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Rubblization of Shaybah Airport Runway Pavement—A Sustainable Circular Economy Solution

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Abstract

Shaybah airport runway upgrade construction work was successfully completed in 77 days, four months ahead of the contractual construction execution schedule. The project was honored with the PMI 2020 Project Excellence Award for Europe, Africa and the Middle East. Rubblization of existing concrete pavement was one of the key factors for the early completion and project achievements and awards. Rubblization technology was used to crush existing worn-out Shaybah airport runway concrete pavement, keeping the integrity of underneath sub-grades, and reused as a structurally strong base course to overlay hot mix asphalt. This paper will share the success story behind the process of selection, definition, sourcing, implementation, validation and acceptance of rubblized concrete pavement, and its contribution to the Shaybah Airport Runway Upgrade Project's achievements. This paper presents Rubblization as a practical, cost effective and sustainable option for repairing deteriorated airfield concrete pavement, and will also demonstrate how the implementation of rubblization of runway pavement contributes to the Saudi Aramco initiative to adopt circular economy principles. The circular economy unlocks economic opportunities, preserves natural resources, and improves environmental performance, an initiative sponsored by Saudi Aramco executive management.

Keywords

Rubblization, Shaybah Airport, Circular Economy, PMI Excellence Award

1. Introduction

On October 20, 2020, Project Management Institute (PMI) during its PMI Virtual Experience Series announced the selection of Shaybah Airport Runway

Project, executed by Oil Facilities Projects Department, as the winner for the Project Excellence Award 2020 in Europe, Africa and the Middle East region. Shaybah airport runway upgrade construction work was successfully completed in 77 days, four (4) months ahead of the 7 months original project schedule.

The old Shaybah Airport Runway pavement was experiencing various degrees of deterioration in the form of cracking, spalling and delamination of the existing concrete pavement. Different options were evaluated for the repair of the concrete pavement with the ultimate objective to shorten the closure of the runway and to achieve the best value in terms of capital investment. The evaluated options include the following: do nothing, continue with the routine repair in the form of patching, replace the runway with concrete or asphalt pavement, providing an asphalt overlay on top of the existing pavement and perform long-term repair using rubblization. The evaluation of the different alternatives for the repair of the runway revealed that rubblizing the existing deteriorated concrete pavement and converting it to a high strength base course to receive an asphalt concrete overlay was the best option among the evaluated methods. Refer to Figure 1.

The runway pavement rehabilitation demanded the closure of the old Shaybah airfield and utilization of a government airfield (Shabitah) located 1.5 hours driving distance from Shaybah community. The Shaybah passengers were commuting daily using several Saudi Aramco 40 seated buses through two-way narrow roads. In addition, Shabitah airfield was shorter than the recommended operational requirements, which restricted its use during the hotter months. Therefore, the constructions work had to be completed during the few months when the temperature was below 30˚C - 35˚C, from November to April.

Shaybah Oil Field, a major and iconic Saudi Aramco production field located in the remote Rub' Al-Khali desert, is visited by high delegates from countries and companies worldwide. This makes Shaybah Airport an indispensable

Figure 1. Deteriorated conditions of the old Shaybah Airport runway concrete pavement.

transportation hub to access the Shaybah Oil Field. Due to its impact on the company's business, it was crucial to accelerate and complete the construction work, minimizing the closure duration of Shaybah Airport.

The rubblization of existing concrete pavement ended up as one of the most ascertained decisions taken by the project during the scope definition phases. The process fully supported the execution schedule by rubblizing the full 112,000 square meters and 30 cm thick concrete in 10 days, with almost zero environmental waste and material disposal, and reduced the cost by 1/3 when compared with full reconstruction of the runway pavement.

This paper will describe the process of selection and implementation of rubblization of concrete pavement for Shaybah Airport Runway Upgrade project, and its benefits in terms of cost, schedule, environment, and how it supports the Saudi Aramco initiative of implementing circular economy principles.

2. Background

2.1. Old Shaybah Airport Runway Pavement

Shaybah Airport is situated within one of the many salt flats (sabkha or dry lake bed) present in the Rub' Al-Khali ("Empty Quarter") desert. This long and narrow salt flat was originally made up of two separate flats, with the interconnecting sand dune removed to construct the runway. The Shaybah airport and adjacent complex is entirely surrounded by sand dunes with heights in excess of 175 meters above the runway, and the closest one being approximately 75 meters north of the runway.

