The Influence of Using Recycled Asphalt Pavement and Crumbed Rubber on Asphalt Pavement: A Review

Sajjad Hashim[1], Hasan Al-Mosawe[2*], Haneen Mohammed[3]

Authors affiliations:
1) Civil Engineering Department, Al-Nahrain University, Baghdad - Iraq
sajjadhashimm2@gmail.com

2*) Civil Engineering Department, Al-Nahrain University, Baghdad – Iraq
hasan.m.almosawe@nahrainuniv.edu.iq

3) İstinye University, Istanbul Turkye.
haneen.mohammed@istinye.edu.tr

Paper History:

Received: 19th Mar 2023

Revised: 31st Mar. 2023

Accepted: 15th May 2023

Abstract

Reclaimed (recycled) asphalt pavement (RAP), the most recycled material worldwide, is the mostly reclaimed material utilized in hot mix asphalt. Polymer (Crumb rubber) incorporation frequently leads to enhanced durability and resistance to heat cracking and rutting, two forms of permanent deformation. It also relieves stiffness and minimizes fatigue damage. This study aims to gather all previous RAP-related research and crumb rubber CR, so that the impact of using these materials on mechanical, physical properties of asphalt pavement, environmental effect and cost effective are clarify and explained. The finding of this research proved that the use of RAP and CR provide considerable structural and financial enhancements to the construction.

Keywords: Crumb Rubber CR, Reclaimed Asphalt Pavement RAP , Pavement Sustainability, Pavement Cost-Effective Materials, Sustainable Pavement Materials

تأثير استخدام الخرسانة الاسفلتية المستدامة والمطاط المطحون على الرصف الاسفلتي : نظرة عامة

سجاد هاشم ، حسن الموسوي ، حنين محمد

الخلاصة:

الخرسانة الاسفلتية المعاد استخدامها تعتبر المادة الاكثر استخداماً كمادة معاد استخدامها حول العالم. حيث يتم استخدامها كمادة مصنعة في الخلطات الاسفلتية الحارة. . اما استخدام المطاط فأنه يؤدي الى تحسن في الديمومة ايضاً بالإضافة الى مقاومة للتشققات الناتجة من الحرارة بالإضافة الى التخددات في الاسفلت كما انها تزيد من الصلادة وتقلل من الاجهاد. هذا البحث يهدف الى تجميع للدراسات السابق و الخاصة باستخدام الخرسانة الاسفلتية المعاد استخدامها او المستدامة بالإضافة الى المطاط المطحون, وبذلك فحص تأثير استخدام هذه المواد على الخواص الميكانيكية للرصف الاسفلتي بالاضافة الى التأثير البيئي والكلف الفعالة. نتائج هذه الدراسة اثبتت ان استخدام الخرسانة الاسفلتية المستدامة والمطاط المطحون اظهر تحسينات مُعتبرة على الصعيدين الانشائي والمالي.

1. Introduction

Any improvement in the service life of road pavements will be of course of great economical advantage and any modifications of asphalt are attempted to increase the performance and increase the service life of asphalt pavements [1]. Long ago, the process of replacing the asphalt paving component began, and previous efforts integrating rubber that are naturally found with asphalt materials in the years of 1840s tried to recreate rubber's flexible quality in a more durable surface of pavement. Unfortunately, the objective was so difficult, and the asphalt with rubber mixtures provided a slight advantage. As a result, the enhanced asphaltic pavement material was so costly and was a shorter in lifespan than standard asphalt. [2]. RAP use has become the standard procedure in many regions of the world. FHWA (The Federal Highway Administration) reports, states that about 70 of such 90 million tons of road pavements discarded every year in the US while overlaying projects and expand of projects are recycled as parts of highways, shoulders, barriers, and roadbeds [3]. New pavements are created by recycling the old asphalt pavement materials, which results in significant material, financial, and energy savings. Even though these pavements have served their purpose, the material and binder they comprise are all still significant.. They have been used for many years to create fresh asphalt pavements with virgin aggregates and binders, proving to be both cost-efficient and successful in conserving the environment. Furthermore, it has been discovered that blends containing RAP function on par with virgin mixtures [4]. However, even if it increases rut resistance and decreases the use of new asphalt binder. The aged RAP binder is considered a possible contributing element for thermal and fatigue cracking failures in asphalt pavement. Picture 1 by [5] shows Fatigue cracking in flexible pavement. Over the past few decades, crumb rubber demand in the US and other nations has increased. The majority of field and laboratory tests have shown that rubberized asphalt concretes (RAC) exhibit improved durability, fracture reflect, stress and skidding resistances, and susceptibility to rutting in addition to an resurfacing but also in layers of (stress-absorbing membrane) which abbreviated as SAM. [6,7]

Picture (1): Fatigue cracking in flexible pavement [5]

Due to the different processing procedures, The HMA uses two different kinds of CR (cryogenic and ambient). Previous studies showed that the interaction effect and fragment effect values for crumb rubber modified (CRM) binders with ambient rubber were more significant than those for CRM binders manufactured with cryogenic rub er.

Additionally, utilizing crumb rubber in road pavement has various benefits, including a lighter lift, a longer asphalt lifetime, resistant to pavement deteriorations such as cracking and rutting, decreased noise made by traffic, and lowering the cost of maintenance/repair. [8]

The physical characteristics of the bitumen binder contains rubber were improved by the addition of CR crumb rubber, as evidenced by a drop in penetration and ductility [9].

