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Investigation of Partial Replacement of Sand by Blending Glass and Rubber Aggregates

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Abstract: The continued disposal of waste glass and waste car tyres have become a nuisance to communities and threaten the environmental sustainability of the world. Therefore, recycling waste glass and rubber materials for application in concrete production can become one of the positive means of managing the waste crisis in the world from discarded waste glass and waste car tyres. This paper reports on the performance strength of concrete by investigating a mixture of waste glass and waste rubber tyre crumbs as an alternative fine aggregate replacement of sand. A blend of equally mixed waste glass (50%) and crumbs from waste rubber tyres (50%) was made. One hundred and eighty (180) concrete specimens in 50 mm by 50 mm cylinders moulds of varying replacement of sand aggregate of: 0%; 10%; 20%; 30%; and 40% by weight were prepared. The specimens were made by design mixes of 1:2 and 1:3 of cement to blend of waste glass combined with waste rubber to sand by weight. Such specimens were cured for 7, 14 and 28 days before determining the unconfined comprehensive, flexural and tensile strengths. The results showed that a mixture of waste glass and crumbs from rubber car tyres as partial replacement of sand were more than the referral conventional concrete at all the replacement levels of the natural sand fine aggregate. The study forms the basis for further research; replication of this study could yield rich lessons for concrete production using blended or mixed wastes of glass and rubber.

Keywords: Mixed Waste, Waste Glass and Rubber, Concrete, Recycling, Environment

1. Introduction

The amount of waste glass and waste rubber tyres is rapidly increasing every year in the disposal sites of the world. The disposal of such waste is being supercharged by an ever-growing demand for glass and rubber products as a result of the rapid industrialization and urbanization of cities around the world. Most of the waste glass and waste rubber from car tyres are dumped into landfill sites in many countries around the globe [1]. Land filling with waste glass and waste rubber car tyres are undesirable and an eyesore because on one hand, waste glass is not biodegradable while on the other hand, waste synthetic rubber tyres are not easily biodegradable which in turn make them both environmentally unfriendly [2, 3]. Furthermore, the acrid plums from waste rubber car tyre fires are difficult to put out, contain various amounts of toxic chemical and the air pollutants thereof cause serious threats to the environment and its inhabitants [5]. Furthermore, stockpiles of the waste rubber car tyres and waste glass become breeding grounds for various insects like mosquitoes which may carry deadly diseases [5]. The landfilling with waste glass and waste rubber car tyres also pose serious ecological threats because of their contribution to reduction of biodiversity [5]. Consequently, the accumulation of stockpiles of waste rubber car tyres and waste glass are a menace to society as they pose great environmental hazards.

However, there is a growing desire to rid the environment of non-biodegradable and slow biodegradable wastes such as waste glass and waste synthetic based rubber car tyres respectively. As a result of the aforementioned desire, recycling waste from glass and rubber car tyres into concrete production is attractive and should draw the attention of the world. The reason for this is underscored by the benefits that can accrue to mankind around the world. Firstly, for mitigating the world against environmental degradation from glass and rubber waste and secondly, by making waste from glass and rubber as suitable aggregates for concrete production. Thus, if such waste glass and waste rubber tyres could be used as alternative materials on a global scale, it could help in eradicating their adverse effects on the environment for sustainable development. There is already a huge potential for using waste glass and waste rubber car tyres in the concrete construction sector [6, 7]. In addition, the use of waste glass and waste rubber car tyres as aggregates is a suitable alternative to minimize the depletion of natural sand in many parts of the world [8, 9]. It is well known that sand being extracted worldwide is also creating a major adverse impact on rivers, deltas and coastal and marine ecosystems leading to loss of land through river or coastal erosion. Furthermore, construction costs continue to rise mainly because of the increase in the cost of conventional construction materials which demand a lot of energy in their production [10]. Cement is the most popularly utilized material on planet Earth, which is used to make concrete at a rate of 150 tonnes per second [11]. Nonetheless, such rate of concrete production is unable to keep up with the world's demand for concrete. Additionally, concrete is one of the most expensive used materials in construction. As such, there is an urgent need to develop or use alternative materials to minimize the cost of concrete [4]. Thus, the production cost of concrete could be lowered if waste from glass and car rubber tyres were used in making concrete products apart from ridding the environment of glass waste and rubber waste.

