Green Asphalt Pavement Mix Design for Kuwait

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Abstract

Kuwait suffers from potholes due to pavement deterioration when exposed to moisture. This paper investigates the feasibility of using recycled asphalt pavement in Hot Mix Asphalt design. Questionnaires were conducted to analyze the effects of pores on the society. The results of a series of laboratory tests, which compared the performance of both the recycled and the regular mixtures, showed that the recycled mixture has higher stability and flow, lower rutting depth for wet and dry samples, and lower voids filled with asphalt and voids in mineral aggregate. On the other hand, the tensile strength ratio test results recommended to reduce the proportion of recycled aggregate. While, the HWTD test required 20% reduction in the wet recycled mixture. Therefore, the recycled mixture reveals a higher efficiency in saving costs and improving mixtures used for potholes maintenance activities. All the results proved that the recycled asphalt mixtures are most preferred since they are affordable and perform reasonably well compared to regular asphalt mixtures. As a future work, smaller percentages of recycled aggregate should be tested to check the robustness and sustainability of the designed recycled asphalt mixture. Furthermore, more experiments can be run to test other mix parameters and properties.

Keywords
Pothole, Recycled aggregate, Maintenance, Pavement, and Stability.

1. Introduction

The world is moving strongly now towards sustainable and resilient societies to reserve resources for future generations, make use of the overwhelmed waste generated and adopt renewable strategies to fight the climate change. In this direction, it is important to look carefully into Circular Economy (CE) concept through highlighting the importance that this theory is gaining over time as well as how this work is linked to this notion. Reike et al. (2018) highlighted 3 stages in the development of CE and emphasized that CE concept is old dated. They indicated that highly recognized levels of circularity had been achieved worldwide in different sciences such as energy recovery and recycling. They concluded that policymakers need to adapt more desirable and shorter loop retention options without affecting the feasibility and overall system performance. Our current work, through encouraging the recycling practice in highway materials for maintenance activities, contributed clearly to the concept of circular economy in developing countries.

Increasingly, greater attention is being paid to investigate the feasibility of using reclaimed asphalt pavement in Hot Mix Asphalt (HMA) designs. Using high quality mixtures made of materials with good properties would ensure designing pavement that don't deteriorate earlier than its expected lifetime. Distresses appear in pavements due to several reasons. High traffic volume, increasing the traffic load, using low quality or weak mixtures, lack of compaction, insufficient pavement thickness, less of bonds between aggregate and asphalt, and water infusion contribute to pavement failure and distresses. Potholes are common distresses found throughout highways in Kuwait. These potholes have been rehabilitated by patching them with asphalt mixtures. It is worthwhile to implement a new patching mixture containing 20% recycled aggregate and polymer. Potholes are a small, bowl-shaped depression that occur only in the pavement surface and can deeply extend to the base course. Potholes most likely occur on roads with thin HMA surface layer. They are also related to water infiltration to the deep layers. Which results in severe problems such as roughness that causes serious damages to vehicles. The key rule in pavement maintenance is the selection of the method and materials to be used based on the surrounded conditions. Potholes have the most expensive maintenance cost compared to other distresses since it can be extended to the base. Thus, it is necessary to increase the performance of the used material as well as reduce potholes maintenance cost (Biswas, 2016). According to the Public Authority for Rods and Transportation (PART), they spent about 530 million Kuwaiti dinars and requested an additional budget to complete roads repair after the winter season in 2018, which is almost twice the average annual budget.

This study aims to find out the most suitable mixture in the case of potholes. To achieve the accurate results, two mixtures were prepared, one of them is the regular asphalt mixture while the other is the recycled asphalt mixture which consists of 20% recycled aggregate. Then a series of tests were conducted on the mixtures to assess the performance of each one, including sieve analysis, Marshall Stability, Hamburg wheel tracking device, bulk density and indirect tensile strength tests. Each of them shows different important parameters that impact the mixture such as stability, tensile strength, density, air voids, etc. The results of the study will lead us to choose the high-quality mixture that will perform well and enhance the life of pavement and delay its failures which will also result in a lower cost of maintenance. Two questionnaires were also included in the study to have an overview of people impression of potholes, their causes and appearing in inner streets and highways and how to treat them. The results were statically analyzed through statistical tests including Chi-square, correlation and independent T tests. The study tests the problems and the solutions from the practical, theoretical and economical sides, which contributes to provide strong evidence of the feasibility of using recycled aggregate mixture and its benefits.

