

## Evaluation for the effect of pavement type on the total life cost and environmental aspects of roads

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### ABSTRACT

There are several types of pavements which have been constructed around the world; flexible and rigid pavement. These pavements have major differences in terms of materials and construction process, giving the differences in their compositions and production process, each one of these pavements has some strength and weak points. The current study presents detailed comparison between these two pavements from the perspectives of the total life cost and environmental aspects using software Athena pavement Life Cycle Assessment (LCA). The assessment using LCA software is based on the construction materials, the construction and maintenance process as well as the machines and vehicles used during the construction, and the life cycle of pavement. Two majors streets were selected for the purpose of the comparison, the first street is called the street of coaches station in Al-Diwaniyah city and the second street is Om Al-Kheil street. The street of coaches station was constructed with composite pavement layers (full rigid pavement layers covered by 5 cm flexible pavement layer). On the other hand, the street of Om Al-Kheil was constructed with full layers of flexible pavement. The results of Life Cycle Cost Analysis (LCCA) showed that initial construction cost of composite pavement is higher than that of flexible pavement by 31%, while the total maintenance cost for flexible pavement is about 24 % more than of composite pavement. The diesel oil and gasoline had consumed by higher quantities during the preparation and construction stages of flexible pavement compared with composite pavement. Therefore, the environmental impact and gases emissions is more consumed during the construction of flexible pavement.

**Keywords:** Athena Pavement LCA software, Environmental impact of pavement, Pavement maintenance, LCA, LCCA,

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### 1. Introduction

The developed infrastructures of each country is mainly based on the development of transportation networks, although, building these networks is one of great challenges face the economy of country and its natural resources, it has a significant effect on the environment [1-3]. The cost of building, operation, routine maintenance and major rehabilitation of these transportation networks are rapidly increased during the last decades[4-6]. The increase in these cost leads to trigger the responsibility for making the decision tools and planning new strategies. For instance, in the area of transportation planning and highways constructions, using advanced software tools could potentially reduce the initial cost and produces high quality works [5, 7]. Using these tools facilitates the making of decisions regarding constructing new roads or estimating the life cost required[3].

LCA software is one of these powerful tools used to assess pavement cost during the construction stages, operation and life span of pavement including the fuel consumption consumes by construction equipment and vehicles. Also, it evaluates the effect of these process on the environment in terms of several types of emissions[6]. The idea of LCA was initially used since about five decades as a tool used to deal with solid waste management and gas emissions. Recently, it is adopted as a tool to evaluate the effect of development of infrastructure especially roads networks on the environment and to conduct a Life Cycle Cost Analysis (LCCA) by accumulating assessment from the beginning to final stage of pavement life[8-10].

Generally, there are two concepts LCA and LCCA. LCA is usually related to the effect of building, operation, routine maintenance and major rehabilitation of roads network on environment. LCCA usually focuses on the total life cost due to mentioned activities which are calculated through extensive cost analysis through all life cycle of pavement. LCCA can be adopted to assess the sustainability of the pavement by using sustainable materials to replace the conventional materials evaluation the effect of these replacement on the total cost. LCCA cannot assess the environmental effect of construction process unless it is converted in terms of cost [11, 12].

The adopted software (LCA) was built by Federal Highway Administration (FHWA) in order to roughly calculate the LCCA during the pavement design life and provide a significant estimation for the effect of construction, operation, and maintenance of roads on the environment. In 2016, the 1<sup>st</sup> edition of LCA app was developed, then several updates were developed until the up-to-date version (V3.2.03) released in 2019.

The LCA computer software was released by FHWA to predict LCCA for highways during its design period and to investigate its effect on environment due to the construction works of highway starting with extraction of materials required for construction process until the last stage of construction and rehabilitation of highway. The initial version of LCA web app was developed in 2016; many versions of software were developed until the up-to-date version, V3.2.03 which was developed in 2019[13].

Several highway agencies have used LCA and LCCA to evaluate pavement of roads. An assessment study was carried out to compare between two types of pavements in Colorado, USA. These types were flexible and concrete pavement. The results of the study revealed that the LCCA for flexible pavement is lower than that of rigid pavement by 7.4%. On the other hand, the LCA ( which is related to gas emission) is lower by 26 % for rigid pavement compared with flexible pavement[12]. Similar results were obtained from other study carried out in Florida, in which, the concrete pavement shows less defects on environment compared with the flexible pavement but the initial cost was higher[14]. These outputs were also confirmed by recent study conducted to evaluate the sustainability of pavement of roads. This study showed that using of concrete pavement causes increasing in total cost by about 35%, however, the consumption of energy and gas emissions were quite less[3].

