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# Analysis of Flexible Pavement Reinforced with Geogrid and Containing Recycled Materials

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**ABSTRACT**
Utilization of aggregates as base or sub-base materials in the construction and maintenance of roadways pavement requires an enormous amount of raw aggregates. This paper aimed to investigate and numerically evaluate the behavior of recycled construction waste reinforced with geogrid when used as an alternative construction material in the base and sub-base layer of roads to apply sustainable development through preserving raw aggregate and resources for future generations. Finite element software Plaxis 2D ( 8.2 ) was used to assess the efficiency of Reclaimed Asphalt Pavement ( RAP ), Fly Ash ( FA ), and Reclaimed Concrete Material ( RCM ) against raw aggregates. Thirteen mixtures were employed in the base layer as an alternative to raw aggregates and three locations for the geogrid layer were also investigated. The study revealed that the reinforced recycled materials led to better deformation results when compared to raw aggregates. The best alternative mixture was 50% RAP + 50% raw aggregate which reduced deformation by 30%. The study concluded that the use of geogrid mesh reduced deformations and this reduction was dependent on the location of the mesh within the layers; the best position was in the middle of the base layer.

***Keywords***: *Plaxis 2D; Recycled material; Geogrid*

## 1. Introduction

Millions of tons of waste are produced annually from building materials. Disposal of these wastes in landfills would cause environmental pollution. On the other hand, there is a continuous need to build new roads that consume large quantities of raw aggregates. The debris from demolitions and construction materials have good structural properties despite being subjected to grinding and crushing. They are composed of natural aggregates such as sand and gravel that do not decompose. This led to the idea of recycling construction and road wastes and reusing them again in the base layers of flexible pavement [1]. The use of recycled materials in pavements has gained a significant attraction in the infrastructure business field/construction, with the goal of lowering the consumption of raw resources. The environmental implications and economic consequences of waste-derived pavements must be included as part of the sustainability analysis in order to accomplish sustainable development goals [2]. Recycled asphalt pavement (RAP) is a high-value and quality material that could replace raw aggregates. There is the possibility to use up to 30 percent RAP in the intermediate and surface layers of pavements according to State transportation department specifications [3]. Reclaimed Concrete Aggregate (RCA) is comprised of 60 to 75% high-quality, well-graded aggregates together with a hardened cement paste. Fly ash is a by-product of municipal solid waste (MSW) incineration that contains heavy metals that can cause contamination if reused. To immobilize these harmful components, fly ash is consolidated with cement [4]. looked at a variety of practice tests to examine the performance of asphalt mixtures with varied RCA proportions. it can be observed that the optimal performance, of asphalt mixtures containing RCA, would require a greater bitumen percentage [5]. The mechanical qualities of RCA were found to be slightly lower than those of natural aggregates, but they were still within the BS criteria. For a given strength, the RCA concrete mixes were found to have equivalent durability properties to the corresponding natural aggregate concrete mixes [6]. The high quantity of added Fly ash (FA) exhibits an inverse effect on the compressive strength and stiffness of stabilized materials, crushed brick (CB) and Recycled asphalt pavement (RAP) stabilized with 15% FA was found to be the optimum proportions for pavement base/sub-base application [7]. Recycling asphalt pavement materials (RAP) produces pavements with better properties, lower cost, and energy. RAP saves energy, reduces the transportation required to obtain high-quality raw aggregate, reduces the quantity of building wastes, and conserves resources. Also, RAP represents a good substitute for raw materials [8]. derived pavements must be included as part of the sustainability analysis in order to accomplish sustainable development goals [9]. In this study, sustainable development was applied through the use of recycled materials to preserve raw aggregates and resources for future generations and to protect the environment by reducing construction, road, and other wastes that require large areas of land for landfilling. From the economic aspect, sustainable development maintains the roads for a long time, up to 50 years, which reduces distortions in the roads and maintenance costs.

