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EVALUATION OF ENFORCING RIGID PAVEMENTS WITH PLASTIC WASTE FIBERS

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ABSTRACT

Greener and more sustainable construction projects have become the target of most agencies and officials, worldwide. With the increase of solid wastes, especially plastic waste, many attempts are made to incorporate these waste materials into construction projects. However, there are sound concerns about the side effects of adding plastic waste to construction materials, mainly Portland Cement Concrete (PCC) mixes. Thus, this study was conducted to investigate the effects of adding plastic waste fibers to PCC mixes when it comes to performance of rigid pavements. Low percentages (0.25%, 0.375%, and 0.5%) of plastic waste fibers were evaluated. KENSLAB software was utilized to determine stresses, deflections, and Cracking Indices in a rigid pavement. Based on conducting tests and analysis, 0.25% plastic waste fibers could be considered the optimal percentage, since it would enhance the performance of a rigid pavement and extend its design life. However, loss of workability of PCC mixes with plastic waste fibers may be a concern and should be taken care of by adding super plasticizers to counter act this loss.

Keywords: rigid pavements, portland cement concrete mixes, plastic waste fibers, workability, compressive strength, flexural strength, cracking index.

INTRODUCTION

With the high bloom of construction projects, the demand and costs of natural resources have increased tremendously. Thus, different agencies are calling for sustainable designs. With the increase of solid waste worldwide, alternative materials (i.e., recycled materials) are being investigated and utilized in construction projects (Angelone *et al*., 2016). Recently, more concerns are directed to reserving natural resources and reducing environmental impacts, thus more attention is focused on the use of recycled materials in the pavement industry (Abu Abdo, 2016; Abu Abdo and Khater, 2018). Molenaar (2012) argued that with the use of recycled and waste materials, the carbon foot print of road construction could be reduced and could have several economic and environmental benefits. Many studies have been conducted to evaluate the effects of incorporating recycled and waste materials in pavement construction projects with the emphasis on using plastic waste materials (Kumari and Srivastava, 2016; Chavan, 2013; Molenaar, 2012; Gawande, 2012; Sangita and Verinder, 2011; Rajasekaran *et al*., 2013; Abu Abdo and Khater, 2018).

However, many concerns were raised when it came to including waste materials in construction materials, especially in Portland Cement Concrete (PCC) mixes, due to effects of adding a weaker material and loss of bond between aggregates and cement paste, leading to a reduction in strength. This may be contributed to the fact that most studies evaluated plastic waste as a replacement of fine and/or coarse aggregates (Alfahdawi *et al*., 2016; Malkapur *et al*., 2014; Dharanidharan *et al*., 2015; Al-Hadithi and Alani, 2015; Santhosh *et al*., 2014; Vanitha *et al*., 2015; Kaothara *et al*., 2015; Rai *et al*., 2012; Al-Tayeb *et al*., 2017; Hama *et al*., 2017; Guendouz *et al*., 2016; Kumar *et al*., 2014; Ghernouti *et al*., 2014). Malkapur *et al*. (2014) investigated PCC mixes mechanical properties mixed with waste plastics as a partial replacement (10–30% by volume) of coarse aggregates. Results showed these mixes performed satisfactorily in terms of workability. However, with the increase of plastic waste content; there was consistent compressive and tensile strength loss. Other studies showed a loss of workability when adding plastic waste to PCC mixes (Kaothara *et al*., 2015; Rai *et al*., 2012; Al-Tayeb *et al*., 2017; Hama *et al*., 2017; Guendouz *et al*., 2016). However, the strength of PCC mixes is the most important factor when it comes to design. Koathara *et al*. (2015) and Hama *et al*. (2017) found that compressive strength at 28-days decreased with increase of plastic waste content, although the difference was insignificant between 0 and 10%. Kumar *et al*. (2014) examined the compressive strength, flexural strength, and split tensile strength of PCC mixes containing a partial replacement of coarse aggregate with E-plastic waste by weight percentages of 0, 5, 10, 15 and 20%. All strengths decreased with increasing plastic replacement percentages. These results were in agreement with other studies (Rai *et al*., 2012; Al-Tayeb, 2017; Ghernouti *et al*., 2014).