2.Literature Review

HMA pavement consists of aggregates and asphalt. Aggregates support vehicle loads and ensure skid resistance, while asphalt ensures the contact between the aggregate (Obaidi and Gomez-Meijide 2017). The main required material for the pavement's construction is aggregates. More particularly, both asphalt concrete and conventional concrete mixtures represent a large volume at the time of production (FHWA 2015). Potholes are not the only reason of causing major problems to vehicle suspension frameworks but in extreme cases they may result in genuine mishaps and perpetual damage (Homji 2005). Flexible pavement deterioration is caused by several factors such as traffic loading, climate conditions, materials quality and aging. (Biswas 2016). Experts believe that potholes formation depends on many variables including Traffic load, Poor subgrade soil, Poor asphalt mixture, Poor drainage systems, Pavement aging, High annual rainfall, Inadequate pothole repair and improper thickness of pavement structure (Maher et al. 2001; Wilson and Romine 2001; Maupin et al. 2003). The oxidation and traffic load result in the wear of asphalt surface which lead to having cracks in old pavement structure (Hixson 2015). Thermal cracking is one of the most critical problems of flexible flooring, particularly in areas where temperature change is critical and quick (Tarefder and Islam 2014). Potholes are categorized according to the depth of the hole in separate severity classifications. In the low severity category, a pothole is less than 25 mm deep. while the moderate severity category the pothole has 25 mm to 50 mm depth. Finally, in high serious category, a pothole's depth exceeds 50 mm (Miller and Bellinger 2003). Potholes are not formed by fatigue cracks only, but also by high severe longitudinal cracks and asphalt raveling (Dong et al. 2014; Dore and Zubeck 2009).

Repair Materials which include Hot-mixes, cold-mixes, heated cold-mixes and recycled mixes are typically used for pothole patching. Hot asphalt mixes from an asphalt plant are the best materials for patching potholes (Eaton et al. 1989). Using the tack coat on the side of the pothole before placing the patching material increases the adherence of the mixture to the existing pavement surface and creating a durable patch (Prowell and Franklin 1996). One of the most significant parameters that make a patch durable is the high-quality materials (Kuennen 2004). Bleeding, edge disintegration, missing patches, shoving, raveling and dishing are the most common patch disorder reported (Prowell and Franklin 1996; Dong et al. 2014; Maher et al. 2001; Biswas 2016). Stability, workability, durability, skid resistance, stickiness, stripping resistance and storage ability are the main properties that should be checked to gain high quality materials (Biswas 2016). The common properties used to repair potholes include good working cohesion, loading traffic and environmental durability, bonding, freezing and rutting potential (Maher et al. 2001). High workability of a mixture makes it less steady that leads in some cases to shoving under vehicular stacking (Rosales et al. 2007; Pimentel 2007). Mixtures that are coated with tarps or polyethylene may have a longer storage time (Maher et al. 2001; Chatterjee et al. 2006; Pimentel 2007). On the other hand, synthetic binder, cementation material and cold-applied bituminous material are used in the process of pothole patching (Nicholls et al. 2014).

The variability in pavement repair performance has been quite significant. As more parts of the pavement have reached or even surpassed their design life, it is essential that best repair procedures and materials are identified (Chen and Won, 2015). Many patching methods for pothole repairing depend on the repair method and facilities required for the operation: (a) throw-and-go, (b) semi-permanent, (c) spray, and (d) edge seal (Maher et al. 2001; Wilson and Romine 2001; Maupin et al. 2003). Throw-and-go is the most common technique since materials are easily used and inexpensive where materials are shoveled into an unprepared pothole, which may contain water and spoil when the pothole is filled. Compacts are left to the traffic, or a shovel compacts the material lightly (Sainz 2016). The semi-permanent procedure is the best procedure besides full-depth replacement of the affected area. The downside is higher labor and materials cost and less productivity than spray injection and throw-and-roll (Wilson and Romine 1994). Spray-injection is most useful for maintenance transverse cracks and potholes. In this Edge-seal, first of all use the throw-and-roll repair, then potholes are being filled and compacted with a heavy vehicle. Then, a strip of asphaltic tack material along the rim of the patch is placed, interfere the pavement and the patch. Finally, sand is put on the tack material in order to prevent sticking to the tires of the car. (Sainz 2016).