## 2. Aim and Research Significance

Highway roads utilize significant amounts of aggregates. In this regard, governments are encouraging the recycling of waste materials and debris from dumping pavements. This study aimed to apply sustainable development through the use of reinforced recycled materials [Reclaimed Asphalt Pavement (RAP), Fly Ash (FA), and Reclaimed Concrete Material (RCM)] to preserve raw aggregates and resources for future generations. Finding out the suitability of using reinforced recycled materials as an alternative to raw aggregates, choosing the best mixes to reduce the deformation, and determining the optimal location of geogrid to improve pavement performance were the most important goals. Finite element software Plaxis 2D (8.2) was used to assess the efficiency of reinforced recycled material.

## 3. Experimental Program

A finite element software Plaxis 2D (8.2) for geotechnical applications was used to simulate the soil behavior. in this study, the linear elastic model was used for the surface layer, and the Mohr-Coulomb model was used for the base, sub-base, and subgrade course . In the present study, 15-noded structural solid elements were used for modeling the pavement section [10]. At the horizontal fixed support was employed to prevent movement. Vertical displacement allowed for both vertical sides of the model and no horizontal movement was allowed at any side of the mesh. A uniform loading of 575 KPa according to a tire inflation pressure of 80 Ib/in2 was used to study the effect of geogrid location on reducing the surface deformation under loading different reinforced recycled materials in the base course.

### 3.1 Materials

### 3.1.1 Geogrid

Geogrid is made of the polymer material of high-density polyethylene. It extruded into a sheet, punched into a regular mesh pattern, then stretched into a grid in longitudinal and transverse directions. For this research, three locations were selected to evaluate the best location for the geogrid mesh in the base layer. Table 1 and Figure 1 illustrate the geogrid locations inside the base layer. The effect of geogrid mesh depends on its shape, its size, and its stiffness. Table 2 illustrates the characteristics of geogrid mesh.

**Table 1:** Description geogrid locations

| Geogrid location | Description |
|---|---|
| | Unreinforced |
| Geogrid location (1) | Reinforcement between base and sub-base course |
| Geogrid location (2) | Reinforcement in the top third of the base course |
| Geogrid location (3) | Reinforcement In the middle of the base course |

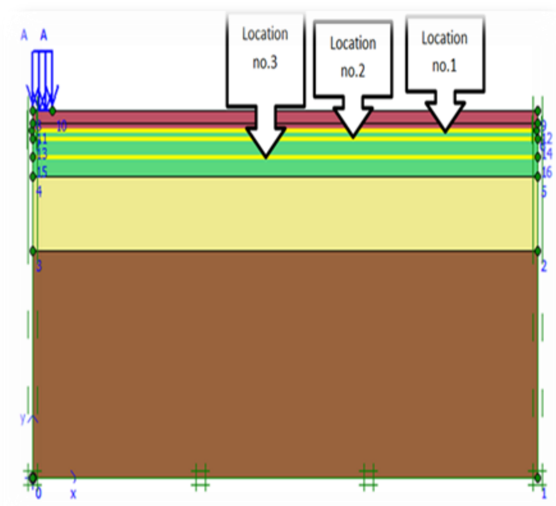


**Figure 1:** Description geogrid locations

**Table 2:** Characters of geogrid mesh [11]

| Material model | Axial stiffness |
|---|---|
| Tensile stiffness at 5% strain | 1500 |
| Aperture dimensions (mm*mm) | 30*30 |
| Percentage of grid open area% | 33 |
| Tensile strength(kN/m) | 200 |

**3.1.2 The aggregate of base course**

Thirteen base course mixtures (Three groups: Reclaimed asphalt pavement (RAP), Fly ash (FA), and Reclaimed concrete material (RCM)) were investigated using finite element software Plaxis 2D (8.2) to assess the performance of pavement reinforced and unreinforced, and to evaluate their suitability as an alternative to raw aggregates.

Table 3 illustrates the hydraulic and mechanical properties of the used aggregate according to the study of Gupta et al.,2009 which was used in the finite element software Plaxis 2D (8.2).