Shaybah Airport was constructed in early 1997 and consists of a runway with a paved length of 3048 meters (10,000 ft.) and width of 30.1 meters with unpaved hardened shoulders of 7.5 meters width on either side, which classifies it as a Code 3C runway in accordance with the International Civil Aviation Organization (ICAO). The airport originally included two taxiways, one apron/ramp and two turn pads.

Shaybah Airport serves the Saudi Aramco fleet, including B737-700 and B737-800, as well as other smaller aircraft, such as the Hawker 900XP, Embraer 170 and King Air 350 CER. On occasion the airport receives aircraft up to Boeing B767 size. The expected annual return flights will be1560 by 2040.

Old Shaybah Airport Runway suffered from poor joint construction, extreme temperature stress, low quality of re-patching work, and windblown sand presented an environmental challenge to the airport that led to joint seal deterioration, requiring extensive maintenance and repetitive repairs to maintain safe flight operations. Project scope included the rehabilitation of the 3048-meter long concrete runway, using the rubbilization method, which is a process of fracturing an existing Portland Cement Concrete Pavement (PCCP) into small, interconnected pieces that serve as a base course for a new hot mix asphalt (HMA) overlay. The scope also entailed the upgrade of the Airfield Ground Lighting (AGL) system from CAT I to CAT II, using a simple approach (barrete type), and upgrade of runway pavement markings as per international codes and Saudi Aramco standards.

2.2. Project Scope Selection—Rehabilitation Options

Several investigations were carried out by a number of engineering offices and Saudi Aramco Consulting Services Department (CSD). All of these studies indicate that the deterioration on the concrete joints (usually expansion joints) is the major cause of the runway deterioration. The site investigations found possible causes of these cracks, some of these due to spalling failure of the expansion joints and corners, and deteriorated compressible joint filler/sealant, which obstructed the concrete thermal expansion/contraction. Deteriorated sealants, together with poor workmanship and lack of quality of the previous repairs aggravated the extent of the runway condition. It was reported that the repaired portion of the slabs shows reoccurrence of cracks and unbounded construction joints. Around 40% to 50% of spall repairs showed random cracks (crazing) and lateral cracks.

Below are some of the studies and reports conducted by Saudi Aramco, led by Aviation Department and Facilities Planning Department, with contributions from local universities (King Fahad University for Petroleum and Minerals (KFUPM)), overseas specialized engineering companies, as well as Consulting Services Department, the Saudi Aramco Technical Authority Department. The studies included:

- "Pavement Maintenance Management and Structural Rehabilitation of Shaybah Airport Runway" by King Fahad University for Petroleum and Minerals (KFUPM), in 2011.
- "Shaybah Airport Runway Rehabilitation Phase 2" by URS Infrastructure & Environment UK Limited, in 2013.
- "Final Report for the Feasibility Study for the Implementation of PBN RNP AR and GBAS for SAUDI ARAMCO—Shaybah Airport" by Hughes Aerospace Corporation, in 2015.
- "Approved Project Scoping Paper—BI 10-01912 Upgrade Airport Runway—Shaybah" by SAUDI ARAMCO Facilities Planning Department, in May 2016.

Several rehabilitation options were studied and pondered, based on their influence on the continuous aviation operations at Shaybah, operational safety, cost, schedule, ground operations and logistical requirements, including:

1) Do nothing.

2) Continue with Routine Repair.

3) Complete replacement using concrete runway.

4) Concrete overlay on existing concrete pavement.

5) Asphalt overlay on existing concrete pavement.

6) Volumetric concrete (Rapid Set).

7) Rubblization of existing concrete pavement and overlay with Hot Mixed Asphalt (HMA).

The final studies were narrowed to the two options:

Option 1: Extend the original Shaybah Airport runway in 6000 feet (1800 meters) to allow partial reconstruction of the runway, keep the runway in operation. This option had an increased operational safety risk, as well as increased capital and maintenance cost. Nevertheless, it was the option with less interference on the Shaybah and Saudi Aramco operational business objectives.