Recent study was conducted in Abu Dhabi by Hasan et al. [10]. The study evaluated the environmental effect resulting from conducting of all extraction of materials and construction process of pavement in terms of factor called the Global Warming Potential (GWP). It also provided a comparison between using natural resources and waste recycled resources used in implementation and maintenance activities. Similar study showed that the improvement bitumen with additive (lignin) by 25% substitution reduced GWP by about 5.7% during all process from starting to final stage of road construction. Same study revealed that the extraction of materials has less effect on environment by 50% compared with production of pavement[15].

Very limited studies were conducted in Middle East countries especially in Iraq on the construction cost and environmental impact of different pavement kinds. Therefore, this study is advocated to assess the effect of the structural design and materials used on total cost during design life, and environmental aspects. Athena LCA software was adopted to address these issues for two major streets in Al- Diwaniyah city in middle of Iraq. The first street (main street of Coaches station in Al-Diwaniyah) was constructed with composite pavement layers and the second street (Om Al-Kheil street) was constructed with full layers of flexible pavement.

## 2. Area of study

Two streets in Al-Diwaniyah city were chosen to assess the influence of pavement kind on the environmental conditions also to implement complete LCCA for these streets due to all activities of construction, operation and maintenance works using Athena LCA software. The chosen streets were the Coaches station street and Om Al-Kheil street, the locations of these streets are shown in Figure 1. Coaches Station Street was built using concrete pavement layers with top layer of flexible pavement, while, the Om Al-Kheil Street was implemented with full layers of flexible pavement. Both streets were implemented based on the Iraqi state commission for roads and bridges (SCRB) requirements. All details of pavement layers for each type are shown in Figures 2 and 3 for Om Al-Kheil Street and Coaches Station Street respectively. The environmental conditions for both streets were approximately similar since both of them are located in same area. A quick traffic survey showed the traffic volume for both streets are ranging from (1000) to (2000) vehicle per/day. The design life of These Streets was 30 years as reported by Al-Diwaniyah municipality. The estimated costs for Om Al-Kheil Street were (\$600000) and (\$84240) for preparation of site and roadway's construction respectively. Also, the

estimated costs for coaches station streets were (\$ 870000) and (\$93600) for preparation of site and roadway’s construction respectively. These costs were reported by Al-Diwaniyah municipality, which is the responsible for the construction of these streets.



Figure 1. Area of study and the selected streets

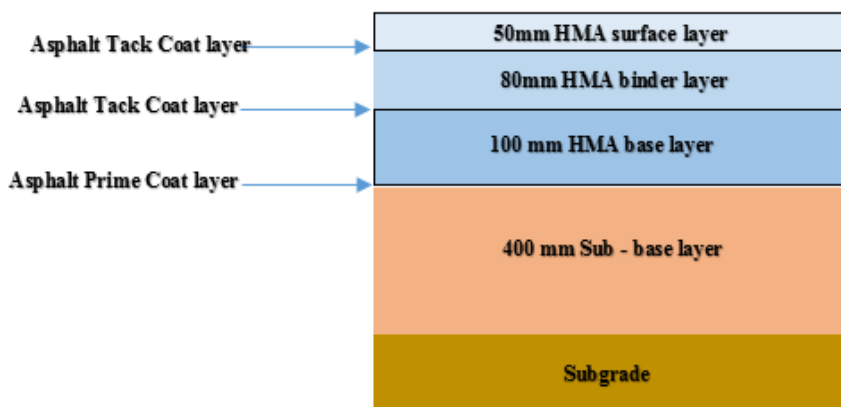


Figure 2. Pavements layers of of Om Al-Kheil Street (flexible pavement)

