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ASSESSING THE PROPERTIES AND USABILITY OF SELECTED RECYCLED FINE AGGREGATES IN COOL PAVEMENT CONSTRUCTION

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ABSTRACT: Risky and expensive management procedures have made construction waste a significant issue. However, construction material demand is rising. The study aimed to assess the selected recycled aggregates (Ceramic, Glass, Slag, and Roof Tiles**)** through physical and mechanical properties, lightness, skid resistance, and light irradiation behaviour. Physical and mechanical properties will characterize the studied materials, and other test results confirm the usability of the selected recycle aggregates as cool pavement construction material. The saturated and dry density of the slag aggregates (2.64 g/cm3 & 2.6 g/cm3) were the highest, and the roof tiles (2.27 g/cm3 & 2.13 g/cm3) were the lowest among the experimental recycled aggregates. Roof tile aggregates absorbed the highest percentage of water (6.61%), and the lowest absorption showed the glass aggregates (0.02%). The highest strength value showed roof tiles and slag aggregate mortar in different mix proportions, and glass aggregate mortar showed the lowest value in all conditions. The highest increased inside and surface temperature showed the slag aggregate made sample block, and the lowest showed the ceramic aggregate block during the light irradiation test. The skid resistance test value was between 75 and 83 for all test aggregate blocks. According to the colour test result, the ceramic block will reflect most of the light and hold the minimum; the slag block will hold the maximum. Ceramic aggregate represents an optimal choice for constructing pavements that exhibit both cool temperatures and high skid resistance. In some cases, the users' mental acceptance of recycled material as a construction material is a real challenge.

Keywords: Recycled Aggregates, Physical Properties, Lightness, Skid Resistance, and Light irradiation.

1. INTRODUCTION

In recent years, industrial and construction waste has become a big problem because of their risky and expensive management systems. On the other hand, the demand for construction materials is increasing daily. This demand is creating pressure on environmental sustainability as the only material-supplying agent, which will cause vulnerable conditions in the future. To ensure a sustainable environment and to continue the present construction in the world, the use of recycled construction aggregates can play a vital role. In Japan, the treatment and disposal of municipal solid waste (MSW) come under the jurisdiction of the municipality where it is generated, and it is the common practice to incinerate the waste and landfill the subsequent residue (bottom and fly ash) [1]. Japan produced 10,947 thousand tons of glass and ceramic waste in 2005, 11,004 thousand tons in 2006, 11,461 thousand tons in 2007, and 8,776 thousand tons in 2008. It also produced 4,555 thousand tons of slag waste in 2005, 4,922 thousand tons in 2006, 5,183 thousand tons in 2007, and 6,174 thousand tons in 2008 [2]. After the recent East Japan earthquake, the government has faced a crucial problem with tsunami waste. The amount of waste in the Pacific Ocean side of Tohoku's three prefectures (Iwate, Miyagi, and Fukushima) is several times larger than the amount of waste that the area usually generates in a year. In 2011 Great East Japan Earthquake, Fukushima, Miyagi, and Iwate prefectures generated 3, 20, and 11 times larger amounts of waste than usual [3]. Recycling ceramic and glass wastes is a challenge for electric power generation companies worldwide. In 2009, Kansai Electric Power Co. Inc. generated 3,100 tons of glass and ceramic wastes that were used as insulators and for other purposes [4]. Crushed clay brick and pumice LWGCs exhibited better thermal insulation and fire resistance characteristics than geopolymer-containing natural aggregates (CGCs) [5]. Uses of industrial waste have been increased due to the demands of the use of resources. With increasing restrictions on landfills, industries have to find effective ways to recycle their wastes and by-products. From the viewpoint of a sustainable society, recycling ceramic wastes from ceramic industries and electric power companies is one of the most important purposes of the global environmental problem [6]. Researchers and investigators have aimed to utilize all types of wastes in environmentally friendly and economical ways as construction materials, such as fly ash, blast furnace slag, recycled aggregates, and red mud. [7].

During the construction and maintenance of this pavement system, a massive number of non-renewable materials and industrial products, such as aggregates, bitumen, cement, lime, and other additives, are consumed. The extraction and production of these virgin materials is an unsustainable practice [8]. WOS (waste oyster shell) sand can be a resource of pure calcareous materials and is effective in the replacement of sand, indicating the sustainable use of oyster shells [9].