On average, Edmonton regularly fills 400,000 potholes and the ordinary annual pothole fixing expenditure plan is about US$ 3 million (Male 2013). Annual United States Commission in accordance with the National Surface Transport Policy and Revenue Research Congress, for the next 50 years, about$185 billion is annually required by all levels of government to merely keep state roads and bridges. In 1999, more than $1 billion in pothole and spall repair were estimated annually to be spent in the United States (Kuo et al. 1999). Today, the States pay $68 billion annually for the price of repairing highways and bridges in the U.S., That's how much the United States Society of Civil Engineers (ASCE) considers that it would cost. The idea about road maintenance is joined by environmentalists and fiscal conservatives: what if there is better than new ones to be redeveloped (Pothole info 2010). In 2017, Saha and others studied the effect of using reclaimed asphalt pavement (RAP) on HMA. The results showed that, mixtures with RAP exhibit higher resistance to rutting distress. In 2018, the effect of using RAP in warm mix asphalt, the effect of two critical factors, mixing time and temperature were studied and the results provided a relation that allows mix designer to predict which conditions would make the hypothesis of full blending reasonable.

A study conducted by experts in civil engineering aims to evaluate the performance of asphalt concrete made of aggregate demolition waste in Kuwait, showed that the recycled mixture satisfied all the requirements of local specifications (Aljassar et al. 2005). Shopeng and others studied the influence of using recycled aggregate in asphalt mixture in China. The results proved that the asphalt mixture perform satisfactory especially in hot and arid environments (Shaopeng et al. 2013). A recent study was also conducted to assess the performance of RAP according to its percentage in the mixture in Kuwait. The results show that adding up to RAP results in 3.6% reduction in the optimum asphalt content and saving in the virgin aggregate. While using more than 25% of RAP in the mixtures lead to a reduction in the performance of the mixture including resistance to rutting, cracking, stability and flow (Ali et al. 2020). Ghabchi and others also studied the effect of using different amount of RSP and RAS on HMA, the results indicated that fatigue life increased with increasing RAP content up to 25% (Ghabchi 2016). While another study focused on the gradation of the aggregate used, showed that the allowable RAP percentages for the gap gradations are lower than those for the dense gradations. The RAP also has a high rutting resistance (Gottumukkala et al., 2021). However, changing the proportion of RAP has no significant improvement in the tensile strength ratio in the HMA. (Tassiri et al. 2021). And to ensure a durable pavement, the performance of asphalt pavement should be improved. A study reveals that substitution coarse aggregate with RAP results in significant improvement in mechanical properties and performance of HMA. Using polymer modified bitumen binder also has an impact on Improving the properties and performance of HMA (AL-Ghurabi & Al-Humeidawi 2021). In general, using recycled materials in HMA such as aggregate is highly recommended because it results in benefits in term of environmental sustainability. Recycled aggregate pavement is also an effective-cost alternative to virgin aggregate (Durrani 2021). RAP provides sustainable benefits and has a major contribution in reducing greenhouse gas emissions and conserving the natural resources (Guangwei et al. 2021). It's proved that as RAP content increases by 20%, the energy consumption reduces by 7-10% while CO_2 emission decreases by 8-10% (Zhang et al. 2021).

3 Methodology

This section of the study represents the methods and tests used to reach the final results. Questionnaires were distributed to analyze the effect of potholes on the society, their causes and treatment. Statistical analysis was used to indicate the relationship between variables, if there is. On the other hand, A prepared sample of regular asphalt mixture that's currently used in Kuwait was compared to a recycled aggregate asphalt mixture consisting of 20% and 80% of recycled regular aggregate, respectively. A series of tests were conducted to assess the performance of each sample and to compare the resulted parameters to find out the preferred mixture, including Material Collections, Sieve Analysis, Marshall, Hamburg wheel tracker device (HWTD), bulk density and indirect tensile strength tests.

