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Promoting the Use of Waste Glass Concrete in Developing Countries

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Abstract - Due to the numerous advantages in conjunction to sustainability as one of the key requirements for construction industry to lower environmental impacts and rapid depletion of natural resources, there has been an increasing interest in production and also investigation of properties of concrete containing waste materials. Glass is amongst the oldest materials that have been used for many years in various applications. Therefore, in recent years several studies have been conducted to evaluate and promote the potential use of waste glass (WG) in concrete production. For the present study, five concrete mixtures in total with varying WG content ratios of 0, 15, 30 and 60% as partial replacement of natural fine aggregate were prepared. The water/cement (W/C) ratio of 0.5 was kept constant for all concrete mixtures. The properties investigated were aggregates sieving analysis, and consistence, density, compressive strength and water absorption of concrete containing varying amounts of WG and in result, promoting the use of this new concrete in developing countries. The compressive strength results indicate that the mixtures containing WG, generally showed lower compressive strength than the control mixtures with the minimum 28 days age strength occurring at 60% WG. However, with appropriate mix design utilisation of WG in concrete production is possible.

Index terms - Aggregate; Concrete; Durability; Environment; Recycling; Strength; Waste glass.

1 Introduction

Concrete as a construction material can be found in all forms of construction ranging from housing to commercial buildings. However, with the growing demand and ambitious environmentalists there has been a shift of trend towards using more environmentally friendly resources in creating concrete which have shown to have related purposes, rather than using up the planets natural resources. Therefore, waste materials in concrete as aggregate replacement will not only reduce the waste produced by people but also conserve the natural resources [1].

According to the literature, reusing and recycling of waste materials are considered the best environmental solutions. In fact, utilisation of waste materials (i.e., plastics, glass etc.) in concrete construction is one of the prime research interests to reach the goal of achieving sustainable construction. One of such waste materials is waste glass (WG). A large quantity of glass is disposed in landfills or dumped in open spaces as a waste. United Nations estimates the volume of yearly disposed solid waste to be 200 million tons, 7% of which is made up of glass cross the world [2]. Collecting WG before disposed in landfill sites in crushed and graded form can be used as aggregates to produce sustainable concrete.

Studies in to WG concrete emphasise that as the amount of WG increases, so does the air content due to the awkward shape of the WG and poor compactness. Compressive, tensile and flexural strengths all decrease when adhesion is not fully achieved in the concrete containing WG. Coarse WG particles, used as aggregate, produced poor concrete strength, due to WG aggregates extremely poor shape, poor surface characteristics, and high friability [3, 4]. Another research [2] revealed that using WG as aggregate did not have a marked effect on the workability of concrete. While WG addition decreased the slump, air content and fresh unit weight, it increased flowing and VeBe values. They also reported that compressive, flexural and indirect tensile strengths as well as Schmidt hardness values were determined to decrease in proportion to an increase in WG. In particular, the compressive strength decreased as much as 49% with a 60% of WG addition. They concluded that using WG in preference to fine aggregate would produce better results assuming that its geometry be more proper and almost spherical.

The main aim of the present study is to set up an experimental programme to create a realistic approach in order to investigate the influence of WG based aggregates on the properties of concrete and produce a sustainable material for construction industry in developing countries including Kurdistan-Iraq. The specific objectives of this study are investigating mechanical properties (e.g. compressive strength) and durability properties (e.g. water absorption) of concrete containing different WG replacement levels at different curing times.

2 Experimental Methodology

2.1 Materials

The Ordinary Portland Cement (OPC) (Table 1), natural fine aggregate and natural coarse aggregate (10mm) was used in concrete mixes. For particle size distribution (sieving) (Figs. 1, 2) test, a representative sample of the aggregates was placed in the oven and dried to a constant weight at a temperature of 110 °C [5]. A WG based aggregate to replace natural fine aggregate was also used in the concrete mixes. The waste glass was collected from different areas of Soran city, Kurdistan, Iraq. The collected waste glass includes flat glass mainly used for windows.

