Disposing waste demolition in concrete as aggregate replacement

Mahmoud Nili, Nader Biglarijoo, Seyed Mehdi Hosseinian, Siavash Ahmadi

***Abstract*—** In this study, the possibility of substituting waste materials with natural aggregates is considered. Used waste materials are limited to recycled concrete aggregate (RCA), waste glass (WG) and waste plastic (WP). Substitution percent (by weight) for all three waste materials are (0, 5, 10, 15 and 20). RCA is substituted by both fine and coarse aggregates, while WG and WP are substituted only as fine aggregate in concrete mixtures. Workability, compressive strength, tensile strength, flexural strength, hardened unit weight, electrical resistivity, dynamic modulus of elasticity and water absorption of the concrete are evaluated. WG and RCA (fine and coarse) had no remarkable effect on mechanical properties of concrete, while WP decreased mechanical properties and hardened unit weight remarkably. Workability reduced by substituting WP and RCA by natural aggregates, while WG had no influences on slump value. Water absorption and electrical resistivity of concretes containing WG and WP were higher than those of control concrete.

***Keywords*—** recycled concrete aggregate, waste glass, waste plastic, electrical resistivity, water absorption.

I. Introduction

Destroying and repairing old constructions or debris of the buildings damaged in destructive earthquakes, floods and wars could make huge volumes of waste materials. These waste materials cause serious environmental crisis. Recently many countries in the world have tried to find a practical solution for this problem. Substituting waste materials as recycled aggregate in concrete is one of the best methods to manage this crisis. For example, in North America, construction waste and demolitions make up about 25-45% of waste stream, depending on the region, while Construction Materials Recycling Association (CMRA) estimates that only 25% of this quantity is recycled [1]. Many of waste materials are non-decaying and will remain in the environment for hundreds, perhaps thousands of years and cause a waste disposal problem [2]. Saving energy and natural resources, improving environmental conditions, decreasing the cost of waste materials to be disposed to landfills and reducing the total cost of concrete, are the main purposes of recycling these waste materials. Among various types of waste materials, concrete waste seems to be a large amount, among total waste production. Studying official figures regarding the quantity of some waste materials and their disposal in Jordan indicates that 20% of the total quantity of waste of 1721.8 tons consists of glass, plastic, and concrete. The weights of these materials are estimated to be: 35 tons of glass, 52 tons of plastic, and 240 tons of concrete [2]. Therefore, in this study waste materials for substituting by natural aggregates are limited to recycled concrete aggregate (RCA), waste glass (WG) and waste plastic (WP). In the last decade, many researchers have focused on making concrete more environmental by replacing RCA with natural aggregate (NA), some of which are presented here. In 2002, Go´mez-Sobero´n reported that porosity increases considerably when natural aggregate is replaced with RCA, which indicates RCA as a porous aggregate [3]. In 2009, Sami W. Tabsh researched on mechanical properties of concrete made by RCA, therefore he reported that strength of recycled concrete was 10–25% lower than that of original concrete made with natural coarse aggregate [1]. Also, lower strength (1-15)% and lower modulus of elasticity(13-18)% of concrete made by RCA were emphasized by Casuccio in 2008 [4]. To maintain the same slump and desirable workability, recycled concrete mixes require more water than control concrete without the use of admixtures [1]. The main difference between natural aggregates and RCA is the mortar content on RCA which makes it more porous and reduces its physical properties. Marta Sánchez de Juan offered a criterion to conclude that only recycled aggregates with mortar content under 44% could be used as structural concrete. With this criterion, aggregates with bulk specific density higher than 2160 kg/m^3, water absorption lower than 8% and Los Angeles abrasion loss under 40% are appropriate [5]. Andrzej Ajdukiewicz considered that properties of original concrete have significant influence on mechanical properties of RCA; therefore, he reached high compressive strength by using aggregates with high quality. Compressive strength was achieved over 80 MPa using recycled aggregate from original concrete about 60 MPa, also adding reasonable content of admixtures. They found that long-term tests showed the higher shrinkage and slightly lower creep in recycled concrete in comparison with concrete made by natural aggregate of similar strength. Of course, the consequences which they achieved were in contrast with other researchers' results [6]. Roumiana Zaharieva worked on frost resistance of concrete containing RCA. They reported that frost resistance of saturated RCA is not satisfying, and their use in structures exposed to severe climate is not recommended. The main reason seems to be the

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high total W/C, inducing higher porosity and lower mechanical characteristics of RCA, as well as the frost resistance of recycled aggregates themselves [7].

