way to recycle this waste in construction of infrastructures not only can be useful to preserve natural resources and environment, it can also improve the quality of mortar and reduce the cost of construction. To evaluate the true potential of spent garnet wastes for new applications, as aggregates replacement, a comprehensive and detailed study of the fundamental properties of the material is highly needed.

2. Methodology

This research consisted of three key activities which involve the preparation of materials, mix design of the specimens and procedure in specimens testing.

2.1 Materials

Mortar constituents are cement, fine aggregates, and water. In this study, the type of cement used is Ordinary Portland Cement type I as stated in the ASTM C150 [14], 'Standard Specification for Portland Cement'. As for fine aggregates, the river sand passing through 5 mm sieve are used in preparing the mortar specimens. Partial replacement for fine aggregates are done by using spent garnet obtained from the Malaysian Marine Heavy Engineering (MMHE) company in southern part of Malaysia. Besides, the spent garnet is sieved through 5 mm sieve before it is used to mix with others materials. Both river sand and spent garnet used are in saturated surface dry condition to ensure that the water cement ratio is not affected. Water used is a normal tap water from the laboratory and the source of water used must be cleaned and free from any impurities.

2.2 Mix Design

Table 1 shows the mix proportion of mortar mixes in accordance to ASTM standard for the mortar mixes. The density of mortar and the ratio used to calculate the mix design are 2250 kg/m³ and 1:3 which is 1 part of cement and 3 parts of fine aggregates, respectively with water cement ratio of 0.5. The mix design is calculated using different percentage of spent garnet content of 0%, 25%, 50%, 75% and 100% as a replacement for fine aggregates in mortar. The effects of spent garnet as fine aggregates replacement on the fresh and hardened properties of mortar are investigated. The mortar specimens are cast using a standard steel cube of 50 mm x 50 mm x 50 mm size and the mould used should be cleaned from the hardened mortar or dirt before assembling the mould. Besides, a thin layer of oil is applied to all the surfaces of mould to facilitate the demoulding process. After that, the mortar is mixed by referring to the mix design calculated. Then, the mixture is poured in two layer followed by compactions on each layer. The specimens are then stored at a room temperature for 24 hours before it undergoes the curing process for 7, 14 and 28 days.

Table 1 – Mix proportion of mortar mixes

Mixes	Cement (kg/m^3)	River Sand (kg/m^3)	Water (kg/m^3)	Spent Garnet (kg/m^3)
CS	565	1685	279	0
SG25	565	1265	279	420
SG50	565	840	279	840
SG75	565	420	279	1265
SG100	565	0	279	1685

2.3 Test Methods

The tests are carried out to study the effects of spent garnet as fine aggregates replacement on fresh and hardened properties of mortar. For the hardened test, the test conducted are density test, Ultrasonic Pulse Velocity followed by compressive strength test and water absorption test. The characterization of spent garnet was determined using grading test, bulk density test and water absorption test. The compressive strength of the mortar mix is verified by casting and testing of cubes size 50 mm x 50 mm x 50 mm after curing for 7, 14 and 28 days in accordance to ASTM C109 [15]. For water absorption test, the sample is dried in an oven for 24 hours at a temperature between 100 – 110 °C. After 24 hours, the sample is taken out and the weight for dry specimen is recorded. The sample is then put in the water for complete immersion at 24 hours. After the immersion process is completed, the specimen is taken out from the water and wiped using the clean cloth. After that, it is weighed and recorded as wet specimen.

3. Results and Discussion

The results on the effect of spent garnet as a replacement for fine aggregates in mortar are discussed herein. The results are analyzed based on the physical characteristic of river sand and spent garnet, fresh and hardened properties of mortar.

3.1 Physical Properties of Spent Garnet

The test results on the physical properties of river sand and spent garnet used are shown in Table 2. From the table, it indicates that the spent garnet material has a higher bulk density value with 1804 kg/m^3 and is followed by river sand with 1430 kg/m^3. The higher bulk density of spent garnet is probably because of the spent garnet contain more fine particle and less void content compared to river sand. In short, when an aggregates contains more fine particles, this means that the particles are closely packed to each other and there is a least amount of air space between the particles which then contribute to higher density. Previous findings reported that the bulk density of spent garnet was in the range of 1700 to 2400 kg/m^3 and it depends on the size of aggregates [2].