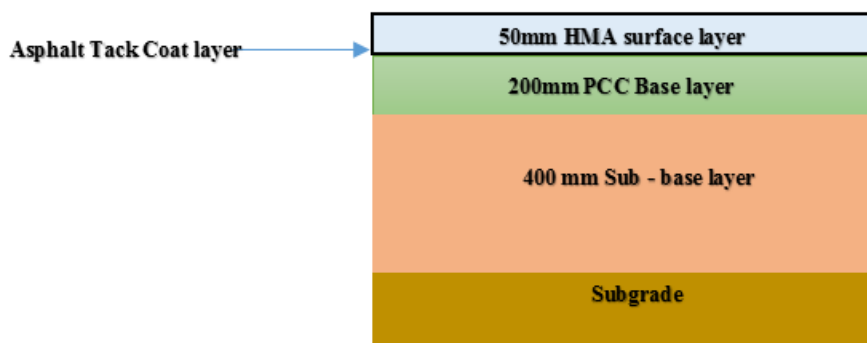


Figure 3. Pavements layers of Coaches Station Street (composite pavement)

The current investigation involved the all activates starting with extraction of materials, going through site preparation, construction of roadway and required maintenance. The selected length of investigated section for each street was 1 km, also, both of them has three lanes 3.65 m each. Figure 4 shows section in each street with full details of road’s elements.

### 3. Construction processing of pavement and its effect on environment and LCCA

The construction process of pavement usually starts with extraction of material from their natural sources then transporting and using these materials to produce Hot Mix Asphalt (HMA) or Portland Concrete Cement (PCC) according to type of pavement, finally constructing of that pavement to get paved roadways. The extraction of materials involved several processes, which consume fuel and cause gases emissions. The quantities of these emissions based on the type of processes required to obtained materials. Both HMA and PCC required aggregate (coarse, fine and mineral filler (in case of HMA)), however, the binder used for each type is different. The bitumen is used as binder for HMA while Portland cement is used for PCC. The bitumen binder is produced under relatively higher temperature than Portland cement which may cause more gas emissions while the initial cost of PCC sometimes is higher.

The transportation of materials from their source location to the site has a significant impact of the environmental aspect and life cycle cost. The collection of materials and transportation techniques are different for each type. This difference is based on the nature of these materials and consequently and cost required for the transportation and the effect of on environment are different.

The construction process of each type of pavement (HMA or PCC) is completely different. Each type required special types of equipments and machines. The transportation process to work site of these equipments and machines are different and consequently its effect on environment and LCCA. The operation of these equipments and machines cause different impact on environment as well. The road using for each type of pavement has a significant impact on the environment. This impact is usually due to the fuel consumption and gas emissions from vehicles. The interaction between the pavement and vehicles has a substantial effect on the fuel consumption by vehicles (cost aspect) and gas emission (environmental aspect) due to that.

#### 4. Rehabilitation program

Usually, the environmental conditions and using of road by traffic cause several kinds of deterioration and distress in pavement, therefore; to keep pavement in a very good or satisfied serviceability, a systematic rehabilitation program are required to overcome these stresses. Some of the common pavement distresses are pavement cracking, pavement rutting and ravelling. The most common distresses and more appeared in Iraq and especially in the city where the study is conducted (based on Al-Diwaniyah municipality information) were pavement rutting, all types of carking (fatigue, longitudinal, reflection of cracks and joints, low temperature cracking) potholes, and particles separation.

The highway agency in Iraq adopted preservation program for pavements of roads to keep satisfactory serviceability during the design life. The rehabilitation program for the HMA pavement and PCC pavement based on municipality of Al-Diwaniyah are illustrated in Tables 1 & 2 respectively:

Table 1. Rehabilitation works required for flexible pavement

Activity Timing		Activity Type	% of Element influenced by the type of activity		
Period in year after construction	estimated duration [Years]		% Surface Area	Quantity	Unit
3	6	Asphalt Partial Depth Reclamation	6	630	m2
6	9	Asphalt Paving	15	1,575	m2
9	12	Asphalt Patching	26	2,730	m2
12	15	Applying the layer of primer coat			
		Application, construction of HMA, sawing of flexible pavement, Patch of pavement	40	4,200	m2
15	18	Spreading of tack coat, construction of HMA	50	5,250	m2
18	21	Asphalt Rout & Seal	55	1,575	m2
21	24	Cleaning of cracks, cracks sealing and sealant materials application	58	1,365	m2
24	27	Patch of pavement, sawing of flexible pavement, construction of HMA	60	1,575	m2
27	30	Spreading of tack coat, construction of HMA	63	2,100	m2

Table 2. Rehabilitation works for composite pavement (PCC and HMA layer at the top)