Another waste material which could be recycled is waste glass (WG). Waste glasses could be obtained from containers, floats, sheets, soda limes, color TV funnel, neon tubing, and demolitions. In 2005, approximately 12.8 million tons of waste glass was disposed in the United States which shows high volumes of this material and indicates it as a sufficient source for recycled aggregate [8]. Being amorphous and containing relatively large quantities of silicon and calcium make glass, in theory pozzolanic and even cementitious when it is finely ground [9]. In 2006 Batayneh considered that waste glass (WG) could be reused successfully as a partial substitution aggregate in concrete mixtures [2]. Bekir Topcu reported that using waste glass (WG) in concrete as aggregate improves some of the concrete properties. Using WG as coarse aggregate didn't have marked effect on the workability of concrete, while WG addition decreased compressive strength, flexural strength and tensile strength [10]. The slump of the concrete containing 20% LCD glass was very close to the design slump. Also, adding WG caused an increase in electrical resistivity which implies concrete becomes denser and more durable [11].

Third waste material is PET plastic which could be substituted by natural aggregates and gives the concrete new properties. Zainab Z. Ismail reported that concrete containing waste plastic tends to decrease the compressive strength, flexural strength and workability. Also, it was declared that waste plastic is a hydrophobic material which may restrict the hydration of cement [12].

The main purpose of this study is to gain more knowledge about the capacity of recycling wastes in concrete mixes, to find a practical solution for the high volumes of waste materials generated recently and to reach friendly-environmental concrete.

II. Experimental work

A. Materials

Cement (C) used in this study, was a Portland cement followed by (ASTM C-150) [13]. In this research three different waste materials including RCA, WG and WP were substituted by natural aggregates which RCA was substituted by both fine and coarse aggregate, while WG and WP were substituted only as fine aggregate. Natural lime stone as fine and coarse aggregates with finesse modulus 2.46 was used. Maximum size of coarse aggregate for both NA and RCA is limited to 19 mm. We substituted coarse and fine aggregates with RCA to have a better comparison, because it was assumed that fine and coarse RCA, could give different characteristics to recycled concrete. Waste glass was prepared from demolitions in Hamadan and then sieved, while plastic aggregate was prepared from a company. Both WG and WP were replaced by fine aggregate because substituting them by coarse aggregate causes inappropriate properties [10, 12]. Bulk density, bulk specific gravity (SSD), water absorption and moisture content of natural aggregates and waste materials were evaluated for mentioned aggregates [14, 15, 16, and 17].

RCA caused an increase in water absorption and a reduction in bulk density and specific gravity. The main reason for this variation is the amount of mortar over these aggregates. As RCA size decreases, difference in their specification increases. It means RCA-F has higher water absorption and lower specific gravity. We can guess that concrete containing RCA; has higher water absorption and shrinkage.

The main difference between WG and WP and other used waste materials, is their water absorption in that they don't absorb any water. Also, bulk density in WP decreased magnificently in comparison with (NA) which indicates that reaching a lighter concrete is possible.

The gradation curve of used fine aggregates including RCA, WG, WP and NA is shown in Fig. 1. In addition, gradation curve for fine RCA, WG and NA is the same, but gradation curve for WP is different. Also, gradation curve of used coarse aggregate including RCA and NA is presented in Fig. 2. Meanwhile, gradation curve for coarse RCA and NA is the same.