In a quest for developing alternative low-cost construction materials that are environmentally friendly or contribute towards sustainable development whilst retaining the desired properties of conventional materials, extensive research has been undertaken on the use of waste glass [10, 12−16] or use of waste rubber car tyres [5, 7] in the production of concrete. However, the aforementioned research studies have mainly focused on examining glass as an individual material to replace the natural fine or course aggregates in concrete. Similarly, waste rubber car tyres have also been investigated as an individual material to replace natural fine or course aggregates in concrete production [18]. For this reason, literature is littered with research on the possibility of individually replacing natural sand with waste glass or replacing sand with waste rubber tyres in concrete as fine aggregates [17, 6] or course aggregates [5]. As a result of such the monolithic investigations of either waste glass or waste rubber, there are hardly any studies which have been reported that have explored mixtures, blends or combinations of waste glass and waste rubber car tyres to replace natural fine or course aggregates in whole or in part. Incidentally, unless incentives are provided for structured waste disposal, waste is normally disposed in mixed form by majority of organizations and individuals. The objective of this paper is to fill that gap by examining the combined effect of waste glass and waste rubber car tyres as a replacement to sand aggregate.

2. Research Design

The research design was conducted by using experimental methods. Therefore, the methodology used in the study was a laboratory experimental procedure. In order to study the effect of a mixture or blend or combination of waste glass and rubber crumbs as partial sand replacement on the strength properties of concrete as seen in Figure 1, a blend of (1:1) or one-part waste glass (λ) to one-part waste rubber (μ) crumbs by weight was initially prepared. Thereafter, varying proportions by weight of glass and rubber blend ($\lambda+\mu$) to sand (δ) of 0%, 10%, 20%, 30%, and 40% of sand were made. Specimens of 1:2 and 1:3 cement (φ) to blended aggregate [($\lambda+\mu$) to sand (δ) in varying proportions were designed. The mixture of 0% blend of waste glass and rubber or with 100% sand acted as control for the experiment for comparability.

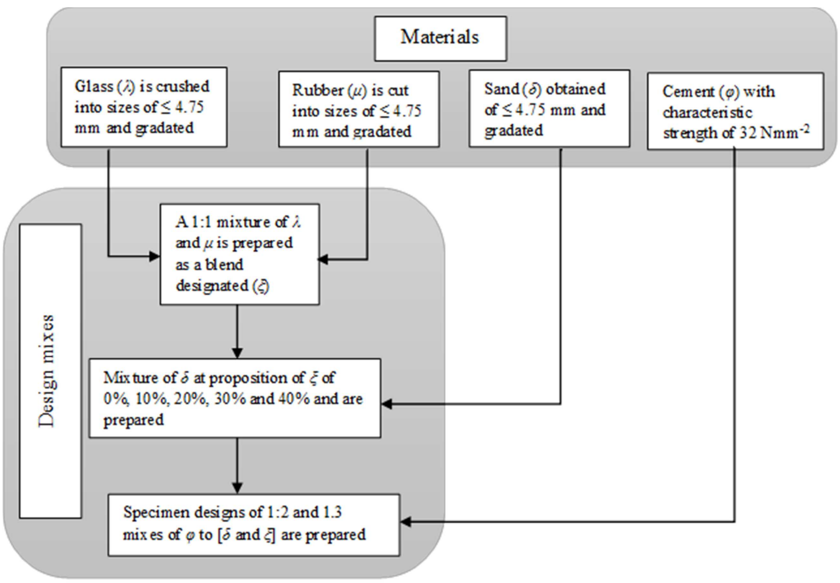


Figure 1. *Research Design.*

2.1. Materials and Methods

Materials for the investigation consisting of cement, glass, rubber and sand were sourced from Malawi one of the countries in the southern hemisphere. The characteristics of the materials are described in the sections that follow.

