Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 43, No. 2, pp. 239-246
Published Year 2020

The Mechanical Properties of Green Cement Mortar Dip-Coated with Polyurethane Polymer

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ABSTRACT: In this work, incorporation of glass powders from three different origins (window sheet glass powder, green-colored and brown-colored glass powders) is accomplished in an attempt to reduce the water absorption property and improve the hardness and compression strength of the cement mortars. Furthermore, the effect of Sikafloor 161 Polyurethane polymer, as a coating material, on the water absorption, hardness, and compression of the cement mortars are investigated and discussed. Results show that there is a noticeable effect of the glass type and glass-to-cement weight ratio on the water absorption and mechanical properties of the mortars specimens. These results were analyzed and discussed in detail. The present works emphasize the usefulness and advantages of utilizing glass powders and the Polyurethane polymer in the synthesis of cement mortars with additional qualities.

KEYWORDS: Glass waste; recycling; cement mortar; eco-friendly; polyurethane.

INTRODUCTION

The incorporation of glass waste in construction materials has attracted the interest of many researchers and engineers worldwide. There have been a large number of experimental investigations on the utilization of glass as partial replacement of some of the natural aggregates of the cement mortars [1, 2]. Glass powders having small particle size distribution are known to exhibit noticeable pozzolanic characteristic [3, 4]. However, the major concern in using glass wastes in cement mortars is the alkali-silica reaction which affects the stability of the cement mortar. This might be avoided by using certain byproducts from industry in addition to the glass powders [5,6]. The glass powder provides a more uniform distribution and a greater volume of hydration products. In addition, glass powders may alter the structure of the cement mortars unexpectedly. Cement pastes containing glass powders are known to have calcium silicate hydrates (CSH) and fewer amounts of the easily soluble calcium hydroxide (Ca(OH)2) than ordinary cement pastes. The CSH represents the source of cement mortar strength and acts as a glue or binding material holding the cement mortar system together while Ca(OH)2 represents the weaker constituent which does not act as a binder but may occupy space or fill concrete voids. Furthermore, Ca(OH)2 may combine with carbon dioxide to form a soluble salt which leaks/diffuse through the concrete leading to efflorescence. Nevertheless, the small particle size of glass particles is advantageous to infiltrate and plug capillary pores leading to higher density of the cement mortar. This may lead to a reduction of permeability and improvement of the bonding of concrete with glass powder compared to conventional concrete [7].

The general advantage of using it might prevent creeping of metals because the ground glass improve workability of concrete that's led to reduce permeability of it all of that due to the high alkali silica reaction (ASR) that present in cement and waste glass [8].

The utilization this type of waste material as a replacement of cement with specific percentage led to reduce the cost of uses cement also produce concrete with less environmental impact with low cost production. Glass is non-crystalline silica have almost the content of ordinary Portland cement; but with different concentrations Therefore it used as a replacement of cement because its pozzolans materials and have limestone that released through hydration reaction [9].

Waste glass milled into micro-scale particle size that is used as a partial cement replacement that sued in recycled concrete. The presence of waste glass in this form improved of the properties of concrete such as moisture absorption resistance, and harmful transportation.

As a result, milled waste glass (about 20- wt. % are not exceeded) as a partial replacement of cement improved many properties of concrete such as abrasion resistance, long-term strength and durability characteristics. Also, it has many advantages in saving environment energy, cost benefits, and played an important role in reducing carbon footprint in structure industry. Recycled concrete glass with 20% of milled glass replacement of the cement is used in the field of pavement and curb that applied over two years of vulnerability (exposure) to mid-Michigan weathering effects [9].

This work aims at investigating the effect of glass powder on the water absorption, hardness and compression strength of the cement mortar is investigated. Glass powders from three different origins are investigated to shed light on the effect of glass powder variation on the quality of the cement mortar. The effect of Polyurethane polymer as a coating material is also investigated in an attempt to improve the mechanical properties of the cement mortars. This work is believed to be in line with the sustainable development goals due to the potential utilization of glass waste and the benefits sought by the huge construction industry.