2. RAP (Recycled Asphalt Pavement)

Early in the 20th century, recycling of roads materials that constructed with asphalt pavement became commonplace. Recycling of asphaltic pavement materials became popular at first in the US during the embargo of oil in 1970s and rising crude oil prices. Economic reductions and environmental advantages are currently the two major factors promoting the implementation of resclaimed/ recycled asphalt pavement RAP in asphaltic pavements [10]. However, If the amount of RAP throughout this area is more significant than 15%, the amount of asphalt cement must be changed., meaning recycle asphalt pavement RAP cannot be classified as black rocks. Most US institutions clearly state that introducing 15% or less of RAP to the asphalt mix does not alter how much bitumen has been added., i.e., RAP is considered black rocks [11,12]. RAP ingredients are blended with fresh materials to create hot mix asphalt mixes during the recycling process.

A lab experiments used to analyze the impact of varying RAP contents on the efficiency of hot recycled mixtures[13]. The study examined combinations of 4 groups of RAP and aggregate (percentages were 0% RAP for virgin mix, 15% RAP content, 25% RAP and the last percentage were 35%) in order to determine the OBC for the asphalt mixes. It also examined the strength to resist rutting of asphalt mixtures with various pavement waste materials content percentages. Making sure the result met the requirements, the Marshall mix design technique was applied. Volumetric analysis was done. The test of the modulus of resilient was used to gauge the mixtures' stiffness, and the wheel tracking test (Hamburg test) used to determine how well they could withstand rutting. According to the study's results, there were no appreciable variations in stiffness, Stability, or volumetric qualities between the control and recycling mixtures. In terms of robust modulus and rutting, it can be said that recycled mixes performed on par with conventional Hot Mix Asphalt (HMA). A researcher produced three high-modulus asphalt mixes with varying ratios of RAP materials (15, 30, and 50%) and a control combination without RAP components. The results showed that the performance of asphaltic mixtures with high modulus incorporating RAP has rutting resistance that are superior to that of the virgin one. [12]. A study [14] also performed experimental studies with somewhat limited outcomes and scenarios to assess the applicability of adding RAP materials to combinations of base and surface layers. Investigation of other RAP sources and their regeneration was also suggested. The study also designed four mixes with three different RAP percentages; they are (0%, 5%, and 15%) and the use of (40-50) asphalt grade and (25%) with the use of (60-70) asphalt grade. The asphalt grade was modified when adding (25%) of RAP to make up for the aged binder in the RAP. All tests revealed that all combinations had beneficial characteristics compared to the virgin mixture. Shows that it was possible to successfully create mixes with RAP content to satisfy the regional volumetric and performance-specification criteria. A research examined using RAP components in a cold asphalt composition. In actuality, cement mixed with water may be to blame for the improvement in moisture resistance. Therefore, more research is required [15].

A study primary focus is on using lean concepts in the process of asphaltic pavement production, especially in the HMA Quality Control (QC) process. Asphalt cement (Bitumen), a waste material produced as result of industry of crude oil, is used to bind the aggregate, gravel, and filler that make up roughly 95% of HMA. This study compares traditional and unconventional mixes' flow and stability values using the Marshal Stability test. According to the test results, the current research involves using RAP to decrease the amount of new aggregate in the suggested mix without affecting the mix's qualities.;

For normal concrete mixtures NCM, we use 10% RAP with 90% new aggregate. Maximum aggregate size (MAS) is 23.0 mm, while nominal full aggregate size (NMAS) is 19.0 mm. Binder is VG 30 grade bitumen. For standard mixes, cement is utilized as a filler, whereas used foundry sand UFS and sand are used for both the third normal conventional mix NCM-III and the second normal conventional mix NCM-II, respectively. Finally, 1% lime is added to bitumen as an antistripping agent to reduce the suggested mix's susceptibility to moisture or to raise its resistance to moisture sensitivity. As a consequence of this investigation, We can see that Normal CM-II outperforms other non-conventional mixes in terms of performance, has slightly lower values in stability than conventional mixes, and has significantly superior Marshall characteristics. The optimal binder content OBC was about 5.71% for Normal CM-II, which is smaller than the 5.75% of the conventional mix [16].

A researcher found that increasing the mass quantity of RAP in the surface layer's hot asphaltic mixture including a restoration agent made of about 10% by mass of asphalt cement led to stronger rutting resistance than the virgin combination [17].

Researchers used resilient modulus (Mr) from laboratory tests to examine the behavior of base layer mixtures incorporating RAP in various amounts. Various amounts of RAP from millings were mixed with local aggregates. Furthermore, densities differed across test specimens. Resilient modulus studies revealed that M R rose as RAP concentration increased. The relationship between M R and density was likewise quite positive, according to the results. Conclusions show indicated RAP might be used in base layer application for pavement in significant amounts. By doing this, a solid pavement base may be created, and a developing environmental concern may be reduced [18].

A research paper examined the impact on material stiffness; 20 resilient moduli (MR) tests were performed on samples with various ratios of aggregate and recycled asphalt pavement (RAP). Because of a gyratory-compacted example had a density that was more similar to the density of the field, it was used to prepare samples rather than a vibratory hammer. According to the specifications of the National Cooperative Highway Research Program 1-28A procedure, estimates of the moist amount and density were made both before the test and during it. The standards for quality control\quality assurance (QC\QA) for MR data, including the rotation angle, signal\noise ratio, and variation co - efficient, were met by approximately 95% of the sequences. At all confining pressures, specimens with a 65% ideal moist amount had better stamina than those with a 100% optimum moisture content. The stiffness of (50% RAP, 50% virgin aggregate) specimens was equivalent to that of specimens made of 100% aggregate under lower squeezing forces; The recycled asphalt pavement RAP specimens were stiffer under tighter confinement. However, On the basis of the observation of axial deformation throughout the conditioning process, it was demonstrated that the models incorporating RAP had much more persistent displacement than that of the 100% aggregate material. [18].