**Table 3:** The composition and properties of recycled base mixture [12]

| Group number | Mixture | Description | Properties | | | | |
|---|---|---|---|---|---|---|---|
| | | | Dry density ($kN/m^3$) | Saturated density ($kN/m^3$) | Cohesion ( C ) ($kN/m^2$) | Friction ( Θ ) (Degree) | Resilient modulus ($M_R$) (MPa) |
| | Control mixture | Raw aggregate | 20.87 | 24.20 | 100 | 42 | 123.42 |
| 1 | Mixture 1 | 50% RAP + 50% Raw aggregate | 20.68 | 22.75 | 335 | 18 | 269.55 |
| | Mixture 2 | 75% RAP + 25% Raw aggregate | 20.66 | 22.53 | 195 | 35 | 262.00 |
| | Mixture 3 | 100% RAP | 20.78 | 22.61 | 182 | 43 | 162.23 |
| 2 | Mixture 4 | 25% RCM + 75% Raw aggregate | 21.14 | 23.84 | 102 | 48 | 157.03 |
| | Mixture 5 | 50% RCM + 50% Raw aggregate | 19.03 | 23.65 | 564 | 4 | 180.57 |
| | Mixture 6 | 75% RCM + 25% Raw aggregate | 19.06 | 23.10 | 325 | 18 | 251.32 |
| | Mixture 7 | 100% RCM | 19.00 | 22.80 | 195 | 35 | 141.69 |
| 3 | Mixture 8 | 5% Fly ash + 70% Raw aggregate + 25% RAP | 19.89 | 23.65 | 321 | 29 | 262.10 |
| | Mixture 9 | 15% Fly Ash 60% Raw aggregate + 25% RAP | 18.24 | 23.74 | 321 | 21 | 164.25 |
| | Mixture 10 | 5% Fly ash + 45% Raw aggregate + 50% RAP | 19.73 | 23.21 | 88 | 54 | 130.24 |
| | Mixture11 | 15% Fly ash + 35% Raw aggregate + 50% RAP | 18.00 | 23.19 | 203 | 39 | 110.55 |
| | Mixture 12 | 5% Fly ash + 20% Raw aggregate + 75% RAP | 19.40 | 22.66 | 158 | 39 | 249 |
| | Mixture 13 | 15% Fly ash + 10% Raw aggregate + 75% RAP | 18.47 | 22.74 | 122 | 47 | 75.16 |

### 4. Results and Discussion

Using finite element program Plaxis 2D (8.2), the surface deformation under loading, and deformation decreasing ratio compared with raw aggregate were determined for each mixture as shown in Table

Table 4: Surface deformation

| Case | | Raw agg. | Mix 1 | Mix 2 | Mix 3 | Mix 4 | Mix 5 | Mix 6 | Mix 7 | Mix 8 | Mix 9 | Mix 10 | Mix 11 | Mix 12 | Mix 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Surface Def. (mm) | 5.6 | 5.1 | 5.1 | 5.4 | 5.4 | 5.3 | 5.3 | 5.5 | 5.1 | 5.4 | 5.5 | 5.7 | 5.1 | 5.9 |
| | Def. decrease, % | - | 8.8 | 8.4 | 3.22 | 2.9 | 4.5 | 5.73 | 1.79 | 8.0 | 3.40 | 1.1 | -1.3 | 7.9 | -6.5 |
| 2 | Surface Def. (mm) | 4.9 | 4.6 | 4.7 | 4.83 | 4.9 | 4.8 | 4.75 | 4.90 | 4.7 | 4.8 | 4.9 | 5.0 | 4.7 | 5.2 |
| | Def. decrease, % | 11.7 | 17.7 | 16.7 | 13.4 | 13.1 | 14.0 | 14.8 | 12.2 | 16.3 | 13. | 12.0 | 10.8 | 16.0 | 7.5 |
| 3 | Surface Def.(mm) | 5.0 | 4.5 | 4.5 | 4.8 | 4.8 | 4.7 | 4.65 | 4.9 | 4.53 | 4.8 | 4.9 | 5.1 | 4.5 | 5.4 |
| | Def. decrease, % | 10.0 | 19.4 | 19.2 | 14.2 | 13.3 | 15.4 | 16.7 | 12.5 | 18.8 | 14.3 | 12.0 | 9.50 | 18.6 | 4.1 |
| 4 | Surface Def. (mm) | 4.5 | 3.9 | 3.9 | 4.2 | 4.3 | 4.2 | 4.0 | 4.3 | 3.9 | 4.2 | 4.4 | 4.6 | 3.9 | 4.9 |
| | Def. decrease, % | 20.1 | 30.5 | 30.1 | 24.2 | 23.7 | 25.6 | 27.6 | 22.2 | 30.1 | 24.4 | 21.7 | 18.5 | 29.6 | 11.8 |