EXPERIMENTAL WORK

The cement mortar prepared in this work is made up of ordinary Portland cement, sand and glass waste all mixed in water at predefined ratios. Table 1 summarizes these compositions properties. The glass waste was collected from recycling centers in Baghdad. Transparent window glass sheets, green and brown glass bottles were collected, washed and crushed to small pieces. The pieces for each glass type were then introduced into a milling machine and processed to a fine powder for 15 minutes. The average particle sizes of the glass powders were measured by particle size analyzer. The glass powders were also investigated by X-ray diffraction Shimadzu-6000 diffractometer. The XRD measurements were accomplished using Cu Kα radiation at 60 kV/80 mA, scan speed of 2°/min in the 2θ range of 3 – 70°. In order to investigate their chemical compositions, inductive coupled plasma optical emission spectroscopy (ICP-OES) was used.

Table 1. Specifications of cement mortar constituents.

Raw material	**Specifications**
Ordinary Portland cement (OPC)	Fine powder with an average particle size of 53 µm (produced by United Cement Company-Tasluja-Bazian, Sulaymaniyah) (Iq.s 5/1984 Type I BS EN 197-1:2011 CEM I 42.5R)
Sand	Particle size less than 600 µm by sieving (ASTM c778-13)
Glass waste	See results section for specifications
Water	Ordinary water (Water to cement ratio = 1/2)

The glass powders were incorporated into the cement mortars substituting cement at 10, 20, 30 and 40 % weight percentages. Three different mortars for each substitution ratio were prepared and investigated. Table 2 shows these mixing ratios in detail. All the cement mortars were prepared in specimens having dimensions of 4.5×4.5×4.5 cm^3. The water absorption of the cement mortars is measured by recording the cement mortar weight before and after immersion in water (i.e. weight of total amount of water being absorbed by the cement mortar specimen). This property was measured for the cement specimen before and after being coated with polyurethane polymer.

Table 2. Glass-to-cement ratios. Sand was fixed at 300 g and water quantity was 50 ml.

Mortar specimen	**Glass waste powder (g)**	**Cement (g)**
1	0	100
2	10	90
3	20	80
4	30	70
5	40	60

RESULTS AND DISCUSSION

Figure 1, a-c, show the particle size distributions of the thee glass powders. The average size of the window sheet glass powder, the green-colored and brown-colored glass powders are found equal to 45.9 µm, 93.3 µm and 0.69 μm respectively. It is clear that the brown-colored glass powder exhibits the smallest average sizes and most homogeneous size distribution compared to window-glass and green-glass powders. This is attributed to the hardness of these materials being the smallest for the brown-colored glass.