Other than that, the other physical properties of the material measured is water absorption. The water absorption for spent garnet is 5.5 %, which is higher than river sand which is 4 % and this is due to the existence of the excess moisture remains on the surface of particles. Although these extra water can increase the workability but it will affect the strength of the mortar. Therefore, the spent garnet must be in saturated surface dry (SSD) condition before it is mixed with other materials in preparing the mortar specimens. Fig. 1 shows the spent garnet and river sand used in this study.

Table 2 - Physical properties of river sand and spent garnet

Properties	River Sand	Spent Garnet
Bulk density (kg/m^3)	1430	1804
Water absorption (%)	4	5.5
Mass passing 75 µm (%)	0	0

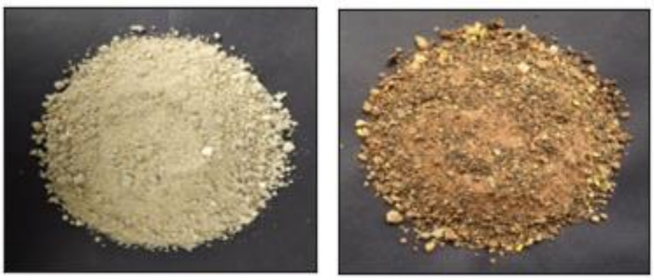

Fig. 1 - Fine aggregates used (a) River sand and (b) spent garnet

3.2 Grading of Fine Aggregates

Fig. 2 illustrates the particle size distribution for river sand and spent garnet as obtained from the sieve analysis. With reference to the figure, the gradation of the two materials used in the study lies within the range of the upper and lower limits where it meets the grading requirements for fine aggregates. Other than that, the river sand and spent garnet material are also classified as a well-graded aggregate since these material conforms to the grading limits whereby it consists of different sizes of aggregate particles as shown in the figure. Therefore, the spent garnet can be used as fine aggregates to replace river sand. This is because fine aggregates that fall within the ASTM C33-13 grading limits usually produce robust and stable mortar [16]. A well graded aggregates, usually reduces the demand for water and thereby, improving the packing density, robustness and workability of the mortar [17].

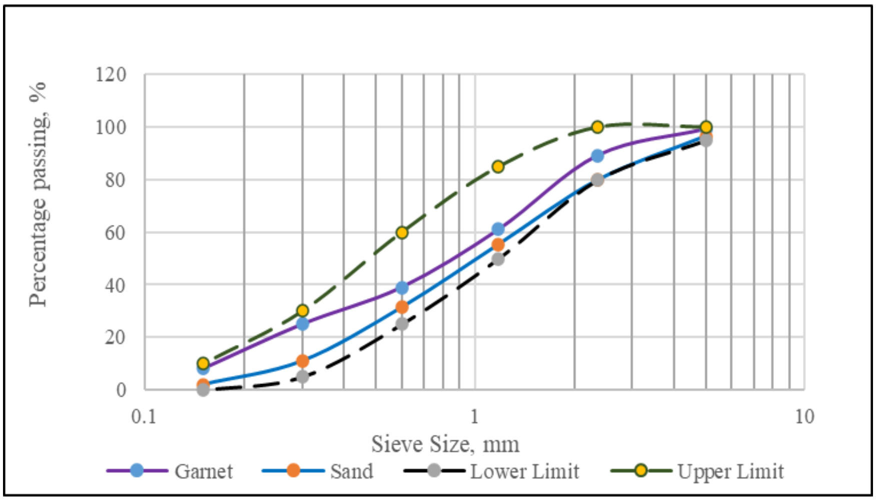

Fig. 2 - Grading curve of fine aggregates and spent garnet

3.3 Workability

Fig. 3 shows the result for the flow ability of control sample and mortar containing 25%, 50%, 75% and 100% of spent garnet as fine aggregates replacement. As can be seen in Fig. 3, it is clearly shown that as the percentage of spent garnet content increased, the higher the flow ability of the mortar. Based on the results obtained, the flow ability of the mortar for 0%, 25%, 50%, 75% and 100% are 137 mm, 141 mm, 169 mm,170 mm and 175 mm, respectively. From the flow test results, 100% replacement by spent garnet in mortar shows the highest value of flow ability up to 22% compared to control sample. This is due to the higher density of spent garnet,that cause the mortar to spread wider and result in higher flow ability.