Case (1): unreinforced, (2) reinforcement location 1, (3) reinforcement location 2, (3) reinforcement location 3

#### 4.1 Unreinforced recycled pavement section

Figure. 2 shows the surface deformation decreasing ratios for each unreinforced recycled base mixture compared with unreinforced raw aggregate as shown in Equation1.

= (Surface deformation difference between mixture and unreinforced raw aggregate ×100) / (Surface deformation of unreinforced raw aggregate) ……... Equation 1.

Can be concluded that the use of recycled material improved the deformation resistance of pavement unless mixtures 13 and 11, as shown in Figure 2. The improvement values for mix no. 1, no.2, no.8, and no.12 were about 8.78%, 8.42%, 8.04%, and 7.89 respectively.

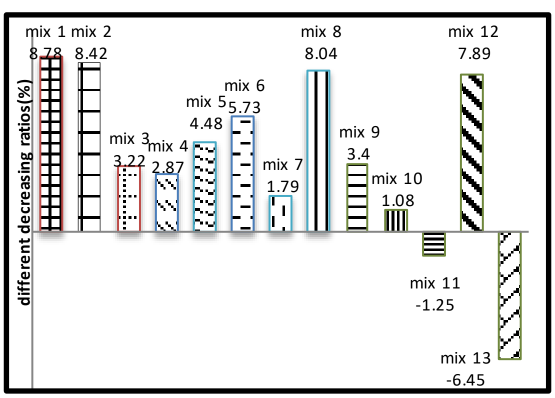


**Figure. 2.** The surface deformation decline ratios for all unreinforced recycled mixes

Moreover, it can be concluded that the mixtures containing reclaimed concrete material (RCM) (Group no.2) performed worse than reclaimed asphalt pavement (RAP) (Group no.1). The addition of fly ash by 15% in mixtures 13 and 11 provided a negative effect on surface deformation where the deformation increased by about 6.45% and 1.25% respectively.

Thus, using fly ash by 15% isn't recommended in base course mixtures. Furthermore, it can be said that the addition of RAP only in base mixtures is the best choice.

#### 4.2 Recycled pavement sections reinforced with geogrid between base and sub-base (Location 1)

Figure. 3 illustrates the surface deformation decreasing percentages for each reinforced recycled base mix (location 1; geogrid between base and sub-base) compared with unreinforced raw aggregate.

From Figure. 3, it can be illustrated that the geogrid at location no.1(between base and sub-base) had clear effect on reducing the surface deformation for all recycled base mixtures compared with unreinforced mixtures that shown in Figure .2.

Using geogrid at location (1) improved the pavement performance by reducing the surface deformation by about [8~17%] more over than the values obtained at unreinforced recycled sections, shown in Figure. 2.

In general, as shown in Figure. 3 mixtures 1,2,8 and 12 provided the better performance where they decreased surface deformation by about 17.65%, 16.67%, 16.31%, and 15.95 respectively according to unreinforced raw material.

The most improved sections by using a geogrid layer between base and sub-base were mixtures 13 and 11 that contained 15% fly ash, where they decreased the deformation by 7.33% and 10.75% respectively. While these two mixtures without geogrid increased the deformation by 6.45% and 1.25% respectively compared with raw aggregate.

