International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:12, No:11, 2018

Construction of Green Aggregates from Waste Processing

Fahad K. Alqahtani

Abstract**—**Nowadays construction industry is developing means to incorporate waste products in concrete to ensure sustainability. To meet the need of construction industry, a synthetic aggregate was developed using optimized technique called compression moulding press technique. The manufactured aggregate comprises mixture of plastic, waste which acts as binder, together with by-product waste which acts as fillers. The physical properties and microstructures of the inert materials and the manufactured aggregate were examined and compared with the conventional available aggregates. The outcomes suggest that the developed aggregate has potential to be used as substitution of conventional aggregate due to its less weight and water absorption. The microstructure analysis confirmed the efficiency of the manufacturing process where the final product has the same mixture of binder and filler.

Keywords**—**Fly ash, plastic waste, quarry fine, red sand, synthetic aggregate.

I. Introduction

THE sustainability is an important concern nowadays in the construction industry due to the depletion of natural resources and shortage of landfill capacity. To cope with the situation, the government sector is promoting sustainable construction industry by using co-products “secondary substances”. Finally, the urge to investigate optimal “secondary substances” for instance, plastic waste to be used as an aggregate in the concrete mix has been increased. Moreover, the plastic products generation has increased from around 5 million tons in 1950s to approximately 100 million tons in [1]. Moreover, according to the Environment Agency Report in 2003, merely 7% waste plastic is recycled, and 80% is dumped in landfill [2]. Unfortunately, the percentage of recycled waste plastic is small as compared to the quantity of plastic waste generated. Therefore, the recycled plastic aggregate (RPA) must be used instead of natural aggregate in the production of lightweight concrete [3]. Furthermore, different researchers [4]-[6] developed synthetic lightweight aggregate (SLA) produce (by melt blending process in twin extruder) using fly ash, LDPE and mixture of various plastics by replacing coarse aggregate in concrete and pavement. The proportion of fly ash to polymer used was in range 0:100, 35:65, 70:30, and 80:20. According to the findings of Sawan et al. [6], the particles colour was found to be dark-grey to black and texture firm to noticeable deformable. Also the researcher noticed that the SLA had less density and specific gravity as compared to normal aggregate. Likewise, Jansen et al. [4] reported that the SLA containing fly ash has angular and round edge together with a rough surface texture (beyond 80% replacement). Furthermore, the density and water absorption capacity of SLA observed increased with higher fly ash content because plastic used had lower bulk specific gravity than fly ash. Similarly, Choi et al. [7], [8] produced waste plastic lightweight aggregate (WPLA) from polyethylene terephthalate (PET) with granulated blast-furnace slag (GBFS) and river sand powder. The authors noticed that WPLA particles had smooth texture and rounded particles shape. Moreover, the fineness modulus, density, water absorption and bulk density of WPLA were observed to be 4.11, 1390 kg/m^3, 0%, and 844 kg/m^3 respectively.

Similarly, Koide et al. [9] had developed lightweight aggregates using pure plastic waste only without any additives (85% PET, 15% polypropylene and polyethylene). The researcher found that aggregates were angular with smooth surface regardless of grain size. Moreover, the density of aggregate was figured out to be 1.2 g/cm^3 with almost no water absorption. On the other hand, Kayali [10] manufactured fly ash aggregate (FAA) by sintering only fly ash in a rotary kiln followed by crushing process. The results revealed that the aggregates had angular shape and rough surface texture. Furthermore, the specific gravity and density of FAA was 13% and 2% higher compared with pelletized fly ash (SP) aggregate respectively, whereas water absorption was reduced by 60%.

In this study, the artificial sustainable aggregates called RPA having different type of fillers such as red sand (RS), fly ash (FA) and quarry fines (QF) were developed by "compression moulding process". The physical properties and microstructure of filler and aggregate were examined and compared with conventional local lightweight aggregate.

II. Methods

The methodology comprises the manufacturing process of synthetic coarse aggregate made from shredded plastic and granular waste using “Compression Moulding Press” technique. The physical properties were examined and compared with conventional LWA according to ASTM C330 [11]. These properties include particle size distribution, shape and texture, unit weight, specific gravity, water absorption, voids and fineness modulus. Moreover, three samples of fillers and RPA composite were prepared for surface and cross-sectional morphologies examination and elemental content determination by Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-Ray (EDX).

