https://doi.org/10.26682/sjuod.2020.23.2.18
Journal of University of Duhok, Vol.23, No.2 (Pure and Eng. Sciences), Pp 222-234, 2020 (Special Issue)

COMPARATIVE STUDY OF USING FLEXIBLE AND RIGID PAVEMENTS FOR ROADS: A REVIEW STUDY

SHAAFAN ABDULLAH TAHER[1,*], SHEYAN ALYOUSIFY[*] and HUSSEIN JALAL ASWAD HASSAN[**]
[*]Technical College of Engineering, Duhok Polytechnic University, Kurdistan region-Iraq
[**]Dep. of Civil Engineering, College of Engineering, University of Duhok, Kurdistan region-Iraq

(Accepted for Publication: December 8, 2020)

ABSTRACT

Roads have become an essential measure and symbol of the development of societies. Road construction projects are essential infrastructure facilities for any countries, and high amounts of the budget allocated every financial year by decision-maker. The construction of road required researches, good plan and design, and excellent builders to discover innovatively and cost-effective engineered products to satisfy the increasing request that would economize the construction as well as increasing durability. Despite the economic factor, this study will present a comparative review on the suitability of using rigid and flexible pavements in road depending on traffic, climate, foundation, life cost, materials, maintainability and safety consideration. The reviewed studies show that the design of concrete pavement is based on flexural strength whereas in the asphalt pavement is based on load distributing characteristics of the component layers. The concrete pavement life is slightly longer than asphalt pavement. The initial cost of the flexible pavement less than the cost of rigid pavement but conversely, the cost of flexible pavement is more than the rigid pavement with the long run because of the incurring costs of maintenance. The rigid pavement has better ability and durability to hold a shape against traffic and difficult environmental conditions than flexible pavement.

KEYWORDS: Rigid pavement; Flexible pavement; Pavement types; Concrete road; Asphalt road; Life cycle cost

1. INTRODUCTION

Generally, road pavement is an open generic route to facilitate moving, transporting and passing. Layering such roads with a pavement makes them strong, durable and solid as well as able to resist the environment and traffic. Many of the oldest paved roads have survived until now due to their high strength and quality, such as the Via Appia in Rome, which was paved with large stones (Berechman, 2003). Economical roads, for instance, Macadam and Telford started to appear as a result of the unutilized stones. To improve the durability and stone cohesion of roads, binding agents were used by around the end of the 18th century (Szostak, 1991). The two main kinds of pavement, rigid and flexible have taken on many of the modern characteristics and were being built all over the world by the end of the 19th century (Berechman, 2003). Nowadays, building roads has become an essential measure and symbol of the development of any country and is often used as an indicator of civilizations' advancement. Pavement, in civil engineering, can be defined as the durable surfacing of a road, airfield, or similar area, whose primary function is to transfer loads to the sub-base and

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

underlying soil. The construction of pavement is the actual surface on which the vehicles travel, whose objective is twofold: to transport normal stresses to the underlying soils and to provide friction for the vehicles (Otti *et al*., 2016). Characteristically, there are three main purposes for pavements building namely load support, smoothness, and drainage.

There are two types of pavements, based on their structural performance and materials used, rigid pavement (Portland cement concrete) and flexible pavement (Hot asphalt concrete). The economic decision has a major impact when choosing pavement type, however, the cost may change due to availability of the material and the contractors in the region, this study will present a comparative review on the suitability of using rigid and flexible pavements in road depending on the design criteria like traffic, climate, materials, whether and life cost. Environmental, maintainability and safety consideration which is important when choosing the pavement type.

Selecting types of pavement could be depending on the economic, environmental, maintenance system, traffic, and other miscellaneous factors. According to the Asphalt Pavement Alliance (APA) (2010) Considerations for pavement type selection depends on many factors, the primary factors which must be considered include construction considerations, traffic, weather, recycling material from an existing pavement, soils characteristics, and cost comparison (AASHTO, 1993). The secondary factors include the availability of local materials, the performance of similar pavements in the area, neighbouring existing pavements, conservation of materials and energy, and traffic safety, among other issues (AASHTO, 1993).

2. TYPES OF PAVEMENT

2.1 Flexible pavement

This type of pavement acts as flexible layers because the total structure flexes under traffic loads. Flexible pavements normally have several layers. Therefore, the design of flexible pavement uses the concept of a layered system. Flexible pavements have enough plasticity to absorb shock (Yazdani, 2018). It works as a flexible sheet by transferring wheel loads during the granular structure by grain to grain contacting aggregate. It is included crushed stone or gravel and sand, consolidated by a binder of bituminous material. Flexible pavement typically consists of surface course, sub-base course and sub-grade on natural compacted sub-grade layers (Figure 1). The materials used for underlying layers, base and sub-base course are crushed stone or gravel, which can be either unbound granular or treated by asphalt, lime or cement (AASHTO, 1993).