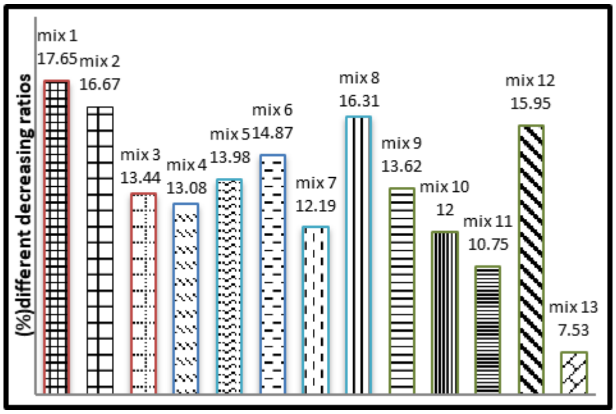


**Figure. 3.** The surface deformation decline ratios for all recycled mixes reinforced with geogrid at location1

**4.3 Recycled pavement sections reinforced with geogrid at the top third of the base course ( Location 2)**

Figure. 4 illustrates the surface deformation decreasing ratios for each reinforced recycled base mix (location 2; geogrid at the top third of the base course ) compared with unreinforced raw aggregate.

From Figure. 4, it can be illustrations that the geogrid at location no.2 (top third of the base course) provided an obvious effect on reducing the surface deformation for all recycled base mixtures compared with unreinforced mixtures that shown in Figure .2.

Using geogrid at the top third of the base course (location 2) improved the pavement performance by reducing the surface deformation by about [4~20%] more than the values obtained at unreinforced recycled sections shown in Figure. 2.

Mixtures 1,2,8 and 12 were the best sections in reducing deformation compared with unreinforced raw aggregate, where they decreased the deformation by about 19.35%, 19.17%, 18.82%, and 18.64 respectively.

By comparing the results of using the geogrid layer in locations 1 and 2, it can be concluded that is no clear difference between them. The recycled pavement sections provided approximately the same performance if reinforced with geogrid located between base and sub-base or located at top third of the base course .

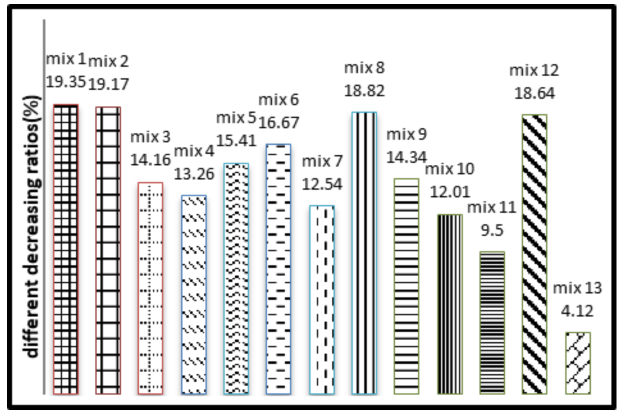


**Figure. 4.** The surface deformation decline ratios for all recycled mixes reinforced with geogrid at location2

**4.4 Recycled pavement sections reinforced with geogrid at the middle of the base course ( Location 3)**

Figure. 5 shows the surface deformation decreasing ratios for each reinforced recycled base mixture (location 3; geogrid at the middle of the base course) compared with unreinforced raw aggregate.

From Figure. 5 it can be concluded that using geogrid as reinforcement layer at middle of the base course (location 3) provided very great impact on reducing the surface deformation for all recycled base mixture compared with unreinforced recycled mixture that shown in Figure. 2.

Using geogrid as reinforced layer at middle of the base course (location 3) greatly improvement the pavement performance by reducing the surface deformation by about [11~30%] more over than the values shown at unreinforced recycled sections.

At using geogrid layer in location 3, the reinforced mixtures 1,2,8 and, 12 provided the best performance compared with unreinforced raw aggregate where they reduced the surface deformation by about 30.47%, 30.12%, 29.74%, 29.57% respectively. The same sections in order provided the best performance in other geogrid locations as well as in unreinforced sections. Thus, it can be concluded that using (50% RAP + 50% raw aggregate) and (75% RAP + 25% raw aggregate) are the ideal mixtures in reducing the surface deformation.