2.1.1. Binder

Ordinary Portland Cement (OPC) meeting the requirements of Malawi Bureau of Standard [21] and having a characteristic strength of 32 Nmm^{-2} with specific gravity of 2.96 and fineness modulus of 2800 cm^2g^{-1} was used. The initial and final setting times of the cement when ascertained were 123 minutes and 423 minutes. Table 1 shows the typical composition of the ordinary Portland cement that was used.

Table 1. *Typical composition of ordinary Portland cement.*

Compounds	Composition (%)
Tri-calcium silicate -C3S	55
Di-calcium silicate -C2S	18
Tri-calcium aluminate -C3A	10
Tetra-calcium alumino ferrite -C4AF	8
Calcium sulphate dihydrate -CSH2	6

2.1.2. Glass

Waste glasses with composition reflected in Table 2 were cleaned and then manually crushed into smaller pieces in size from 0.075 mm to no more than 4.75 mm. The waste glass was then subjected to sieve analysis for gradation conforming to the gradation procedure of BS 812: Part 1 specification [19]. The specific gravity of glass aggregate was 2.5 and its fineness modulus for the same was 2.94.

Table 2. *Waste glasses with composition.*

Compounds	Composition (%)
SiO_2	70.4
Al_2O_3	1.9
Fe_2O_3	1.2
MgO	10.3
Na_2O	14.0
K_2O	0.4

2.1.3. Rubber

Figure 2 shows the material composition of the disposed automobile rubber tyres as waste which were shredded into fine aggregates. The rubber car tyres consist of four fundamental ingredients, namely: rubber, carbon black, reinforcing materials and facilitators. Waste rubber car tyres were manually shredded to generate rubber crumbs ranging in size from 0.075-mm to no more than 4.75 mm. The rubber crumbs were subjected to a sieve analysis test for gradation conforming to the gradation procedure of BS 812: Part 1 specification [19].

2.1.4. Sand

Locally available river sand was used in the investigation, passing through 4.75 mm size was analysed conforming to the gradation procedure of BS 812: Part 1 specification [19]. Specific gravity of sand fine aggregate was 2.3 and its fineness modulus for the same was 2.75. The sand was subjected to a sieve analysis gradation.

2.1.5. Water

Fresh water free of organic materials with pH value of 7.0 was used for mixing cement and a blend of glass and rubber as a replacement of sand in the entire investigation. Such fresh water was also used for curing all the specimens of cement mixed with a blend of glass and rubber as a replacement of sand aggregates.

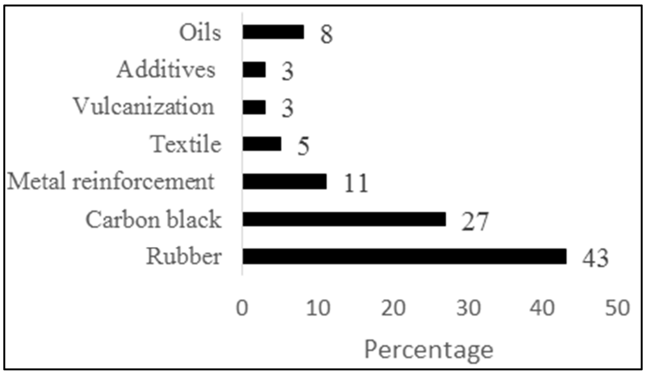


Figure 2. *Typical material composition.*

2.2. Specimens for Investigation

Based on the mix and design ratios which have previously been described in the preceding sections, one hundred and eighty (180) specimens were made in 50 mm by 50 mm cylinders moulds of 1:2 and 1:3 cement to blend aggregate. Such specimens were cured for 7, 14 and 28 days in fresh water of pH 7. Laboratory tests were performed to check the effects of waste glass and rubber car tyres on physical performance of concrete cylinders. The specimen strength (in terms of compressive, flexural and tensile strength) was the dependent variable which was observed and measured to determine the effect of the independent variables of the specimens in terms of proportions of waste glass, rubber and sand replacement as well as the period of curing.