Activity timing			% of Element influenced by the type of activity			
Year after initial construction	estimated duration [Years]	Activity type	% Surface area	Quantity	Unit	
5	10	Cutting, Cleaning, and Drying of cracks, and sealant materials application	3	315	m <sup>2</sup>	
10	15	Asphalt Paving	11	1,155	m <sup>2</sup>	
15	20	Concrete Seal Joint	18	1,890	m <sup>2</sup>	
20	25	Spreading of tack coat, construction of HMA	26	2,730	m <sup>2</sup>	
25	30	Cleaning of cracks, cracks sealing and sealant materials application	33	3,465	m <sup>2</sup>	

## 5. Results and discussion

The current study focused on estimation environmental effect and LCCA of different types of pavements using LCA software. Both type of pavement was modelled using this software by defining and input the required parameters. These parameters involved the construction materials of each layer, the dimensions of each layer (width and thickness), and a proportion of each material in whole mix. Other factors are also required to be input, for example the distance of transporting materials to work site. The design life for each pavement was adopted as 30 years, during this period the rehabilitation processes were conducted each 3 years for flexible pavement and 6 years for composite structure.

The most important output obtained for the software were Global Warming Potential (GWP) and Acidification Potential (AP) for each type of pavement. GWP is an expression used to show the magnitude of increasing in atmosphere and oceans temperature, while the AP is an environmental pollution or defect resulting from the altering the pH of rivers, and soil caused by air contaminants e.g. SO<sub>2</sub> and NH<sub>3</sub> [16]. The mobilization of metals in earth leads to increasing in AP and may cause some negative effects such eutrophication [17]. The GWP and AP units refer to standard normalising parameter illustrative each category of pollution [18].

### 5.1. LCCA Results

Tables 3 and 4 present the maintenance cost for both selected streets as estimated by LCA software. These costs were estimated according to the required maintenance activities carried out during the design life of the selected street using the current prices of construction in Iraq. The results revealed that that entire cost of maintenance of the street constructed by asphaltic pavement (flexible) is more by 24% than the street constructed with composite pavement. This can be attributed to nature of flexible pavement which is show more distresses due to weather condition such as rainfall, level of water table and temperature especially in absence of effective drainage system. These factors increase the premature failures of pavement, in addition to that distress related to traffic load. The high level of water table and low subgrade strength of Al-Diwaniyah city cause locally reduction in the strength of supporting layers of flexible pavement and consequently damage the top layers of that pavement. On the other hand, the PCC can act as bridge over the small weak area and consequently the required maintenance cost decreases.

Figures 4, 5, and 6 illustrated magnitude of diesel oil consumption estimated by LCA software due to the process of materials manufacturing, preparation of site and construction of the selected streets. The results obtained from analysis of construction process of these streets revealed that flexible pavement cause consuming of diesel fuel by double of that of composite pavement. This can be explained by that the HMA requires higher temperature during the stage of binder production and HMA production and transportation. Also, the compaction of HMA require using compactors which consume diesel oil. The preparation of work site and construction underlying layers of flexible pavement consume 56 % of diesel fuel than that of composite pavement due to more layers are required for flexible pavement compared with composite pavement. The consumption of diesel oil can essentially contribute to the increase of the construction and rehabilitation cost of flexible pavement.

The gasoline consumption for the selected streets throughout the construction stage is presented in Figures 7 and 8. These figures show that gasoline consumption during the construction stage of street with flexible

pavement is 33.34 % greater than composite pavement. The gasoline usually used in production of tack coat which is applied at between pavement layers to increase the bond between these layers and making them act as one unit. Since the flexible pavement consists of several layers of HMA, more quantity of tack coat is required and consequently more quantity of gasoline is consumed.

Table 3. Maintenance costs of Om Al-Kheil Street (flexible pavement)

Activity Timing		Maintenance costs
Period in year after construction	estimated duration [Years]	
3	6	\$11,970.00
6	9	\$27,195.00
9	12	\$52,675.00
12	15	\$170,275.00
15	18	\$221,025.00
18	21	\$231,525.00
21	24	\$244,265.00
24	27	\$274,190.00
27	30	\$294,490.00

Table 4. Maintenance costs of Coaches Station Street (composite pavement)

Activity Timing		Maintenance costs
Period in year after construction	estimated duration [Years]	
5	10	\$2,100.00
10	15	\$13,265.00
15	20	\$20,545.00
20	25	\$20,545.00
25	30	\$70,035.00