Oyster shells are used as a partial replacement for steel fly ash in harbor sediment and lightweight aggregates (LWAs), aiming to both prepare LWAs for lowering the temperature and solve the disposal problem of oyster shells [10]. Increased O.S. substitution significantly affects strength, elastic modulus, drying shrinkage, freezing and thawing resistance, and permeability, particularly for long-term performance [11]. The crushed seashells can be used as the fine aggregate for self-compacting mortar by ensuring the essential properties of mortar [12]. In recent years, recycling of waste material has become a key issue in the construction industry. Ensuring that construction material waste can be recycled will achieve the goal of resource circulation, which will relieve some pressure from the increasing shortage of natural resources while avoiding the wastefulness of these limited earth resources [13]. Researchers are continuing their efforts to incorporate by-products and waste materials from different industries as alternatives in concrete to reduce the dependency on virgin materials for construction. Seashell waste, such as oyster shells, mussel shells, and scallop shells, among others, originates from the fishery industry. It is available in huge quantities in certain regions and is usually dumped or landfilled without any reuse value [14].

Precast concrete floor blocks could be made with recycled aggregate that meets thermal, cost, and environmental requirements [15]. Traditional roof tile powder in self-compacting concrete is an effort to the sustainable use of recycled waste and a new development in environmentally friendly concrete material technology [16]. Clay bricks and roof tile aggregates are thermally stable, which is why they perform well in concrete subjected to high temperatures. The resistance of clay bricks and roof tiles to high temperatures is an important characteristic; it has been confirmed that the spread of fire could be prevented in the case of masonry and clay roofing [17]. To reduce the surface heat, crushed oyster shells, roof tile debris, pottery debris, glass cullet, crushed escallops, and coral sand were used [18]. Population growth, continuous industrial development, construction of infrastructure, and house-building activities create huge amounts of C&D waste and, hence, the dire need for waste recycling. The demand for natural resources in the construction industry has reasonably increased, and the production of global aggregate has doubled from 21 billion to 40 billion tons in 7 years of duration. Countries such as China, India, Indonesia, Malaysia, Thailand, the Gulf States, Turkey, Russia, Brazil, and Mexico have recorded some of the strongest increases in the demand for waste recycling [19]. Recycling construction materials is not only the optimum solution in a "greater sustainability" context, but also it is preferable to prepare and implements the specific strategies that can reduce the use of virgin materials and prevent the production of waste [20].

Development has inflicted severe adverse effects on the environment and endangered its sustainability. The Uses of natural resources, particularly the non-renewable resources for construction leads to millions of tonnes of construction and demolition waste every year [21]. Concrete is the major construction material that plays a crucial role in improving infrastructure such as highways, bridges, and buildings. It is estimated that the total annual production of concrete worldwide is more than 10 billion tons [22]. The gradation and degree of saturation of recycled concrete aggregate significantly influenced the workability and mechanical properties of concrete [23]. To minimize the generation of concrete waste from construction industries, concrete recycling waste is one of the best methods to ensure a sustainable environment [24]. Surface heat reduction can be measured by "Light Irradiation Test" in laboratory or control conditions, as in open and natural conditions [18, 25]. There is little doubt that hot cities would be benefitted from having their pavements as light-coloured as possible [26].

A significant volume of municipal solid waste is generated in Japan, with the majority being incinerated. Most municipal solid waste incineration residues are typically buried in final disposal sites; however, decreasing the volume of these residues is essential due to the limited disposal capacity in Japan's final disposal sites. To decrease the volume of municipal solid waste incineration residues, it is essential to recycle municipal solid waste incineration ash, which constitutes a significant portion of these residues. Conversely, municipal solid waste incineration ash is characterised by the presence of heavy metals, raising concerns regarding the leaching of these metals contingent upon the recycling method employed. One potential method for recycling municipal solid waste incineration ash while mitigating the leaching of heavy metals is to incorporate the ash into concrete [27]. Waste output is rapidly growing in quantity and diversity on a global scale. Effective and efficient techniques must be developed to properly dispose of and recycle the trash generated. Reducing the impact on our environment and using non-renewable resources are also essential. More than 13.5 million square meters of tiles were created worldwide in 2017, and as society has advanced [28]