From the analysis of results for all recycled pavement sections reinforced with geogrid layers located in three locations, it can be said that the location 3 (at middle of the base course ) is recommended for using in pavement section for its huge effect on reducing surface deformation.

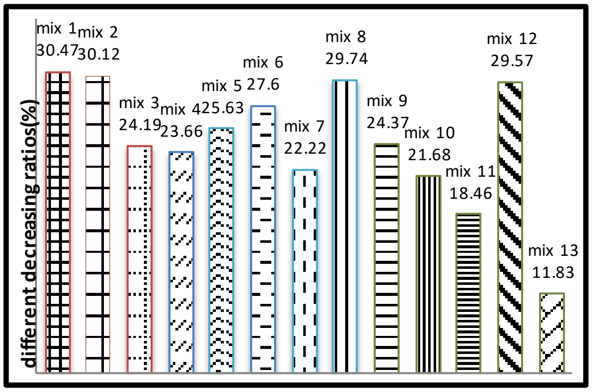


**Figure. 5.** The surface deformation decline ratios for all recycled mixes reinforced with geogrid at location 3

### 4.5 Effect of recycled base mixtures compositions on pavement performance

#### 4.5.1 Base mixtures containing RAP + raw aggregates (Group no.1)

Figure. 6 illustrates the percentage of surface deformation under loading for recycled base mixtures in group no.1. that consists of raw aggregate and RAP compared with deformation of raw aggregate only.

From Figure. 6, it can be observed that the reinforced base course be achieved better performance than unreinforced section. Geogrid located at the middle of the base course location 3 provided the highest decreasing ratio in surface deformation. Geogrid locations 1 and 2 provided the same performance approximately.

From group1, mix 1 that consists of 50% RAP + 50% raw aggregate followed by mix1 that consists of 75% RAP +25% raw aggregate showed the best performance for both unreinforced or reinforced sections. This results may be due to the different properties of base mixtures that obtained in Table 3 such as cohesion (C), friction (Ɵ) and, resilient modulus ($M_R$).

Resilient modulus ($M_R$) is a measure of material stiffness and provides a means to analyze the stiffness of materials under different conditions, such as moisture, density, and stress level. Wherefore, it can be observed that the base mixture with a higher modulus of resilient ($M_R$) provided a very great impact on improving pavement performance. Increased the resilient modulus ($M_R$) for mixtures 1 and 2 that consistency of 50% RAP + 50% raw aggregate, 75% RAP + 25% raw aggregate from 123.42 MPa to 269.55 MPa and, from 123.42 MPa to 262.00MPa respectively compared with raw aggregate. In addition, Increased the cohesion coefficient (C) from 100 kN/m$^2$ to 335kN/m$^2$ and, from 100 kN/m$^2$ to 195kN/m$^2$ respectively compared with raw aggregate. Where cohesion refers to shear strength under high stress which means an increase in the stability of the mixtures; due to the added mineral and organic fibers present in the RAP blends and oils being absorbed during a performance before their reuse.

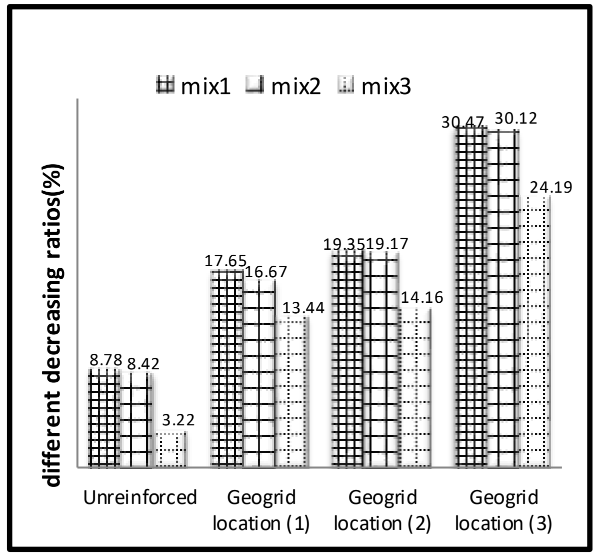


**Figure. 6.** The surface deformation decline ratio for group no.1 reinforced and unreinforced mixtures

#### 4.5.2 Base mixtures containing RCM + raw aggregates (Group no.2)

Figure. 7 shows the percentages of surface deformation under loading for recycled base mixtures in group no.2. that consists of a raw aggregate and RCM compared with deformation of raw aggregate only.