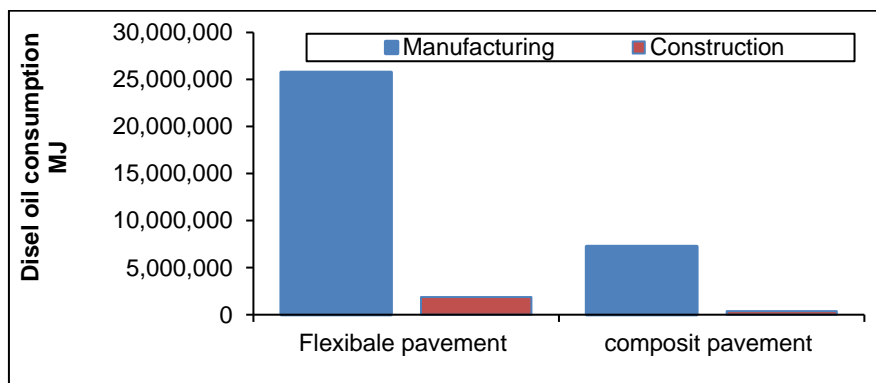


Figure 4. Consumption of diesel oil for the selected streets throughout manufacturing and construction stages

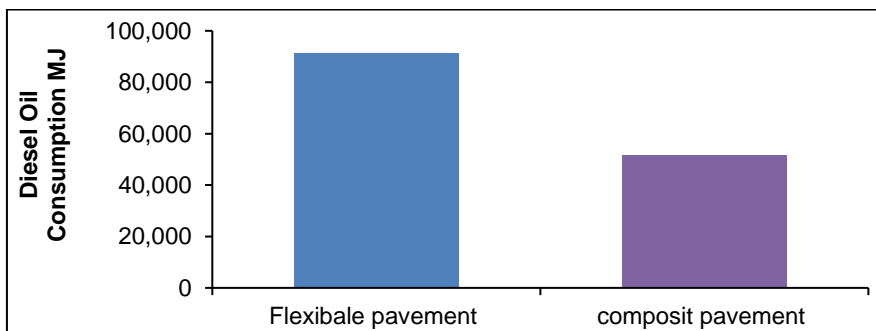


Figure 5. Consumption of diesel oil for the selected streets throughout stage of preparation of site

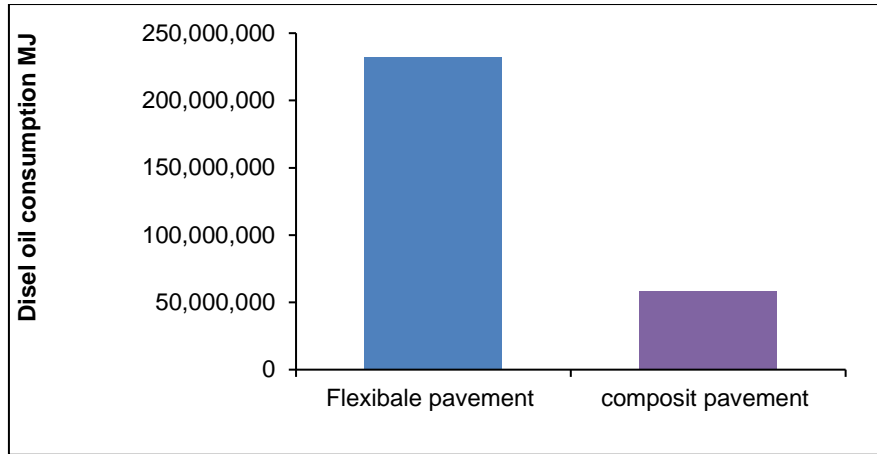


Figure 6. Consumption of diesel oil for the selected streets throughout operation stage