Presently, the predominant material utilised in many construction applications is concrete, a composite comprising cement, water, and aggregate. These ingredients are substances obtained from occasionally restricted natural resources [29]. In recent years, it has been difficult for the environment and the construction industry due to the decline in natural aggregate sources and the accompanying increase in massive amounts of construction and demolition debris. Recycling building and demolition debris into usable aggregate is a big step in the right direction. The use of recycled concrete aggregate in concrete, however, raises a number of contentious concerns and presents a number of challenges in terms of quality management [30]. During the period from 2016 to 2017, Australia generated around 1.1 million tonnes of waste glass, with around 467 kilotonnes sent to landfills and 612 kilotonnes recycled. The existing recycling methods for broken waste glass are inadequate, leading to an escalating environmental issue. Consequently, there is a keen interest in the advancement of innovative technology for recycling discarded glass [31].

This research explores the physical and mechanical properties of recycled aggregates, focusing on their potential use in cool pavement construction. While recycled aggregates have been studied in general contexts, their application as a sustainable material in cool pavements remains underexplored. This study emphasizes novel testing methods, such as lightness, light irradiation motive, and skid resistance tests, which are specifically tailored to assess their performance for mitigating urban heat and enhancing safety in pavement applications. By characterizing the unique properties of recycled aggregates, this research advances the understanding of their suitability for specialized applications beyond traditional uses, addressing critical environmental and functional challenges. The study bridges the gap between material characterization and practical implementation, offering new insights into the development of sustainable, high-performance pavement solutions that align with modern urban infrastructure demands.

2. RESEARCH SIGNIFICANCE

Industrial and construction waste management poses significant challenges due to dangerous and costly practices, threatening environmental sustainability. The heavy reliance on virgin materials exacerbates this issue, straining resources and creating an uncertain future. Recycled construction aggregates offer a promising alternative, supporting both environmental sustainability and the ongoing demands of global construction. This article focuses on the characterization of recycled aggregates by examining their physical and mechanical properties. Innovative tests, including lightness, light irradiation motive, and skid resistance, reveal the suitability of these materials for use in cool pavement construction. The findings demonstrate that recycled aggregates not only reduce waste but also enhance urban infrastructure by mitigating heat effects and improving pavement safety. This research paves the way for sustainable construction practices, promoting the use of recycled materials in advanced applications that address both environmental and functional challenges.

3. MATERIALS AND METHODS

The investigation was accomplished with four recycled fine aggregates: ceramic, roof tiles, glass, and slag aggregate, and one traditional standard fine aggregate, sand.

3.1 Materials Used in the Study

3.1.1 Sand

River bed sand was used in this study as a reference fine aggregate to compare the performance of other aggregates. The density of the used sand was 2.60 g/cm3, and the fineness modulus (F.M.) was 3.13. Size of the used river bed sand was 0-5 mm.

3.1.2 Cement

Ordinary Portland cement (OPC) with the density of 3.16 g/cm3 and specific surface area of 3,290 cm2/g was used in this study as binder.

3.1.3 Ceramic Aggregate

The ceramic tile aggregates were collected from Yamamura Co. Matsusaka City, Japan (Fig. 1). The size of the recycled ceramic aggregates in this study was 0-3mm.

Fig. 1 Ceramic aggregate

3.1.4 Roof Tiles Aggregates

The used roof tile aggregates were collected from Manen Co. Tsu City, Japan (Fig. 2). This recycling centre produces roof tile aggregates by crushing used roof tiles. The size of the recycled roof tile aggregates in this study was 0-3mm. The collected recycled roof tiles aggregates was not a single color material. That was a mixed of different color roof tiles.

Fig. 2 Roof tiles aggregate

3.1.5 Glass Aggregates

The used glass aggregates were collected from Yamamura Co., Matsusaka City, Japan (Fig. 3). The size of the recycled glass aggregates used in this study was 0-2.5mm.

Fig. 3 Glass aggregate

3.1.6 Slag Aggregates

The used Slag aggregates were collected from Yokkaichi City, Mie, Japan (Fig. 4). The size of the recycled slag aggregates in this study was 0-5mm.