From Figure. 7, It can be observed that the recycled base course section using RCM (Group 2) obtained worse performance than using RAP in group1 for both unreinforced or reinforced sections. Thus, it can be concluded that the using RCM in base course is not recommended if compared with using RAP. As observed in mixtures of group 1, geogrid located at the middle of the base course (location 3) achieved the highest decreasing ratio in surface deformation compared with unreinforced raw aggregate. Moreover, mixture 6 that consistence of 75% RCM + 25% raw aggregate provided better performance than other mixtures in group 2.

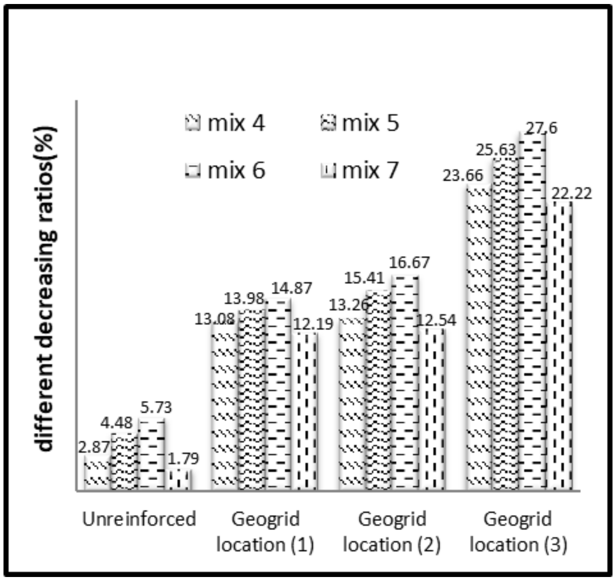


**Figure. 7.** The surface deformation decline ratio for group no.2 reinforced and unreinforced mixtures

**4.5.3 Base mixtures containing FA+RAP + raw aggregates (Group no.3)**

Figure. 8 illustrates the percentages of surface deformation under loading for recycled base mixtures in group no.3. that consists of raw aggregate, RAP, and, FA compared with deformation of raw aggregate only.

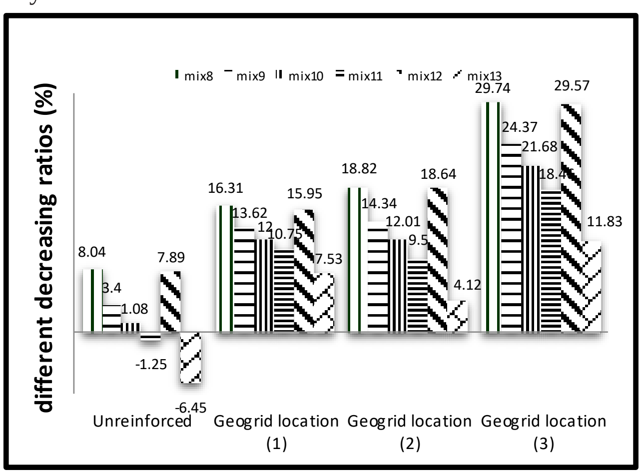


**Figure. 8.** The surface deformation decline ratio for group no.3 reinforced and unreinforced mixtures

From Figure. 8, it can be observed that the reinforced base could acquire good performance than unreinforced section. Mixture 13 (15% Fly Ash + 10% raw aggregate + 75% RAP), and mixture 11 (15% Fly Ash + 35% raw aggregate + 50% RAP) without geogrid increased the deformation by 6.45% and 1.25% respectively compared with raw aggregate.

The decrease of the resilient modulus ($M_R$) for mixtures 13 and 11 from 123.42 MPa to 75.16 MPa, and from 123.42 MPa to 110.55 MPa respectively compared with raw aggregate. The associated increases in deformations were 6.45% and 1.25%, respectively.