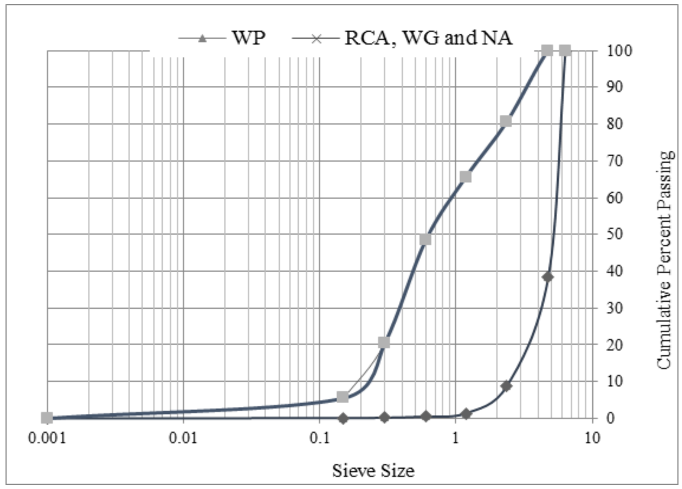

Fig. 1. Gradation curve of used fine aggregates including RCA, WG, WP and NA

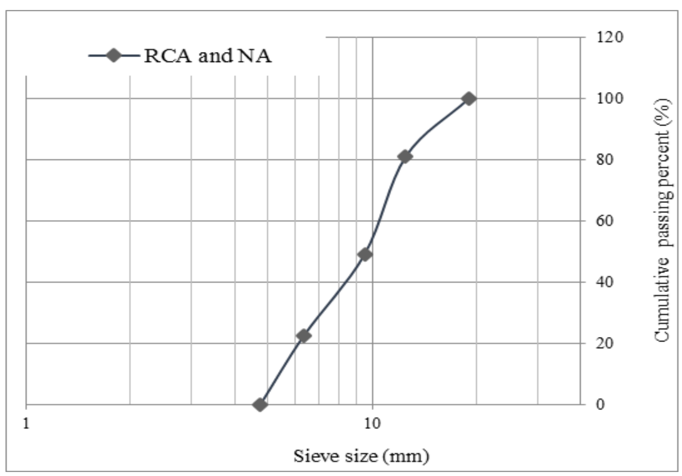

Fig. 2. Gradation curve of used coarse aggregates including RCA and NA

B. *Method*

In order to consider recycled concrete properties, RCA, WG and WP were substituted by natural aggregate. RCA was substituted by fine and coarse aggregates, while WG and WP were substituted by fine aggregates. Substitution percents for all waste materials were (o, 5, 10, 15 and 20). Therefore some tests on fresh and hardened concrete were prepared. Cubic specimens (100*100*100 mm) were held to evaluate compressive strength, water absorption and electrical resistivity. Also, cylindrical specimens (150*300 mm) were held to measure tensile strength (splitting) and beams (400*100*100 mm) were prepared to evaluate flexural strength and dynamic modulus of elasticity. All specimens were cured for 28 days in water 23 degree Celsius according to ASTM C192 [18]. These tests were held all together to let us have a correct deduction of waste materials performance.

C. *Mix Design*

In this study, 17 different concrete mixtures were prepared and water-cement ratio was a constant value($w/c = o.61$). The reason for this water to cement ratio, is to avoid using any super plasticizer in recycled concrete. We assumed that one of the most important aspects in recycling waste materials is the economic aspect. Therefore, recycling waste materials for new production is a cost effective method that helps to protect the environment. All prepared mix designs, consist of a control mix design without any substituted waste material, 4 mix designs for each substituted waste materials including coarse RCA (RCA-C), fine RCA (RCA-F), WG and WP. In this study, RCA-C5 means 5% substitution of RCA by coarse aggregate in concrete mixture and WG-10 means 10% substitution of waste materials by fine aggregate and so on.

III. RESULTS AND DISCUSSION

A. *Workability*

In this research, workability is considered as fresh concrete property. The workability was evaluated by conducting slump test, according to ASTM C-143 [19] as shown in Fig. 3. Glass had no negative effect on slump values while workability of concrete containing WG as a partial replacement was better than other mixtures. In addition working by concrete containing WG was easier than control concrete. The main reason for great performance of WG in workability could be its smooth surface texture; also it doesn't absorb any water. In contrast, replacing WP as fine aggregate decreased the slump value. WP in 20% replacement, decreased slump value more than 80%, therefore it is not recommended when workability is required. Probably this reduction is because WP is a flaky material. RCA as fine and coarse aggregate caused a reduction in slump, for instance, fine RCA in 20% replacement decreased the slump value about 25 percent, while coarse RCA caused a reduction about 20 percent (in 20% replacement) in comparison with control concrete. Meanwhile, fine RCA was more angular than coarse RCA, so the main reason for different slump value in concrete containing RCA-C and RCA-F could be this matter. As a whole it can be induced from the Figure that concretes containing RCA-C, RCA-F and WG, had an acceptable performance in workability and working with them was not difficult.