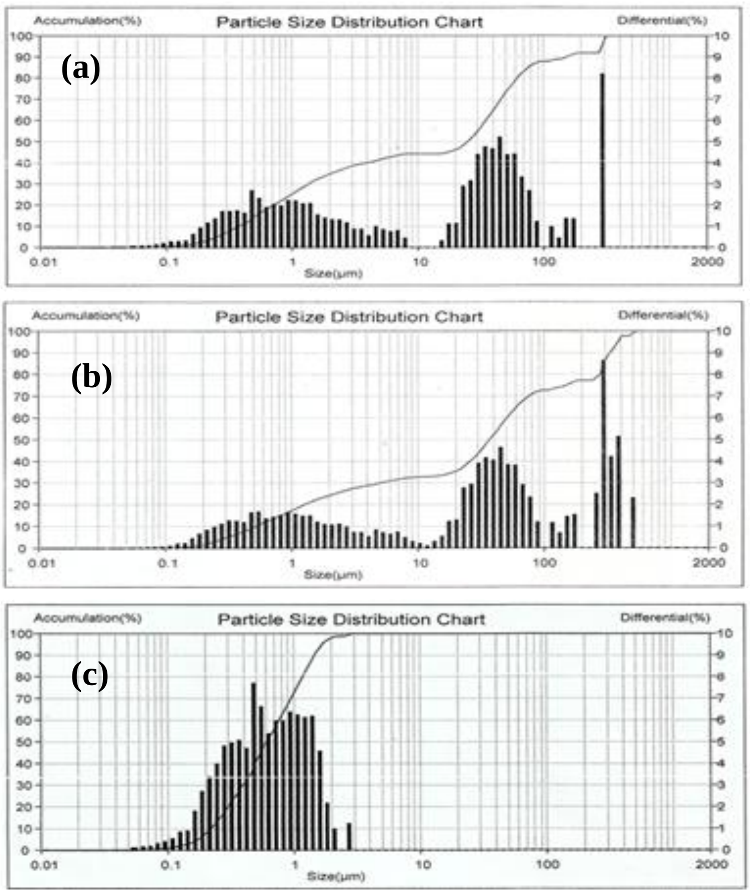

Figure 1. The particle size distributions of the glass powders. (a) Window sheet glass powder (b) Green-colored glass powder (c) brown-colored glass powder.

The XRD patterns of the three glass powders are found to exhibit similar features to those shown in figure 2. The XRD pattern with hump-like structure and no diffraction peak emphasizes the amorphous nature of the glass powders.

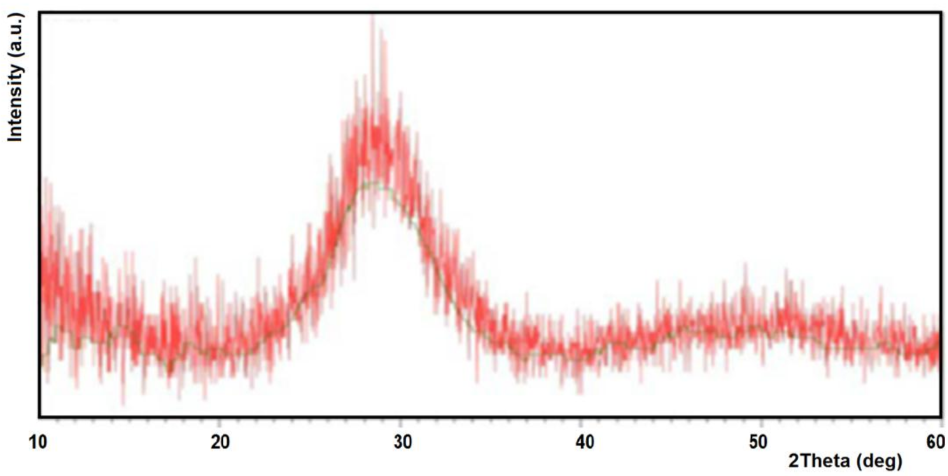

Figure 2. The XRD pattern of glass powders. All glass powders exhibited identical features to those measured

here

Results of the chemical composition measured by ICP spectrometry is listed in table 3. It is clear that the small changes in the chemical compositions are responsible for the phenotypic and color traits in addition to the hardness of the glass types considered in this work [10].

Table 3. Results of the ICP spectrometry analysis of window-sheet, green-colored and brown-colored glasses.

Chemical composition (%)	Window sheet glass	Green glass	Brown glass
SiO_2	69.72	64.03	57.41
Al_2O_3	1.02	1.6	1.68
Fe_2O_3	0.55	0.52	0.86
CaO	8.76	12.41	4.88
MgO	3.43	3.31	2.75
Na_2O_3	8.42	7.76	6.42
K_2O	0.13	0.32	0.60
SO_3	0.2	0.11	0.18
Total	92.55	94.14	94.08

The water absorption of the cement mortar before dip-coating with polyurethane polymer is shown in figure 3. Results show that water absorption decreases for all specimens with respect to the standard specimen (i.e. the cement mortar containing no glass powder). In addition, the water absorption increases with the increase of glass-to-cement ratio for window-glass and green-colored glass specimen. The opposite occurs with cement mortars containing brown-colored glass powders (increase of water absorption with glass-to-cement ratio).