On the other hand, other studies showed plastic waste fibers incorporation in PCC could improve strength properties. Guendouz *et al*. (2016) argued that depending on the specific plastic types, higher compressive and flexural strengths could be observed (e.g., around 25% compressive strength increase for 1.5% of PET bottle plastic fibers added to PCC mix and 25% flexural strength increase for 1% of PET bottle plastic fibers added to PCC mix. Foti (2011) evaluated the effects by adding plastic waste fibers on reinforced concrete, the results illustrated that the ductility of concrete mixes was improved. Nibudey *et al*. (2013) used waste PET bottles as fibers in concrete mixes, with two aspect ratios 30 and 50 of plastic waste

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fibers. It was reported that a reduction of a slump, compaction factor and dry density of concrete when fiber content increased and reduction in these values were found higher for a larger value of aspect ratio. They concluded that the compressive, split tensile, and flexure strengths improved with 1% of the plastic waste fiber content.

While exploring studies conducted on evaluating the addition of plastic waste to PCC mixes, it was clearly noticed that the majority of the studies were conducted with high percentages of plastic waste (e.g., 5%, 10%, 20%, and higher), which lead to the undesirable effects on PCC mixes strengths. Thus, adding lower percentages of plastic waste should be investigated.

OBJECTIVES

The main objective of this study was to investigate the effects of enforcing a rigid (Portland Cement Concrete (PCC)) pavements with low percentages (less than 1%) of plastic waste fibers, and to determine the optimum percentage of plastic waste fiber content to improve the engineering properties of PCC mixes utilized in rigid pavements.

EXPERIMENTAL PROGRAM

Materials

A typical PCC mix was used in this study; details are shown in Table-1. PET bottles were shredded and cut to obtain 30x5x1mm fibers (Figure-1). Previous studies (Rai *et al*., 2012; Al-Tayeb, 2017; Ghernouti *et al*., 2014) investigated PCC mixes with high percentages of plastic and showed a reduction in strength of PCC mixes with plastic. Thus, in this study low percentages of plastic waste fibers were investigated; 0.25%, 0.375%, and 0.5% by weight of the mix. In addition, a control mix with 0% plastic waste fibers was prepared to compare results. Three 150mm diameter by 300mm high cylinders and 150x150x500mm beams were prepared for each condition. When plastic waste fibers were added to PCC mix, it was observed that there was an increase in volume of PCC mixes and materials saving by 4.3%, 4.8%, and 5.9% for PCC mixes with 0.25%, 0.375%, and 0.5% plastic waste fibers, respectively, as shown in Figure-2.

Table-1. PCC Mix Constituents.

Material	Percentage by Weight, %
Cement	15
Water	7
Coarse Aggregates	42
Fine Aggregates	36

Figure-1. Plastic Waste Fibers.

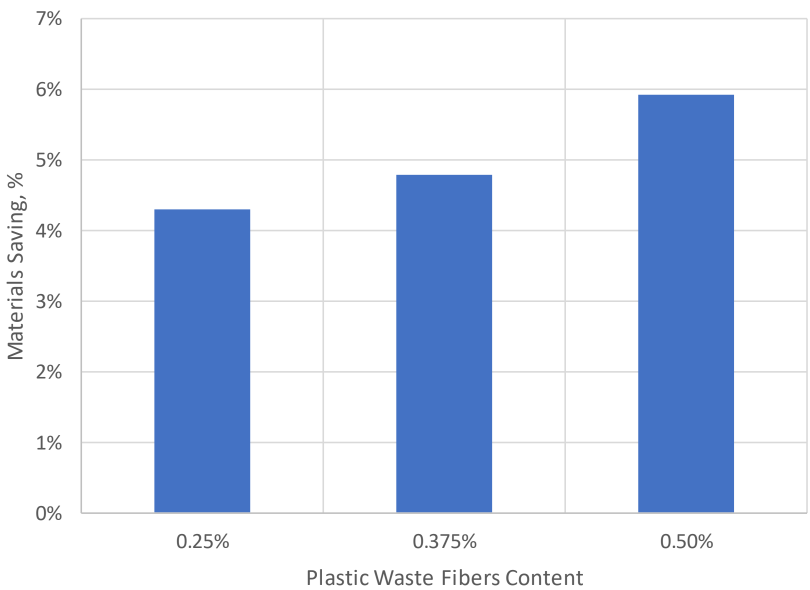

Figure-2. Materials Increase of PCC Mixes.