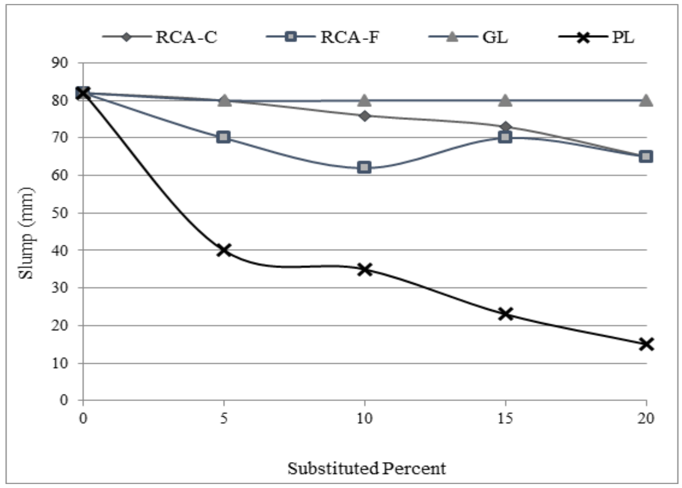

Fig. 3. Relationship between slump and substituted percent

B. *Compressive Strength*

To evaluate compressive strength, cubic specimens were prepared and cured for 28 days. Results for compressive strength are shown in Fig. 4. As the substitution of coarse RCA increased, we observed a slight reduction in compressive strength (less than 5%), so they could be replaced sufficiently in concrete according to their behavior in compression. Fine RCA increased compressive strength more than 15 percent (in 20% replacement), which is in contrast with previous researchers' results. But as Andrzej Ajdukiewicz expressed, properties of parent concrete has significant influence on mechanical properties of RCA [6], therefore compressive strength in parent concrete and its paste must have been high. Probably the main reason for acceptable performance of RCA in concrete in compression could be its rough surface and angular shape, which makes an intensive bonding in the matrix.

WG substituted by fine aggregate, decreased the compressive strength slightly (less than 10%), so it performed as a neutral aggregate. This performance is because WG is generally siliceous and hard enough. In contrast, WP decreased the compressive strength more than 60 percent, which is not desirable. Probably the higher porosity in concrete containing WP caused this reduction in compression. Also low binding between WP and paste might have been effective.

C. *Tensile and Flexural Strength*

Results for tensile strength and flexural strength are presented in Fig. 5 and Fig. 6 which due to the similar trend in tensile and flexural strengths, they are not discussed separately. Concretes containing WG caused a reduction about 20 percent (in 20% replacement) in both tensile and flexural strengths. In addition, the effect of WP was remarkable in both strengths, which caused a dramatic decrease. The main reason for the weak performance of WG and specially WP is probably the plane surface of the mentioned aggregates which cannot make intensive bonding in the matrix and aggregates may slide over each other and decrease these two strengths. The significant difference between WG and WP is the sharp edges of WG which helps them to stick to concrete better than WP.

Concretes containing RCA had better performance than WG and WP. The main reason for this observance may be the rough surface angular shape of the RCA, which makes the strong bonding in the matrix. It is notable that reductions in tensile and flexural strengths for RCA-C concretes (in 20% replacement) were 11% and 19% respectively. These values for concretes containing RCA-F were 21% and 19% respectively which may seem to be appropriate for recycled aggregates.