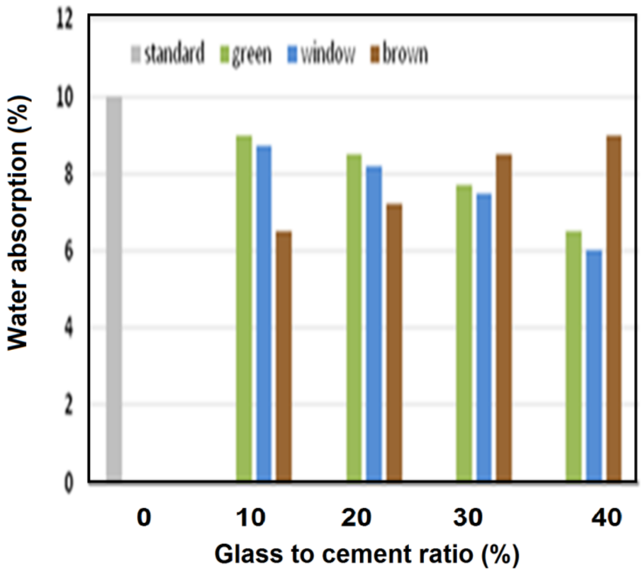

Figure 3. The water absorption of the cement mortars at different glass to cement ratios before dip-coating with polyurethane polymer

The water absorption of the cement mortars specimen after dip-coating with polyurethane polymer is shown in figure 4. Similar behavior is observed in terms of a general reduction of the water absorption value with the addition of glass powder compared with the pure mortar regardless of the glass type being incorporated. In opposite to what was observed in figure 3 for mortars containing brown-colored glass powder, the water absorption decreases with the increase of glass-to-cement ratio for all the mortars containing glass powders. This might be attributed to the fact that polyurethane polymer may have filled the voids that are otherwise filled with water in the uncoated cement mortars specimens.

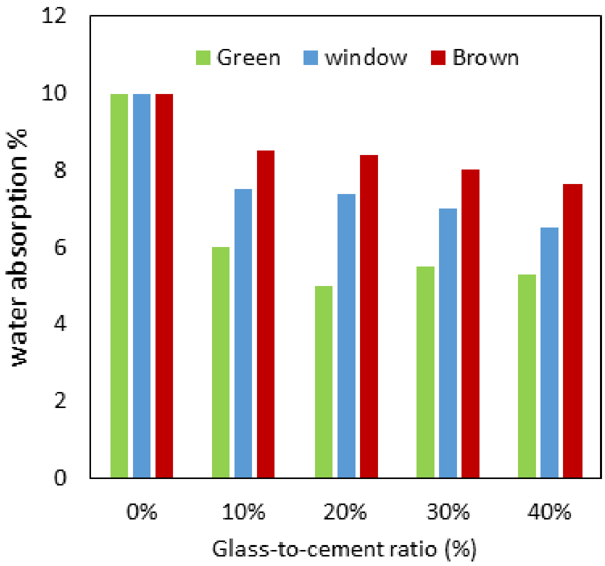

Figure 4. The water absorption of the cement mortars at different glass to cement ratios after dip-coating with polyurethane polymer

The hardness of the cement mortars before dip-coating with polyurethane polymer is shown in figure 5. Results show that addition of glass powders affects the hardness value positively. Hardness increases from 80 to 95 due to addition of 10% wt. green-colored glass-to-cement ratio. This is the highest hardness compared to the other types of glass powders. Further increase of this glass (green-colored) constituent leads to gradual decrease of hardness. The same behavior occurs with the other types of glass powders (i.e. window glass and brown-colored glass powders). This might be attributed to the fact that increasing the glass powder in the cement mortar affects the elastic property of the mortar which is an intrinsic atomic property of the pozzolanic effect of the cement material.