Fahad K. Alqahtani is Assistant Professor with the Civil Engineering Department, King Saud University, P. O. Box 800, Riyadh 11421, KSA (phone: 966-11-4677022; fax: 966-11-4677008; e-mail: bfahad@ksu.edu.sa).

A. Materials Used

The prime materials used in this research were shredded plastic and fillers as shown in Fig. 1. The waste plastic (LLDPE) used was supplied by local plastic waste recycling supplier in form of shredded particles. The unit weight of plastic used was 918 kg/m^3. The physical properties of FA, QF and RS fillers were also examined and tabulated in Table I. The analysis of specific gravity and absorption of RS and QF fillers was done according to ASTM C128 [12], whereas FA filler was examined in accordance with ASTM C618 [13]. Similarly, the unit weight of RS and QF was measured by following ASTM C29 [14]. The particles size distribution of fillers was performed using laser particle size analyzer from Horiba as shown below in Fig. 2. From the gradation curve, the median size distribution (D_{50}) of FA, QF and RS fillers was figured out and tabulated in Table I. Furthermore, the grading analysis test result showed that FA is finest among three types of fillers and RS is coarser filler material.

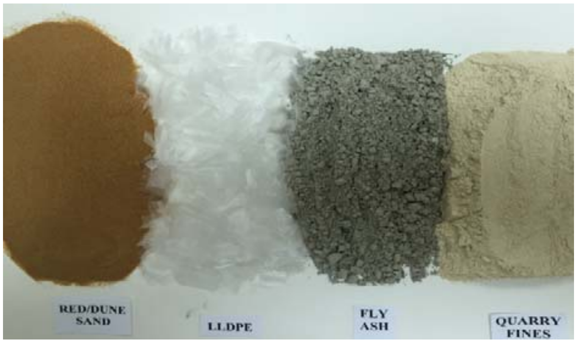


Fig. 1 Plastic and fillers used in manufacturing RPA

The Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-Ray (EDX) analysis of FA, QF, and RS fillers was performed using Versa 3D FESEM and Bruker-Nano EDX respectively as shown in Fig. 3. The images showed that the FA comprised of plane spherical particles (< 10µm) and irregular spherical shape particle (10-20 µm). Furthermore, the EDX analysis of the FA particles showed the presence of oxygen, silicon and aluminum as the major elements and very small percentage of potassium and iron. Similarly, FESEM images of QF showed the presence of angular particle having size vary from few microns to 100 µm. Furthermore, EDX point analysis of QF particles showed the presence of calcium and oxygen as the major elements with some traces of silicon and aluminum. The images of RS filler showed that the RS particles appear to be irregular angular shaped having particles (≤150 µm). Also the elemental mapping of RS showed the presence of oxygen and silicon elements.

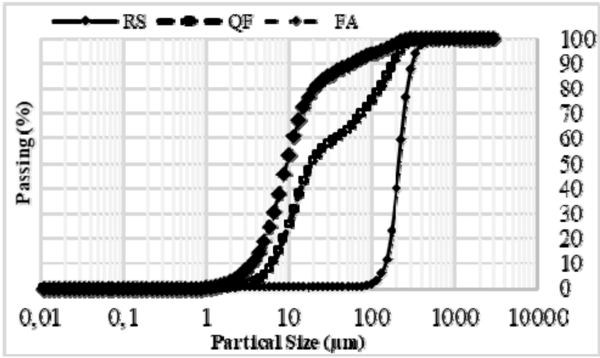
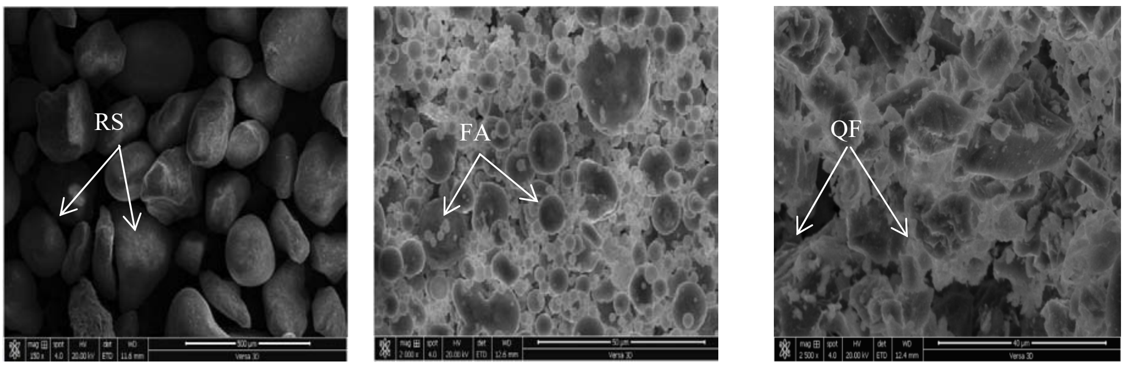