Option 2: Full closure of Shaybah Airport runway and transfer all aviation operations to an alternative airport, to allow the full rehabilitation of the Shaybah runway. This option posed a reduced aviation operational safety risk, as well as a cost around 50% below Option 1. This Option conflicted with Saudi Aramco strategic objectives at Shaybah, as an iconic oil site attracting visits from VIP delegates from around the world.

As a recommendation from final assessments and tests, Option 2 was selected as the one with fewer safety risks for the project, Shaybah community and Saudi Aramco Aviation operations.

2.3. Project Scope Definition—Rubblization of Concrete Pavement

The concept selection phase recommended implementation of rubblization of concrete pavement as an innovative technology. Rubblization of concrete pavement was implemented for the first time in Saudi Aramco, after mitigating all the risks associated with the novelty technology, initial learning stage, lack of company standards and benchmarking, and ultimately the possible impact on construction schedule. In the Kingdom of Saudi Arabia, rubblization of concrete pavement was previously implemented at the King Abdulaziz Airport in Jiddah.

Due to the novelty feature of the scope, the project team took some initiatives to mitigate all the risks associated with the implementation of this technology, including:

- A site visit and interaction with the International King Abdulaziz Airport took place to collect all the lessons learned from the sole previous in-Kingdom rubblization experience.
- "Site Investigation Studies and Concrete Evaluation Testing" prepared by Gulf Engineering House (GEH) in February 2017, to assess and conclude about the feasibility of the rubblization technique.
- Several workshops and meetings with a rubblization specialist—Antigo Construction Inc.
- Long-term engineering agreement with Saudi Aramco Consulting Services Department (technical authority).

3. Rubblization of Concrete Pavement

3.1. Definition

Rubblization isa process of breaking existing concrete pavement as per specific particle sizes, without damaging the pavement subgrade. It is a process whereby the existing worn-out concrete pavement, which normally is only used as disposal material, is converted into a high-quality aggregate base, by breaking the concrete pavement into small pieces, thereby eliminating any slab action in the pavement. The slab action is eliminated by breaking the concrete pavement into small particles ranging from sand size to 75 mm (3 in) at the surface, 150 to 230 mm (6 - 9 in) on the top half, and 305 to 380 mm (12 - 15 in) at the bottom half of the concrete pavement layer(Reference [1]). This rubblized base layer is the perfect starting point to build a perpetual hot-mix asphalt pavement.

Compared to demolishing and replacement, the rubblization repair method is more cost effective (materials and transportation cost), much faster, sustainable, lower water and carbon foot prints, and has lower risk of disturbing the existing subgrade of the repaired structure. The rubblization technique also offers the elimination of reflective cracking in AC overlays; and minimizes disruption to traffic operation.

In many aspects, the rubblization of pavement systems is a more complex engineering task than the design of new pavement systems. Rubblization is generally considered to be the action taken to significantly extend the service life of an existing pavement. Routine maintenance is considered an action that preserves the existing pavement to accommodate present traffic loading. **Figure 2** provides a representative impact of rubblization on existing concrete pavement.

3.2. Rubblization of Concrete Pavement—Equipment

Rubblization requires the use of highly specialized equipment to break the concrete down to a specified maximum particle size. There are two basic types of self-contained, self-propelled devices for rubblizing concrete pavement, and four types of machines, which can be used to rubblize the concrete pavement. Refer to **Figure 3** and **Figure 4**.

3.3. Multi-Head Breaker

The multi-head breaker (MHB) (see Reference [2]) has 12 to 16 nos. of 545 to 680 kgs drop hammers mounted laterally, either in pairs offset between two