3. Crumbed Rubber as a sustainable material

Asphalt pavements were once made from recycled tire rubber waste more than a century ago. In the 1840s, bitumen and natural rubber were first mixed together. A study looked at how asphalt and rubber's natural flexibility could be used to make a long-lasting pavement surface. California Public record investigated the effects of rubber coatings on pavements in the 1950s by using powder of reclaimed tire rubber into asphalt mixtures. In 1960s, a researcher (Charles H. McDonald) developed and researched the wet asphalt method, which primarily comprises recycled tire rubber reacting with asphalt cement [20]. Hicks greatly enhanced the rubber asphalt for use in hot mix asphalt cement, crack repairs, and spray solutions [21]. In the same time frame, the pavement industries in Sweden and the USA utilized discarded tires. Non-biodegradable inorganic tire wastes offer significant environmental and public health risks [22,23].

Every year, with about one billion tires (also called as end-of-life tyres, or ELTs), near the end of their useful lives. More than half of these tires are disposed of improperly[24]. By 2030, it is predicted to be a total of at around 1.2 billion ELTs worldwide. Tire trash burning further worsens contamination of the air, water, and soil, which has another detrimental effect on the environment. [25]. Hence, the looking for alternate storage and/or disposal options for the massive quantity of tyres debris is crucial to preventing environmental impact and disposal sites depletion [26] .Reusing and recycling tire rubber in various applications has been investigated using many methods. For instance, research has demonstrated that discarded tires may be burned to create biofuel in boilers and burners for energy recovery [27, 28]. A study claimed that waste tires can be turned into fuels. Their claim is made using thermochemical methods such as gasification, hydrothermal liquefaction, and pyrolysis [29].

A research explained that wet and dry processes are the two fundamental methods for incorporating crumb rubber into asphalt mixtures [30]. According to Cao [31], heated asphalt is mixed with crumb rubber in the damp procedure, allowing the two materials to interact. The rubber expansion during the wet process is a significant step. Before adding the bitumen in the method of “dry process”, CR (Crumb Rubber) is combined directly the hot virgin aggregate. In order to make dried asphalt mixtures to be have better resistance to cracking and permanent deformation at lower temperatures, tire rubber may be added. Zhang [32] proved that the elastomeric asphalt mixture might achieve the requisite volumetric characteristics by using a wet procedure.

Gong et al. [33] prove that there are fewer applications for the dry approach than for the wet process. Despite being simpler to employ than the wet method, the dry method, Because some particles were substituted with rubber granules, the mixtures produced by the technique of dry process exhibit instability of volume and decreased stiffness.

3. RAP and crumbed rubber applications

Ebrahim [34] undertook a study to determine the benefits of the (economy and environment) of using HMA, which is created from recycled asphalt pavement. This study was carried out to protect collective resources and save money. Gradation, Coarse Aggregate Angularity (CAA), specific gravity, Los Angeles Abrasion (LA), Flat and Elongation (F&E), and impact test were only a few of the tests carried out to assess the qualities of the RAP aggregate. Styrene Butadiene–Styrene SBS, CR, and recycled atactic polypropylene PP, three different additive material types, were combined in three percentages of 3%, 5%, and 7% with the recovered asphalt mixtures. The aged and recovered binders passed the standard testing for asphalt binders. The value of penetration and flexibility of the asphalt cement reduced as the proportion of additional elements rose. When varying quantities of the SBS component were added, the blends' elastic recovery rose from around 7% to 80%. The softening points of the mix rose as the proportion of the added elements increased. After adding additions, the specific gravities of the recovered combinations were little altered. When the percentage of PP admixture material was added to blends, the temperatures of fire and flash points went up; however, when the ratio of SBS and CR additive material was added, the flash and fire point temperatures went down. Depending upon the usual variance of the RAP binder contents, it was concluded that the mixture blend should be 40% RAP and 60% fresh material. The 60/70 grade virgin soft-grade asphalt binder was mixed with the aged RAP binder. The process of designing Superpave mixes was carried out to determine the ideal asphalt concentration and understand the impact of additives on the mixtures' susceptibility to moisture. The recovered mixes' susceptibility to moisture is improved by adding additional ingredients. The additives with the best impact on the recycled mixes' moisture sensitivity were 3% CR, 7% SBS, and 5% of PP, which resulted in ITSRs of 99.71%, 97.1%, and 90.7%, respectively, using Superpave efficiency grade tests, the chosen most good mixes of the recovered binder with additives were further examined. The addition of the additives caused the PG of the blending recycled binder to alter for 7% SBS, from 64 -22 °C through over 88 °C, 76 °C for 3% CR, and 82 °C for 5% PP, respectively. For warmer areas, it was advised to add 7% SBS to the recovered asphalt mixes and 3% CR for cold climates.

Shen [35] proved that because some recycled asphalt pavements with modified binders with CR are more than ten to fifteen years old in parts of the US of America, recycling is a significant concern. This study investigated whether RAP that had been changed in the lab to incorporate crumb rubber could be recycled in Superpave mixes under standard recycling procedures. Three mixtures containing lab-made modified rubber with RAP with three basic reference mixtures were developed and analyzed, totaling six mixtures. The combinations contained two kinds of asphalt cement AS and three kinds of raw aggregates treated with CR. The crumb rubber-modified RAP utilized in the study underwent an accelerated ageing process in the lab. Fifteen per cent of the RAP was included in the recycled combinations. Indirect tensile strength, resilient modulus, asphalt pavement analyzer, and gel permeation chromatography were the testing methods used to evaluate each combination. The study demonstrated that (a) 15% crumb rubber-modified RAP may be added to HMA using standard recycling techniques. In addition to, (b) There is no apparent distinction between the raw and recycled combinations regarding the attributes stated.