The surface layer of the flexible pavement is constructed of hot-mix asphalt (HMA) according to blending equation which is a mixture of bitumen and aggregate at eminent temperatures to make a strong and hard structure form at ambient temperatures when cooled. HMA is known by many names, for instance, asphalt, asphalt concrete (AC), asphalt concrete pavement (ACP), bitumen or blacktop. Three main types of flexible pavements are commonly used namely: conventional layered flexible pavement, contained rock asphalt mat (CRAM) and full-depth asphalt pavement (Mohod and Kadam, 2016).

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

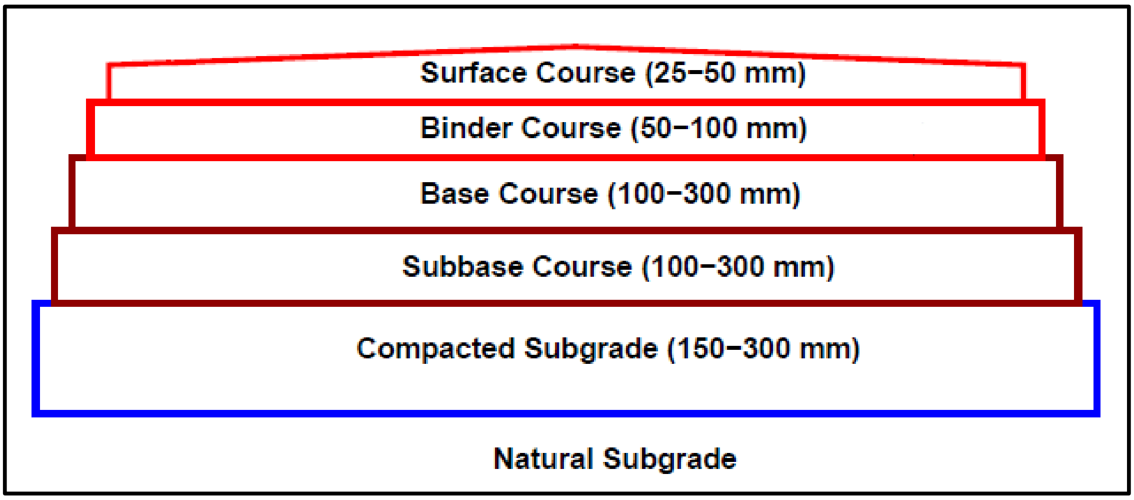

Fig. (1): Typical cross section of a flexible pavement (Suryakanta, 2015)

2.2 Rigid pavement

This type of pavement acts as rigid due to the hard stiffness of the material compared to asphalt pavement. It is work as a rigid plate by transferring wheel loads to the underground layer by flexural strength (Wimsatt *et al.*, 2009). The rigid pavement is composed of coarse and fine aggregate, water, Portland cement and commonly reinforced with mesh or steel rod. Scheving (2011) demonstrated that the rigid pavement should be constructed in three layers, a prepared subgrade, sub-base or base and a concrete slab (Figure 2). They are usually used in constructing airports and major highways, such as those in the highway system which have the ability to carry the weight of heavy vehicles. Four main types of concrete pavements are commonly used namely: continuously reinforced concrete pavement (CRCP), jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP) and Pre-stressed concrete pavement (PCP) (Mohod and Kadam, 2016).

Portland cement concrete (PCC) is the most common material used in the construction of rigid pavement slabs which is identified by different names involving concrete and cement. Production methods and design are used to distinguish PCC. The reason for its popularity is due to its availability and the economy, which was fundamentally invented in the 19th century and the first PCC pavement was built in 1889 (Soedirdjo *et al.*, 2003).

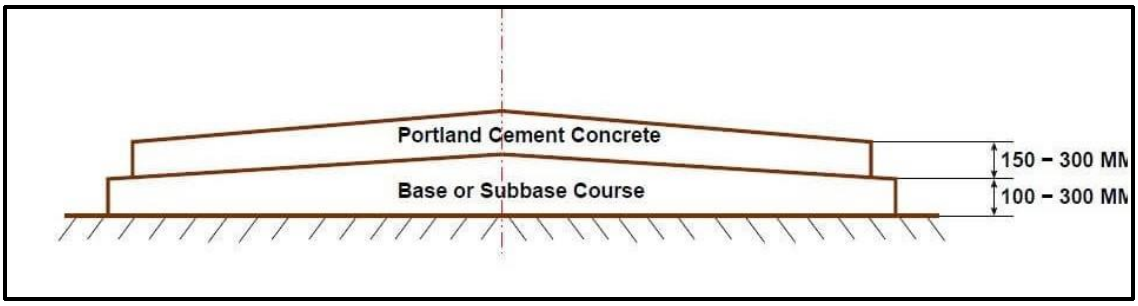

Fig. (2): Cross section of Rigid Pavement (Suryakanta, 2015)

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

3. DESIGN

Historically, the methods of flexible pavement design can be classified into five categories, empirical methods, limiting shear failure methods, limiting deflection methods, regression methods and empirical mechanistic methods (Ghanizadeh, 2016). Opposite to flexible pavement, rigid pavement includes analytical solutions, numerical solutions and other developments include pumping erosion and fatigue damage.