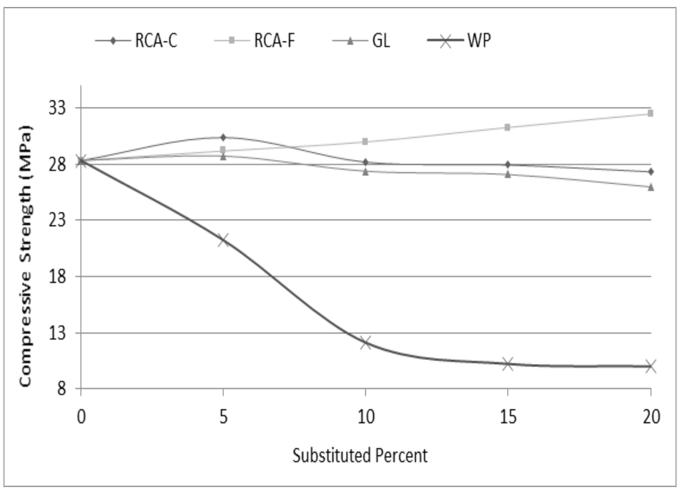

Fig. 4. Relationship between compressive strength and substituted percent

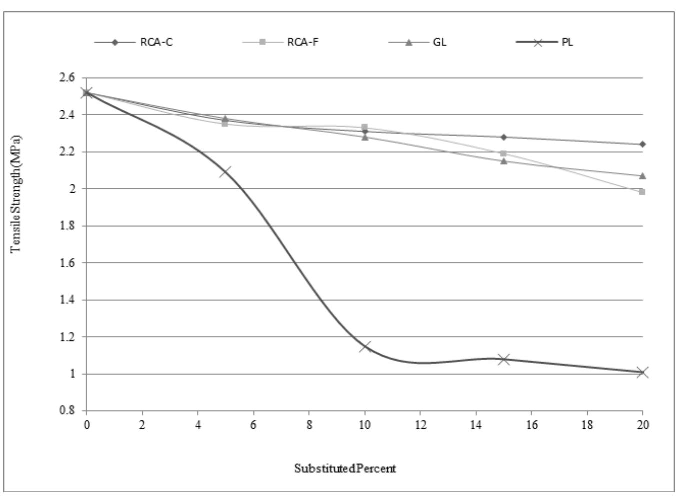

Fig. 5. Relationship between tensile strength and substituted percent

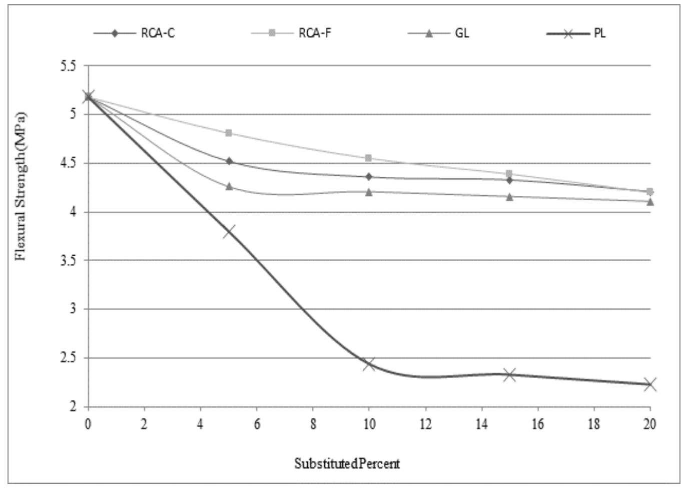

Fig. 6. Relationship between flexural strength and substituted percent

D. Hardened Unit Weight

To have a better comparison about hardened unit weight, Fig. 7 is prepared. WG and RCA did not decrease unit weight a lot. This reduction was less than 2 percent (in 20% replacement) while WP decreased hardened unit weight more than 15 percent, which is obviously because of the lower density of WP. Of course, this slight reduction in concrete containing RCA is because of its porous aggregate. Reaching lighter concrete is an appropriate property for concrete because of its behavior in earthquake. Therefore, all these waste materials could help to decrease unit weight of concrete.