Xiao et al. [36] investigated the utilization of the reused and output components in asphalt blends, A greater comprehension of the technical and rheological properties of “Rubberized Asphalt Concrete RAC” pavement, which includes RAP, is required. RAP and polymer asphalt has a history of being used in hot mixed concrete asphalt (HMA) combinations throughout the USA and the rest of the world. It is cost-efficient, ecologically friendly, and efficient. Investigating was the goal of this study. The bitumen and mix quality features of these modified asphaltic mixtures were evaluated in a number of laboratory experiments, including parameter of fatigue, G*sind, ability to resist rutting , elastic modulus, and fatigue life. The findings of this study showed that the testing revealed that applying CR & RAP to HMA can considerably enhance these pairings' engineering qualities.

The characteristics (engineering characteristics) of size and type of the CR effects on RAP mixes were assessed by Xiao et al. [37]. Two kinds of rubber (cryogenic or ambient) with different three sizes were used in the compound containing 25% RAP mixes in the experimental for this investigation. The conclusions of this study's studies showed that regardless of the size and kind of rubber used, adding crumb rubber helped to increase the air voids in the mineral aggregate (VMA) in the Superpave design mix and improve the mixture's resistance to rutting. On the contrary, ITS values for combinations prepared with three types of rubber diameters show no discernible differences. Nevertheless, regardless of the kind of rubber used, increasing rubber size decreased resilience modulus values while extending the overall fatigue performance of the changed mixes.

Researchers Xiao and Amirkhanian [38] examined how dampness affected RAC containing RAP. ITS “the indirect tensile strength” analysis, toughness, and viscosity of the binder were all determined in the tests. Several combinations with crumb rubber kinds, two separate sources of RAP, and various rubber and RAP content ratios were assessed. The outcomes showed that including RAP in mixtures leading to improving the indirect tensile strength values and decreased the mixture's susceptibility to moisture.

However, the use of crumb rubber had a slight adverse impact.

Fakhri and Azami [39] explores the possible application of CR and RAP in "warm mix asphalt" WMA. Aims of this study were to reduce the environmental impacts of used tires and ageing asphalt pavement while also enhancing the effectiveness of asphalt pavement. In the current study, three different amounts of crumb rubber powder (0, 10%, and 20%) were added to seven distinct asphalt mixes, which included RAP with 30% and 60% percentages (through the weight of 19 virgin aggregates). Various proportions of RAP and rubber crumbed were added to the asphaltic mixtures in place of natural aggregate to accomplish that. Additionally, mixtures containing 30% and 60% RAP were added to large amounts of the organic additive Sasobit (4% and 5.5%, respectively). This investigation's tests on Marshall Stability, susceptibility of moisture, fatigue cracking, and instant deformation show that adding a lot of Sasobit to an asphalt mixture lowers the temperature degree of both mixing and compacting and produces a sophisticated asphalt mixture with rubber crumbed modifications. In addition, it allows for storing waste materials like tires wastes and RAP, which is a practical way to combat global warming. Comparison to the reference sample, the rubberized asphalt mixtures with high RAP, and the Sasobit addition demonstrated better performance versus humidity sensitivity, permanent deformation and fatigue cracking.

Xiao and Amirkhanian [40] examined the properties of rubberized asphalt binders. They mixed formed with 64-22 performance grade PG and softer binders 52-28 performance grade that had a significant amount of recycled asphalt pavement 30% RAP in the laboratory. Dynamic shear rheometer (DSR), viscosity, bending beam rheometer (BBR), robust modulus, indirect tensile strength (ITS) and fatigue life assessments were a few of the tests utilized in this study. The experimental design involved the use of two raw aggregate and RAP origins, as well as two virgin binder grades with performance grade PG of (64-22 and 52-28),two kinds of rubber crumbed particles cryogenic and ambient, and four different rubber contents of (0, 5, 10, and 15) percentages. The findings showed that: (1) the fatigue performance of combinations containing 0% RAP was prolonged and the aged binder's deteriorating resistance was increased. Additionally, the outcomes demonstrated that, irrespective of the kind of rubber employed, the ITS and resilient modulus values decreased as rubber content increased. (2) The softer binder lessened the impact of the aged binder and decreased the mixtures' resilient modulus values. Generally speaking, regardless of the kind of rubber used, rubberized mixes that contains RAP of 30% and created with performance grade 52-28 polymer did not exhibit a noticeably longer fatigue life than those prepared with 64-22 performance grade binder.

Xiao et al. [41] enhanced understanding of asphalt concrete with rubber and RAP's resilience to rutting. Promoting the usage of rubberized asphalt mixes, RAP is crucial. RAP has been used in the past to increase the resistance to rutting deformation of asphalt mixes, and it has shown to be affordable, ecologically friendly, and successful. Around the nation and the world, asphalt pavement that is rubberized has been utilized to successfully improve the physical properties of typical HMA mixtures, such as rutting resistance. Through a laboratory testing program, this study aimed to explore the rutting resistance properties of rubberized asphalt mixtures. The cryogenically produced and ambient are the two types of rubber that are included in the experimental setup with four rubber contents and three different sizes of crumb rubber. The trials' findings showed that adding RAP and crumb rubber to HMA may significantly increase these mixtures' rut resistance.