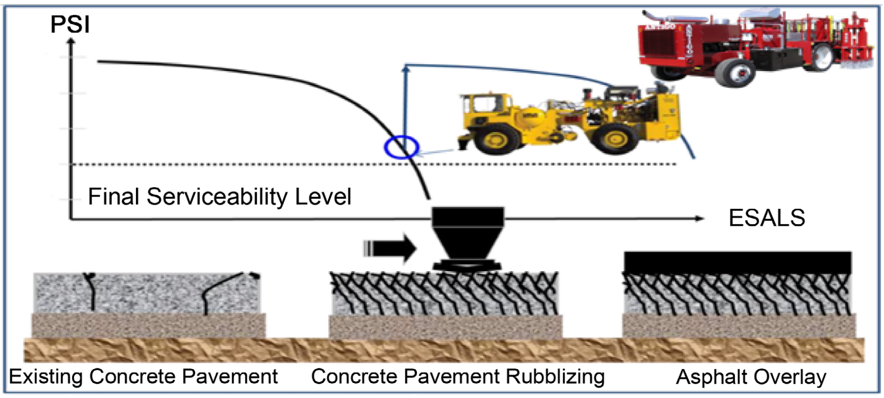

Figure 2. Definition of Rubblization.

Figure 3. Equipment used for the execution and quality control of rubblization (courtesy from Antigo construction inc. and gulf engineering house).

Figure 4. Antigo Construction Inc. equipment (MHB Badger Breaker on the left and 8600 Badger Breaker on the right) on operation at Shaybah Airport Runway.

rows, or singularly in-line. Both hammer configurations ensure continuous breakage from side to side. The hammers are attached to a hydraulic lift cylinder, which can be operated independently of the others to provide for custom breaking patterns.

Each hammer (or pair of hammers) develops between 1356 to 10,847 Watt-Second of energy depending upon the drop height selected and cycles at a rate of 30 to 35 impacts per minute. The drop height of each hammer (pair of hammers) and the distance between impacts can be adjusted during production to control the amount of breaking energy that is transferred to the concrete pavement.

The eight-foot wide machines carry at least 12 hammers eight inches in width. Wing additions can be attached to each side for a total breaking width of up to 14 - 16 feet (427 - 488 cm). Due to individual control of each lifting cylinder, breaking can be as narrow as one foot or increased in increments to as wide as 16 feet (488 cm). The MHB is capable of rubblizing a full lane width of the pavement in a single pass.

3.4. Resonant Frequency Breaker

The resonant frequency breaker (see Reference [3]) is the alternative to rubblization process. The resonant frequency breaker (RFB) is a self-propelled device that utilizes high-frequency, low-amplitude impacts with 907 kgs per each foot (30.5 cm). The foot is located at the end of a pedestal that is attached to a beam and counter weight. The force applied to the pavement is achieved by vibrating the large steel beam connected to the foot. The foot is moved along the concrete surface at the front of the machine. The breaking principle is that low-amplitude, high-frequency, resonant energy is delivered to the concrete slab, resulting in high tension at the top. Since concrete has low tensile strength, the slab fractures on a shear plane at approximately 45 degrees through the pavement. The foot, beam size, operating frequency, loading pressure, and speed of the machine can be varied.

Using the RFB, the breaking begins at the outside free edge and proceeds across the pavement. The breaking pattern is approximately 8 inches wide, thereby requiring approximately 18 to 20 passes to break a 13-foot wide lane. The RFB is generally required to operate at maximum amplitude of one inch to avoid disruption of base and prevent damage to underground structures. The RFB encroaches up to three feet (91.5 cm) onto the adjacent lane to rubblize near the centerline of the pavement. When the pavement foundation is weak, flotation tires are used to spread the weight of the 28,000 kgs machine.

3.5. Z-Pattern Steel Grid Roller

The equipment consists of a vibratory steel wheel roller with a Z-pattern grid cladding bolted transversely to the surface of the drum. The vibratory roller shall have a minimum gross weight of 10 tons.

3.6. Vibratory Steel Wheel Roller

This roller should have a minimum gross weight of 10 tons. Pneumatic-tire Roller—This roller should develop a compression of not less than 345 kgf/cm, nor more than 576 kgf/cm, of width of the tire tread in surface contact.

3.7. Rubblization of Concrete Pavement—Benefits

Several options were may be considered for the rehabilitation of existing concrete pavements, including:

- Short-term and continuous maintenance repair.
- Fiber reinforced concrete pavement overlay.
- Prestressed reinforced concrete overlay.
- Reconstruction with fiber reinforced concrete pavement.
- Full concrete pavement reconstruction, replacing the existing concrete pavement with a new asphalt pavement.
- Overlay of existing concrete pavement with a new concrete layer.