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Lab tests

To evaluate the effects of adding plastic waste fibers on PCC mix engineering properties, the following tests were conducted:

- Slump of Freshly Mixed Portland Cement Concrete Test (ASTM C143),
- Compressive Strength of Cylindrical Concrete Specimens Test (ASTM C39), and
- Flexural Strength of Concrete Test (ASTM C78).

KENSLAB software

The KENSLABS software (Huang, 2004) utilizes the finite element method to determine the stresses and deflections of rigid (PCC) pavements and damage ratio (cracking index) due to tyre loading. Rigid pavement slab is divided into rectangular finite elements with a large number of nodes. Both wheel loads and subgrade reactions are applied to the slab as vertical concentrated forces at the nodes. To evaluate the effects of adding different percentages of plastic waste plastic to PCC pavements, a concrete slab, 250mm thick, was used in the analysis. The slab was supported by a subgrade with a modulus of subgrade reaction of 55 MN/m^3. A 5500kg dual-wheel load spaced at 350mm was applied in the corner of the slab to determine deflections and at the edge of the slab to determine the resulting damage due to the load. The contact pressure was 550kPa. The Elastic Modulus values were obtained by utilizing the compressive strength of tested mixes, using Eq. 1. KENSLAB utilizes PCC Modulus of Rupture in Portland Cement Association (PCA) models (Eqs. 2-4) to determine the cracking index (CI), which is defined as the summation of ratio of number of load repetition to maximum allowable number of load repetitions (N_f) and is a function of the flexural strength of PCC mixes. Failure of pavements occurs when CI reaches a value of 1.0 (Packard and Tayabji, 1985; Huang, 2004).

$$E_c = 4700\sqrt{f_c'} \qquad \text{(Eq. 1)}$$

where,

E_c: Elastic Modulus of PCC mix, MPa.
f_c': Compressive Strength of PCC mix, MPa.

$$For\ \frac{\sigma}{S_c} \geq 0.55: logN_f = 11.737 - 12.077\left(\frac{\sigma}{S_c}\right) \qquad \text{(Eq. 2)}$$

$$For 0.45 < \frac{\sigma}{S_c} < 0.55: N_f = \left(\frac{4.2577}{\sigma/S_c - 0.4325}\right)^{3.268} \qquad \text{(Eq. 3)}$$

$$For\ \frac{\sigma}{S_c} \leq 0.45: N_f = unlimited \qquad \text{(Eq. 4)}$$

where,

σ : Flexural Stress in Slab, MPa.
S_c: Modulus of Rupture of PCC mix, MPa.

RESULTS AND ANALYSIS

Lab tests

Slump Test is utilized to determine the workability of PCC mixes. It is always a concern when casting PCC mixes. Results showed (Figure-3-a) that with an increase of plastic waste fibers, workability of PCC mixes decreased significantly. Especially, with the addition of 0.5% plastic waste fibers at which slump value has shown a decrease of 90%. However, compressive and flexural strengths of tested PCC mixes showed an increase with the addition of plastic waste fibers, with the highest increase at 0.25% plastic waste fiber content, as shown in Figures 3-b and 3-c, with an increase of 60% and 90% of compressive strength and modulus of rupture, respectively, when compared to the control PCC mix (0% fibers). Furthermore, results showed drop-in strengths with an increase with plastic waste fiber content. Results from a PCC mix with 0.5% plastic waste fiber were near the control sample. Thus, it was speculated that with plastic waste fibers contents higher than 0.5% would lead to a reduction in strength of PCC mixes, which was reported in earlier studies. It might be explained by the loss of bond between cement paste and coarse aggregates with the inclusion of higher smooth surfaced plastic waste fibers as shown in Figure-4.