Ukar *et al*. (2007) explain that the layer theory that is formed from the Boussinesq theory is used to analyse flexible pavement, which can find solutions to the deflections, strains and stresses in the layered system at any point by using this theory as a structural model. Empirical mechanistic methods are commonly used to design the flexible pavement and the number of repeated axle loads that are allowed for configuration pavement is founded based on the response of the pavement to axle loads action. Conversely, for rigid pavement design, the designs of joints are required to ensure the environmental stresses. Additionally, the concrete pavement slab thickness is decided based on two points. First, the flexural strength of concrete should be more than critical environmental stress and the maximum bending tensile stress resulting out of maximum wheel load stress. Second, the repeated number of axle loads within the design life should be withstood by the concrete pavement (Kazda and Caves, 2007).

While concrete pavement life can be designed from 30 to 40 years, asphalt pavement can be designed from 15 to 20 years (Tare and Chaurasia, 2018). However, AASHTO guide for design of pavement structure state that, in the past, the typical analysis for pavement design was 20 years which was considered as the pavement life, nowadays, highway condition (location, used material and traffic volume) is considered when estimating the pavement life, generally, concrete pavement can be designed from 30 to 40 years, asphalt pavement can be designed up to 30 years. These indicate that the age of the concrete roads is relatively more than asphalt roads.

Transportation Systems Center (TSC) (2013) has revealed that the major factor considered in the design of rigid pavement is the structural strength of the concrete such as stiffness and rigidity. This comparatively tends to distribute the load over a wide area of natural soil that means loads distribute horizontally (Figure 3). As a result, small changes in subgrade strength have a small impact on pavement structural. The strength of layer combinations in the flexible pavement design is considered as the main factor, which is constructed with less stiff and strong materials. Hence, for optimally transferring the load to the soil layer more layers and greater thickness are required in the flexible pavement that indicates loads distribute vertically (Medani *et al*., 2016), as shown in Figure 3.

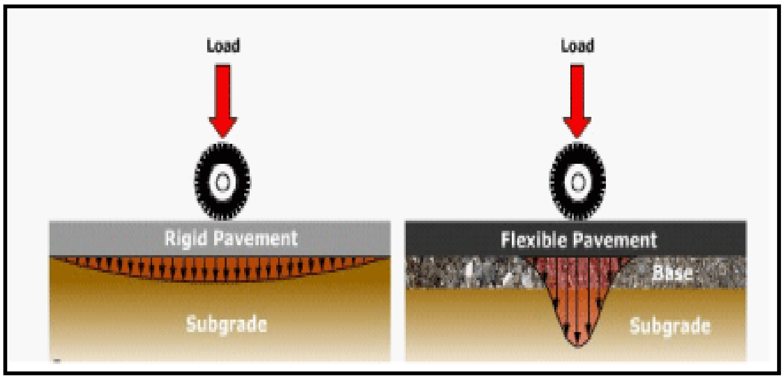

Fig. (3): Loads distribution under a rigid and flexible pavement (TSC, 2013)

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

The fatigue cracking has been considered as the major criterion for concrete pavements design while the major asphalt pavements failures are thermal cracking, fatigue cracking and rutting (Mohod and Kadam, 2016). The aggregate requirement for asphalt pavement is more than twice that of concrete pavement (Ketema *et al*., 2016). Moreover, flexible pavement requires more material for base course and sub-base than rigid pavement (Ketema *et al*., 2016).

The rigid pavement is considered inadequate for low traffic road. When designing of concrete pavement for low thickness, the deterioration of the slabs accelerated and showing an inherent inappropriateness due to the lower loading (Jain *et al*., 2013). The rigid pavement could be a better choice, especially for the heavy traffic roads which require a large thickness of asphalt layers (Bansal, 2018). The concrete road might be used with advantage in locations prone to submergence for the period of monsoon (Bansal, 2018).