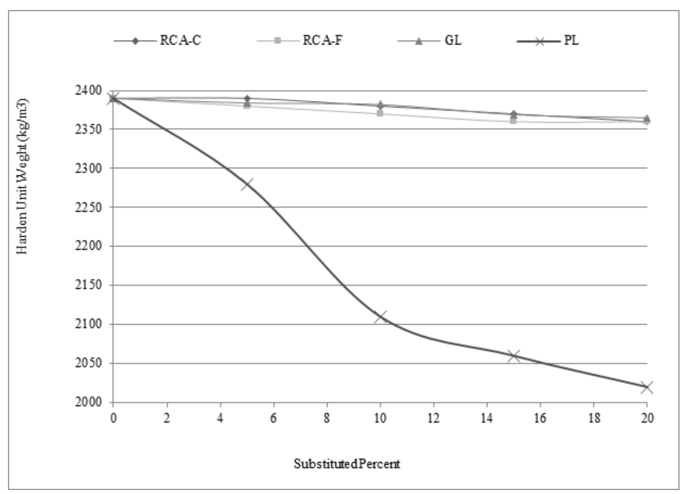

Fig. 7. Relationship between harden unit weight and substituted percent

E. Electrical Resistivity

The electrical resistivity of concrete is a material property that may be useful for monitoring and inspection of concrete structures with regard to reinforcement corrosion in combination with other non-destructive techniques [20]. Electrical resistivity result is shown in Fig. 8. WG caused an increase in electrical resistivity, which is more than 15 percent in comparison with reference concrete. Electrical resistivity depends on some factors such as moisture content (environment) and the composition (material) of the concrete. Therefore, when electrical resistivity in concrete containing WG increased, it was probably because of the WG which was made of silica, or because it had filled the pores, reduced the conductivity of concrete and made the concrete much denser. Plastic is an insulator, which increased electrical resistivity of concrete. WP increased electrical resistivity in 10% replacement and then had a decrease. This reduction is because of the pores in concrete containing WP, which made the compaction of the concrete a hard work and caused WP concrete to be a porous concrete. As a whole, WP caused a significant increase in electrical resistivity and in 20% replacement was still higher than reference mixture. Concrete made by RCA had a reduction in electrical resistivity. The main reason is that, they are aggregates with higher porosity which could cause a decrease in electrical resistivity. Of course fine RCA had better effects on electrical resistivity in comparison with coarse RCA. It is notable that the effect of material on electrical resistivity is completely apparent in this test. It means that concretes containing WP and WG in spite of the lower mechanical properties, had higher electrical resistivity in comparison with RCA concretes.

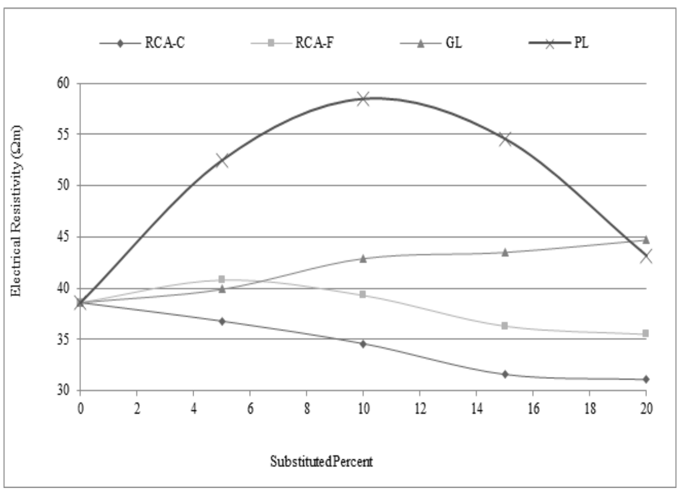

Fig. 8. Relationship between electrical resistivity and substituted percent

F. Dynamic Modulus of Elasticity

Dynamic modulus of elasticity of concrete is shown in Fig. 9. To evaluate modulus of elasticity, beams were tested. Modulus of elasticity could be a definition of porosity of concrete, which helps to understand the behavior of replaced waste materials in concrete. Dynamic modulus of elasticity is usually used to show cracks in concrete after freezing and thawing cycles. In this research, we conducted this test to compare porosity of concrete with different substituted aggregates. Substituted RCA and WG decreased modulus of elasticity less than 3 percent (in 20% replacement), which is acceptable. But concrete containing WP as a porous concrete, decreased dynamic modulus of elasticity about 24 percent (in 15% replacement). Also because of high porosity in concrete containing 20% WP, evaluating dynamic modulus of elasticity seemed impossible.

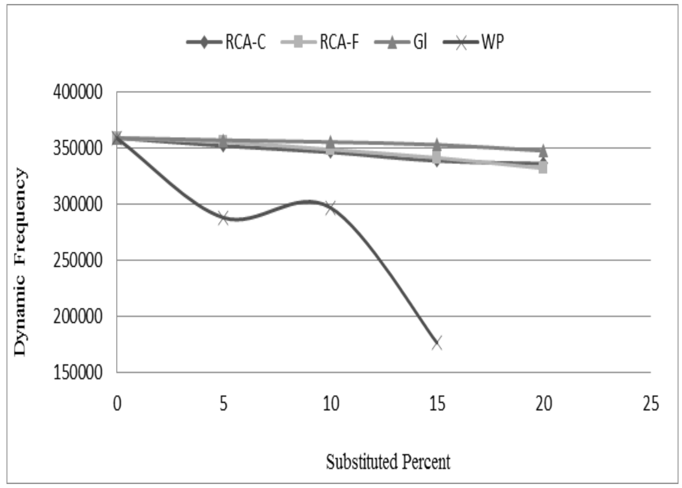

Fig. 9. Relationship between dynamic modulus of elasticity and substituted percent