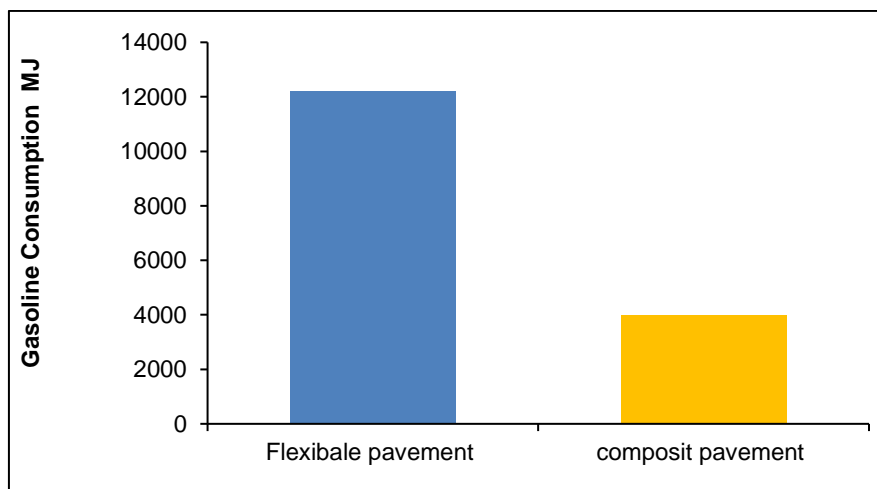


Figure 7. Consumption of gasoline for the selected streets throughout the stage of construction

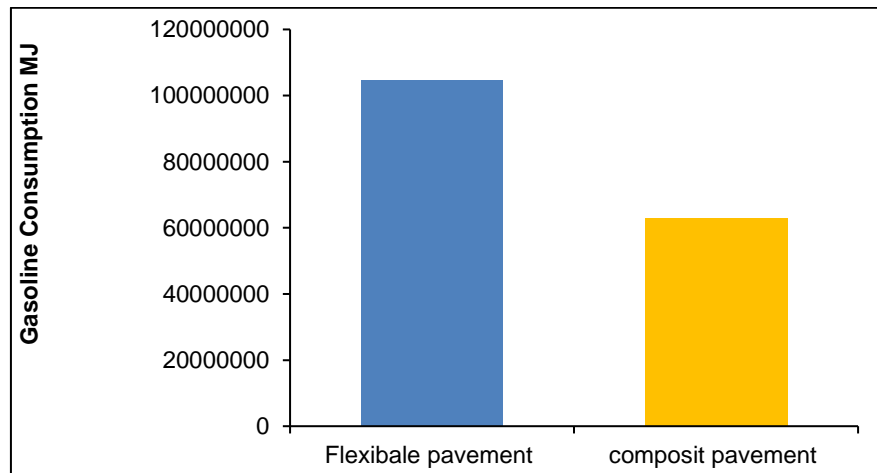


Figure 8. Consumption of gasoline for the selected streets throughout the stage of roadway operating

**5.2. The influences on Environmental**

The GWP for each street in kilograms of carbon dioxide was estimated based on the type of pavement used in each street. The GWP can be considered as a future indicator for the impact of emissions due to each type of pavement on the atmosphere [18]. As presented in Figure 9, no significant deference can be observed between flexible and composite pavement during the manufacturing stage in terms of GWP, since both of them have similar effect on environment. While during the construction stage the GWP for flexible pavement is 5.1 times of composite pavement. Figure 10 shows that throughout the site preparation the GWP for flexible pavement is

1.84 times of composite pavement. Similarly, from Figure 11, the GWP for the GWP for flexible pavement is 1.74 times of composite pavement. This response is related to more gas and carbon dioxide emission related to all construction stages of flexible pavement starting with extraction of material up to final stage of construction.

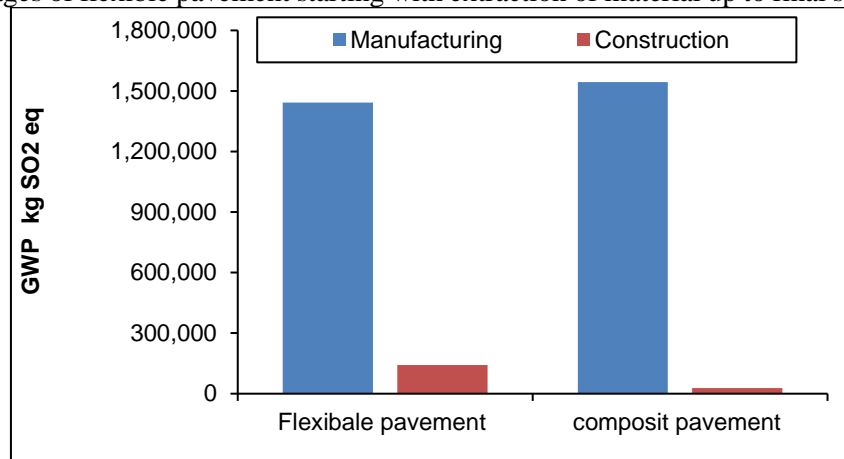


Figure 9. GWP for the selected streets (according to pavement type) during manufacturing and construction stages