Fig. 4 Slag aggregate

3.2 Methods of the Study

The basic physical parameters of the above-mentioned recycled aggregates were determined using standard methods to achieve the objectives.

3.2.1 Sieve Analysis

Sieve analysis was accomplished according to the “JIS A 1102: Method of test for sieve analysis of aggregates” [32].

Dense and well-graded aggregates are desirable for making concrete; gap-graded aggregates can also make good concrete. Only a few sizes dominate the bulk material for uniform grading; the open grade contains too many small particles and is easily disturbed by a hole [33].

3.2.2 Test of Density and Absorption

The experiment aimed to determine the saturated density (ds), oven dry density (dd), and absorption of the fine aggregates. It followed the instructions of “JIS A 1109: Method of test for density and water absorption of fine aggregates” [34].

3.2.3 Color Test

This test was performed with a Digital Color Reader (Fig. 5) (CR -13, Konica Minolta Optics Inc.) according to the direction of the instrument manufacturer, following Japanese Industrial Standard JIS Z8721 Colour specification – specification according to their three attributes [35].

Fig. 5 Photographic view of color test

3.2.4 Light Irradiation Test

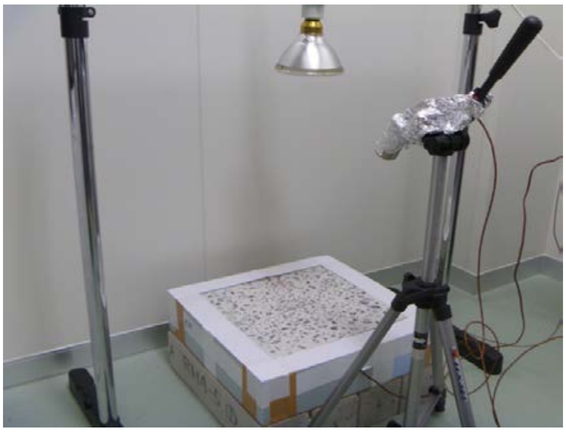

Fig. 6 Photographic view of light irradiation test

The concrete-mortar samples were stored for the test in a controlled room at 25℃ and with R.H. 50%. Every sample was placed in a cork sheet frame (30cm × 30cm × 5cm) and was kept in the light irradiation test room for 24 hours before the test for temperature adjustment of the sample at room temperature. The beam lamp Irradiation was continued on the sample block for four hours (Fig. 6). The data logger received and stored data for a total of about 24 hours. The surface temperature was measured by both a contact sensor (thermocouple) and a non-contact sensor for confirming the results.

3.2.5 Skid Resistance Test

The test was performed by using a British Pendulum Tester. The experiment was accomplished by following the "ASTM E 303: Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester" [36].

3.2.6 Strength Test

The experiment was accomplished by following "JIS R 5201: Physical testing methods for cement" [37]. Type-A (cement: fine aggregate=1:2) and Type-B (cement: fine aggregate=1:3) samples were prepared for the test.

4. RESULTS

4.1 Sieve Analysis Test Result

Sieve analysis results were expressed as fineness modulus (F.M.) and as a graphical presentation by gradation curve (Fig. 7). The fineness modulus of sand, roof tiles, ceramic, slag, and glass were 3.1, 2.9, 3.0, 4.0, and 3.4, respectively. The limit of the fineness modulus of fine aggregates is 2 to 3.5 [38].

