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Use of Recycled Windshield Glass as Sand Replacement in Cement-Based Mortars

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***Abstract* –** The construction industry is essential for social development in the world and the concrete is one of the most used materials for that purpose. Moreover, the manufacture of the concrete requires large quantities of sand and coarse aggregates, causing the depletion of natural resources. According to the above, the use of discarded or recycled materials as partial substitute of natural aggregates for concrete is attracting the attention of researchers around the world. One of these discarded materials is the windshield glass (WG), a special glass used for automobiles, which is available in large quantities around the world causing disposal issues because the difficulty of being recycled. In this research, the use of WG is proposed for the preparation of cement-based mortars as a first step before to be used in concrete mixtures. A low energy treatment is proposed to remove the WG from the adhesive polyvinyl layer that makes up the windshield. After that, different percentages of sand were replaced by WG for the preparation of the cement-based mortars. The flow of the mortars in fresh state was evaluated. Also, the compressive strength of the hardened mortars was evaluated at 7 and 28 days. The results indicated that the up to 80% WG can be used as partial substitute of sand for structural mortars.

***Keywords*:** Ecological cement-based mortar, windshield glass, sand, low-energy treatment.

1. Introduction

The concrete is one of the most used construction materials for civil infrastructure around the world. However, the manufacturing of the concrete requires large quantities of natural aggregates causing the depletion of the natural resources around the world. In general, the aggregates for the concrete are obtained from mining activities to obtain raw materials altering the lands. Is obvious that greater infrastructures consume massive quantities of aggregates. Considering the above, the use of alternative materials as substitute of natural aggregates for concrete is attracting the attention of different research groups, moreover, the limited knowledge about the benefits of these unconventional materials and their quality creates a gap for it use [1].

In another hand, there are different discarded materials which can be used as alternative for natural aggregates in concrete mixtures. The physical properties of these materials can be changed to obtain concretes with proper fresh and hardened properties. The change of the physical properties of these materials depends on the adopted methodology as for example crushing and sieving. However, each discarded material needs a specific treatment depending on is nature, a research focus to find the adequate and the most viable methodology for each material needs to be investigated to break down the gap to be used in the construction industry.

The river sand is an important aggregate in concrete mixtures and different researchers have been focus on changing it for alternative materials such as ceramic waste, crushed rock, recycled brick aggregates, granite dust, recycled rubber aggregates, recycled plastic aggregates and recycled glass aggregate. Moreover, the physical properties of the fine alternative materials for concrete play a crucial role in the fresh properties such as the workability and setting time. Also, the physical properties can change the hardened properties of the cement-based composites [2-3].

A first criteria to select a discarded material to be used as fine aggregate in cement-based composites is the availability. Most of the mentioned materials in the last paragraph are available around the world, moreover transportation must be considered. A second criteria to select a discarded material as fine aggregate is how the size of the material can be reduced, in general these materials came from large pieces. In some cases, a proper granulometry, like a river sand, may not be reached or the process to reach an adequate granulometry demands large quantities of energy increasing the cost of the materials and consequently the cost of the infrastructure.

Glass fine aggregate has been used in several research to be considered a sustainable material for cement-based composites. In general, crushed glass is the most used material because it improves the workability and the slump of the cement-based mixtures [4], likewise it maintains and increase the mechanical and durability performance of the cement-based composites [5].

In recent years, toughened waste glass (TWG) has been evaluated as aggregate replacement in cement-based composites. The TWG is a special glass type used for security purposes, this glass is more resistant than glass because is heated to a high temperature and then cooled rapidly. Researchers affirm that the TWG can be used as aggregate replacement in cement-based composites enhancing the mechanical and microstructural properties of these [6]. Another study affirms that the TWG reduce the water absorption, permeability and sorptivity [7].

According to the above, the use of recycled windshield glass (WG) is proposed in this research. The difference between the TWG and WG is the polyvinyl layer in which the WG is manufactured for security purposes. The toughened glass is difficult to separate from the polyvinyl layer. The obtained glass waste was used as sand replacement in mortars and the fresh and mechanical properties were evaluated.