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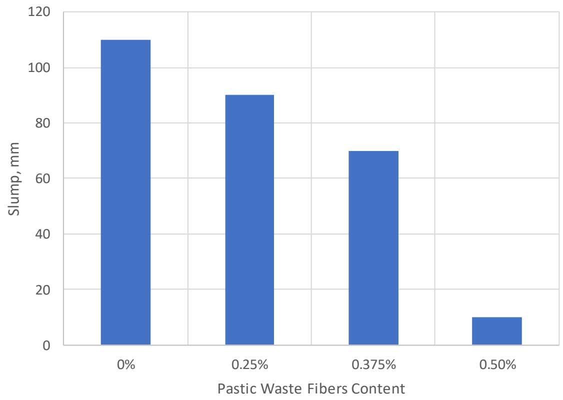
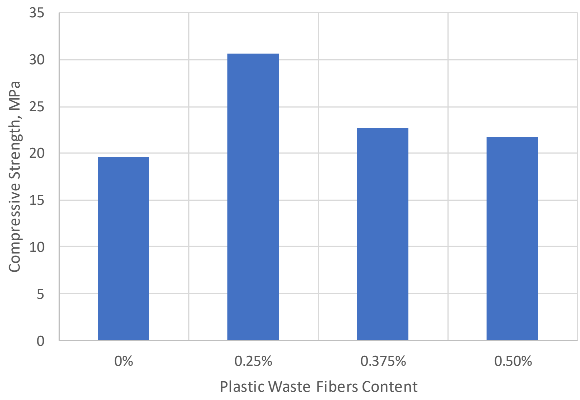
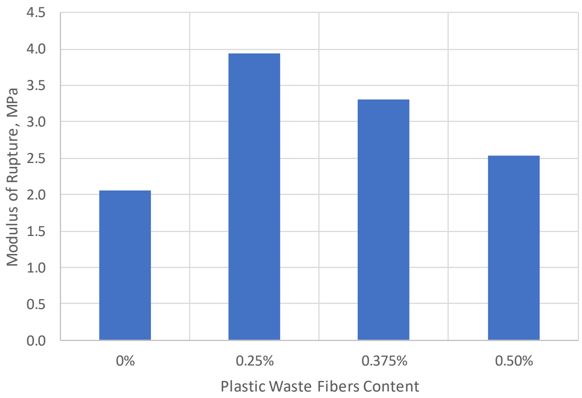


a) Slump Results



b) Compressive Strength, f_c'



c) Modulus of Rupture, S_c

Figure-3. Lab Test Results for PCC Mixes with Different Plastic Waste Fibers.

Figure-4. Image of Tested PCC Mix with 0.25% Plastic Waste Fibers.

KENSLAB software analysis

Upon running KENSLAB software for PCC mixes with the different plastic waste percentages, the maximum compressive stresses (+ve) and maximum tensile stresses (-ve) were determined, as shown in Figure-5. The maximum compressive stress was located in mid-span in both directions and the maximum tensile stress was located at the corner of the slab. As for vertical deflection, PCC mix with 0.25% showed the lowest deflection, when compared to the other mixes and the highest deflection was in the control mix (0 plastic waste fibers), as illustrated in Figure-6. However, the overall results were approximately close. The