G. Water Absorption

Water absorption test was carried out to give a better comparison about the role of waste materials as substituted aggregate in concrete. The results (Fig. 10) indicate that concrete containing plastic and glass had lower water absorption due to their properties. Water absorption in concrete containing WG decreased due to the increase of substitution, which means WG could decrease the porosity of concrete. In contrast, concrete containing WP decreased the water absorption totally, but caused an increase in water absorption by the increase of substitution. It could define the higher porosity of concrete containing WP in comparison with WG concrete. Also concretes RCA showed higher water absorption values. The main reason for higher water absorption value in concrete containing RCA-F and RCA-C is their mortar content attached to the aggregates which could absorb more water.

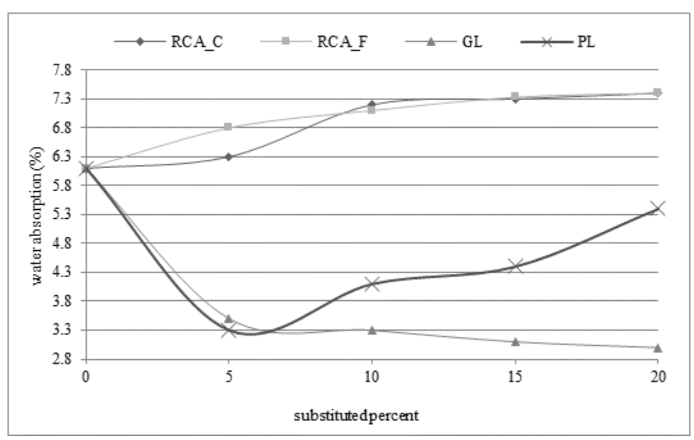

Fig. 10. Relationship between water absorption and substituted percent

IV. Conclusion

In this research, some tests were established to evaluate concrete made by waste materials. Waste materials including WP, WG, and RCA were substituted by natural aggregates. The main purposes of recycling are: disposing waste materials in concrete, saving energy and natural resources (using fewer raw materials), improving environmental conditions and decreasing the cost of these materials to be disposed to landfills. Based on the research and results presented in this paper, the following conclusions were reached:

- RCA as a waste material, in comparison with natural aggregate, has lower bulk density and bulk specific gravity (SSD) and higher water absorption. The main reason for these phenomena is the amount of mortar over these aggregates. Water absorption was assumed to be zero for WG and WP.
- Substituted WG caused no difference in slump value, while RCA and WP decreased this fresh concrete property. Especially WP decreased workability more than 80 percent in comparison with control mix design. In addition WG gave efficient workability to the concrete.
- Replacing WG and RCA didn't make remarkable difference in hardened unit weight of concrete, whereas WP decreased this value.
- RCA and WG were almost neutral as replaced aggregate in compressive strength, but plastic decreased this property. The main reason for the reduction of compressive strength in concrete containing WP, is their flaky shape that doesn't make proper bonding in concrete. In contrast, WG and WP are angular and make efficient bonding in concrete.
- Tensile strength and flexural strength decreased when all waste materials were substituted, specifically WP decreased this value more.
- Substituted WG and WP caused an increase in electrical resistivity, while RCA decreased it slightly.
- Concrete containing WG and RCA decreased the value of dynamic modulus of elasticity a bit. Whereas WP caused a remarkable reduction in this value.
- WG and WP caused a decrease in water absorption in concrete, which is desirable. Of course WG was considered as great filler in concrete, which could fills the pores. Concrete containing RCA had higher water absorption.

According to the results of this investigation, WG and fine and coarse RCA performed an acceptable role as substituted aggregate in concrete, but WP decreased some mechanical properties in concrete and seemed to have a porous concrete, while using WP as replaced aggregate in concrete could help to decrease the unit weight of concrete. As a whole, concrete could be one of the solutions for disposing waste materials in it.

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