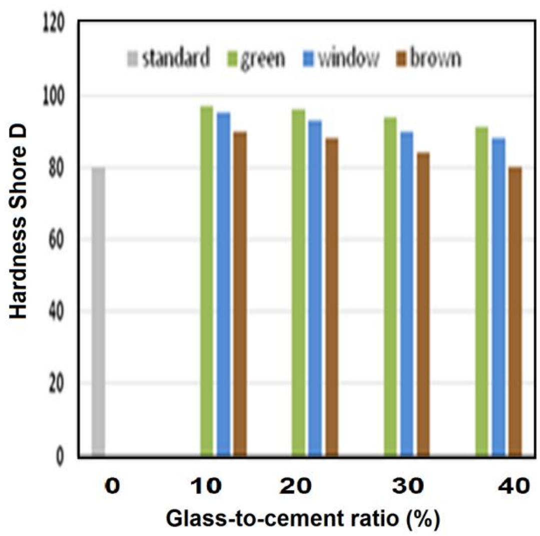

Figure 5. The hardness of cement mortars before dip-coating with polyurethane polymer

Figure 6 shows the hardness shore D of the cement mortars after being dip-coated with polyurethane polymer.

The same behavior is observed which is a general increase of hardness with the addition of glass powder at 10% wt. glass-to-cement ratio and a gradual decrease of this property at a further increase of glass powder about 10%. A comparison of the hardness values before and after dip-coating with polyurethane polymer shows that the dip-coating does not affect the dependence of hardness on the amount of glass powder in the cement mortar.

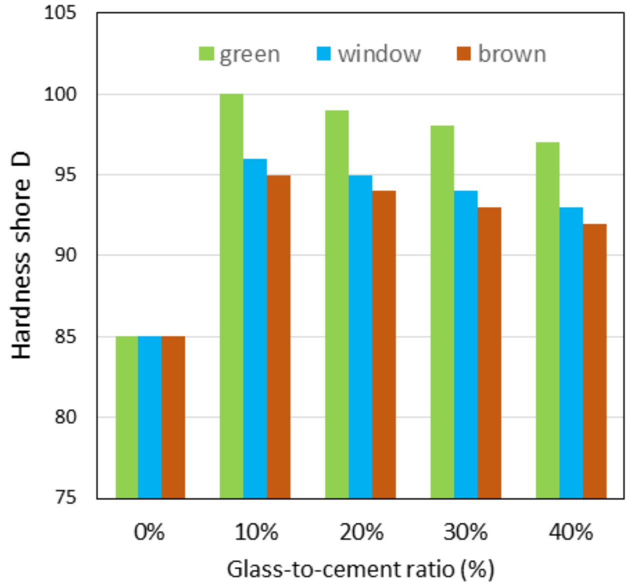

Figure 6. The hardness of cement mortars after dip-coating with polyurethane polymer

The dependence of compression strength of the cement mortars on the glass-to-cement ratio for the uncoated specimens is shown in figure 7. Results show that the addition of a small amount of glass powder improves the compression strength quality of the mortar prominently. The compression strength increases from 5 MPa for the glass-free cement mortar to 13 MPa for the cement mortar containing the green-colored glass powder. The compression strength decreases gradually from this value with the increase of glass powder concentration. Thus the 10% wt. of the glass-to-cement ratio is the best ratio to achieve higher compression strength. This might be attributed to the effect of glass particles as microstructures responsible for eliminating tensile stresses and resolving forces into compressive stresses at micro-scale in a manner similar to arches spanning spaces and supporting weights in buildings [11-13].