Fig. 2 Particle size distribution of different fillers

TABLE I
PHYSICAL PROPERTIES OF FILLERS

Properties	Fillers		
	FA	QF	RS
Dry unit weight (kg/m^3)	1000	1531.49	1649.53
Specific gravity	2.3	2.71	2.62
Absorption (%)	-	1.52	0.28
Median size (µm)	6.14	19.27	186.37
Colour	Dark Grey	Cream	Red
Shape	Spherical	angular	irregular



(a) (b) (c)

Fig. 3 Microstructure analysis of (a) RS, (b) FA and (c) QF

B. Manufacturing Process

Using a compression moulding process, one types of plastic, Linear Low Density Polyethylene (LLDPE) was mixed by 30% and 50% with RS or different types of granular waste such as FA or QF to develop the artificial synthetic sustainable aggregate [15]. Hence, one type of plastic was mixed with three different types of filler, as described above, leading to six different mixtures as shown in Table II. The produced aggregate was then crushed to a small size with maximum size of 10 mm, as shown in Fig. 4.

TABLE II
DIFFERENT TYPES OF RPA

Designation	Plastic Type	Plastic Content (%)	Filler Type	Filler Content (%)
RP1F1A	LLDPE	50	RS	50
P1F2A	LLDPE	50	FA	50
RP1F3A	LLDPE	50	QF	50
RP2F1A	LLDPE	30	RS	70
RP2F2A	LLDPE	30	FA	70
RP2F3A	LLDPE	30	QF	70