4. Life Cycle Cost

Generally, the cost is a major factor for selecting the pavement type of road. This is including the initial cost, which is the cost of the initial new construction or reconstruction, future cost or long cost, which include subsequent facility operation, maintenance and rehabilitation activities performed during the life cycle until the pavement is reconstructed. The initial cost of the flexible pavement is normally lower than the cost of rigid pavement if both of them are constructed in the same conditions (Mohod and Kadam, 2016; Skrzypczak *et al.*, 2018). This is because the asphalt components materials, especially bitumen, are cheaper than Portland cement. Also, the materials themselves used for the mixing process to create asphalt require less time. Moreover, the surface layer of asphalt pavements can be used for traffic within 48 hours or less, but the surface layer of concrete pavements cannot be used until 15 days of curing, which means it takes a long time to build and as a result, it requires more cost.

On the other hand, the future cost of the concrete road is less than the asphalt road, and it requires less maintenance over the whole life cycle (Jain *et al*., 2013). The potential cost advantage of rigid pavement is due to their inherently slower deterioration. Ketema *et al*. (2016) observed that the concrete road has lower maintenance and rehabilitation cost when compared with the asphalt road. Asphalt pavement is expected to require major rehabilitation in around half the time of concrete pavement. Therefore, paving with concrete means less need for cost over the life of the road.

However, in 2005, (APA) conducted a synthesis on life-cycle cost of pavement using actual cost data. According to the study, hot mix asphalt pavements have lower costs comparer Portland cement concrete pavements by 10 to 25 percent in both initial construction and life-cycle costs (Villacres, 2005; Medani *et al.,* 2016). The planners often think that the flexible pavement is cheaper than the rigid pavement. In fact, this is not always the case, because sometimes the price of bitumen or asphalt increases dramatically. According to Ukar *et al*. (2007), in the last decade because of the increase in crude oil prices, the price of bitumen, which is the main ingredient of flexible pavement, has increased, whilst the rigid pavement's main component cement price has decreased. With expanding oil costs, the expense of black-top asphalts will be significantly higher therefore rigid pavement must be extremely considered in preference the pavement types (Hayat *et al*., 2019).

Several economic analysis techniques, for example, the Internal Rate of Return method (IRR) and the Net Present Worth method (NPW) can be used to assess pavement type options. Asphalt pavements have a lower initial construction cost, which leads to more

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac

[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

productivity with less funding. Nonetheless, paving with asphalt requires more costly maintenance over the life of the project compared with concrete. However, Tare and Chaurasia (2018), Kumar (2017), and Bezabih and Chandra (2009) observed that asphalt roads are more economical for the lesser volume of traffic.

Concrete pavement was shown to have higher initial and overall costs than asphalt pavement in the case of low traffic. Studies by Kristowski *et al.* (2018) on three traffic category typical constructions for light, medium and heavy traffic over a period of 30 years for each type of pavement structure; concrete and asphalt pavements. The total costs of heavy and medium traffic for rigid pavement are almost similar to the flexible pavement. Conversely, specific savings in the long-term are visible for the light traffic category which the total cost of construction and maintenance of a concrete road in 30 years is 45.4% higher than the cost of maintaining asphalt road during this period (Kristowski *et al.*, 2018).

5. MAINTENANCE WORKS

Pavement maintenance or pavement preservation is a program of activities intended at preserving roads system. It is now obvious that additional emphasis should be located on maintenance to preserve and extend the life of the paved roads. Roads' maintenance depends on many factors, such as weather, traffic loads and pavement type. According to Grzyl *et al.* (2017), the main factors that affect the cost related to the repairs of road pavement: road conditions, road type, year season (summer, winter), maintenance standard acceptable, a road course (road curve, straight section), passing vehicles type, vehicles intensity, load-bearing capacity and durability of the surface, road permissible speed, road lanes number and regional conditions.

The road maintenance and repair works influenced by accepted design standards, the constructed structure quality and the quality level and strategy of the executed repair activities. Estimating the size of the above components required for determining the road surface ideal life cycle cost (Kristowski *et al.*, 2018). Rigid pavement requires regular work associated with expansion joints maintenance in a perfect technical condition. For flexible pavement surfaces, repairs procedure is only executed in the event of damage, and the wear layer must be substituted in accordance with the maintenance system acceptable. (Kristowski *et al.*, 2018).

As a rule, the flexible pavement is more influenced by changing temperature and traffic load, unlike concrete pavement which is a rigid surface and does not deform under heavy vehicle loading and therefore is less susceptible distortion and deflection (Taha *et al.*, 2017). Asphalt pavement is viscoelastic and therefore sensitive to both temperature and loading. This feature makes asphalt pavement more vulnerable to the formation of heavy vehicle wheel ruts. Scheving (2011) has advised that whereas a concrete road would require less maintenance above three decades, an asphalt road would need major resurfacing in just 15 years. Data of survival and performance for concrete and asphalt pavements treatments in Missouri State at the United States obtained by the Missouri Department of Transportation (MoDOT) during 35-year life-cycle cost analysis (LCCA) design period treatments, shown in Table 1, (Wimsatt *et al.*, 2009).