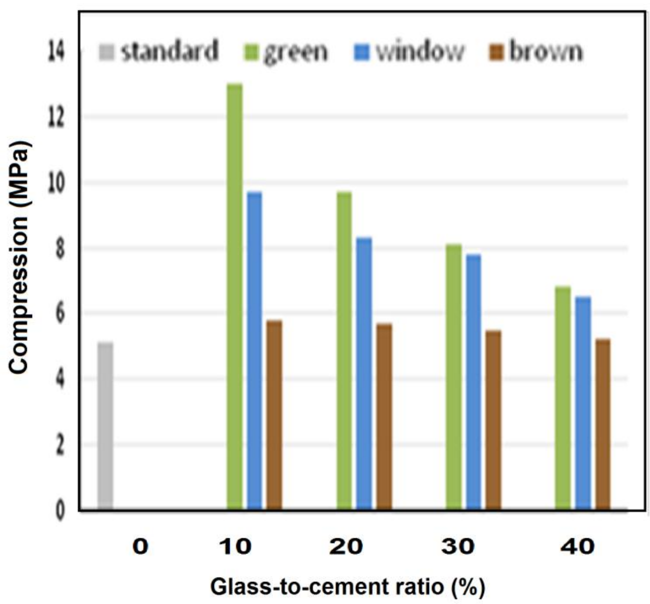

Figure 7. Compression of cement mortars before dip-coating with polyurethane polymer

Figure 8 shows the dependence of compression behavior on the glass-to-cement weight ratio for the cement mortars after being dip-coated with polyurethane polymer. A general decrease of compression strength with the addition of polyurethane polymer is observed. This behavior observed repeatedly is independent of the type of glass powder being incorporated in the cement mortar. While the decrease of compression strength with the further increase of glass powder is explainable and similar to that concluded with the uncoated specimens, the higher value of compression strength of the glass-free specimens compared to the coated ones are still not clear. Further investigation of this observation is required. [14-16]

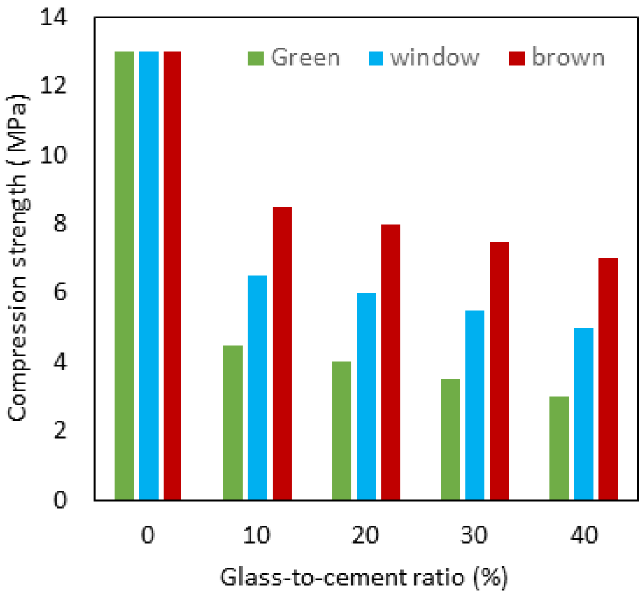

Figure 8. Compression of cement mortars after dip-coating with polyurethane polymer

CONCLUSIONS

Glass powders, from three different glass waste origins, were incorporated in cement mortars in an attempt to improve the water absorption quality and some of the mechanical properties (hardness and compression strength) of the end product. In addition to that, the cement mortars were dip-coated with Polyurethane polymer to investigate the effect of the latter on the properties of the specimens. Measurements showed that water absorption decreases with the increase of glass powder in the cement mortars. The green-colored glass powder was found to achieve the lowest water absorption. It was found that there is a prominent effect of dip-coating with Polyurethane polymer on the water absorption property of the cement mortars. These results were discussed and analyzed. The effects of the glass-to-cement weight ratio on the hardness and compression strength were also investigated and analyzed. It was found that the incorporation of glass powders in the cement mortar improves the hardness of the mortar compared with the glass-free specimens whether specimens were coated with Polyurethane polymer or not. The compression behavior was in line with that observed for the hardness property except that the uncoated and glass-free specimens exhibited higher compression strengths than the glass-containing ones. These results were discussed in detail signifying the advantages of utilizing glass powders and polymers in the cement mortars development for specific applications.

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