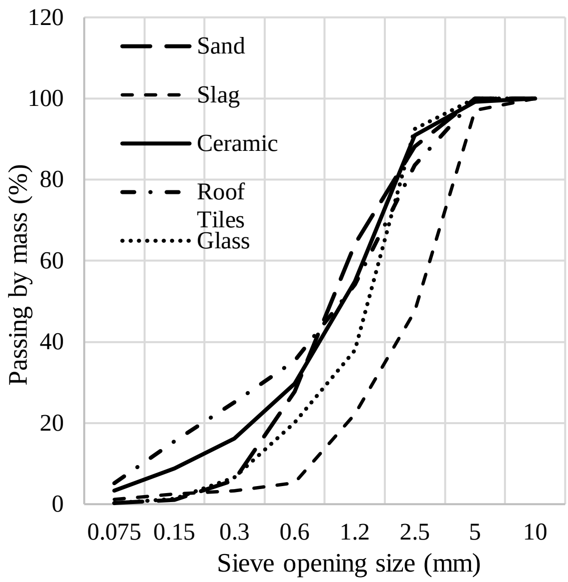

Fig. 7 Gradation curve of the experimental aggregates

According to the gradation curve, sand can be defined as uniformly graded. In contrast, ceramic tiles and glass aggregates can be defined as well-graded, slag is densely graded, and roof tiles aggregate is gap-graded [6]. The recycled slag, ceramic tiles, and glass aggregates were desirable for making concrete. As gap-grading aggregates lack one or more intermediate sizes, roof tiles could be used to prepare concrete with relatively low workability, and with high workability, segregation might occur, which could cause a problem.

4.2 The Density and The Water Absorption Test Result

The saturated and dry density of the slag aggregates (2.64 g/cm3 & 2.6 g/cm3) was the highest. The roof tiles (2.27 g/cm3 & 2.13 g/cm3) were the lowest among the experimental recycled aggregates when the value for the standard reference aggregate sand was 2.61 g/cm3 & 2.58 g/cm3 (Fig. 8). Roof tiles aggregates absorbed the highest (6.61%), and slag absorbed the lowest (1.51) percentage of water within the recycled experimental aggregates (Fig. 9). The absorption of the glass aggregates (0.02%) was very negligible and could be counted as zero absorbent.

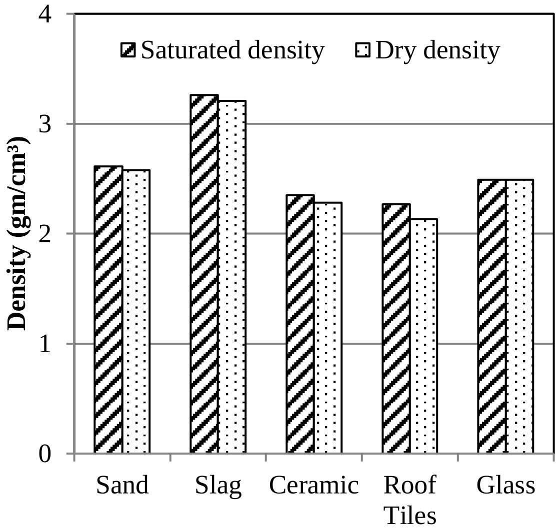

Fig. 8 Saturated and dry density of the aggregates

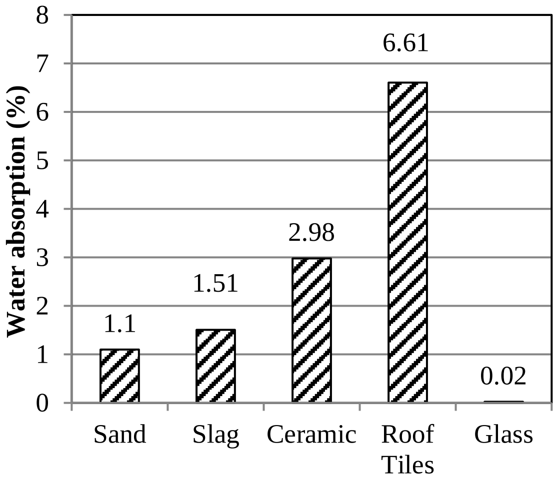

Fig. 9 Water absorption of the aggregates

Generally, density is directly proportional to the compressive strength of concrete. In the present study, slag shows lower compressive strength than traditional aggregate sand due to its higher moisture absorption, as shown in Fig. 9.

4.3 Color Test Result

The value of the lightness parameter indicates the lightness, reflection, and heat control properties of the sample block. According to the color test result, a ceramic block will reflect most of the light and hold the minimum; a slag block will hold the maximum (Fig. 10). More light-holding property indicates a hotter surface, and less indicates a cooler block surface.