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TABLE 1
CHEMICAL PROPERTIES OF CEMENT CURRENTLY AVAILABLE IN KURDISTAN-IRAQ

Compounds	(% by weight)
CaO	64.43
SiO2	21.14
Al2O3	5.78
Fe2O3	3.59
SO3	2.35
MgO	1.52
Loss of ignition	0.89
Lime saturation factor	0.92
Insoluble residue	0.34
Main compounds (Bogue's equation) % by weight	
C3S	50.83
C2S	22.30
C3A	9.25
C4AF	10.90

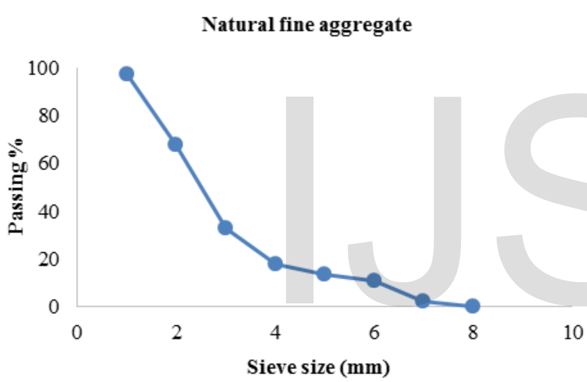

Fig. 1: Particle size distribution of natural fine aggregate

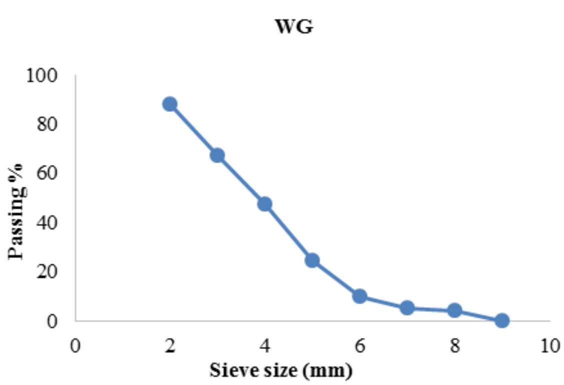

Fig. 2: Particle size distribution of WG

2.2 Concrete Mix Proportion

A comprehensive summary of the concrete details (ingredients) are presented in Table 2. In order to investigate the effect of the WG aggregate on physical, mechanical and durability properties of concrete, mixtures were prepared in different aggregate replacement levels. Four concrete mixtures in total were used for the present study.

The control mixture had a proportion of 1 (cement): 2 (natural fine aggregate): 4 (natural coarse aggregate). The replacement levels of natural fine aggregate by WG were 0, 15, 30 and 60%. The water to cement ratio (W/C) of 0.5, amount of water, cement and natural coarse aggregate was kept constant for all mixtures.

The mixing of materials was done in a specific arrangement, by placing a part of the water with adding the dry aggregates, which was thoroughly mixed for about 2 minutes to get the aggregates wetted with water. Then, the remaining materials were added to the container and the remaining water was gradually added while the mixing was in progress. The mixing was continued until a mix of uniform consistency was achieved. The slump test [6] was done immediately after mixing for all the concrete mixtures.

Standard test specimens have already chosen for investigating the various properties. Specimens were cast in steel moulds. After casting, specimens were covered and left in the laboratory for 24 hours. Then, specimens were de-moulded and placed in water for different curing times. Mix preparation is very important when using sharp materials like WG and enough care was exercised during mixing, pouring and compacting processes.

2.3 Test Procedure

2.3.1 Slump Measurement

Slump test [6] was carried out to measure the concrete workability (consistence).

2.3.2 Density

Cubes of 150×150×150mm size were used for the determination of dry density [7]. The cubes were dried until a constant dry mass was attained. The dry density test was carried out on three cubes for each concrete mix and the average was used for analysis purposes.

2.3.3 Compressive Strength

Cubes of 150×150×150mm size were used for the determination of compressive strength at 7, 14 and 28 days. These specimens were cured in normal water until testing. Compressive strength test was carried out using testing machine of 3000 KN capacity at the loading rate of 0.6 MPa/s according to BS EN 12390-3:2009 [8]. Compressive strength test was carried out on three cubes from mix combination and the average was used for analysis purposes.

2.3.4 Total Water Absorption (WA)

Specimens of 150×150×150mm size were used for total water absorption test at 28 days. The specimens were cured in normal water until testing. Saturated surface dry cubes were kept in a hot air oven at 110 ºC until a constant dry mass was attained. Specimens were immersed in water and the weight gain was measured at regular intervals until a constant weight

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is reached. The absorption at the final (total) absorption (at a point when the difference between two consecutive weights at 12-hour interval is almost negligible) was reported to assess the concrete water absorption [9].