3.1 Questionnaire Methodology

Two questionnaires were made, the general questionnaire investigated the potholes in inner streets and Highways, cars malfunction due to potholes, cost of fixing it, and the general impression of the quality of the potholes repair in Kuwait as shown in table 1. The sample size was chosen to be 361 after the confidence level being assumed to be 92% , Z= 1.5, P=0.5 and the confidence interval c to be within ± 0.046. The number of participants was 368, the majority of them were females. All the responders are suffering from potholes and noticed their proliferation except one responder. Most of the responders noticed the proliferation of potholes just after the rainy season in November 2018. While 54.4% of participants in the questionnaire had an alarming frequency of facing potholes which is more than 10 potholes/day. Also, most of the responders noticed potholes in the inner streets while only 6% of them didn't face or even notice potholes there. On the other hand, 90% of responders noticed potholes in the highways which is less than those in the inner streets. Almost half of responders faced more than 10 potholes in the highways. And more than 60% of responders had at least one malfunction in their cars due to potholes in roads, most of them spent up to 200K.D to fix their cars from responders' view, potholes are the number one reason of traffic disruption. responders also noticed that potholes returned within a year after repair as a result of bad materials quality. Overall, responders described the performance of the Ministry of Public Works (MPW) in Kuwait regarding potholes repair as poor.

Table 1: General Questionnaire Results

Gender	Female				Male	
	85.9%				14.1%	
Nationality	Kuwaiti				Non-Kuwaiti	
	93.5%				6.5%	
Age Group	18-25		25-35		35-45	Above 45
	44.6%		19.3%		15.2%	20.9%
Governate	Al-Ahmadi	Al-Farwanya	Al-Jahra	Hawalli	Kuwait City	Mubarak Al-Kabeer
	11.1%	15.8%	10.9%	22.6%	32.1%	7.6%
Licensed to drive	No			Yes		
	13.3%			86.7%		
Drive yourself	No			Yes		
	20.9%			79.1%		

The second questionnaire investigated the characteristics of the transport network, the causes of the pothole, the treatment methods and the materials used for the patching and pavement repair budget which was sent to Public Authority for Roads & Transportation, the Ministry of Public Works and Combined Group Contracting Company in March & April 2019. Questionnaires were queried from Pothole Condition in Canada and Evaluation of Maintenance Material by Biswas 2016, and made it fit the situation in the State of Kuwait. The sample size, after careful studying, was chosen to be 368 after assuming the confidence level to be 92%, Z= 1.75, P=0.5 and the confidence interval c to be in between ±0.01. According to the results in figure 1, potholes are most likely caused by poor drainage followed by poor asphalt mixture, while a high ground water table has the least contribution to potholes appearing. It's also found from figure 2 that the edge disintegration, missing patch and raveling are the most types of distresses that may cause failure of repaired potholes. The quality of material was not determined because most of the patch mixture was not tested in the lab which is another factor of patch failure. According to potholes severity degree which increases with depth shown in figure 3, low severity and Moderate severity potholes are more repaired compared to the high severity. Pothole's repair is also affected by seasons, most of potholes are repaired during winter.