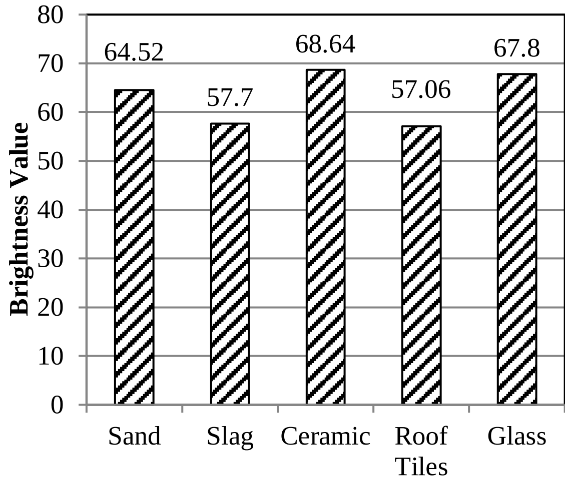

Fig. 10 Brightness status of the sample blocks surface.

4.4 Light Irradiation Test Result

During the contact measurement, the highest increased surface temperature was confirmed the slag aggregate-made sample block, and the lowest was in the ceramic aggregate block during the light irradiation test (Fig. 11).

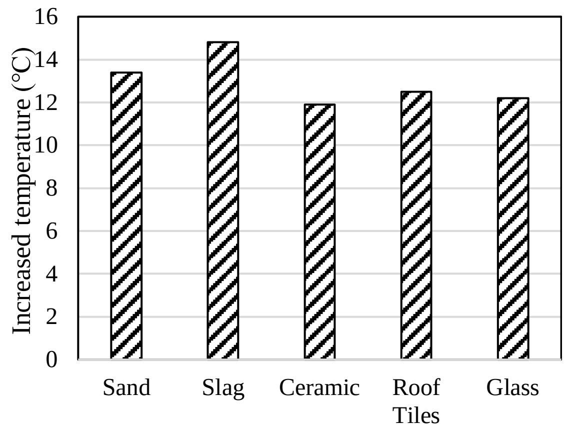

Fig. 11 Increased surface temperature measured by a contact sensor (Thermocouple)

During the non-contact measurement, the highest increased surface temperature was confirmed the slag aggregate-made sample block, and the lowest was in the ceramic aggregate block during the light irradiation test (Fig. 12).

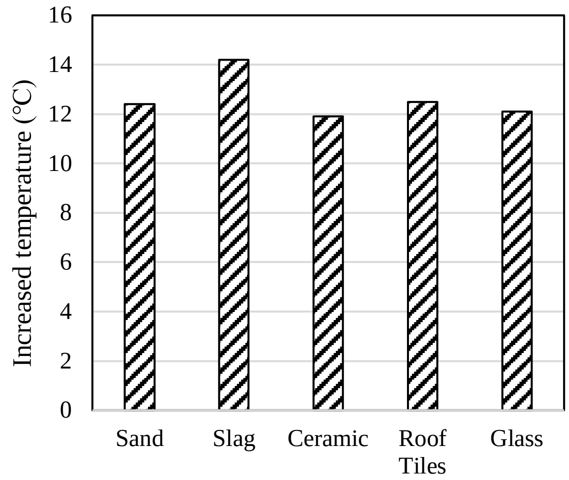

Fig. 12 Increased surface temperature measured by a non-contact temperature sensor

The highest increased surface temperature was confirmed the slag aggregate-made sample block, and the lowest was in the ceramic aggregate block during both the contact and non-contact light irradiation test. Also, confirmed that other materials showed the same pattern of temperature development in both tests.

4.5 Skid Resistance Test Result

The highest skid resistance test value was for the ceramic tile aggregate block surface, and the lowest value was for the sand-made mortar block surface (Fig. 13).