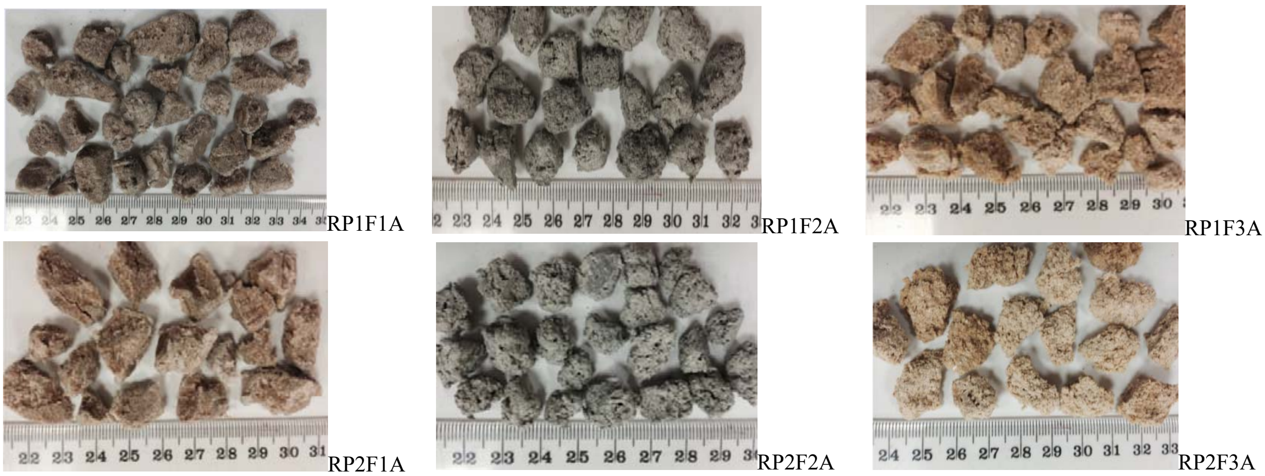


Fig. 4 Different types of RPA

III. RESULTS AND DISCUSSIONS

A. Particles Shape, Size and Texture

The RPA produced using RS and FA and QF were sub-angular, sub-rounded, and angular, respectively, whereas, the surface texture of RPA made with same types of fillers was partially rough, smooth and rough, respectively. The aggregate shape and texture significantly affect workability and other fresh and hardened concrete properties. Similarly, the angularity and roughness of aggregates would enhance the interlocking between cement paste and aggregate matrix. The gradation curve as presented in Fig. 5 showed that all RPAs were in the permissible minimum and maximum limits of lightweight aggregate (LWA) requirements in accordance to ASTM C 330-99 [11]. Nonetheless, samples of RP1F1A and RP2F1A deviated (at sieve 9.5 mm) from the minimum LWA limits by 32% and 26%, respectively because the particle size of the RS filler was coarser as compared to other types of fillers. Furthermore, RP2F3A (at sieve 1.18 mm) was found to be partially outside the maximum permissible limit by 41% because of the fineness of the QF filler as compared to other types of fillers. Therefore, the RPA aggregate manufactured using RS filler was coarser (as RS is coarser amongst the fillers used), whereas RPA formed using FA was finer (as FA was finest among all fillers, see Fig. 2) as compared with other types of RPA. The gradation curve of conventional LWA was observed not achieving 100% the permissible gradation limit of LWA, whereas the RPA aggregates were in the permissible minimum and maximum limits for LWA.

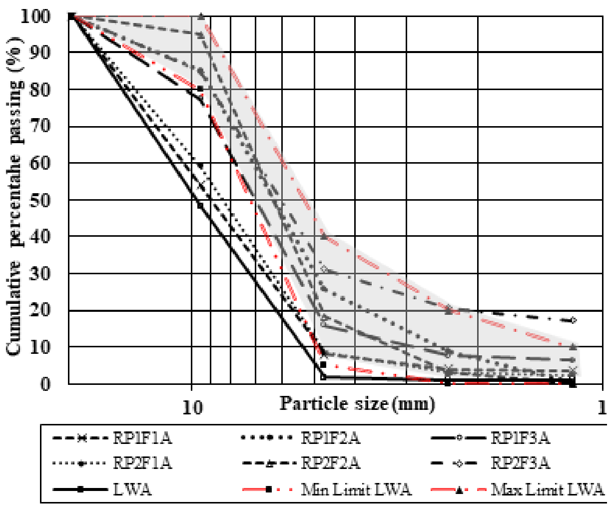


Fig. 5 Gradation curve for LWA and RPA

B. Fineness Modulus

The conclusions drawn of fineness modulus of all types of aggregates are displayed in Fig. 6. The general trend revealed that the fineness modulus of all RPA is observed to be less than the conventional LWA. The percentage reduction in of RP1F1A, RP1F2A, RP1F3A, RP2F2A and RP2F3A was observed to be 2%, 10%, 8%, 3%, 10%, and 10% respectively as compared to control lightweight aggregates. Also, the RPA results revealed that with the increase in percentage of FA, QF and RS fillers from 50% to 70% the fineness modulus insignificant decreased by 0.5%, 2%, and 1%, respectively.

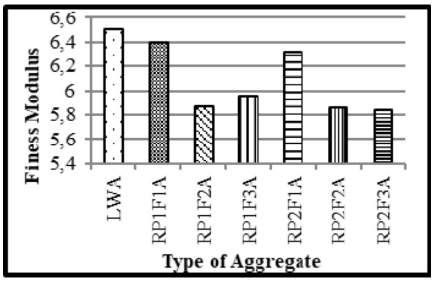


Fig. 6 Fineness modulus of various aggregates

C. Specific Gravity and Absorption

The results of bulk specific gravity (OD basis) of all types of aggregates are shown in Fig. 7. The general trend demonstrated that the bulk specific gravities of all types of produced aggregates (i.e. RPA) were less than that of conventional LWA with exception of RP2F1A (5% increased). The percentage decrease in bulk specific gravity of RP1F1A, RP1F2A, RP1F3A, RP2F2A and RP2F3A was 15%, 43%, 23%, 17%, and 16% respectively lower as compared to that of conventional LWA. Also, the percentage increase of FA, QF and RS fillers from 50% to 70% increased the bulk specific gravity of RPA by 31%, 9% and 19%, respectively. Generally, the decrease in specific gravity was due to lighter weight of plastic waste used in manufacturing of RPA as compared to lightweight aggregate. Additionally, the specific gravity of RP2F1A was highest among all developed aggregate. This is due to the fact that the specific gravity of RS filler was the highest among all fillers. However, the specific gravity of RP1F2A observed the least weight due to least specific gravity of FA fillers. The same trend of specific gravity of different types of manufactured aggregates was reported elsewhere [6]-[8].