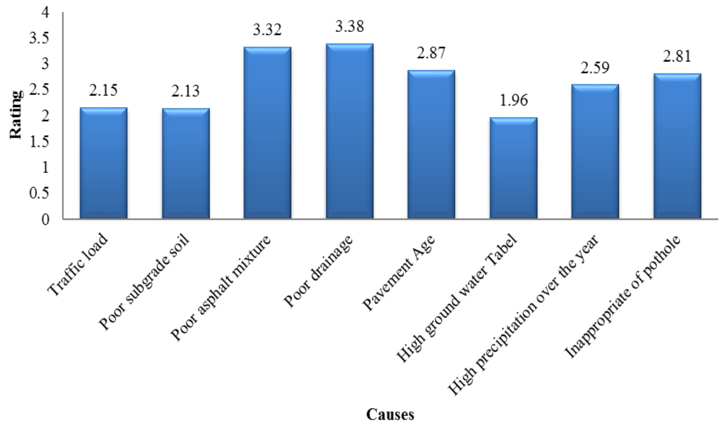

Figure 1: The probable causes of pothole according to questionnaire

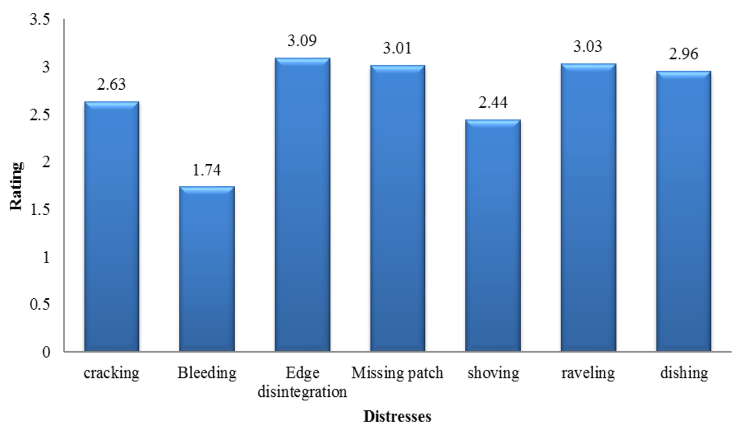

Figure 2: The types of distresses cause failure of repaired pothole according to questionnaire

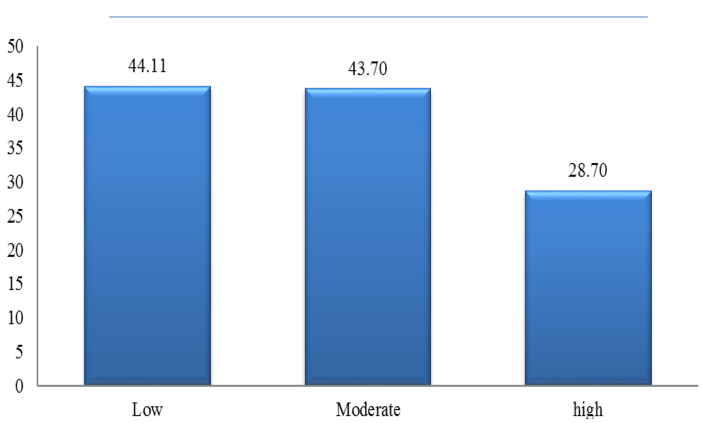

Figure 3: The severity of most of the potholes according to questionnaire

3.2 Marshall Test

This test was undertaken to compare the air voids, stability, flow and specific gravity of each mixture. during the experiment, the plastic deformation strength of the bitumen mix is evaluated. when the whole sample is loaded at a deformation rate of 50 mm per minute, The stability of Marshall is also calculated, which the maximum sample load at a record temperature of 60 ° C. (MS-2, 2014).

3.3 Tensile Strength Ratio (TSR) Test:

This test was conducted to measure the tensile strength of the wet and dry sample to calculate the ratio of the tensile strength of the saturated sample to the dry one. In the test, the resistance to wetness damage is measured by compressed mixtures of asphalt concrete. The sample is packed with a stable deformation rate of the vertical ram motion of the sample (2 inches / minute) until failure.

3.4 Hamburg Wheel Tracker Test:

The values of rutting depth of each sample will be obtained during this test. The test simulates the actual repetitive loads on the road in order to detect material rutting performance on the pavement samples (Saha et al. 2017). 5600 g of aggregate was added to 288g of bitumen; therefore, the total weight of the regular asphalt mixture will be used is 5888g, and 5600g of aggregate was added to 257.7g of bitumen. Therefore, the total weight of recycled asphalt mixture will be used is 5857.7g.

4 Results and Discussions

4.1 Questionnaire Analysis

4.1.1 Chi-Square Test Results

Firstly, two questions were selected to discover if they were significantly related to the car malfunction, the questions are if people noticed potholes in the (a) inner streets and (b) the highway. Secondly, two questions were selected to discover if they were related to each other, these questions are (a) If traffic is disruption is caused by potholes and (b) Number of potholes per day. The results showed that P value is more than 0.05 which revealed that there is no strong relation between car malfunctions & potholes in both inner streets and highways. Also, the relationship between Traffic disruption & Number of Potholes per day is very significant since P value is 0. Finally, there was no significant relationship between Governorate & Potholes in the highway streets because P value exceeds 0.05 unlike the relationship between Governorate & Potholes in the inner streets.