Aghapour and Babagoli [42] showed that the utilize of CR and RAP is a practical, ethical, and cost-efficient technique to improve the quality of asphalt pavement. This study's objective was to assess the utilization of rubber crumbed in asphaltic pavements with a significant amount of RAP. Wet processing was used to combine the unmodified binder with CR (0, 10, and 20 percentages by mass of bitumen), and the RAP concentration was 0%, 20%, 40%, or 60%. Through a series of laboratory experiments, the performance traits of these modified asphalt mixes were examined, including ITS, elastic modulus, rutting resistance, moisture susceptibility and fatigue behavior. The conclusions of the trials showed that increased RAP concentration lowered the fatigue life of the mixes. The addition of CR extended the fatigue life of the compounds. Additionally, the rut resistance of the CR-modified combinations significantly increased as the quantity of RAP in the mixtures rose. A statistical study revealed that including RAP and CR significantly reduced the mixes' persistent deformation. The findings indicate that employing 10% CR and 40% RAP is wise because it little affects the performance of the asphalt mixture.

4. Cost-effective of using sustainable materials

In the UAE, the projects of new roads are valued at 122.6 billion USD [43]. From 2019 through 2038, the nation is estimated to spend an additional USD 354 billion on constructing roads and other facilities to sustain its planned economic development, or almost USD 18 billion annually [44]. However, El Gergawy's [45] research on Abu Dhabi infrastructure projects indicated that average cost overruns were over $10 million (adjusted for inflation). The study found that a lack of understanding of lifetime costs and poor estimation were the primary causes of cost overruns, This provides an assessment opportunity studied in this work. Also, the pricing of recycled content vs the conventional materials approach for roadworks was assessed in this study, includes concrete roadside improvements and asphalt cross-section; this study used the lifecycle cost analysis

LCCA method. The "B1" example is based on actual data for the section of road constructed of virgin materials, conventional asphalt manufacturing mixture for asphalt works, and concrete made with Portland cement for the concrete outcomes. The second base course, binding material, and wearing courses all make use of virgin HMA asphalt concrete. The sub-base and foundation courses use virgin, unbound granular aggregates. For example, on a road section, emulsion of HMA prime coat is applied on top of a u-base layer, and the asphalt base layer and asphalt binder course are both covered with a tack coat that is applied at a rate of 0.5 kg/m2. The consequences of employing RAP and WMA, containing RCW recycled waste and Blast furnace slag, are then explored as alternatives. Hasan et al. [46] conducted a study to calculate the first agency expenses for both options (raw and recycled materials), The required government agencies and local component suppliers in the case study site were contacted to organize the input samples and unit pricing data. This covers the price of the initial plans, the expense of contracting site trucks and equipment, as well as labor costs. The proposed approach can then be used to examine alternative pavement materials for any road transport system using the recommended selection criteria based on the anticipated immediate economic discounting operating, repair, and end-of-life (EOL) costs. Additionally, it might be used as a possible case study to begin an examination into the actual costs of applying sustainable techniques and supplies for underdeveloped countries' road construction, where a sizable fraction of projects still use traditional materials for construction.

Hasan et al. [47] conducted an urban expressway's complete life cycle cost analysis (LCCA). Stretch "E10" is a highway in Abu Dhabi, which has a hot, humid environment as typical weather in the Middle East. The study used basic cost information under various situations, RCW through the layers of aggregate, and RAP. The use was across base course, binder layer, and asphalt wearing courses. Blast furnace slag is now being analyzed as a potential replacement for part of the asphalt in road construction projects. According to the findings, sustainable building is less expensive. When RAP and RCW consumption was aggregated, the cost decrease was the greatest. Over a 30-year period, the best cost scenario cut costs by $ 2.6 million (about 15%), from 2015 to 2045, by utilizing 15% RAP in the binder and wearing layer, 65% slag for concrete repairs, 25% recycled construction waste in the sub-base, 80% recycled construction waste in the unbound base, 25% warm-mix RAP (WMA) RAP in the bitumen base.

A case study studied by Qiao et al. [48] found that For the inquiry, a case study of different highways constructions on Interstate in New Hampshire (NH), United States of America, was done. The findings of dynamic modulus testing on local virgin hot mix asphalt and hot mix asphalt with 40% RAP (as primary option of material) were used in the case study to forecast the life cycle performance of the chosen pavement constructions while considering future weather change with lower temperatures. A life cycle cost analysis was then used to quantify and compare the life cycle cash flow of the road infrastructure under consideration (LCCA). This study also considered responsive maintenance (overlay) and efficacy. It was discovered that utilizing 40% RAP in HMA can lower agency expenses by up to 18% under the expected climate for 2020–2040. Therefore, In order to reduce agency expenses in the future environment, NH should take this approach into consideration.

Mousa and Mousa [49] studied a technique for doing cost/benefit assessments for employing RAP-sand blend in subgrade and subbase layers is presented. This approach considers the overall process of RAP-sand blend from various sources until it is engaged in construction. Applications of RAP-sand blends were thought of in eight different circumstances. Each scenario was assessed using the mechanistic-empirical method and comprised two pavement portions (control and alternative). When comparing the savings in asphalt thickness under various equivalent single axle loads (ESALs) ranging between 1 and 12 million, the advantage of adopting the RAP-sand blend in the alternative section was determined. The findings of Option 1 (new RAP and site mixing) showed considerable savings ranging from -$ 0.48 to $9.29/m^2, depending on the scenario of RAP blend consumption. Four mixing possibilities were discovered. This strategy likewise had the best benefit-cost ratios. Depending on the method and choice taken into consideration in the research, the estimated benefit-cost percentages ranged from 0.58 to 18.64, with Scenario 3 being connected with uneconomic conditions. In our investigation, ESALs with values beyond one million had no appreciable effects. The RAP-sand mixture generally reduces the amount of asphalt used, mainly as a subgrade or subbase layer under thinner unbound aggregate layers. The considerable savings realized could stimulate further use of this combination.