- Overlay of existing concrete pavement with a new asphalt layer.
- Build a new runway adjacent to the existing one, and utilize the existing runway as taxiway.
- Rehabilitate existing concrete pavement by a new technology named rubblization and overlay with polymer modified asphalt.

The rehabilitation of existing concrete pavement by rubblization and overlay with polymer modified asphalt was selected as the preferred option.

Some of the justifications to select this long-term rehabilitation option were based on the significant reduction of cost and schedule, when compared with other long-term rehabilitation work.

The advantages that rubblization offers include(see Reference [4]):

- Rubblization extends the life of the pavement to a further 20 or 40 years based on the design criteria.
- Elimination of reflection cracking.
- Improvement in smoothness with the placement of Hot Mix Asphalt as the new surface.
- Elimination of Alkali Silica Reactivity (ASR) and D-cracking problems with the existing concrete pavement.
- Dramatic decrease in construction time relative to concrete pavement reconstruction.
- Improved maintenance of traffic and increase in service life of the HMA overlay, increasing the period required for preventive or corrective maintenance.
- Reduction in cost versus reconstruction of concrete pavement.
- Rubblization can be done in 1/5 the time at 1/3 the cost of concrete pavement reconstruction.
- Reduction in cost versus Concrete Pavement Restoration (CPR).
- Improved public and stakeholder relations due to the decrease in construction time and work zone delays.

Furthermore, the implementation of rubblization of concrete pavement would result in less environmental impact when compared with other options. This is a process whereby the existing worn-out concrete pavement, which normally is only used as disposal material, is converted into a high-quality aggregate base. This offers a significant benefit in terms of environmental protection, cost benefit and therefore the circular economy initiative and parameters.

The reduced number of Specialist Suppliers worldwide is one of the bottlenecks for the implementation of rubblization of concrete pavements. In addition, rubblization is a trial process and therefore it requires site investigation and adjustments during the execution process.

4. Implementation, Evaluation and Acceptance

The use of correct pavement modulus, design and construction is unique as there are no particular tests to determine the rubblization process apart from visual inspection as per technical standards. Test pits and a heavy weight deflectometer were used to assess the intended design modulus, and are the only methods that can be used to assess whether the rubblization of pavement is feasible. Rubblization is only applicable when there is minimal slab integrity and structural capacity of the original concrete pavement.

Rubblization is not used for projects with the following features or conditions.

- Projects that have a weak foundation or soft spots—in place soil modulus values less than 15,000 psi.
- Projects that have a high-water table, unless a drainage system is installed prior to rubblization for drying out the soils.
- Old-brittle utility lines located near the surface, which do not need to be replaced (generally within 3 feet (91.5 cm) of the concrete pavement layer).
- Concrete pavement pavements with low levels of structural distress; such as mid-panel cracks, faulting, corner cracks, etc. If the concrete pavement has remaining life, rubblization may not be a cost-effective solution.
- Concrete pavement pavements with potential slope stability problems along the shoulder, which will practically makes it difficult to rubblize.

4.1. Test Strip (or Mock-Up) for Rubblization

Before the rubblization process started, a designated test section of approximately 50 meters long by 3.6 meters wide was selected within the runway pavement. The contractor rubblize the test section using varying degrees of energy and/or various striking heights until a procedure was established that will rubblize the pavement to the required extent as contained in project specifications. The rubblized layer was visually assessed for the size of rubblized particles. After the rubblization a test pit was dug of size 1.2 meters square to determine that the breaker is producing pieces of the specified sizes as contained in the specifications. The rubblized particle sizes were checked throughout the entire depth of the pavement. The test pit material was removed from the test strip and the hole filled using aggregate base coarse material. The replacement material was placed in layers and was properly compacted.

Rubblization of concrete pavement is a trial process. Rubblization machine parameters and process specification shall be defined within a range of values that:

- Will break the concrete pavement as per the required particle sizes.
- Will keep the integrity of the existing pavement sub-grades and sub-bases.

In case of a particular pavement area is over broken or damaged by rubblization process, this entire area shall be replaced and reconstructed.