4.1.2 Independent T-test Results

If Significance > 0.05, then the assumption of equal variances was holds. On the other hand, if Significance < 0.05, then equal variances are not assumed. Based on the results, male participants had significantly faced more potholes per day (2.63 ± 0.715 potholes / day) compared to female (2.27 ± 0.824 potholes / day). An independent t-test found this pattern to be significant, since t (75.193) = -3.341, and o is less than 0.05 and equals 0.001. The results are logical because males are more familiar with using different and far roads than females. The relation between self-driving and noticing the return of the potholes after repairing them was also studied. It's revealed that drivers who don't drive by themselves didn't notice the return of the potholes after repairing them (1.47 ± 0.598) as much as those who drive by themselves (1.69 ± .546). The test is found to meet the pattern, where t (111.853) equals -2.919 and p value of 0.004 which is less than 0.05.

4.1.3 Correlation Test Results

This test is considered valid if the p-value was found to be <0.05 which means a strong relationship exists. First, two questions were selected to discover if they were related to each other (a) the percentage of truck traffic, (b) average number of potholes in the same network. The statistical results including the mean and standard deviation of the correlation test proved that there is a very significant correlation between average number of potholes and the percentage of truck traffic because the significance is - 0.430 which is less than 2 Therefore, the increase in traffic has a substantial impact on potholes.

4.2 Sieve analysis test results

4.2.1 Sieve analysis test for regular and recycle patching mix:

Using aggregate size = 3/4”, 3/8” and crushed sand for both the regular and recycle patching mix. The regular samples weight before entry were 5135.3 g, 3349.2 g, 1146.9 g., respectively. While for the recycle mixture, The samples weight before entry were 4893.7 g, 2999.4g, 1020 g. respectively. The values of combined gradation must be close to the general specification values. As the difference between the values increases, the aggregate becomes a bit coarser. For combined gradation values for both mixtures are close to the general ones which makes the sample accepted.

4.2.2 Quantity of Bitumen

Values of bitumen are calculated using the computational formula and the results are presented in table 2. The dust bitumen ratio is found from the bitumen content. To ensure having three trials for the mix, 0.5 and 1.0% will be added to the bitumen quantity.

Table 2: Bitumen Content & Ratio

Bitumen %	Dust-bitumen ratio	
	Regular Patching mix	Recycled Patching mix
4.9	1.29	1.26
5.4	1.17	1.15
5.9	1.07	1.05

4.2.3 Total weight of the mixture

The total aggregate weight in a patch, weight of aggregate, crushed sand, filler and bitumen of the regular mixture is calculated after each. The total weight of each trial is 3600 g. it’s noticed that the weight of the sample decreases with trials.

4.3 Marshall Test for Regular patching mix and Polymer Modified Bitumen

Table 3 shows the results for both regular and polymer modified calculations, and the changes of stability, air voids, flow and specific gravity with bitumen percentage. According to the results, the polymer modified mix has more air voids, higher values of stability and flow compared to the regular one, while the specific gravity is close to the regular mixture. Based on the values in table 3, it’s concluded that for both cases, as bitumen percentage increases, both specific gravity and flow increases while air voids decrease. It’s noticed that stability reaches its maximum value at bitumen content of 4.9%.

Table 3: Marshall Test results

% BIT	Stability (KN)		S.G		FLOW (mm)		air voids%	
	Regular	Recycled	Regular	Recycled	Regular	Recycled	Regular	Recycled
4.9	14.58	21.6	2.54	2.38	27.99	13.1	3.78	6.28
5.4	13.1	23.9	2.55	2.44	23.09	15.7	2.2	2.9
5.9	13.6	21.8	2.56	2.545	20.17	17.7	0.091	1.2

4.4 Tensile Strength Ratio (TSR) Test results:

After applying the TSR test, the average tensile strength of recycled asphalt mixture for dry and wet subset were found to be 1497 Kpa and 1038 Kpa, respectively. Therefore, the Tensile Strength Ratio which is the ratio of dry sample tensile strength to the wet one is 69.3% while the required percentage should exceed 75%. Therefore, the proportion of recycled aggregate should be reduced to satisfy the requirements.