ISSN 1819-6608

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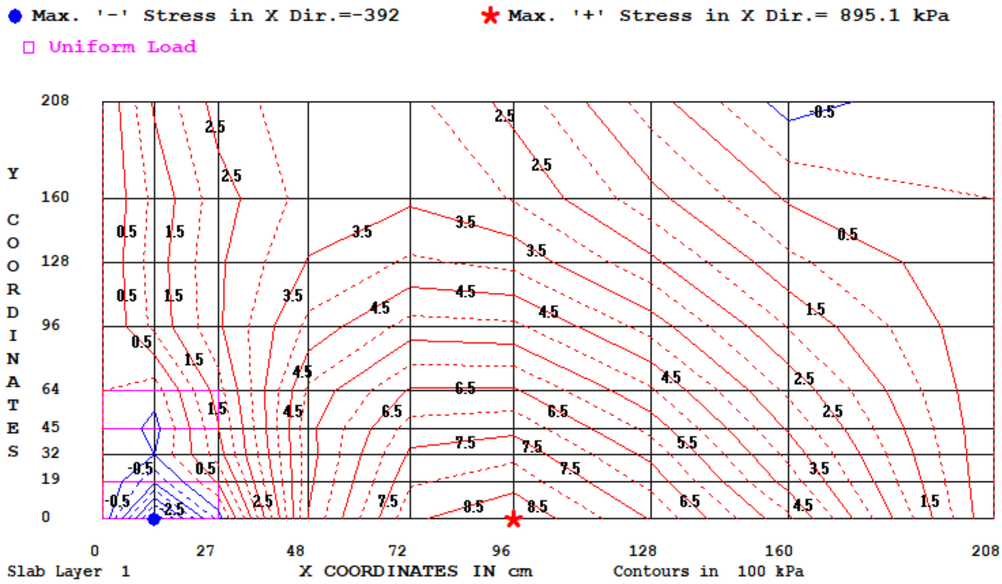
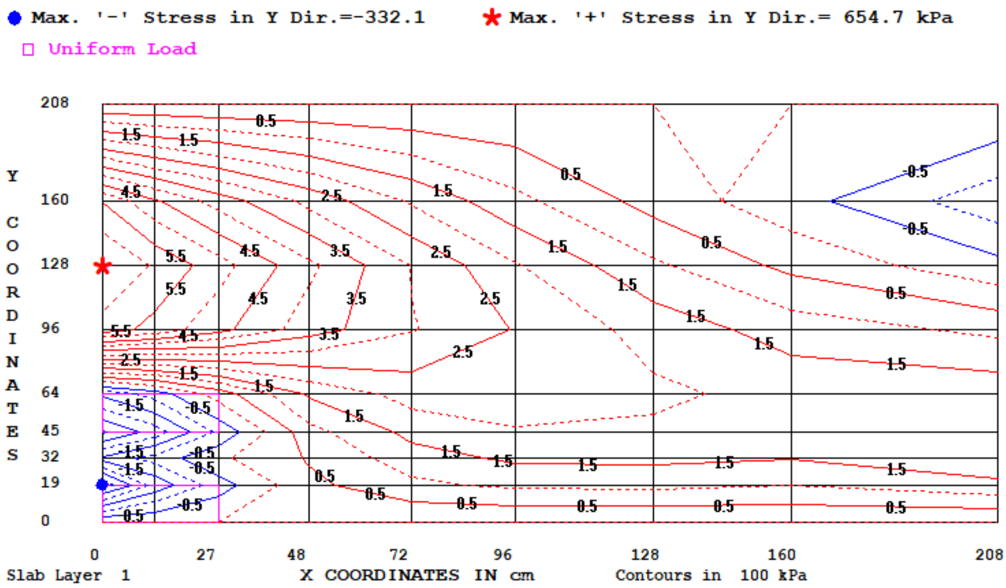
damage analysis results varied significantly among different mixes (Figure-7). Cracking Index for a slab with 0.25% plastic waste fibers was the lowest with a value of 8.53E-06 and a maximum Cracking Index for the control mix (5.40E-04) which indicated a huge improvement in performance and a longer life for rigid pavement reinforced with 0.25% plastic waste fibers by weight of PCC mix.



a) x-direction



b) y-direction

Figure-5. Maximum Compressive (+ve) and Tensile (-ve) Stresses Contours by KENSLAB.

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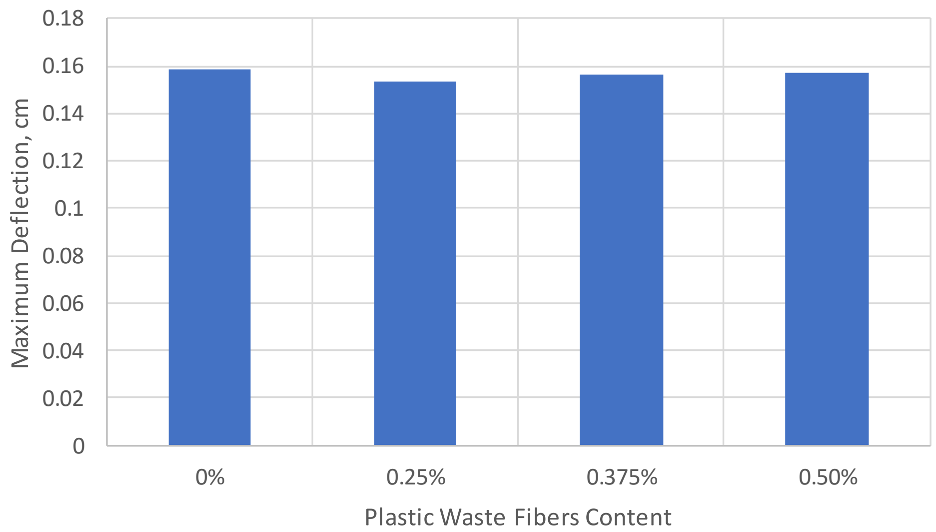

Figure-6. Deflection Results by KENSLAB Software.