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

Table (1): Existing 35-Year LCCA Design Period Treatments (MoDOT, 2004)

Initial Treatment	1st Rehabilitation Time	1st Rehabilitation Treatment	2nd Rehabilitation Time	2nd Rehabilitation Treatment
New Full-Depth HMA	Year 15	Cold mill and replace travel-way HMA wearing surface	Year 25	Cold mill and replace entire HMA wearing surface
New JPCP	Year 25	Diamond Grinding (and 2 percent full depth repairs)	None	None
Conventional HMA Overlay	Year 15	Cold mill and replace travel-way HMA wearing surface	Year 25	Cold mill and replace entire HMA wearing surface
Unbounded JPCP Overlay	Year 25	Diamond Grinding (and 2 percent full depth repairs)	None	None

However, one of the main disadvantages of concrete pavement is that it is not easy to repair and rehabilitate. Due to the frequent need to service utilities in urban settings, concrete pavement is considered inadequate for these cases which consequence in higher repair costs than would be expected with the flexible pavement. TSC (2013) states that if there are any cracks developed or potholes in the concrete, repairs cannot be done effectively, therefore, a large area should be removed around the damaged place, which is the main problem in maintenance works and it is required to be repaved again. Conversely, if there are any cracks or potholes in asphalt, repairs can be done effectively with crack sealing products that are inexpensive and readily available. In addition, they do not need heavy machines or expensive tools to repair asphalt. Nevertheless, the flexible pavement damaged by certain chemicals, oils and greases conversely than rigid pavement.

6. THE ENVIRONMENT

6.1 Fuel Consumption and Emissions

Types of pavement are greatly affected by the fuel consumption of vehicles, where the fuel consumption on asphalt roads dramatically increases as compared to fuel consumption on concrete roads. Gadja and VanGeem (2001) proved that measuring rolling resistance on different pavement types indicated that flexible compared to rigid pavements increase fuel consumption by 5% at 30 miles per hour for large trucks. Also, at 40 miles per hour, fuel consumption increases by 7% on asphalt surfaces compared to concrete surfaces.

When a vehicle runs over an asphalt road the fuel consumption is more than that is on the concrete roads by about 15-20%. This is as a result of the fact that a concrete road does not acquire deflected under the wheels of loaded trucks. However, pavement deterioration has a negative influence on fuel consumption. According to American Concrete Pavement Association (ACPA) (2007), numerous studies up to now have proposed that the resistance on the concrete pavement that is occurred by the wheels of heavy trucks is mainly less than the deflection or resistance on the asphalt pavement. For this reason, in order to transfer heavy trucks on the flexible pavement more energy and fuel are needed. Studies have revealed that heavy

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac

[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

vehicles on concrete pavements could consume statistically less fuel consumption than from those who are moving on asphalt pavements (ACPA, 2007).

However, the construction of asphalt road pavements requires much energy. ACPA (2007) deducted that the fuel usage factor for asphalt pavements is 12 litres/m^3, and for concrete pavements is 4.9 litres/m^3. Nevertheless, as these fuel usage factors are informed in different units, which is slightly difficult to make a direct comparison. From an economic point of view, fuel consumption in concrete pavements may be better than asphalt pavements; this leads to enormous environmental benefits.

6.2 Colours of Road Surface

In general, material colours have a relationship with reflection and absorption of the sunlight, while materials that appear to be light coloured have a high reflection of the sun's rays, and those that appear dark coloured have low reflection and high absorption of the sun's rays. According to Gadja and VanGeem (2001), to achieve this point, the surface temperature was measured on various materials by testing in California, where the air temperature was 13 °C. The darker materials such as asphalt attained a maximum temperature of 61 °C, while white colours, for instance, concrete or Portland cement had a temperature of 23 °C.

Gadja and VanGeem (2001) have argued that dark coloured pavement surfaces might provide certain benefits in cold weather. While no quantifiable study was identified, pavement colour could affect the frequency or quantity of deicer chemical applications. In certain circumstances, dark pavements are warmer and appear to shed ice and snow more rapidly than light coloured pavements (Gadja and VanGeem, 2001). Therefore, flexible pavements might lead to an increase in atmospheric temperature compared with rigid pavements.

6.3 Visibility at Nights

Street lighting is considered as public services, which is found since ancient times when the streets were lit with lamps of oil or timber, though, in present time, street lightings are made by electric poles. Darkness at night increases the possibility for risks on the roadways because the visibility is decreased. The daylight-time fatality rate is approximately three times less than during the night hours, the fatality rate can be reduced by artificial lighting of pavements during the night, but this represents an additional cost for governments. The estimated costs of illumination differ depending on many factors such as the type of lighting and location. In addition, the type of roads pavement is another factor that affects lighting costs, for example, a concrete pavement needs less lighting than asphalt pavement. Concrete roads light colour reflects street lighting better than asphalt roads which enhancing driver vision at night (Taha *et al*., 2017).