4.5 Hamburg Wheel Tracker results:

The rut depth for both regular and recycled asphalt mixtures is shown in table 4. According to the specification of Qatar road and highway transportation, rut depth must not exceed 12.5 mm and have minimum passes of 20000. The results show that rutting depth of the Recycled Asphalt Mixture of dry sample reaches 0.13 mm and passed the test. On the other hand, the wet sample reaches 4.52 mm, and it didn't reach 20000 passes but only 17952 passes. Therefore, it didn't pass the test. In order to pass the test, the sample supposed to be decreased by 20%. The results show that for both wet and dry samples for recycled and regular mixture, the wet sample didn't pass the test while the dry one passed while HMA prepared using recycled aggregate have lower rut depth values. This can be explained by the fact that the amount of asphalt absorbed by recycled aggregate could strengthen the bond between asphalt and aggregate after being compacted.

Table 4**:** Rut Depth Comparison

Samples / **mixtures rut depth**	**Recycled asphalt mixture rut depth (mm)**	**Regular asphalt mixture rut depth (mm)**
Wet samples	4.52	7.68
Dry samples	0.13	1.56

4.6 Volumetric Properties results

The following table compares between the some of the Volumetric Properties regular and recycled asphalt mixtures, more properties are shown in appendix B8. It's shown that the recycled mixture contains less voids filled with asphalt (VFA) and voids in mineral aggregate (VMA) in comparison with the regular mixture at the same bitumen content. At the maximum bitumen content which is 5.9%, the VFA are 25% lower than those in the regular mixture.

Table 5: Regular patching mix in Bitumen

	Regular			**Recycled**		
	4.4 %	**5.4 %**	**5.9 %**	**4.9 %**	**5.4 %**	**5.9 %**
VFA	48.45062	80.6781	99.00906	44.36872	70.154	73.8682
VMA	13.05904	11.5054	11.83517	11.29203	9.725205	9.281594

4.7 Discussion

This study is discussing the pavement deterioration solution through effective mixtures. So, it is vital to effectively discuss the outcomes and findings. Reviewing the above results and outcomes related to the mix design and testing shows a number of interesting findings. Potholes' severity degree increases with depth; thus, they require immediate maintenance to prevent problems. The tensile strength of the wet sample calculated through the tensile strength test is 69.3% of the dry one, which didn't meet the requirements. Therefore, recycled aggregate amount should be reduced to exceed the minimum limit which is 75%. While the Marshall test helped to test the stability, flow and air voids of each mixture, the results proved that the recycled mixture have a better stability and higher values of flow and air voids than the regular mixture. According to HWTD, the recycled aggregate asphalt mixture shows a low rutting depth for both wet and dry samples compared to the regular mixture. This makes the recycled mixture a better choice for pavement design. The results show that rutting depth of the Recycled Asphalt Mixture of dry sample reaches 0.13 mm and passed the test. On the other hand, the wet sample reaches 4.52 mm, and it didn't reach 20000 passes but only 17952 passes. Therefore, it didn't pass the test. In order to pass the test, the sample supposed to be decreased by 20%. Physical properties of the recycled mixture are most preferred since the mixture contains less VMA and VFA. It's shown that the recycled mixture contains less voids filled with asphalt (VFA) and voids in mineral aggregate (VMA) in comparison with the regular mixture at the same bitumen content. At the maximum bitumen content which is 5.9%, the VFA are 25% lower than those in the regular mixture. Mixtures made of recycled aggregates perform well in maintenance activities and have a lower pavement design cost.

4.8 Maintenance of Potholes

Road maintenance includes activities to maintain their construction or renovation as quickly as possible of their sidewalks, shoulders, slopes, sanitary facilities and all structures, and other property within the road margins to ensure they remain strong, efficient and safe. In the last five years, the agency's average annual paving is 5000 KD / month, and 4% of its average annual repair work is done on the potholes. According to table 6, it's obvious that potholes with shallow depths can be monitored but not repaired automatically, while other potholes with medium depth require about 6 months to be repaired. On the other hand, the deepest potholes get repaired within least time of 24 hours. It can be concluded that as depth increases, repair time decreases.