Franke and Ksaibati [50] identified the best cost-effective technique to use recycled asphalt pavement (RAP) in different road applications. A methodology was built to evaluate the costs and advantages of employing RAP in hot plant mix using a technique created by the National Asphalt Pavement Association. A comparable procedure was created to gauge the benefits of using RAP in bases and gravel roads. As a way of a fair comparison, the approach normalizes all costs and gains into savings per ton of RAP. Considerations were made for dust savings, layer coefficients, transport, and reduced demand for fresh aggregates. Finally, a case study utilizing these three distinct applications was carried out. Other organizations who want to find the best economical ways to employ RAP in road building might use this analysis. This research demonstrates that using RAP in this roadway application results in financial savings. RAP in gravel roads costs $18.82/ton less than before ($17.07/ton of RAP). This was made possible by the savings from using virgin aggregate and the savings from dust reduction, which will preserve the small particles embedded in the road and maintain it in better shape. The decrease in dust will also enhance the quality of the air. The three RAP applications each produced savings, particularly in material costs. RHPM had a $45.07/ton cost reduction. Savings of $17.30/ton were created using RAP in the road base. Savings on gravel roads with RAP were $18.82/ton.

Souliman et al. [51] studied three gap-graded mixtures—unmodified, Asphalt Rubber (AR), and polymer-modified—which were tested in a lab. According to AASHTO T321, strain-controlled fatigue tests were performed. The gap-graded mixes with AR and polymer modifications would have substantially longer fatigue lifetimes than the reference (unmodified) mixture, according to the findings of the beam fatigue tests. A cost-effectiveness analysis was conducted based on the three combinations' fatigue performance and a mechanical analysis utilizing the 3D-Move program. The research revealed that compared to the unmodified HMA mixture, the AR and polymer-modified asphalt mixes were much more cost-effective. Although AR and polymer modification raises the material's cost, studies revealed that they are more cost-effective than the unmodified combination.

Bueno et al. [52] used several construction types, asphalt binders, and load intensities to calculate a cost-benefit ratio. The program AEMC (SisPav) was used to first identify typical pavements before analyzing them to derive the horizontal tensile strain (t) values at the base of the asphalt pavement layer and then the NFATIGUE value which is the values of permissible fatigue solicitations. It was discovered that the repeated load NFATIGUE value for the pavement constructions under study might decrease by around 50% when weight increases within legal bounds. Economic effects included a mean increase of 120% in the cost of repeatedly loading pavement constructions (cost per repeated load R$ NFATIGUE-1) due to the same weight increase. Additionally, it was discovered that buildings with more robust asphalt concrete layers might offer the most excellent R$ NFATIGUE-1 ratios. For granular materials, smaller layers, in combination with a thicker covering, produced the most significant results. The assessments of the best structural solutions demonstrated the advantages of modified binders: both the polymer-modified binder and the rubber asphalt binder provide considerable structural and financial enhancements to the construction.

NFATIGUE can be calculated for each of the three types of asphalt binders according to Franco [53] as follows :

1- The equation below is applicable to conventional mixtures

$$N = sf * 1.904 * 10^{-6} * \left(\frac{1}{\varepsilon_t}\right)^{2.821} * \left(\frac{1}{RM}\right)^{0.74} \quad R^2 = 0.805$$

2- The equation below is applicable to SBS or EVA-modified binders.

$$N = sf * 4.455 * 10^{-7} * \left(\frac{1}{\varepsilon_t}\right)^{3.798} * \left(\frac{1}{RM}\right)^{1.493} \quad R^2 = 0.813$$

3- The equation below is applicable to asphalt rubber binder.

$$N = sf * 7.26 * 10^{-3} * \left(\frac{1}{\varepsilon_t}\right)^{3.103} * \left(\frac{1}{RM}\right)^{1.918} \quad R^2 = 0.676$$

Where:
ε_t = horizontal tensile strain on the bottom of surface layer (m m-1);
RM = resilient modulus of AC (MPa);
sf = shift factor = 100000

5.Conclusion

Based on the previous researches presented in the preceding headings, the following conclusion can be illustrated in the following paragraph:

1- The aged RAP binder is considered a possible contributing element for thermal and fatigue cracking failures in asphalt pavement.
2- When compared to the reference mix, the resistance to rutting in samples with higher modulus of asphalt mixtures containing RAP was greater.
3- Adding of reclaimed asphalt pavement to the surface layer's hot mixture, along with a percentage of 10 by weight of bitumen regeneration agent, resulted in greater resistance to rutting. Rubber's inherent flexibility may be combined with asphalt to produce a long-lasting pavement surface. By adding recycled tire rubber powder to asphalt mixes.
4- For warmer areas, it was advised to add 7% SBS to the recovered asphalt mixes and 3% CR for cold climates.
5- adding RAP and crumb rubber to HMA may significantly enhance these mixtures' engineering qualities.
6- including RAP enhancing the indirect tensile strength values and decreased the mixture's susceptibility to moisture. However, the use of crumb rubber had a slight adverse impact.
7- Sustainable materials are less expensive. When RAP and RCW consumption was aggregated, the cost decrease was the greatest.
8- The RAP-sand mixture generally reduces the amount of asphalt used, mainly as a subgrade or subbase layer under thinner unbound aggregate layers. The considerable savings realized could stimulate further use of this combination.
9- Polymer-enhanced and RAP asphalt mixtureses were much more cost-effective.
10- the use of RAP and CR provide considerable structural and financial enhancements to the construction.