4.2. Execution

The results of two implemented test strips were used to adjust all the technical specifications, including the weights and loads to be used with the MHBs and Guillotines, the number of MHBs and Guillotines, the execution speed, the number and location of test pits, the acceptance criteria and the quality control parameters.

4.3. Compaction after Rubblization

The purpose of compacting the rubblized pavement surface is to ensure adequate seating of the rubblized segments and to provide a compacted surface upon which the HMA overlay can be placed. A vibratory roller is used to compact and prepare the rubblized surface for placement of the HMA overlay.

For the MHB, the first compaction passes are performed with a vibratory roller that are fitted with a "Z" or Elliott grid. The purpose of the Z grid is to further pulverize the broken concrete particles at the surface. A vibratory roller with a smooth drum is used for two final passes.

4.4. Rubblization Quality Control

The quality of the design and construction was ensured by performing a comprehensive concrete pavement testing that included pavement condition survey to evaluate pavement performance index, heavy falling weight deflectometer (H-FWD), execution of two test strips as a mock up to confirm acceptance of the technology. Rubblization works was successfully completed and accepted based on quality control assessments: test pits, compaction check, visual check and H-FWD after first layer of asphalt, which resulted in pavement strength above minimum requirements.

4.5. Overlay with Hot Mix Asphalt

The paving of an HMA overlay on a rubblized and compacted PCC surface is very similar to paving on a prepared crushed aggregate base. Care was taken to maintain the compacted condition of the rubblized surface up to the time of paving. A vibratory steel roller was used to recompact the rubblized surface whenever the local and/or construction traffic had loosened the rubblized surface.

The use of hot-mix asphalt (HMA) overlays presents a long-term and economical solution to the pavement rehabilitation challenge. HMA overlays increase the structural capacity of the existing pavement system and improve the long-term functional pavement performance, including: ride, noise reduction, splash and spray, friction, and general appearance.

5. Project Cost and Schedule Impact

Based on industrial literature, rubblization is expected to reduce in 1/5 of time and 1/3 of cost of traditional concrete pavement reconstruction.

During the study phases, Design Basis Scoping Paper (DBSP) and Project Proposal (PP) phases, the rehabilitation of Shaybah Airport using rubblization of concrete pavement and overlay with hot mix asphalt was estimated to cost of 1/3 to 1/2 of alternative options that entailed the full reconstruction of concrete pavement or expansion of existing runway pavement to allow parcial rehabilitation. In addition, the full reconstruction of Shaybah Runway (or alternatively the expansion to allow partial rehabilitation) was estimated to be 24 months for the construction work, while the rehabilitation of Shaybah Airport using rubblization of concrete pavement and overlay with hot mix asphalt was estimated to be seven months.

The construction work was executed in 77 days, less than three months.

The overall project cost saving (or cost avoidance) by selecting and successful implementation of rubblization of runway pavement estimated as 25% of project budget (CAPEX), and resulted on operation cost (OPEX) reductions equivalent to 9% of project budget related to the reduced costs for the leasing of an alternative airport runway.

The project cost savings were calculated comparing the below major factors. Refer to **Figure 5** and **Figure 6**:

Using rubblization of concrete pavement for runway pavement rehabilitation	Full reconstruction of existing runway pavement
Construction related costs	
Rubblization execution costs—112,000 m^2 or 35,000 m^3.	Concrete pavement dismantling, demolition and disposal, and transportation to an approved landfill—35,000 m^3.
Rubblization testing and third-party quality control.	Removal of loose sub-grade, disposal and transportation to an approved landfill—20,000 m^3.
Additional aggregate material for shoulders enlargement—8800 m^3.	Additional aggregate material for new pavement and shoulders—85,000 m^3.
Hot mix asphalt overlay costs—30,000 m^3.	Hot mix asphalt overlay costs—30,000 m^3.
Construction logistics and overhead costs	
Direct and indirect manpower for construction duration of four months—350 Manpower avg.	Direct and indirect manpower for construction duration of 12 months—550 Manpower avg.
Accommodations and services for four months.	Accommodations and services for 12 months.
Other indirect costs and logistics	Other indirect costs and logistics.