According to ACPA (2007), lighting reflects on concrete surfaces readily. This distinguishing of concrete has advantageous for several reasons. It can considerably improve both vehicular and pedestrian safety by enhancing night-time visibility on along the distance of the concrete roadways. It minimizes the amount of energy required for artificial roadway lighting during the night. Concrete pavement improves night-time visibility. It reflects light from a vehicle or lamppost better than the darker coloured asphalt, as shown in Figure 4.

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

Fig. (4): Visibility at night between concrete road (Left) and asphalt road (Right) (ACPA, 2007)

6.4 Traffic Noise

Traffic noise is becoming a serious problem. People have started feeling bothered by traffic noise. There are many causes of road traffic noise which have an effect on the environment, and this affects humans' psyche. There are two main sources of road traffic noise. The first, interaction between the road surface and vehicle tyres and the second is engine noise (Soedirdjo *et al*., 2003). The characteristics of the road surface are the most important factors in propagating this tyre road noise when the vehicles are travelling at constant speeds exceeding about 40 km/h (Soedirdjo *et al*., 2003).

Roads that are made from asphalt pavements produce less noise than ones that are made from concrete pavements. Many people have complained about road traffic noise, which is generating by vehicles, especially on the concrete road. Rigid pavement can be very loud because the concrete is less absorbing sound. Ahammed (2009) observed that the Stone Mastic Asphalt and Superpave asphalt mixes were shown to absorb 6.3%, 7.5% of the sound, respectively more the conventional asphalt pavement. While textured concrete pavement surfaces were shown to absorb 5% to 6% the sound more the conventional rigid pavement. Concrete pavement was shown to be 4.4 dBA louder than asphalt pavement when the pass-by noise level perceptible was compared (Ahammed, 2009).

6.5 Temperature

The human's actions impact the environment both in a negative or positive way. Concrete and asphalt roads are essential to transport people and goods but the general impact should be analysed correctly. Thermal energy is also produced due to increasing the pavement's temperature from the energy of the sunlight that is not reflected in pavement surfaces, this increases the air temperature around the pavement. According to Scheving (2011), in urban areas, the higher atmospheric temperature that happens as a result of pavements and other surfaces absorbing the sun's heat is recognised as the heat island effect. In central areas of Northern America, the temperature is up to 5°C warmer than surrounding rural and suburban areas (Gadja and VanGeem, 2001).

Concrete pavements are cooler and reflect significantly more sunlight than asphalt pavements. This might help alleviate urban heat island effects. According to APA (2010), research conducted at the Lawrence Berkeley National Laboratory suggests that, when exposed to sunlight, lighter-coloured concrete

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac

[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

pavements typically have surface temperatures approximately 21°F (12°C) lower than darker coloured asphalt pavements.

7. SAFETY

Roads that are paved by concrete require less maintenance than those that are paved with asphalt (Scheving, 2011; Wimsatt *et al*., 2009). Consequently, there is less need for repair staffs to deal with the maintenance of concrete roads. This means less disruption and congestion to work areas and equally less danger to drivers and road crews. In addition, for transporting goods by road sectors especially at night, concrete roads would be better in terms of safety due to their visibility and lighting that will make people feel safer travelling on them. Furthermore, the concrete road is also more durable than asphalt road, which means that roads paved with rigid concrete are less possible to have potholes.

In the winter season vehicles tend to slip or slide on roads due to rain or snow that this may increase the proportion of traffic accident victims. Also, snow melts slowly on the road surface especially in the mountain roads, this leads to having poor frictions between the surface road and wheel vehicles. A rigid pavement surface is better preventing the vehicles from sliding. Rigid pavement dries out much faster after rain. Additionally, the braking distance is lower on the rigid pavement rather than on flexible pavement. Taha *et al*. (2017) revealed that using concrete road does not cause sliding of vehicles when surfaces are wet. During heavy rain weather, water collects in the ruts and this leads to hydroplaning (when vehicle loss of traction and friction due to a layer of water builds between the wheels of the vehicle and the road surface). Consequently, concrete can be preferable to asphalt because it offers better resistance to rut formation and eliminating this risk.

Ahammed and Tighe (2009) found that the surface friction of asphalt pavement was shown to decrease more than concrete pavement. They showed that the surface friction of pavement long-term affected by accumulative traffic passes, speed, pavement age and temperature. The surface friction of asphalt pavement long-term was revealed to be more sensitive in comparison to the concrete pavement. Asphalt pavements surface friction were shown to be influenced more by predominant weather conditions compared to concrete pavements surface. The surfaces friction were shown to decline thereafter with age, fundamentally because of traffic related to the wear and polishing (Ahammed and Tighe, 2009).