6. References

[1] Sienkiewicz, J. K. Lipka, H. Janik, and A. Balas, WasteManagement, vol. 32, 2012.
[2] D. D. Carlson and H. Zhu, “Asphalt-Rubber - An Anchor to Crumb Rubber Markets,” in Proc.

Third Joint UNCTAD/IRSG Workshop on Rubber and the Environment, International Rubber Forum, Veracruz, Mexico, October 7, 1999

[3] Federal Highway Administration Superpave Mixture Expert Task Group. Guidelines for the design of Superpave mixtures containing reclaimed asphalt pavement. Washington (DC), 1997.

[4] Kandhal PS. Recycling of asphalt pavement – an overview. J Assoc Asphalt Paving Technol 1997;66.

[5] Alfayez, S. A., Suleiman, A. R., & Nehdi, M. L. (2020). Recycling tire rubber in asphalt pavements: State of the art. Sustainability, 12(21), 9076.

[6] Putman BJ. Quantification of the effects of crumb rubber in CRM binder. PhD dissertation. Clemson University, Clemson, SC, 2005.

[7] Rubber Manufacturers Association (RMA). US scrap tire markets 2006 edition. Rubber Manufactures Association, Washington (DC), 2006.

[8] Amirkhanian, Serji N. "Utilization of crumb rubber in asphaltic concrete mixtures–South Carolina's Experience." See ref 3 (2001): 163-174, USA.

[9] Wulandari, P. S., & Tjandra, D. (2017). Use of crumb rubber as an additive in asphalt concrete mixture. Procedia engineering, 171, 1384-1389.

[10] David E. Newcomb, E. Ray Brown, Jon A. Epps. 2007. Designing HMA Mixtures with High RAP Content. A Practical Guide. Quality Improvement Series 124. National Asphalt Pavement Association, Lanham, MD.

[11] Mcdaniel, r. S. & anderson, r. M. 2001. Recommended use of reclaimed asphalt pavement in the Superpave mix design method: technician's manual. National Research Council (US). Transportation Research Board.

[12] Abdalhameed, A. M., & Abd, D. M. (2021). Rutting Performance of Asphalt Layers Mixtures with Inclusion RAP Materials. Anbar Journal of Engineering Sciences, 9(2).

[13] Arshad, A. K., Abd Karim, Z., Shaffie, E., Hashim, W., & Abd Rahman, Z. (2017, November). Marshall properties and rutting resistance of hot mix asphalt with variable reclaimed asphalt pavement (RAP) content. In IOP Conference Series: Materials Science and Engineering (Vol. 271, No. 1, p. 012078). IOP Publishing.

[14] MOHAMMED , H. H. 2019. Assessment of Sustainable Modified Asphalt Paving Mixtures.

[15] ISMAEL , A. D. 2018. Evaluation of Cold Asphalt Emulsion Mixtures (CAEMs) With Different Percentages of Recycled Aggregate.

[16] NagaRajesh, K., Kumar, B. G., Jagadeesh, G., & Rao, R. S. A Study on Asphalt Pavements by using RAP, Sand & UFS Mixtures as Replacements.

[17] PRADYUMNA, T. A., MITTAL, A., JAIN, P. J. P.-S. & SCIENCES, B. 2013. Characterization of reclaimed asphalt pavement (RAP) for use in bituminous road construction. 104, 1149-1157.

[18] Alam, T. B., Abdelrahman, M., & Schram, S. A. (2010). Laboratory characterisation of recycled asphalt pavement as a base layer. International Journal of Pavement Engineering, 11(2), 123-131.

[19] Kim, W., Labuz, J. F., & Dai, S. (2007). Resilient modulus of base course containing recycled asphalt pavement. Transportation Research Record, 2005(1), 27-35.

[20] Heitzman, M.A. State of the Practice—Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier; Research Report No. FHWA-SA-92-022, 1339; Federal Highway Administration: Washington, DC, USA, 1992; pp. 1–8.

[21] Hicks, R.G. Asphalt Rubber Design and Construction Guidelines; Rubberized Asphalt Concrete Technology Center: Alhambra, CA, USA, 2002

[22] Segre, N.; Joekes, I. Use of tire rubber particles as addition to cement paste. Cem. Concr. Res. 2000, 30, 1421–1425.

[23] Presti, D.L. Recycled tyre rubber modified bitumens for road asphalt mixtures: A literature review. Constr. Build. Mater. 2013, 49, 863–881.

[24] Thomas, B.S.; Gupta, R.C.; Panicker, VJ Recycling of waste tire rubber as aggregate in concrete: Durability-related performance. J. Clean. Prod. 2016, 112, 504–513

[25] Pollutant emissions of a biomass gasifier inside a multifuel energy plant. Atmos. Pollut. Res. 2019, 10, 2000–2009

[26] Garrick, G.M. Analysis and Testing of Waste Tire Fiber Modified Concrete. Master's Thesis, Louisiana State University (LSU), Baton Rouge, LA, USA, 2005; p. 217.

[27] Martinez, J.D.; Veses, A.; Mastral, A.M.; Murillo, R.; Navarro, M.V.; Puy, N.; Artigues, A.; Bartroli, J.; Garcia, T. Co-pyrolysis of biomass with waste tyres: Upgrading of liquid bio-fuel. Fuel Process. Technol. 2014, 119, 263–271.

[28] Zhang, L.; Zhou, B.; Duan, P.G.; Wang, F.; Xu, Y.P. Hydrothermal conversion of scrap tire to liquid fuel. Chem. Eng. J. 2016, 285, 157–163.

[29] Rowhani, A.; Rainey, T.J. Scrap Tyre Management Pathways and Their Use as a Fuel—A Review. Energies 2016, 9, 888.