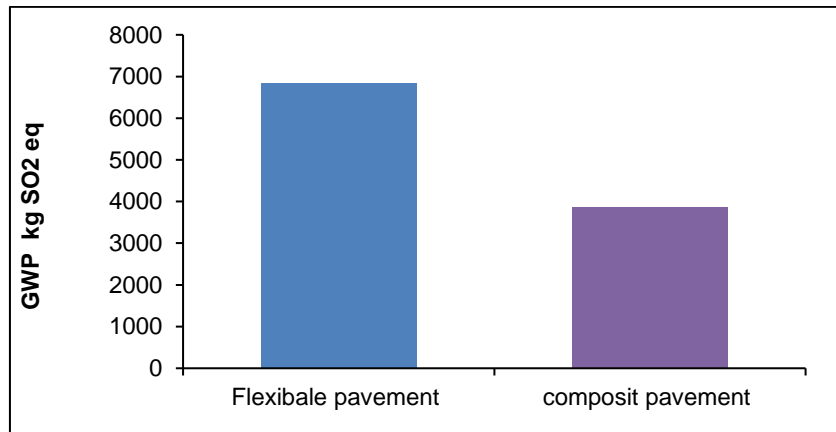


Figure 10. GWP for the selected streets (according to pavement type) during preparation of site

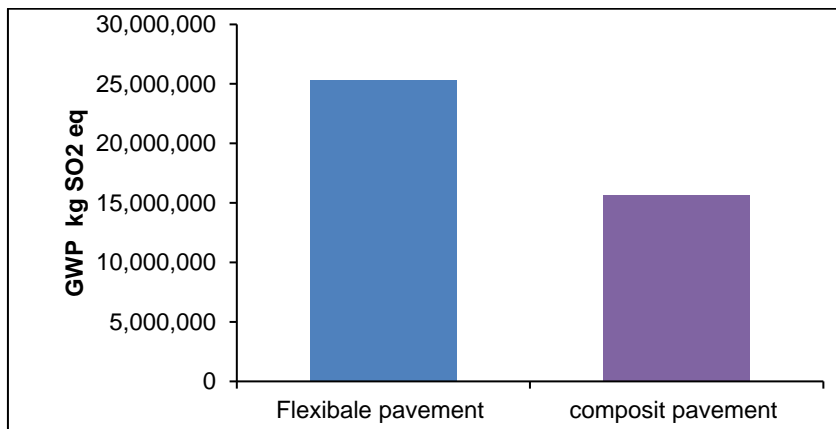


Figure 11. GWP of the selected streets (according to pavement type) during roadway operation stage

The Acidification Potential (AP) in units of kilograms of carbon dioxide during the manufacturing of materials, preparation of site, construction, and operation stages for both selected streets are presented in Figures 12 to 14. These figures showed that the CO2 emissions during manufacturing of materials of flexible pavements are more than that of composite pavement by about 6.67 %, while during the construction process the magnitude of increase reached up to 4.5 times for flexible pavement compared with composite pavement.



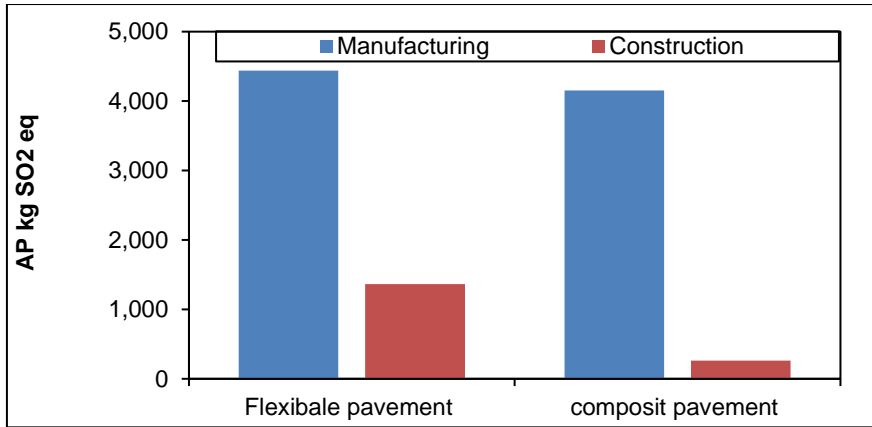


Figure 12. AP for the selected streets (according to pavement type) during manufacturing and construction stages