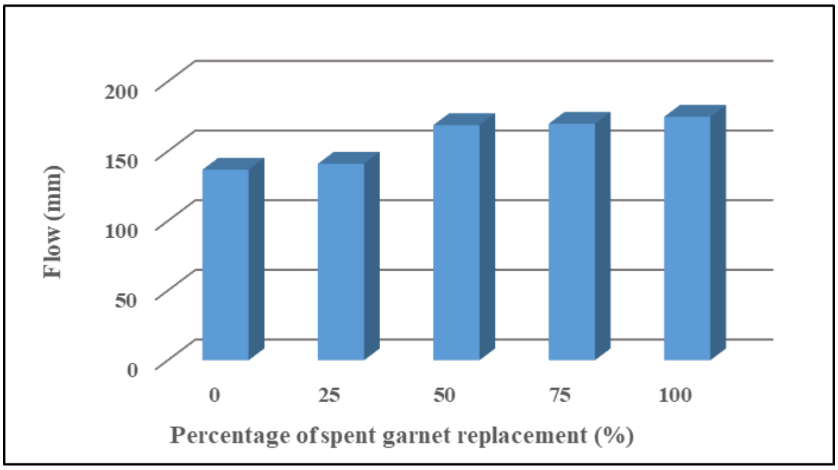

Fig. 3 - xxxx

3.4 Hardened Density

Fig. 4 presents the results for the density versus percentage of spent garnet as fine aggregates replacement in mortar. From the results shown in the figure, the density of mortar with spent garnet is increasing as the percentage of spent garnet content increases for all curing periods. This may be due to the higher formation of Calcium Silicate Hydrate (CSH) gel content produced from the hydration process of cement and also higher density of spent garnet compared to sand. Besides, the results for density of mortar at 28 days are 2333.3 kg/m³, 2440.0 kg/m³, 2466.7 kg/m³, 2560.0 kg/m³ and 2706.7 kg/m³ for 0%, 25%, 50%, 75% and 100% fine aggregates replacement, respectively. The highest density value at 28 days is shown by mortar containing 100% of spent garnet content compared to control sample with an increase of 14%. This is most probably due to the its higher density than sand thus, causes the density of mortar increases.