[30] T. Butz, J. Muller, G. Riebesehl, Innovative methof for producing crumbed rubber modified asphalt, 5th Eurasphalt & Eurobitume Congress, Istanbul, 2012

[31] W. Cao, Study on properties of recycled tire rubber modified asphalt mixtures using dry process, Construction and Building Materials (21), 2007, 1011-1015

[32] D. Zhang, X. Huang, Y. Zhao, S. Zhang, Rubberized asphalt mixture design using a theoretical model, Construction and Building Materials (67), 2014, 265-269

[33] Gong, F.; Guo, S.; Chen, S.; You, Z.; Liu, Y.; Dai, Q. Strength and durability of dry-processed stone matrix asphalt containing cement pre-

coated scrap tire rubber particles. Constr. Build. Mater. 2019, 214, 475–483.

[34] Ebrahim, S. M., & Karim, H. K. (2019). Evaluation of Characteristics of Recycled Asphalt Pavement (RAP) Materials with and without Using Additive Materials. Sulaimania Journal for Engineering Sciences, 6(4).

[35] Shen, J., Amirkhanian, S., Lee, S. J., & Putman, B. (2006). Recycling of laboratory-prepared reclaimed asphalt pavement mixtures containing crumb rubber–modified binders in hot-mix asphalt. Transportation Research Record, 1962(1), 71-78.

[36] Xiao, F., & Amirkhanian, S. N. (2010). Laboratory investigation of utilizing high percentage of RAP in rubberized asphalt mixture. Materials and structures, 43(1), 223-233.

[37] Xiao, F., Amirkhanian, S. N., Shen, J., & Putman, B. (2009). Influences of crumb rubber size and type on reclaimed asphalt pavement (RAP) mixtures. Construction and Building Materials, 23(2), 1028-1034.

[38] Xiao, F., & Amirkhanian, S. N. (2009). Laboratory investigation of moisture damage in rubberised asphalt mixtures containing reclaimed asphalt pavement. International Journal of Pavement Engineering, 10(5), 319-328.

[39] Fakhri, M., & Azami, A. (2017). Evaluation of warm mix asphalt mixtures containing reclaimed asphalt pavement and crumb rubber. Journal of Cleaner Production, 165, 1125-1132.

[40] Xiao, F., Amirkhanian, S., Putman, B., & Shen, J. (2010). Laboratory investigation of engineering properties of rubberized asphalt mixtures containing reclaimed asphalt pavement. Canadian Journal of Civil Engineering, 37(11), 1414-1422.

[41] Xiao, F., Amirkhanian, S., & Juang, C. H. (2007). Rutting resistance of rubberized asphalt concrete pavements containing reclaimed asphalt pavement mixtures. Journal of Materials in Civil Engineering, 19(6), 475-483.

[42] Aghapour, M., & Babagoli, R. (2020). Effect of reclaimed asphalt pavement on performance of rubberised asphalt mixtures. Proceedings of the Institution of Civil Engineers-Construction Materials, 173(6), 284-297.

[43] Abbas, W. UAE Invests More in Transportation. Khaleej Times, 23 December 2017.

[44] Arulrajah, A.; Disfani, M.M.; Horpibulsuk, S.; Suksiripattanapong, C.; Prongmanee, N. Physical properties and shear strength responses of recycled construction and demolition materials in unbound pavement base/subbase applications. Constr. Build. Mater. 2014, 58, 245–257.

[45] El Gergawy, Y. Life Cycle Cost Analysis as a Technique to Reduce Project's Cost Overruns of Assets in UAE: A Case Study-Based Research; British University in Dubai: Dubai, United Arab Emirates, 2011.

[46] Hasan, U.; Whyte, A.; Al Jassmi, H. Life cycle assessment of roadworks in United Arab Emirates: Recycled construction waste, reclaimed asphalt pavement, warm-mix asphalt and blast furnace slag use against traditional approach. J. Clean. Prod. 2020, 257, 120531.

[47] Hasan, U., Whyte, A., Al Jassmi, H., & Hasan, A. (2022). Lifecycle Cost Analysis of Recycled Asphalt Pavements: Determining Cost of Recycled Materials for an Urban Highway Section. CivilEng, 3(2), 316-331.

[48] Qiao, Y., Dave, E., Parry, T., Valle, O., Mi, L., Ni, G., ... & Zhu, Y. (2019). Life cycle costs analysis of reclaimed asphalt pavement (RAP) under future climate. Sustainability, 11(19), 5414.

[49] Mousa, R. M., & Mousa, M. R. (2019). Cost–benefit analysis of RAP–sand blend applications in road construction. Transportation Research Record, 2673(2), 415-426.

[50] Franke, R., & Ksaibati, K. (2015). A methodology for cost-benefit analysis of recycled asphalt pavement (RAP) in various highway applications. International Journal of Pavement Engineering, 16(7), 660-666.

[51] Souliman, M. I., Mamlouk, M., & Eifert, A. (2016). Cost-effectiveness of rubber and polymer modified asphalt mixtures as related to sustainable fatigue performance. Procedia Engineering, 145, 404-411.

[52] Bueno, L. D., Specht, L. P., da Silva Pereira, D., & Ribas, J. (2016). < b> Cost-benefit analysis of the construction of different flexible pavement structures considering the axle load and type of binder. Acta Scientiarum. Technology, 38(4), 445-453.

[53] Franco, F. A. C. P. (2007). Método de dimensionamento mecanístico-empírico de Pavimentos asfálticos – SisPav (Tese de Doutorado). Universidade Federal do Rio de Janeiro. Rio de Janeiro, RJ.