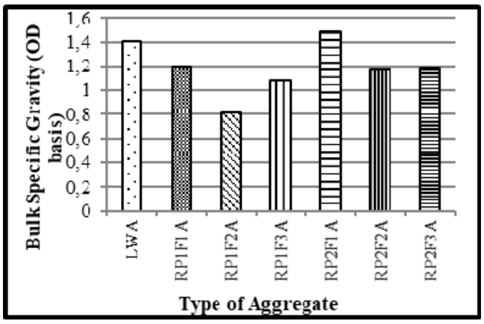


Fig. 7 Bulk specific gravity of various aggregates

Furthermore, the conclusions drawn from the absorption of all types of aggregates are displayed in Fig. 8 below. The general trend showed that the RPA showed less absorption compared to that of conventional lightweight aggregate. The water absorption of RP1F1A, RP1F2A, RP1F3A, RP2F1A, RP2F2A and RP2F3A was 85%, 67%, 68%, 85%, 51%, and 47% respectively lower compared to conventional LWA. The reduction in water absorption was due to hydrophobic nature of the plastic existing in RPA matrix. Also the RPA results revealed that the increase in percentage of FA, QF and RS fillers from 50% to 70% decreased water absorption by 33%, 39% and 1%, respectively. This results suggest that the increase in the FA filler percentage had negligible effect on the percentage of water absorption. Similar findings for different types of manufactured aggregates were reported by Jansen et al. [4] and Kayali [10].

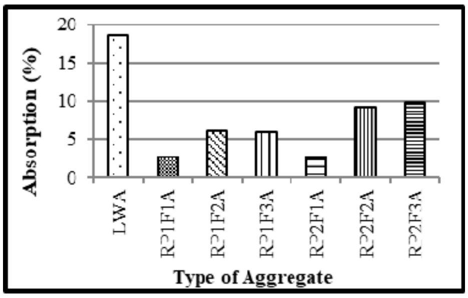


Fig. 8 Absorption of various aggregates

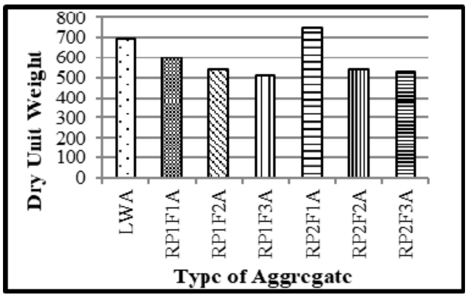


Fig. 9 Dry unit weight of various aggregates

D. Unit Weight and Voids

The findings of dry unit weight of all types of aggregates are shown in Fig. 9. The general trend from the figure showed that the dry unit weight of recycled novel synthetic aggregates is less than the conventional LWA with the exception of RP2F1A (7% increased). The percentage decrease was observed to be 14%, 23%, 27%, 23% and 24% in dry unit weight of RP1F1A, RP1F2A, RP1F3A, RP2F2A, and RP2F3A respectively as compared to conventional LWA. The decrease in dry unit weight was observed due to incorporation of lightweight RP as compared to the heavy conventional lightweight coarse aggregates. Moreover, the results showed that, for the percentage increase of FA, QF, and RS fillers from 50% to 70%, the dry unit weight of RP aggregates were increased by 1%, 5% and 20%, respectively. Furthermore, the unit weight of RP2F1A was found to be maximum as the unit weight of RS being highest among all fillers similarly the RP2F3A unit weight was least due to unit weight of FS least among all fillers. Likewise, these results are in a good agreement with those findings observed in previous published studies [4], [6]-[8], [14].

Additionally, Fig. 10 presents the results of void percentage in dense condition for all types of RPA as compared with LWA. The general trend showed that the RPA had higher void percentage in comparison with that of conventional LWA with exception of RP1F2A (33% decreased). The percentage increased varied from 3-10% as compared to that of LWA. Similarly, the percentage increase of FA, QF, and RS fillers from 50% to 70% increased the void percentage of RPA by 38%, 5%, and 3%, respectively. This suggest that the percentage increase in filler percentage of RS, QF had insignificant effect on the void percentage of the developed RPA.