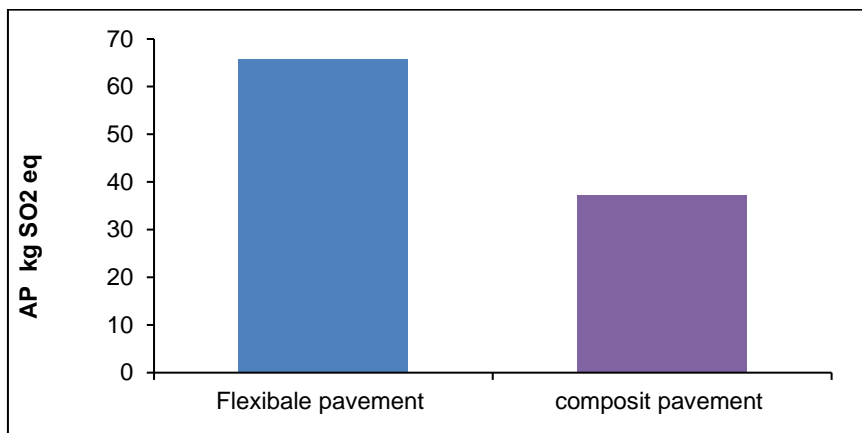


Figure 13. AP for the selected streets (according to pavement type) during the site preparation stage

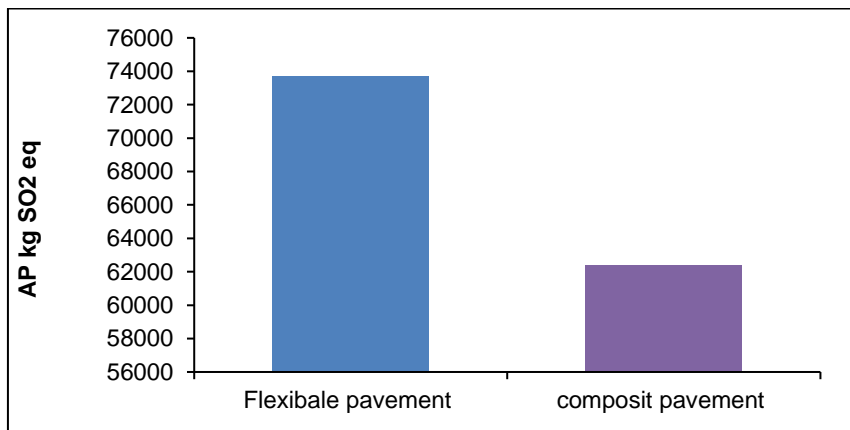


Figure 14. AP for the selected streets (according to pavement type) during roadway operation stage

## 6. Conclusions

The transportation and highway networks is essential component in developing of the countries. The construction of pavement of these highways needs huge amounts of materials, fuel consumption and energy, which have considerable effect on the environment. To adopt best alternative and make the wright decision in road networks construction and rehabilitation. LCA software is used as a powerful technique by many agencies and transportation departments.

This tool was used to compare two types of pavements by selecting two main streets in the city of Al-Diwaniyah. The comparison focused on the LCCA and environmental impact of each type. All stages of construction were investigated starting with extraction of materials until the last stage of construction and rehabilitation.

Several conclusions are obtained from this investigation.

1. The initial construction cost of composite (PCC and HMA layer) pavement is 31% more than that of full layers flexible pavement.
2. The general cost of maintenance works needed to produce a flexible (HMA) pavement is 23.74% more than the cost needed for composite pavement, this can be attributed to more periodic rehabilitation and maintenance works required for asphalt pavement through its design period.
3. The results obtained from analysis of construction process of these streets revealed that flexible pavement cause consuming of diesel fuel by double of that of composite pavement.
4. The Gasoline consumption during the construction stage of street with HMA is higher by 33.34 % compared with composite pavement.
5. No significant deference can be observed between flexible and composite pavement during the building-up stage in terms of GWP, since both of them have similar effect on environment. While during the construction stage, the GWP for flexible pavement is 5.1 times of that of composite pavement.
6. The CO<sub>2</sub> emissions during manufacturing of materials of flexible pavements are more than that of composite pavement by about 6.67 %, while during the construction process the magnitude of increase reached up to 4.5 times for flexible pavement compared with composite pavement.

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