3. Results and Discussion

Figure 3 shows participle size distributions of sand, rubber and glass which were used to explore the effect of partial replacement of sand with 0%, 10%, 20%, 30% and 40% with a 50% mixture or blends of waste glass and rubber. The coefficients of uniformity were 3.3, 4.1, and 3.1 respectively indicating composition of different particles sizes particularly for waste glass and rubber fine aggregates. The coefficients of curvature were 1.1, 0.91 and 0.32 respectively depicting ungraded part of the material. However, a further analysis of variance of the distributions using *t*-test of sand with rubber and sand with glass yielded $p = 0.26$ and $p = 0.56$ which indicated that the differences of the material distributions were not significant at $p < 0.05$. The foregoing is important particularly when one is going to use waste materials in concreting work.

Figure 4(*a*) shows comprehensive strength of samples with replacement of sand aggregates ranging from 0% to 40% of equal mixture of rubber (50%) and glass (50%). Such samples were made by mixing one-part cement to two-parts (1:2) of the aforementioned aggregates by weight which were cured for 7 days, 14 days and 28 days. The unconfined comprehensive strength of samples with 0% replacement of sand which acted as a control and had the highest unconfined comprehensive strength. All the samples which were cured for 7 days, 14 days and 28 days show a general decrease in strength irrespective of amount of sand replaced.