8. TYPICAL PROPERTIES OF FLEXIBLE AND RIGID PAVEMENTS

The summary of the comparison between the properties of rigid and flexible pavements are shown in Table 2 below:

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

Table (2): Comparison between properties of flexible and rigid pavements

Property	Rigid pavements	Flexible pavements
Subgrade Deformations are Transferred to the Upper Layers	No	Yes
Design is Based on	Flexural Strength or Slab Action (Rigid)	Load-Distributing Characteristics of the Component Layers
Flexural Strength	High	Low
Load Transfer	Flexural Action	Grain to Grain Contact
Materials	Cement Concrete, Reinforced or Pre-stressed Concrete	Hot asphalt concrete, Granular Material
Good Subgrade	Required	Significantly Required
Initial Cost	High	Low
Repairing Cost	Low	high
Life Span	Longer	Shorter
Thickness	Less	More
The Surfacing can be Laid Directly on the Subgrade	Yes	No
Rolling of the Surfacing	is not Needed	is Needed
Thermal Stresses	Critical	No Critical
Expansion Joints Needed	Yes	No
Vehicles Fuel Consumption	Less	More
Opening to Traffic	Road cannot be Used Until 15 Days of Curing	Road can be Used for Traffic Within 48 Hours or Less
Damaged by Oils and Certain Chemicals	No	Yes
Night Visibility	Good	Poor
Generate Traffic Noise	High	Low
Underground Works	Difficult	Easy
Temperature	Stress is Produced	No Stress is Produced
Excessive Loading	Causes Cracks	Causes Rutting

9. CONCLUSIONS

In this review study, the differences between rigid and flexible pavements have been discussed, and the following conclusions were drawn:

- Design of asphalt pavements is based on load distributing characteristics of the component layers while the design of concrete pavements is based on flexural strength or slab action.
- The initial cost of concrete pavements are high but when comparing the total cost of pavement through the lifespan, concrete pavements are more economical than asphalt pavements.
- Flexible pavement is more economical for the lesser volume of traffic and fractionally more expensive under high traffic conditions.
- Asphalt pavements are considered more adequate for urban settings.
- Rigid pavement have less need for maintenance than flexible pavement over the life of the project.

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac

[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

- In terms of safety, concrete roads have better skid resistance and provide good traction. It seems that rain dries faster on concrete roads, which are environmentally expected to be better than flexible pavements.
- In the summer season at the very hot claim, asphalt pavements could be damaged under the heavy traffic load; therefore, concrete pavements would be good for this situation.
- The fuel consumption on asphalt roads dramatically increases as compared to fuel consumption on concrete roads.
- Night time visibility in the rigid pavement is better than flexible pavement.
- Flexible pavement has less traffic noise than rigid pavement.

Acknowledgements

This study as a student paper was submitted in partial fulfilment to the Pre-sessional Course in English for Academic Purposes, University of Birmingham. The authors would like to express his gratitude to the staff of the EAP Pre-sessional Course, University of Birmingham. The authors wish to also thank the Directorate of Roads and Bridges in Duhok.

REFERENCES

AASHTO (1993). *Guide for Design of Pavement Structures, Transportation Research Board*, National Research Council, Washington, DC.

Ahammed, M. A. (2009). Safe, quiet and durable pavement surfaces. Doctoral dissertation, *University of Waterloo, Canada*.

Ahammed, M. A., and Tighe, S. L. (2009). Early-life, long-term, and seasonal variations in skid resistance in flexible and rigid pavements. *Transportation research record*, *2094*(1), 112-120.

Alliance, A. P. (2010). Pavement type selection. *IM-45. Asphalt Pavement Alliance. Lanham, MD*.

American Concrete Pavement Association (ACPA) (2007). Green Highways Environmentally and Economically Sustainable Concrete Pavements. *Concrete pavement research and technology special report,* (3), 10-20.

Bansal, P. (2018). Evaluation of Design and Cost Aspects of Flexible and Rigid Pavements.

Berechman, J. (2003). Transportation—economic aspects of Roman highway development: the case of Via Appia. *Transportation Research Part A: Policy and Practice*, *37*(5), 453-478.

Bezabih, A. G., and Chandra, S. (2009). Comparative study of flexible and rigid pavements for different soil and traffic conditions. In *Journal of the Indian Roads Congress* (pp. 153-162).

Gadja, J. W., & VanGeem, M. G. (2001). A comparison of six environmental impacts of Portland cement concrete and asphalt cement concrete pavements. *PCA R&D Serial*, (2068), *USA: Portland Cement Association*.

Ghanizadeh, A. R. (2016). An optimization model for design of asphalt pavements based on IHAP code number 234. *Advances in Civil Engineering*, *2016*.