6. Impact of Rubblization on the Circular Economy

6.1. Circular Economy—Definition

The Circular Economy initiative is sponsored by Saudi Aramco Executive Management, and documented through the Circular Economy Process OE 5.4

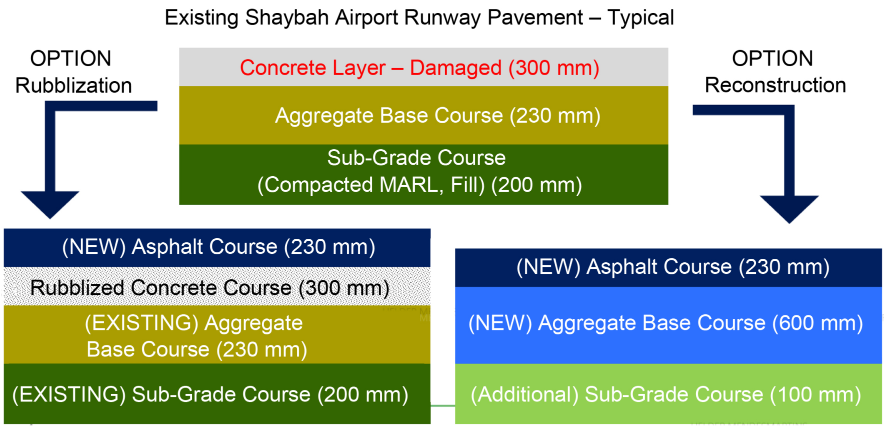

Figure 5. Shaybah Airport Runway Upgrade rehabilitation comparison—rubblization of existing pavement vs. reconstruction of existing pavement.

Figure 6. New Shaybah airport runway pavement after implementation of rubblization and overlay with hot mixed asphalt (HMA).

Document Template (by Saudi Aramco Operational Excellence Department). This initiative marks the transition from a linear business model of "take, make, dispose" into a circular framework where the design, production, distribution, use and consumption of materials are performed, to accomplish the following:

- Wastes are prevented, minimized, used as a resource, or recycled.
- Product efficiencies and life-cycles are maximized.
- Energy production is shifted to be from renewable sources.
- Natural systems are regenerated.

The Circular Economy framework is supported by seven strategies (Refer to Figure 7):

1) Designing for a Circular Economy.
2) Building Circular Supply Chains.
3) Improving Environmental Performance.
4) Extending Resource and Asset Life-cycle.
5) Utilizing Regenerative and Renewable Resources.
6) Turning Waste into Resources.
7) Adopting Digitization and Technologies.

In addition, the Circular Economy initiative adopts sustainability and leveraging