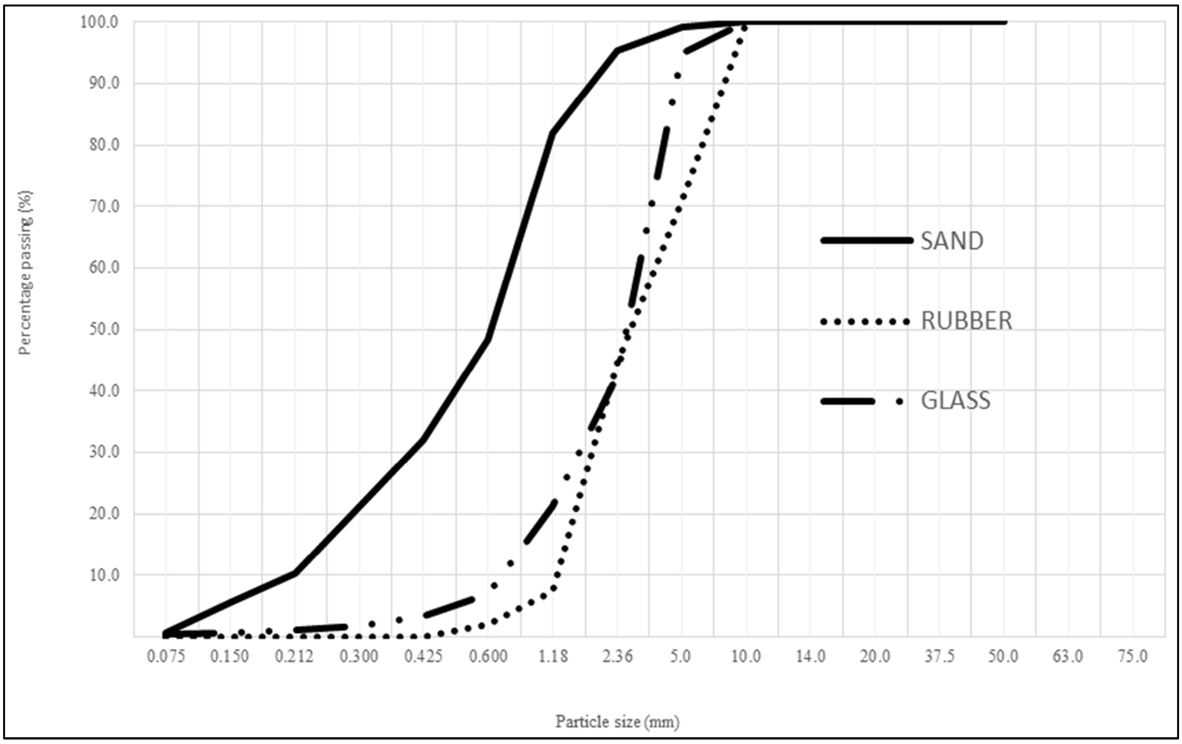
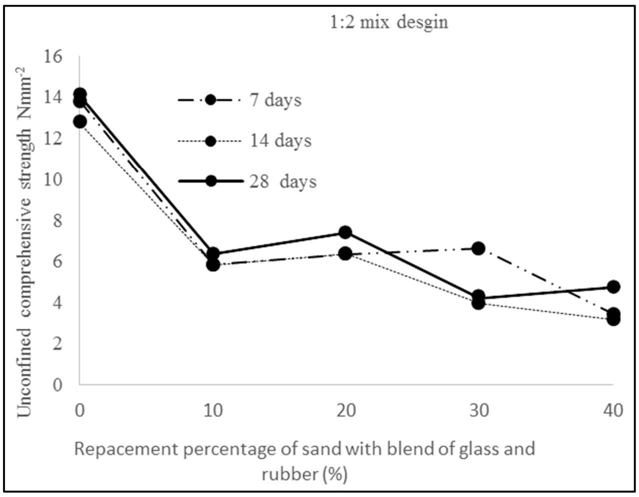
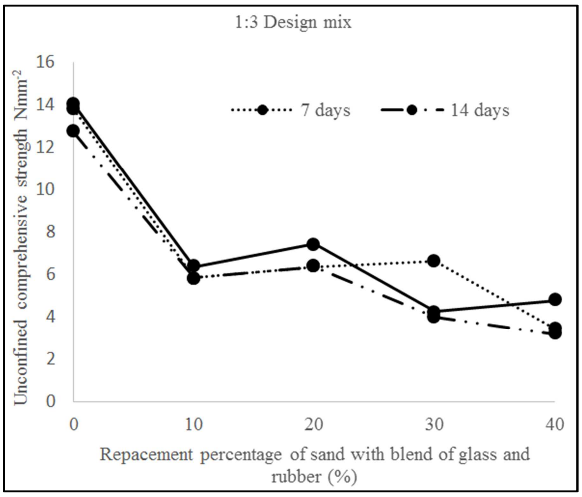


Figure 3. *Particle size distribution.*

Figure 4(*b*) representing samples that were mixed with one-part cement to three-parts of aggregates (1:3) of replacement with waste glass and waste rubber to sand aggregates, show a similar trend. There are some fluctuations particularly at higher percentage of replacement of the sand with waste glass and rubber aggregates. Equally, as the cement content decreased the fluctuations also increased at early stages of curing. According to L. H. Chuo et al. [20] such fluctuations are expected and are associated with lack of bonding between cement paste and the surfaces of rubber and glass which can be overcome.



(a)



(b)

Figure 4. *Unconfined comprehensive strength with curing.*

Figure 5 shows the tensile strength of the specimens decreasing rapidly from the strength values of the control of 0% replacement where there was no replacement of sand with waste glass and rubber. The foregoing characteristic is similar between 1:2 and 1:3 cement to blend of waste glass and waste rubber design mixes. The behaviour was not significantly different for the conventional design mixes of cement and sand. It can further be observed that even the control design samples when compared between 1:2 and 1:3 there is a general decline in tensile strength. These results are promising in the application of mixtures of wastes in concrete that are usually dumped in disposal sites in mixed forms not in monolithic forms of waste disposal unless prior arrangements are made with various industries that discard waste to manage their heterogeneity.