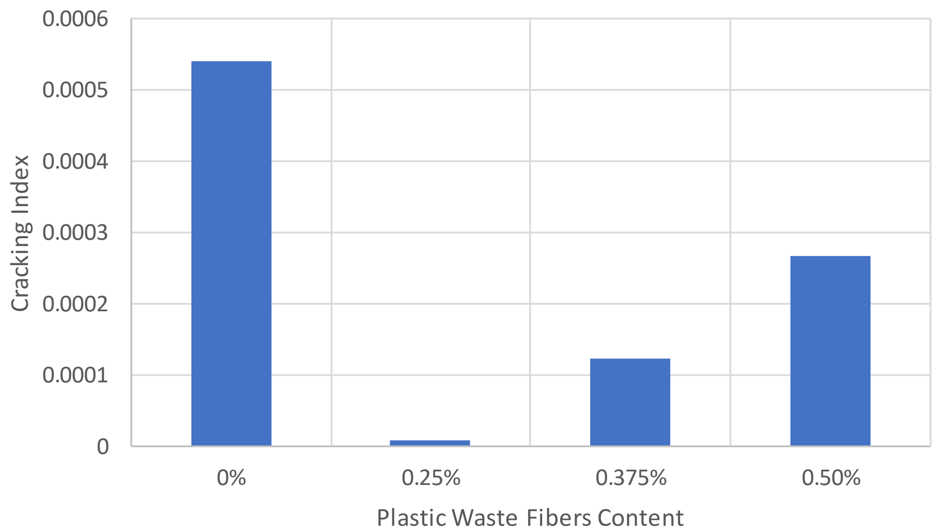

Figure-7. Cracking Index by KENSLAB Software.

CONCLUSIONS

Based on the results presented, the following observations and conclusions were made:

a) With the increase of plastic waste fiber content in a PCC mix, it was observed that there were materials savings with 4.3%, 4.8%, and 5.9% by weight for PCC mixes with 0.25%, 0.375%, and 0.5% plastic waste fibers, respectively.
b) The workability of PCC mixes was affected significantly with the addition of low percentages of plastic waste fibers. The slump of PCC mixes was reduced by 90% for PCC mixes with the addition of 0.5% plastic waste fibers.
c) Adding plastic waste fibers to PCC mixes in low percentages increased the compressive and flexural strengths, especially at 0.25% fiber content of PCC mix weight. However, it was observed that the compressive and flexural strengths tended to decrease with the increase of the plastic waste content beyond the addition of 0.25% plastic waste fibers by weight of PCC mix.
d) KENSLAB software analysis showed that the addition of low percentages of plastic waste fibers did not affect compressive and tensile stresses, in the x and y directions, induced in a rigid pavement nor the deflection, with approximately the same results. However, damage analysis showed that incorporating low percentages of plastic waste fibers in a PCC mix, would reduce Cracking Index and increase rigid pavement life. A rigid pavement with 0.25% plastic waste fibers resulted in a reduction in the Cracking Index by more than 60 times.

In conclusion, incorporating 0.25% plastic waste fibers in a PCC mix would enhance the performance of rigid pavements with a reduction of needed materials. Thus, achieving an eco-friendly and sustainable rigid pavement

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design. However, due to the drop-in workability due to the presence of plastic waste in the mix, super plasticizers are recommended to make up for the loss in workability.

ACKNOWLEDGMENT

Authors would like to extend their gratitude to the American University of Ras Al Khaimah, UAE and the University of Idaho, USA for the provided support. In addition, special thanks go to Eng. Rashad Abdelhadi, Eng. Yamen Kaeed, and Eng. Mohamed Abdi for their contributions toward completing this study.

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