Table 6: Timescales for repairing a pothole (Southampton 2016)

Depth of pothole on a road	Depth of pothole on a pavement	Timescale for repair
Less than 4cm (e.g., a golf ball)	Less than 2cm	Monitored but not repaired auto matically
Between 4 and 7.5cm (e.g., a tennis ball)	Between 2 and 4cm	Within 6 months
More than 7.5cm	More than 4cm	Within 24 hours

4.9 Cost Estimation

The price of asphalt mixtures varies widely among countries depending on several factors such as oil availability and its prices. By comparing the total cost of both regular and recycled aggregates according to the local prices in Kuwait, it was found that the total savings due to using the recycled aggregate mixture instead of the regular one, reach a total value of 38 KD. Nationally, total savings cost due to using the recycled mixture instead of the regular one may be much higher than the savings in Kuwait. The value also increases as the road length increases, this is another factor that makes the recycled mixture cost-efficient and a preferred one to be used.

5. Conclusions

This paper shows how to improve asphalt mixtures used for potholes maintenance by providing a better alternative mixture which is the recycled aggregate asphalt mixture. After conducting several tests and questionnaires, very effective and helpful results were gained. People showed their disappointment on potholes appearing in roads, because potholes cause major damages to cars which requires an additional budget to fix them. A lot of people think that the edge disintegration, missing patch and raveling are the most types of distresses that may cause failure of repaired potholes. Not testing the patch mixture in the lab also contributed to patch failure. Potholes' severity degree increases with depth; thus, they require immediate maintenance to prevent problems. The tensile strength of the wet sample calculated through the tensile strength test is 69.3% of the dry one, which didn't meet the requirements. Therefore, recycled aggregate amount should be reduced to exceed the minimum limit which is 75%. While the Marshall test proved that the recycled mixture has a better stability and higher values of flow and air voids than the regular mixture. According to HWTD, the recycled aggregate asphalt mixture shows a low rutting depth for both wet and dry samples compared to the regular mixture. This makes the recycled mixture a better choice for pavement designs. The results show that rutting depth of the Recycled Asphalt Mixture of dry sample passed the test, while the wet sample didn't pass the test so it is supposed to be decreased by 20%. Physical properties showed that the recycled mixture contains less voids filled with asphalt (VFA) and voids in mineral aggregate (VMA) in comparison with the regular mixture at the same bitumen content. At the maximum bitumen content which is 5.9%, the VFA are 25% lower than those in the regular mixture.

Mixtures made of recycled aggregates perform well in maintenance activities and have a lower the pavement design cost. The previous outcomes support the decision of using the recycled mixture instead of the regular one and motivate us to conduct more studies to test other parameters and properties such as durability.

The research team faced some delays in conducting the tests due to COVID-19 regulations by Ministry of Health. Working in laboratory requires permissions, number of labors and working hours in the laboratory have been reduced which requires additional days to apply the tests. In Kuwait, waste is not separated so the team tried to collect aggregate demolition waste that will be used as recycled aggregate in the mixture from projects under construction which consumes a lot of time and efforts. The laboratory conditions are different than those in the field. Thus, the mixture may perform differently in the field. It's recommended to apply some in-situ tests, if possible, to ensure having a good pavement mixture that performs well.

During this study several laboratory tests were conducted and gave substantial results. Some of the results showed that the sample require some reduction or improvement. Thus, these tests will be repeated soon after applying the recommendations to satisfy the specifications. Mixture' performance will be assessed after that. This study provided us with some parameters of the asphalt mixture while more important properties haven't been checked. Workability, durability, skid resistance, stickiness, stripping resistance and storage ability will be checked in the following studies to have a high-quality pavement and improve it if requires. On other hand, the temperature, environment and conditions in the laboratory are different than those in the field. Thus in-situ tests are required to be conducted to ensure having a good pavement. Cooperating with other researchers and experts is highly recommended and will provide us with the best results.

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