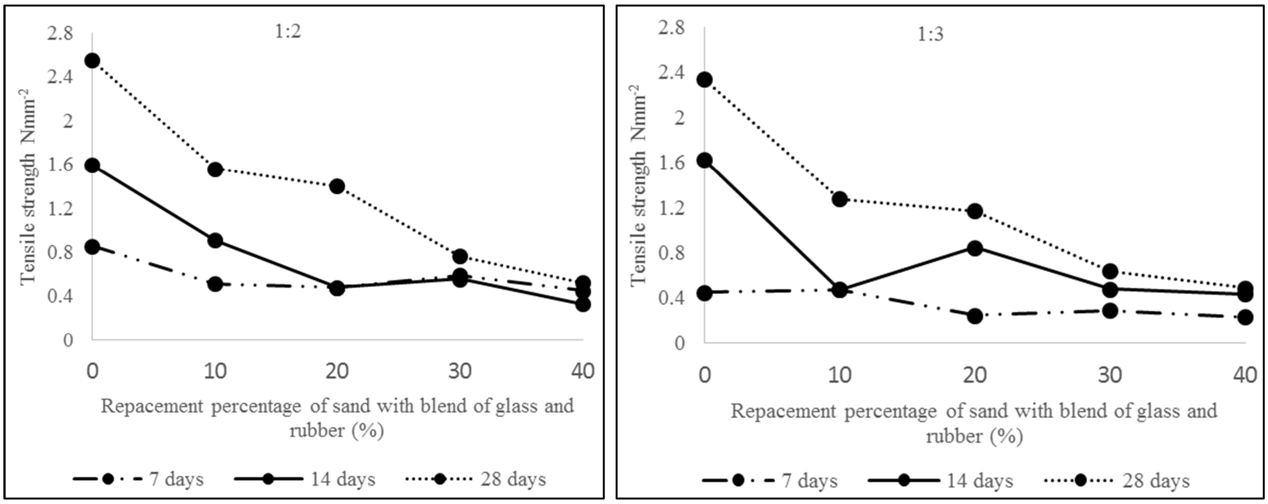


Figure 5. *Tensile strength with age of curing.*

Figure 6 shows the tensile strength of specimens that were cured for 7 days, 14 days and 28 days with respect to varying percentages of sand replacement at 0%, 10%, 20% 30% and 40% by weight. The design mixes of cement to blend of waste glass and waste rubber of 1:2 and 1:3. The tensile strength of the specimens decreased rapidly from the strength values of the control of 0% to 40% replacement of sand with waste glass and waste rubber. It can be observed that as the curing period increases fluctuations of the tensile strength values decreases. The fluctuations of the tensile strengths particularly for 28 days curing are not as severe as those of 7 days and 14 days of curing.