TABLE 2
ACTUAL DETAILS OF CONCRETE INGREDIENTS

Mixture	WG replacement (%)	Fine agg. (kg) Natural	Fine agg. (kg) WG	Coarse agg. (kg)	Cement (kg)	Water (kg)
Control	0	21.6	0.0	43.2	10.8	5.4
2	15	18.4	3.2	43.2	10.8	5.4
3	30	15.1	6.5	43.2	10.8	5.4
4	60	8.6	13.0	43.2	10.8	5.4

3 Results and Discussion

3.1 Workability

The workability (slump) values for concretes containing varying amounts of WG aggregate are presented in Fig. 3. Slump test measurements were carried out on all four mixtures. Slump test is one of the methods to measure the workability (consistence) of fresh concrete. The slump values are in the range of 12-16mm.

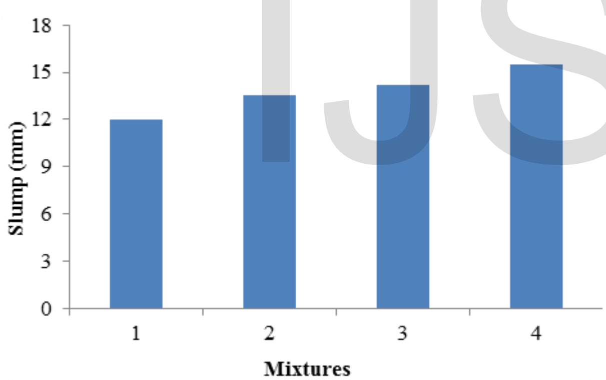

Fig. 3: Slump values of concrete containing varying amounts of WG

As it was reported in literature review [2], using WG as aggregate did not have a noticeable effect on the workability of concrete but using a high proportion of WG in concrete decreased the workability. However, due to the fact that WG does not absorb water and that the water layer over the surface of WG is thinner the workability of the concrete slightly increased with the increase in WG content.

3.2 Density

The fresh and dry density of concrete containing varying amounts of WG is presented in Figs. 4 and 5. The densities for concretes containing varying amounts of WG were in the range of 2413-2330 and 2395-2328 kg/m^3 at fresh and dry conditions, respectively. Generally, there is a decrease in concrete density with increase in WG content. However, it is interesting to see that the density of the concretes decreased with the increase in WG up to 15% then slightly increased at 30% and finally decreased at 60% WG replacement. The decrease in density was 4% only for concrete containing 60% WG compared to control. The decrease in the fresh density of the WG concrete mixtures can be attributed to the specific gravity of the waste glass, which is approximately 14.8% lower than that of the natural fine aggregate [10]. In spite of the decrease in the fresh density values of waste glass concrete mixes, they are still comparable to the control mixes. That means there is not noticeable difference between density of natural fine aggregate and WG aggregates. As we know, density of concrete depends upon the density, volume, moisture content and grading of the aggregates, mix proportions, cement content, water/binder ratio, chemical and mineral admixtures, method of compaction and curing conditions [11].

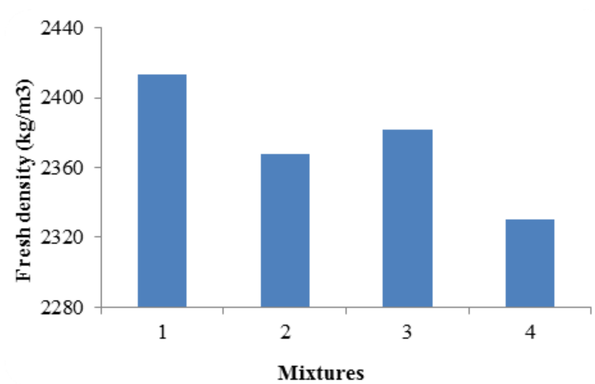

Fig. 4: Fresh density of concrete containing varying amounts of WG

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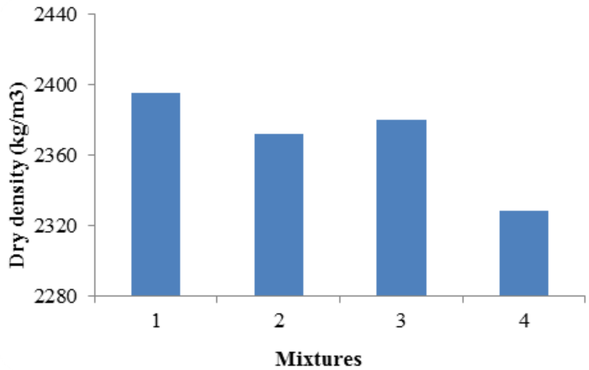