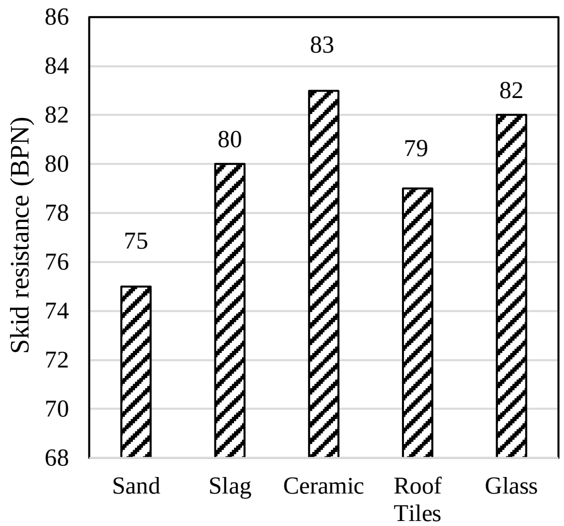

Fig. 13 Skid resistance test result

The skid resistance value should be ≥ 65 for round, bend, gradient, and unrestricted roads. It should be ≥ 55 for motorways and ≥ 45 for all other sites [39]. So, all of them could be used safely to make walkways and pavements, including bend and slop conditions, without any extra safety measures in terms of skid resistance. In terms of skid resistance properties in wet conditions, Slag blended Eco-mortar could be used in pavement construction [40].

4.6 Compressive Strength Test Results

Within the recycled aggregates at the age of 21 days after casting, glass aggregates showed the lowest Compressive strength for both types of samples (Type A and Type B). Roof tile and ceramic aggregate samples showed the same compressive strength for sample type A (Fig. 14), while roof tile samples showed slightly higher strength for sample type B (Fig. 15).

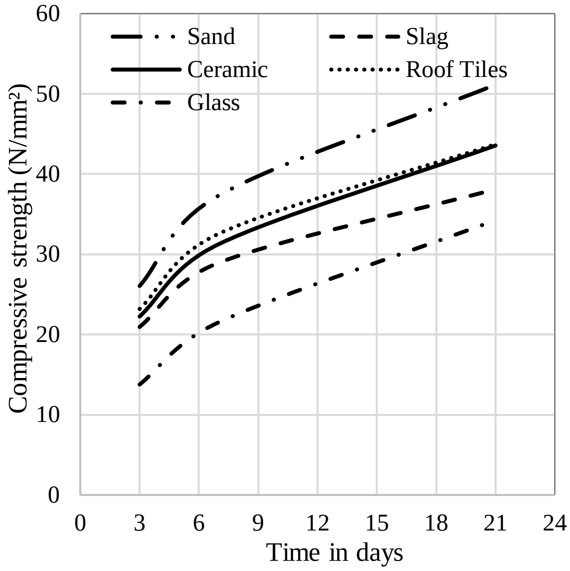

Fig. 14 Strength of type-A mortar samples

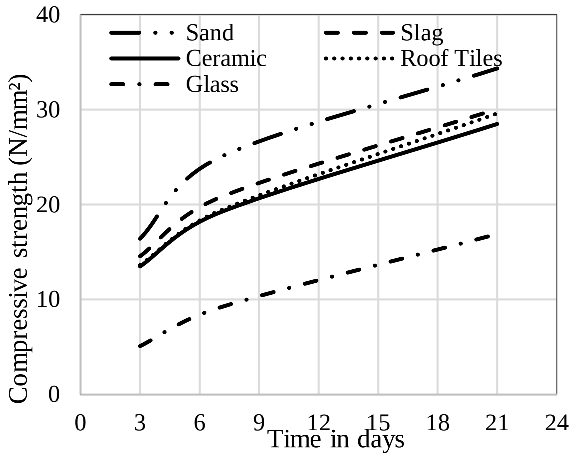

Fig. 15 Strength of type-B mortar samples

Slag samples showed higher strength for sample type B. However, they showed lower strength for sample type A compared with ceramic and roof tiles samples. Slag has a positive impact on the compressive strength of mortar. Up to 85% slag content can be used in partial replacement of cement, and 75% slag content will give the best result [41].

5. CONCLUSION

The outcomes of the experiment can be concluded as follows:

The experimental aggregates can be used in cool pavement construction as the replacement of sand and other traditional fine aggregates to reduce the cost and save the environment for green and sustainable construction. Ceramic aggregates would be a good choice where a normal surface temperature is needed, and slag could be used where a hot surface temperature is needed. Other aggregates could also be used with satisfactory light irradiation motive. Ceramic aggregates would be the best choice where high skid resistance is needed, and other aggregates could also be used in all conditions (walkways, motorways, with bend or slop conditions) to make road and pavement surfaces with a higher level of satisfaction.

There are no technical challenges to using recycled aggregates in construction, like availability and costs. However, in some cases, the users' mental acceptance of recycled material as a construction material is a challenge.

6. ACKNOWLEDGMENTS

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