2. Methodology

In this research the use of recycled glass form discarded windshields is proposed to manufacture mortars. The windshields were collected from local replacements companies and only the transportation to the construction laboratory cost was included. The first step was the degradation process using a wood hammer; however, this process did not separate the glass from the polyvinyl layer, but it was useful for the next steps. The next step was to cut the windshields in small pieces. After that, the small pieces of windshields were processes by abrasion and impact in the Los Angeles Machine, this process helped to separate the glass from the polyvinyl layer and to reduce the size of the glass particles. The final product is presented in Fig. 1. It can be observed that the WG fine aggregate has angular shapes, similar to the natural sand, it was observed that this material does not cut to the touch. This material was used as sand replacement in percentages of 0, 10, 20, 30, 50, 70 and 80 (mixtures WG0, WG10, WG20, WG30, WG50, WG70, WG80 respectively) (Table 1).

Fig. 1: The WG aggregate.

The processed WG, river sand, blended Portland cement and potable water were used to preparate the mortar mixtures. All mortars were design with 0.60 water/cement ratio and a 1:3 cement to sand/WG ratio. The proportions of the mortars are showed in the able 1. The flow table test (ASTM C1437) was carried out for each mortar mixture. After that cubes of 5 x 5 x 5 cm were elaborated to evaluate the compressive strength at 7 and 28 days (ASTM C39).

Table 1: The experimental design and proportions of the mortar mixtures

Mixture	WG, gr	Sand, gr	Cement, gr	Water, ml
WG0	0.0	1375.0	500.0	300.0
WG10	137.5	1237.5	500.0	300.0
WG20	275.0	1100.0	500.0	300.0
WG30	412.5	962.5	500.0	300.0
WG50	687.5	687.5	500.0	300.0
WG70	962.5	412.5	500.0	300.0
WG80	1100.0	275.0	500.0	300.0

3. Results

The implemented methodology for the windshield was adequate to obtain WG whit proper physical properties, it means that the obtained WG had similar sizes and shapes than the river sand. Likewise, the WG does not cut to the touch making a proper material for practical applications.

The results from the fresh and hardened properties of the mortars are showed in Table 2. The flow of the mortar mixtures increased as the content of the WG was greater, moreover, all mixtures maintain the flow according to the ASTM C1437 standard. A possible explanation for the increment of the flow as the WG content increased is that the WG particles does not have edges because they were subjected to an abrasion process.

The compressive strength of the hardened mortars increased from 7 to 28 days. This increment was observed for all the mortars. However, it can be observed early development of the compressive strength when using 20, 30, 50, and 70% of WG in comparison to the WG0 mortar (control mortar). A possible explanation for this is that the WG is more resistant than river sand. From the results, it can be concluded that the WG/cementitious matrix is uniform.

The results indicate that up to 70% of WG as sand replacement is proper for mortar mixtures, a higher percentage decreased the compressive strength of the mortars.

Table 2: Fresh and hardened properties of the mortar mixtures (average of 3 cubes)

Mixture	Flow, %	Compressive strength (Mpa)	
		7 days	28 days
WG0	20.6	10.1	22.6
WG10	20.7	9.0	24.6
WG20	20.9	24.1	26.9
WG30	21.1	20.1	26.5
WG50	21.4	22.5	24.1
WG70	21.5	20.9	23.5
WG80	21.5	15.2	15.5

4. Conclusions and further works

The selected treatment for the WG is appropriate to obtain an adequate fine aggregate which meet the granulometry for sand replacement. The shapes of the WG particles are similar in shapes of the river sand.

The use of WG does not decrease the flow of the mortar mixtures. The flow is maintained in the limits from the standard. It was observed that the flow increased as the sand replacement was greater.

The WG does no effect negatively the compressive strength in mortar mixtures. However, the recommended replacement is up to 70%.

An analysis of the cost and time consumption to obtain the WG aggregate is recommended. Actually, the windshields are discarded, it means that only transportation cost are considered in this research.

Microestructure and durability tests are recommended in order to discard possible issues with the use of WG and after that it can be recommended for structural purposes.

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