Grzyl, B., Kristowski, A., Jamroz, K., and Gobis, A. (2017). Methods of estimating the cost of traffic safety equipment's life cycle. In *MATEC Web of Conferences* (Vol. 122, p. 02003). EDP Sciences.

Hayat, A., Khan, M. J., and Naeem, M. M. (2019). Study of Failure in Rigid Pavements: A Review. *International journal of multidisciplinary sciences and engineering,* vol. 10, no. 2.

Jain, S., Joshi, Y. P., and Goliya, S. S. (2013). Design of rigid and flexible pavements by various methods and their cost analysis of each method. *International Journal of Engineering Research and Applications*, *3*(5), 119-123.

Kazda, A., and Caves, R. E. (2007). *Airport design and operation*. Amsterdam: Elsevier.

Ketema, Y., Quezon, E. T., and Kebede, G. (2016). Cost and Benefit Analysis of Rigid and Flexible Pavement: A Case Study at Chancho–Derba-Becho Road Project. *International Journal of Scientific and Engineering Research*, *7*(10), 181-188.

Kristowski, A., Grzyl, B., Kurpińska, M., and Pszczoł, M. (2018). The rigid and flexible road pavements in terms of life cycle costs.

Kumar, A. (2017). A Study of Design and Methods of Rigid and Flexible Highway Pavements.

Medani, T. O., Ziedan, A. S., and Hussein, A. G. (2016). Initial Cost Comparison of Rigid and Flexible Pavements Case Study: Khartoum State. *University Of Khartoum Engineering Journal*, *4*(2).

Missouri Department of Transportation (MoDOT) (2004). Pavement Design and Type Selection Process. *Jefferson City, Missouri*.

Mohod V. Milind and Kadam N. K. (2016). A

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac
[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq

Comparative Study on Rigid and Flexible Pavement: A Review. *IOSR Journal of Mechanical and Civil Engineering,* (13), 84-88.

Otti, V. I., Nwolun, C., and Ezechukwu, M. D. K. (2016). Rigid pavement as an alternative to flexible pavement failure in ogbaru swampy area. *Civil and environmental research (IISTE)*, *8*(3), 2225-0514.

Scheving, A. G. (2011). Life Cycle Cost Analysis of Asphalt and Concrete Pavements. Doctoral dissertation, *Reykjavík University, Iceland.*

Skrzypczak, I., Radwański, W., & Pytlowany, T. (2018). Durability vs technical-the usage properties of road pavements. In *E3S Web of Conferences* (Vol. 45, p. 00082). EDP Sciences.

Soedirdjo, T. L., Hendarto, S., and Triadi, A. (2003). Evaluation of traffic noise in arterial road with different road roughness. In *Proc. Eastern Asia Soc. Transportat. Studies* (Vol. 4, pp. 1376-1389).

Suryakanta (2015). *2 most common types of pavements [flexible and rigid]*. Available at: https://civilblog.org/2015/09/09/2-most-common-types-of-pavements-flexible-and-rigid/.

Szostak, R. (1991). *Role of Transportation in the Industrial Revolution: A Comparison of England and France*. McGill-Queen's Press-MQUP.

Taha, E. A. M., Yousef, K. A., and Ibrahim, O. Y. A. (2017). *Comparative Design of Rigid and Flexible Pavement* (Doctoral dissertation, Sudan University of Science and Technology).

Tare, V., and Chaurasia, P. (2018). Development of EDC software for economic analysis of pavements. *Development*, *5*(03).

Transportation Systems Center (TSC) (2013). Inspector's Manual for Hot-Mixed Asphalt and Portland Cement Concrete Pavement Construction. New York: Taylor and Francis.

Ukar, S., Akakin, T., and Engin, Y. (2007). Cost Comparison of Rigid and Flexible Pavements: Applications in Turkey. In *ERMCO, Seville Congress*.

Villacres, J. N. (2005). Pavement Life-Cycle Cost Studies Using Actual Cost Data–A Synthesis. *Asphalt Pavement Alliance Report, Maryland, USA.*

Wimsatt, A. J., Chang-Albitres, C. M., Krugler, P. E., Scullion, T., Freeman, T. J., and Valdovinos, M. B. (2009). *Considerations for rigid vs. flexible pavement designs when allowed as alternate bids: technical report* (No. FHWA/TX-09/0-6085-1). Texas Transportation Institute.

Yazdani, G. (2018). Effect of Nanopolymer Modified Binder on Hot Mix Asphalt. Thesis, *University of North Dakota, USA.*

en.shevan@yahoo.com, Sheyan.khaled@dpu.edu.krd, hussein.hassan@uod.ac

[1]Corresponding author: Directorate of Roads and Bridges in Duhok, Kurdistan Region, Iraq