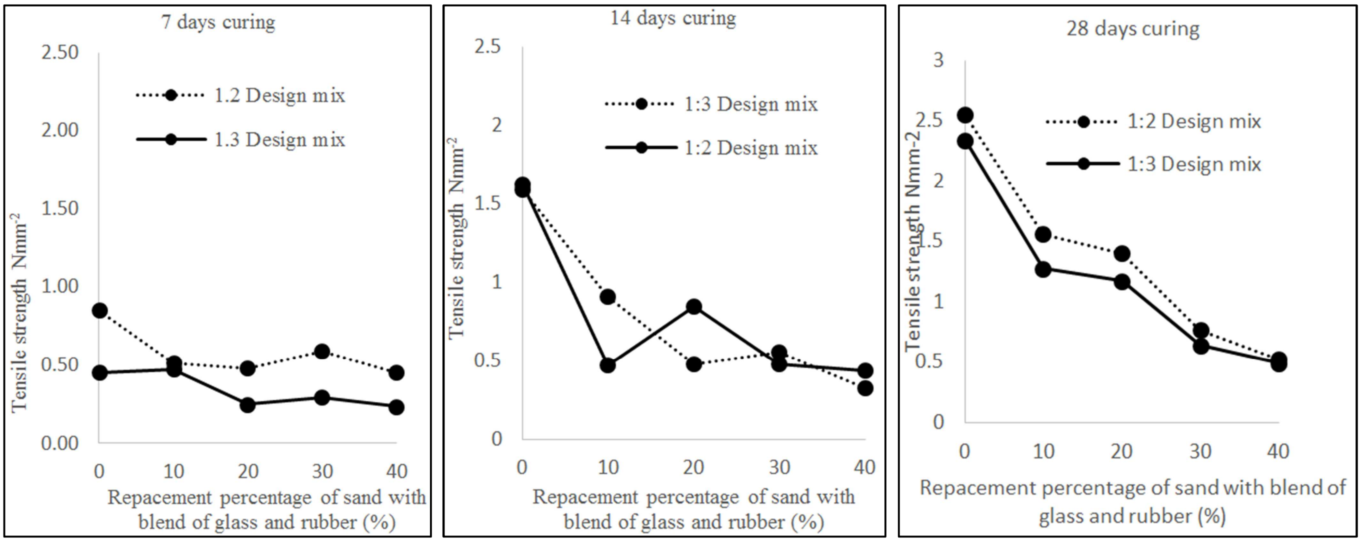


Figure 6. *Tensile strength at 1:2 and 1:3 design mix ratios.*

Figure 7 shows the flexural strength of the specimens of design 1:2 and 1:3 cement to blend of waste glass and rubber cured for 7, 14 and 28 days with varying replacement percentages. It can be shown that as the proportion of the blend increased the flexural strength decreased with insignificant differences among the 7, 14- and 28-days curing ages. However, with higher percentages (40%) of blend of waste glass and rubber generates a lot of fluctuations. The foregoing typifies the behaviour of ordinary concrete.

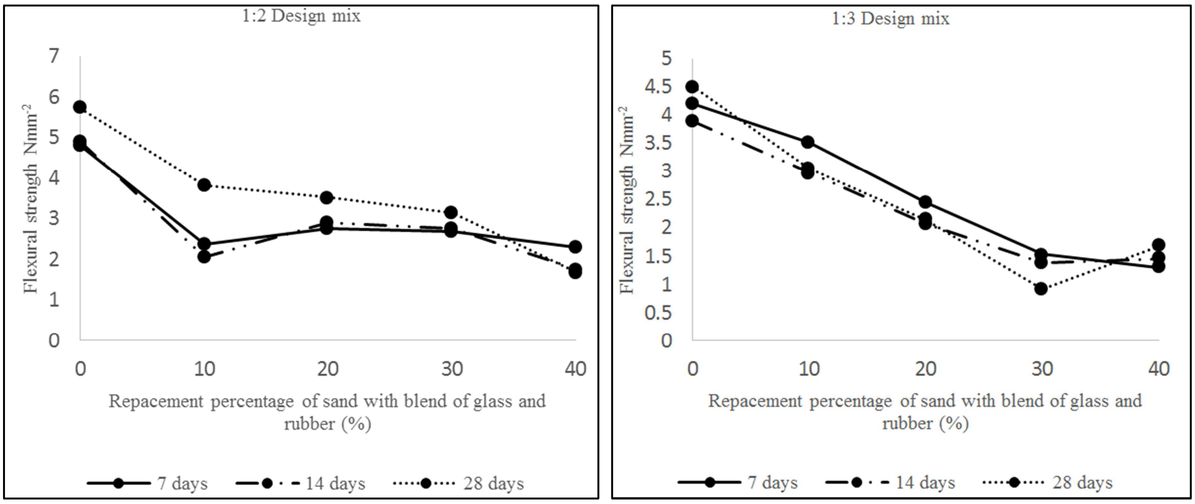


Figure 7. *Flexural strength with age of curing.*

Figure 8 shows further analysis of two separate design mixes (1:2 and 1:3) cured and tested after 28 days, 14 days and 28 days. It can be shown that as the specimens aged particularly for the 28 days fluctuation minimized. However, fluctuations can be seen for the specimens that were tested at 7 days and 14 days. The bond strength is associated with the fluctuations which is expected with increased mixture of waste glass and rubber in replacing sand [22]. However, the specimen tested after curing for 28 days demonstrated the possibility of utilizing mixtures or blends of waste glass and rubber as potential substitutes particularly when these wastes are generally found in mixed forms.