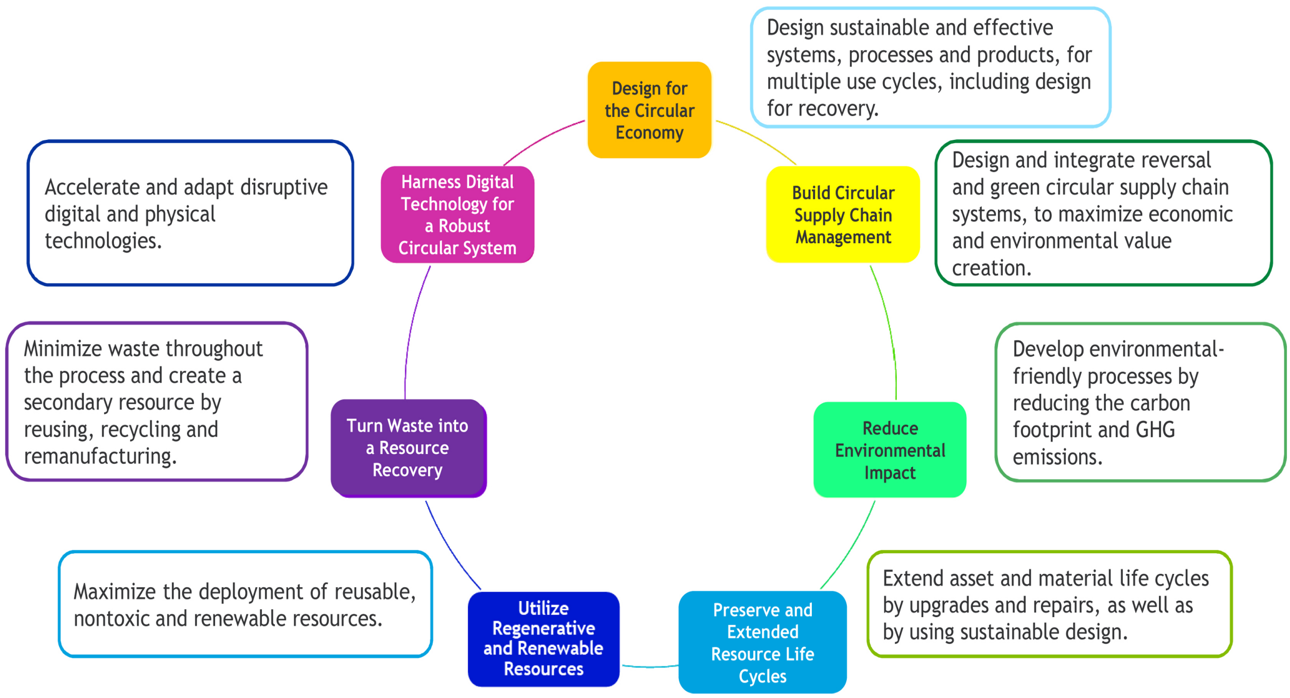

Figure 7. Circular economy—7 principle strategies.

emerging projects towards reducing greenhouse gas (GHG) emission based on the seven (7) principle strategies and 4Rs:

- Reduce—reduce the amount of carbon entering the system.
- Reuse—convert carbon to another useful industrial feedstock.
- Recycle—recycle carbon through natural processes, decomposition and combustion.
- Remove—remove carbon from the system.

6.2. Rubblization—Also a Circular Economy Testimony

Implementation of rubblization of concrete pavement at Shaybah Airport Runway upgrade, by utilizing wastes (rubblized concrete) as a raw material for rehabilitation of existing deteriorated concrete pavement, demonstrates adherence to the following Circular Economy Strategies:

- Designing for the Circular Economy, "Designs employing recycled content in a product, includes utilizing byproducts or wastes as raw material".
- Improving Environmental Performance, by "Facilitating the recovery of industrial waste and diverting it from landfills".
- Extending Resource and Asset Life-cycles, by "Extending assets and materials life cycles, by maximizing: 1) Reuse; 2) Repair; 3) Upgrade".
- Turning Waste into Resources, "Capturing opportunities to convert waste and byproducts of a system into secondary resources used as inputs for the same or another system, and minimizing waste throughout the processes".

The performance measurement of the Circular Economy implementation for the Shaybah Airport Runway Upgrade project is indicated by many factors, including the cumulative cost saving, avoidance, and revenue generation. The cost savings due to implementation of this technology is estimated as 25% of project budget (CAPEX), and resulted on operation cost (OPEX) reductions equivalent to 9% of project budget.

7. Conclusions and Future Work

Rubblization technology is more than 20 years old and recognized by many engineering societies, such as the Federal Aviation Administration (FAA), Transportation Research Board-USA and the National Asphalt Pavement Association (NAPA) as a viable option for the repair of airfields and highways deteriorated concrete pavement. Rubblization technology has been widely implemented in some countries, including the USA, Canada, and China.

Rubblization of concrete pavement is an ideal solution for pavement that has served its useful life and cannot be repaired further, or repairs will not provide further value to the asset. Concrete pavements for airfields, highways, ports, helipads and other areas that involve aircraft or vehicular traffic can be rubblized to increase the life of existing pavement.

Despite the novelty, rubblization of concrete pavement was successfully implemented for the first time in Saudi Aramco, led by the Saudi Aramco Project Management Team and Consulting Services Department throughout all of the project phases, managing the early mobilization of rubblization specialists from the USA, managing and mitigating all the risks associated with the design and implementation of the technique, procuring and managing the execution of work, and ensuring all the quality control procedures, as well as acceptance criteria, are defined early and properly monitored during the construction work.

Rubblization of concrete pavement has been effectively implemented in Saudi Arabia. As a cost and schedule effective process, rubblization is an environmentally friendly technique that supports the Circular Economy Operational Excellence initiative, and rubblization is expected to be implemented in several Saudi Arabian airfield and highway pavement projects.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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