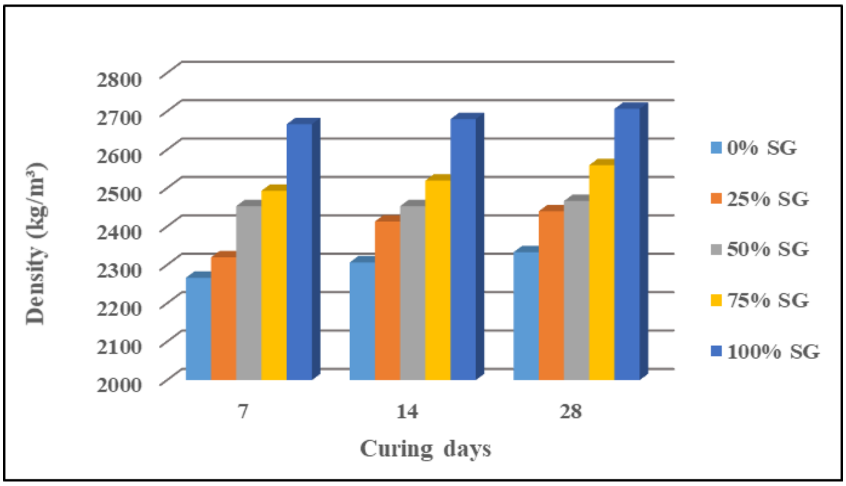

Fig. 4 - Density of mortar against curing periods

3.5 Ultrasonic Pulse Velocity

The UPV value versus percentage of spent garnet replacement are shown in Fig. 5. Based on the results obtained, the UPV values at 28 days are 4120.9 m/s, 4021.5 m/s, 4090.0 m/s, 3937.0 m/s and 3866 m/s for 0%, 25%, 50%, 75% and 100% of spent garnet replacement, respectively. As can be seen in the figure, the pattern shows that the UPV values is increasing with the increment of curing ages. This is because of the increased of CSH gel content in the mortar during the hydration process. At 28-day test, 50% of spent garnet replacement give the comparable UPV values compared to control sample. Meanwhile, 100% replacement of spent garnet as fine aggregates show the lowest UPV values when compared with the conventional mortar. This is probably due to the porosity in mortar and have less CSH gel content thus result in decreases of the UPV values. Besides, high content of spent garnet may decrease the bonding between aggregates and cement paste.

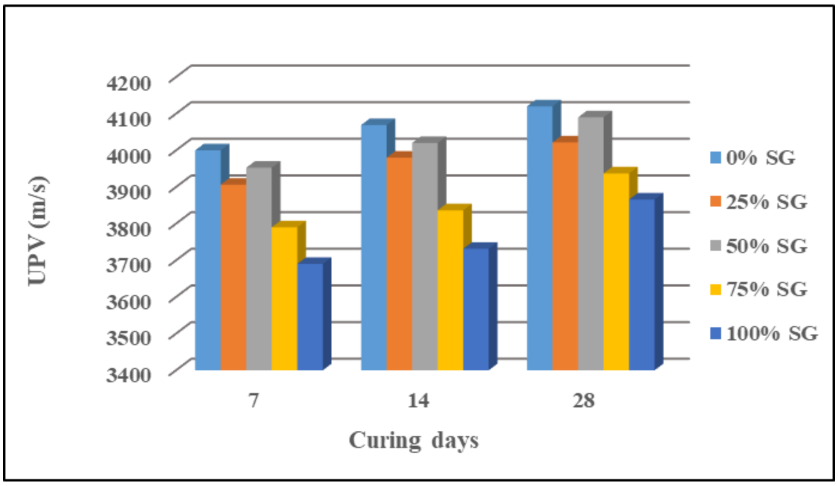

Fig. 5 - UPV against curing periods

3.6 Compressive Strength

The compressive strength result for the control and spent garnet mortar at 7, 14 and 28 days are shown in Fig. 6. From the figure, it can be summarized that the longer the curing period, the higher will be the compressive strength of the mortar. This may be due to the increased formation of CSH gel content from the hydration process of cement. Meanwhile, the compressive strength at the age of 28 days for mortar that contains 0%, 25%, 50%, 75% and 100% of spent garnet content are 43.1, 37.9 MPa, 41.8 MPa, 37.3 MPa and 36.5 MPa respectively. However, the results showed that the compressive strength of spent garnet mortar increased until 50% replacement by spent garnet and it starts to decline gradually when the amount of spent garnet used increases. Based on the results obtained, it can be seen that 50% of spent garnet replacement shows the best comparable strength when compared to conventional mortar. This may be due to the filling effect by spent garnet particles that fill in the void or pores in the mortar mixes which lead to dense mortar and increase the strength. On the other hand, 100% spent garnet replacement in the mortar gives the lowest compressive strength compared to the control sample. This may be due to the presence of excessive spent garnet particle in the mortar which can weakening the bond between the aggregates and cement paste. For that reason, the mortar becomes less dense has lower bonding strength and therefore it reduces the mortar strength. In short, the spent garnet material can be used as fine aggregates replacement up to 50% since it has a comparable strength with the conventional mortar.