Fig. 5: Dry density of concrete containing varying amounts of WG

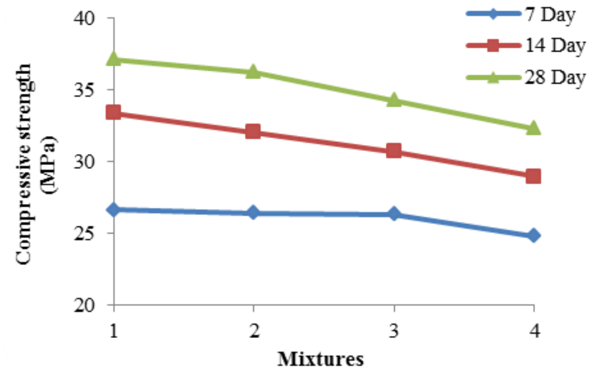

Fig. 6: Compressive strength of concrete containing varying amounts of WG at different curing periods

3.3 Compressive Strength

The compressive strength of concretes containing varying amounts of WG aggregate at different curing periods is presented in Fig. 6. The compressive strength values are in the range of 32.3-37.1 MPa at 28-day age.

Due to the lower strength of WG particles, the incorporation of WG caused a reduction in the compressive strength. The decrease in compressive strength of the concretes at 28 days age was 2%, 8%, and 13% at WG contents of 15, 30 and 60%, respectively, compared to the control concrete of the same age. This may be due to the unimodal grain size distribution of WG, as presented in Fig. 2, may have led to less optimal compacting and therefore larger volume of pores. Larger pore volume would lead to a decrease in compressive strength. The low compressive strength of WG concretes could also be attributed to the decrease in the adhesive strength between the surface of the WG aggregates and the cement paste.

In the present study, the compressive strength increases with curing age for all mixes as expected. Control mix (0% WG) gained 72% of 28-day strength in the first 7 days of curing. This strength development for mixes 2 (15% WG), 3 (30% WG) and 4 (60% WG) is 73%, 77% and 77%, respectively. The strength development for concrete mixes slightly increasing with increase in WG content.

According to the recognized standards [12], a minimum strength of 7.5 MPa is required for special purposes and heavy duty bearing blocks. Therefore, for a target compressive strength of 7.5 MPa, all concrete mixtures with varying WG aggregate contents (15%, 30% and 60%) are suitable to produce all types of blocks including heavy duty bearing blocks. The concrete containing lower amounts of WG with 36 MPa can comply with the necessary minimum requirements of structural concrete.

3.4 Water Absorption

The water absorption of concrete containing varying amounts of WG is presented in Fig. 7. At the 28-day age, the total water absorption of all concretes was about 5%. An increase in water absorption is an indication of an increase in the volume of pores. This may be due to the unimodal grain size distribution of WG, as presented in Fig. 2, may have led to less optimal compacting and therefore larger volume of pores. Larger pore volume would lead to an increase in water absorption [13].

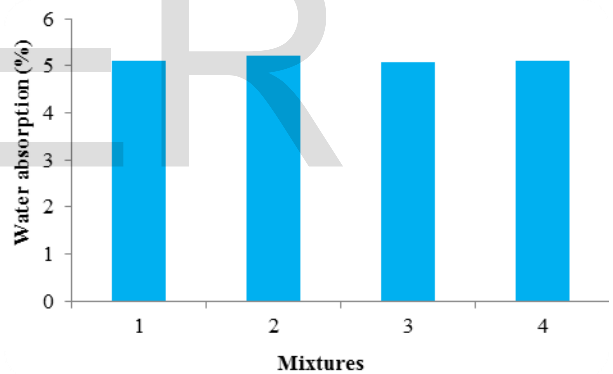

Fig. 7: Total water absorption of concrete containing varying amounts of WG

4 Conclusions

According to the present study, reusing and recycling of waste materials can be the best technique to solve the environmental problems of municipal solid wastes in developing countries including Kurdistan-Iraq. According to the experimental results obtained the influence of an increase in WG content in concrete on workability and water absorption was not noticeable. The compressive strength and density of concrete decreased with increase in WG content. However, with appropriate mix design, the utilisation of WG in concrete production is possible. The concrete mixtures with varying WG aggregate contents are suitable to produce all types of blocks including heavy duty bearing blocks. The main recommendation for further possible work is to investigate the durability properties of concrete incorporating WG e.g. resistance to chemicals or freezing & thaw before this novel environmentally friendly concrete could be proven OK to use in civil engineering applications in developing countries.

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