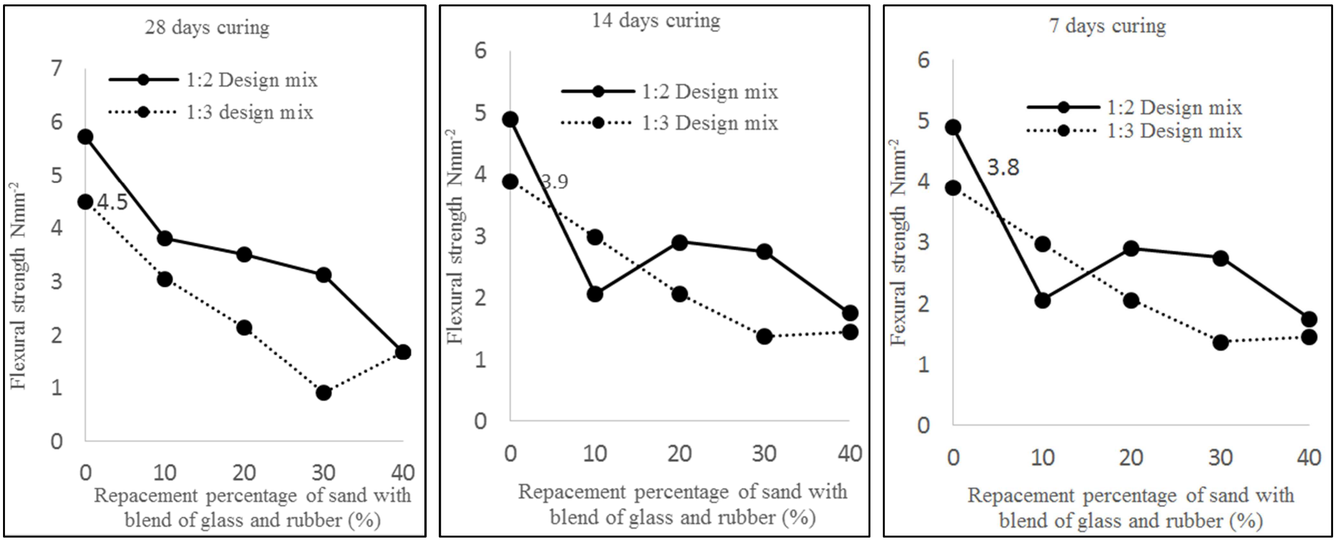


Figure 8. *Flexural strength at 1:2 and 1:3 mix ratios.*

4. Conclusions

It should be noted that when users of glass and rubber dump their waste, unless incentives are provided, they dispose them in mixed forms. Thus, the study of a mixture, combination or blend of glass and rubber wastes as fine aggregates replacement of natural sand has considerable potential for concrete production and mitigation measure for sustainability of the environmental. The results showed that a mixture of waste glass and waste rubber crumbs from tyres as partial replacement of fine aggregate were more than the referral conventional concrete at all levels of replacement of natural sand as fine aggregates. The growing need to cleanse the environment of non-biodegradable glass and rubber waste can be achieved to avoid a potential ecological disaster on the planet. The foregoing, can be achieved if waste glass and waste rubber tyres as replacement of sand natural aggregates could be used in concrete production on a global scale. Furthermore, the use of waste glass and waste rubber as aggregates as replacement is a suitable alternative to minimize the depletion of natural sand which is over-extracted worldwide with corresponding negative environmental consequences. The study forms the basis for further research particularly in exploring an area with limited or no studies focusing on a mixture, combination or blend of glass and rubber wastes as fine aggregates replacement of natural sand. Replication of this study could yield rich lessons for concrete production using blended or mixed wastes to mimic disposal behaviour by organizations and individuals that use glass and rubber.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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