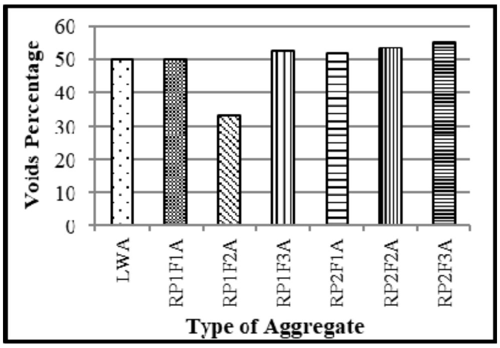
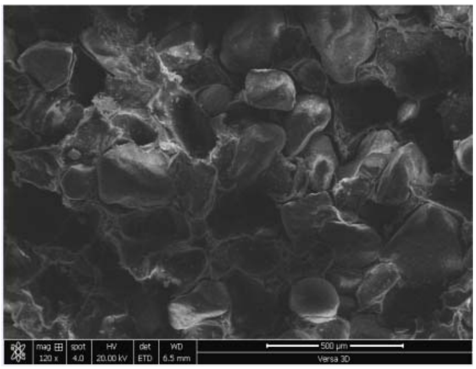


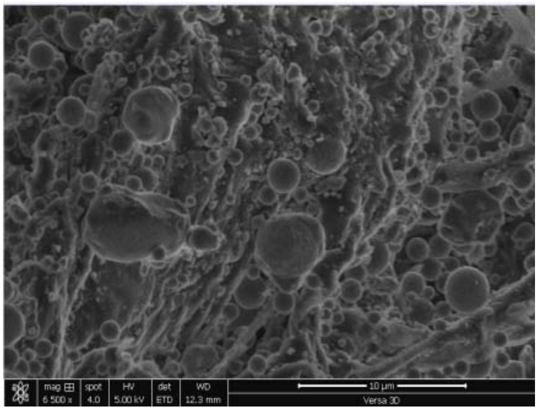
Fig. 10 Void percentage of various aggregates

E. Microstructure Analysis

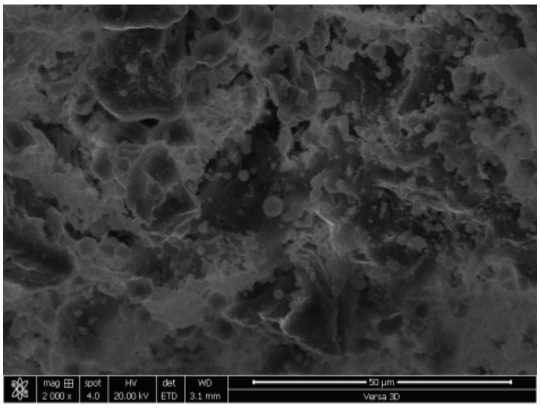
The elemental mapping of RS and LLDPE aggregates showed the presence of RS particles by the presence of O and Si. The microstructure of the RPA by SEM analysis is shown in Fig. 11. The surface examination of all samples showed non-uniform distribution of filler particles composed of finer particles, concentrated regions of finer particles and a few coarser particles. The cross-sectioned samples also showed non-uniform distribution of complete and fractured pebble shaped filler particles. The matrix of LLDPE could also be seen by the presence of carbon element. The particle shape of the QF was found to be angular like cement particles which resulted better interlocking with LLDPE matrix to form hard aggregates.



(a)



(b)



(c)

Fig. 11 SEM images for RPA made with plastic and (a) RS, (b) FA and (c) QF

IV. Conclusion

The study results showed the potential of RPA as it can be used as replacement of the natural local lightweight aggregate for the production of concrete. From the analysis and discussion of the study results, the following conclusions can be drawn:

1) Synthetic aggregate was successfully manufactured using optimized technique (i.e. Compression Moulding Press) technique.
2) The gradation curve of fillers revealed that FA particles were the finest, and RS were the coarsest amongst all fillers. Likewise, the same effect was revealed in RPA grading where fillers were the controlling factor.
3) The RPA had lower unit weight, specific gravity, absorption and fineness modulus compared to those of conventional LWA.
4) The RPA aggregate had higher voids percentage with respect to that of the LWA.
5) The microstructure analyses (SEM and EDX) of RPA showed that the QF filler is best type of filler for RPA production due to its better interlocking with plastic matrix.

ACKNOWLEDGMENT

The author is grateful to the King Saud University (KSU) for sponsoring this research project. The author also extends his appreciation to the laboratory staff of KSU for their full assistance.

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Fahad Alqahtani obtained his BSc in Civil Engineering in 2008 from King Saud University in Riyadh, Kingdom of Saudi Arabia. In 2009 he joined the University of Birmingham where he obtained his MSc in Construction Management (2010). He then continued at the same university, where he then obtained his PhD degree in 2017. He is now an Assistant professor at King Saud University in Civil Engineering. He is actively involved in both teaching and research duties. He has published two patents and more than 7 journal and conference papers.