Generally, the use of geogrid reduces surface deformations for all studied locations of geogrid. But, location (3) was higher than other ones in reduction of deformation.

From group 3, mix 8 which consists of 5% fly ash + 70% raw aggregate + 25% RAP followed by mix12 that consists of 5% fly ash + 20% raw aggregate + 75% RAP showed the best performance than other mixtures in group 3. These results may be due to the different properties of base mixtures obtained in Table 3 such as cohesion (C), friction (Θ), and, resilient modulus ($M_R$).

Increasing the resilient modulus ($M_R$) for mixtures 8 and 12 which consists of 5% fly ash + 70% aggregate + 25% RAP and, 5% fly ash + 20% raw aggregate + 75% RAP respectively from 123.42 MPa to 262.1 MPa, and from 123.42 MPa to 229.16 MPa compared with raw aggregate. In addition, increasing the cohesion (C) from 100 kN/m2 to 321 kN/m2, from 100 kN/m2 to 158 kN/m2 compared with raw aggregate. The associated decreases in deformations were 8.04% and 7.89%, respectively. where cohesion refers to shear strength under high stress, which means an increase in the stability of the mixture.

It can be said that the recycled base course section using RCM (Group 2) obtained worse performance than using RAP in group1 and RAP & fly ash in Group 3 for both unreinforced or reinforced sections. Moreover, it can be observed that the recycled base course section using RAP in group1 recommended economically if compared with using RAP& fly ash (Group 3). Addition of RAP only in base mixtures is the best choice through deformation results evaluation.

**5. Conclusions**

This study applies sustainable development through the use of reinforced recycled materials [Reclaimed Asphalt Pavement (RAP), Fly Ash (FA), and Reclaimed Concrete Material (RCM)] as an alternative to raw aggregates to preserve raw aggregate and resources for future generations and reduce environmental pollution by reducing wastes and exploiting landfills. Finding out the suitability of using reinforced recycled materials as an alternative to raw aggregates, choosing the best mixes to reduce the deformation, and determining the optimal location of geogrid to improve pavement performance were the most important goals. Finite element software Plaxis 2D (8.2) was used to assess the efficiency of reinforced recycled material. The study accomplished its main goals through the following:

- Reinforced recycled base course section using mixtures that consists of 50% RAP + 50% raw aggregate, 75% RAP + 25% raw aggregate, 5% Fly Ash + 70% raw aggregate + 25% RAP and 5% Fly Ash + 20% raw aggregate + 75% RAP provided better performance where they decreased surface deformation by about [29 ~30%] compared with raw aggregate.
- Recycled base course using RCM (Group 2) obtained worse performance than using RAP in group1 and RAP & fly ash in Group 3 for both unreinforced or reinforced sections. Moreover, recycled base course section using RAP in group1 is recommended economically if compared with using RAP& fly ash (Group 3). Geogrid located at the middle of the base course (location 3) achieved the highest decreasing ratio in surface deformation compared with the unreinforced raw aggregate.
- Mixture 6 consists of 75% RCM + 25% raw aggregate provided better performance than other mixtures in group 2.
- Using geogrid at reinforcement between the base and sub-base course (location 1) improved the pavement performance by reducing the surface deformation by about [8~17%] for all studied cases, while at reinforcement in the top third of the base course (location 2) it was found that deformation value was reduced by about [4~19%] for all studied cases. Moreover, the middle of the base course (location 3) was found to provide performance in terms of deformation by about [11~30%]. Reinforcement in the middle of the base course (location 3) was higher than other ones in the reduction of deformation.
- The most improved sections by using a geogrid layer between base and sub-base were mixtures 13 and 11 that consist 15% Fly Ash + 10% raw aggregate + 75% RAP and 15% Fly Ash + 35% raw aggregate + 50% RAP, where they decreased the deformation by 7.33% and 10.75% respectively. While these two mixtures without geogrid increased the deformation by 6.45% and 1.25% respectively compared with raw aggregate.

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