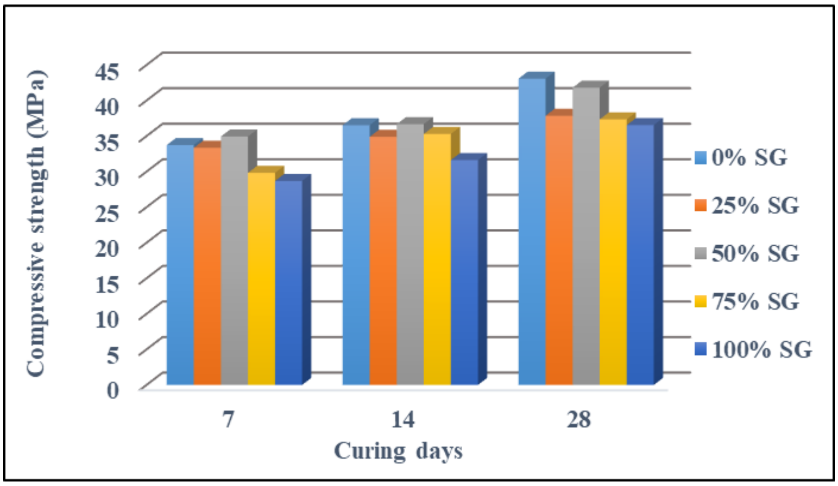

Fig. 6 - Compressive strength against curing periods

3.7 Water Absorption

Fig. 7 represents the test results of water absorption for control and spent garnet mortar over percentage of spent garnet replacement. From the results shown, there is a gradual decline in water absorption from 0% to 50% of spent garnet replacement but it then started to rise again as the increase of the percentage of spent garnet replacement in mortar. Based on the 28 days' results, the water absorption for 0%, 25%, 50%, 75% and 100% replacement of spent garnet in mortar are 3.9%, 3.6%, 3.2%, 3.8% and 4 %, respectively. Other than that 100% of spent garnet replacement in mortar shows the highest water absorption when compared with the conventional mortar by 4%. This is probably due to the low formation of CSH gel content that causes the presence of pores in mortar structures which allows the water to be absorbed and consequently resulting in less dense mortar. In contrast, the mortar that contain 50% spent garnet replacement gives the lowest percentage of water absorption up to 16% compared to the conventional mortar. This is probably due to less void in mortar from the filler effect of spent garnet particles.

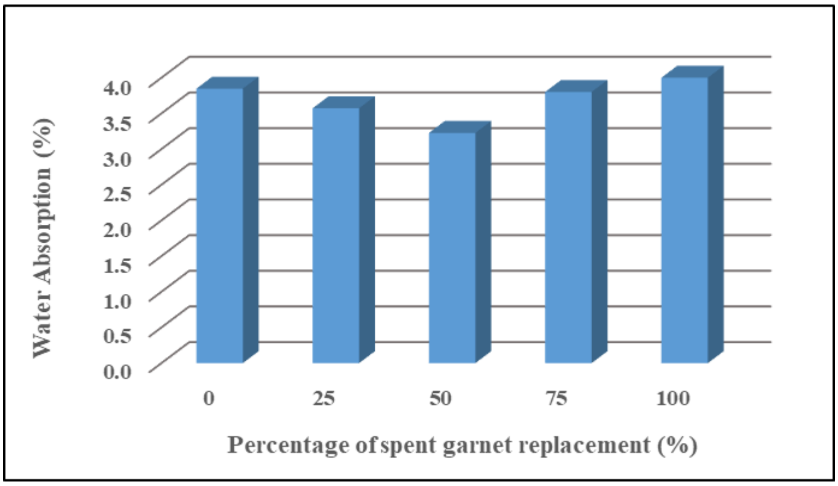

Fig. 7 - Water absorption at 28 days' tests

4. Conclusion

In overall the effect of spent garnet as a replacement for fine aggregates in mortar at physical, fresh and hardened state are determined. The spent garnet is suitable to be used as a replacement for fine aggregates in mortar as its physical properties are relatively similar to river sand. Besides, spent garnet can be used up to 50% replacement since it has a comparable strength with the conventional mortar (40 MPa at 28 days) and low water absorption. This research concludes that, the use of spent garnet as fine aggregates replacement in mortar can possibly avoid the over-usage of natural river sand thus, reduce the space of the landfill that can cause further problem on the environmental issues.

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