ISSN (e): 2250 – 3005 || Volume, 08 || Issue, 12|| December – 2018 ||
International Journal of Computational Engineering Research (IJCER)

Review of Recycling Of Waste TYRE Rubber Deposits in Airfield Runway

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ABSTRACT
In the recent years, the aviation industry has extended its passenger services by deploying more number of large Aircrafts connecting all possible places across the globe. Though the passenger services are significantly increased on the one side, it has also created a serious threat on the other side with more deposition of rubber at the time of landing leading to reduced payment skid-resistance and the frictional coefficient which decides the safe landing and take-off of any aircraft in the landing area. In this paper, an attempt has been made to review and discuss the various methodologies that are used for recycling the built-up rubber deposits in the airfield runway by comparing the vehicular tyre rubber recycling methodologies.
KEY WORDS: *Rubber Deposits; Recycling of Rubber; Runway Pavement Friction*

I. INTRODUCTION

The recent introduction of larger aircrafts and the increase in aircraft operations has accelerated the deterioration of airport pavements. Nevertheless, the performance of airport pavements must still be maintained at a satisfactory level for the entire design life **(Hachiya Y. et al, 2013)**. Removal of rubber on the runway is the part of the maintenance of the runway, which is considered as a worldwide environmental threat that requires immediate attention **(Nicola Fiore et al 2017)**. The deposition of the rubber on the runways is increasing day by day in the large international airports, which produce a high amount of rubber waste on the runway. It is important to understand the fact that the non-renewable resources are decreasing in time and an efficient recycling of the waste could provide a balance between resources consumed and wastes produced. The collected rubber from the runway can be used in the fabrication of bitumen-related materials for various road construction activities and also as a part of fine aggregate in the production of concrete. Sand is commonly used as fine aggregate in concrete, but is an exhaustible material and becoming expensive due to the excessive cost of transportation from available sources **(Trilok Gupta et al 2015)**.

The available studies regarding utilization of worn-out rubber provide a strong recommendation for the use of this waste as a partial replacement of fine aggregate in concrete production **(Sallam H.E.M. et al 2008)**. This would facilitate the effective use of the solid waste, minimize the accumulation of the rubber and reduce the consumption of natural sand **(Trilok Gupta et.al 2015)**. In general, the characteristics of concrete show low tensile strength and ductility. Concrete also tends to shrink and crack during the hardening and curing process. These limitations are being tested for the improvement by the introduction of new techniques **(Mohammed Mudabheer Ahmed Siddiqui 2016)**. One such method may be an introduction of rubber to the concrete mix. The possibility of making concrete tough has been generally pursued by introducing runway deposited rubber among the traditional components like cement, water, and aggregates **(H.E.M.Sallam et al 2008)**. The rubberized concrete is reasonable with the ability to withstand more pressure, impact, and temperature when compare it with conventional concrete **(Parul Mangal 2015).**

Moving to the asphalt, experiments are being performed on the use of waste rubber in asphalt mixes to enhance the high performance, protect the environment and provide low-cost roads **(Minakshi Singhal 2016)**. The efficiency of the bituminous binders is being reduced; causing bleeding in hot conditions, cracks in a cold climate, rutting, and potholes **(Prakash somani et al 2016)**. This makes the significance in the conversion of bitumen binder to meet the increasing demand of heavy loads and traffic strength. Despite the disposal of rubber wastes, the partial replacement of bitumen with rubber in the construction of flexible pavement may give a better solidity, durability, resistance, and strength to the road as compared to the conventional asphalt **(Prakash somani et al 2016)**. Also, asphalt rubber pavements are expected to have lower maintenance costs, lower noise generation, higher skid resistance and better nighttime visibility due to the contrast in the pavement and striping **(Davide Lo Presti 2013)**. Hence in this paper, an effort has been made to understand the options that are available for the recycling and reuse of airfield runway waste rubber and its effectiveness.

II. THE AIRCRAFT TYRE WEAR

Reasons for the accumulation of the rubber depositing on the Runway

The accumulated runway rubber would be extremely soft and flexible to adopt because of its special design to absorb some of the shock when landing. Before touching the ground, the aircraft tyres are stationary but they touch the ground, wherever the rubber meets the surface, the tyres will gain rotational speed up to 1000feets or 300 meters. At that time, the aircraft tyres and runway surface is under a very high pressure right at the interface which generates friction and heat. This time is generally known as "spin up speed". The heat that is produced during the spin up speed will cause the polymerization of the rubber, or leads to a chemical reaction, which results to turn the rubber material into a very hard material that is spread as a thin layer on the runway surface. Because of the repeated landings this accumulation will be more which causes difficulty for the aircraft to land or even dangerous particularly when the pavement is wet.

According to the investigation done by "Goodyear" and "Michelin" tyre companies' maintenance manuals, the aircraft tyre has to sustain heavy loads and high impact forces along with the acceleration to the high speed within a very short period of time. Hence they suffers with much compression, shear and tensile forces because of the high temperature and centrifugal forces. These results to the damage of the tyre and hard breaking may occur at heavy high speed landing.

Centrifugal force

The strong centrifugal forces that act on the aircraft tyres are contributed by the heavy loads and high speeds which normally generates the relationship of speed versus centrifugal force. In general, the tyre rotates counter clockwise and because of the pneumatic condition of the tyre it deflects when it comes into contact with the ground. When the tyre leaves the deflected area, it attempts to return to its normal shape. Due to the generated centrifugal force and inertia, the tread surface doesn't stop at its normal periphery, thus distorting the tyre from its natural shape. Hence the tread surface sets up a traction wave.

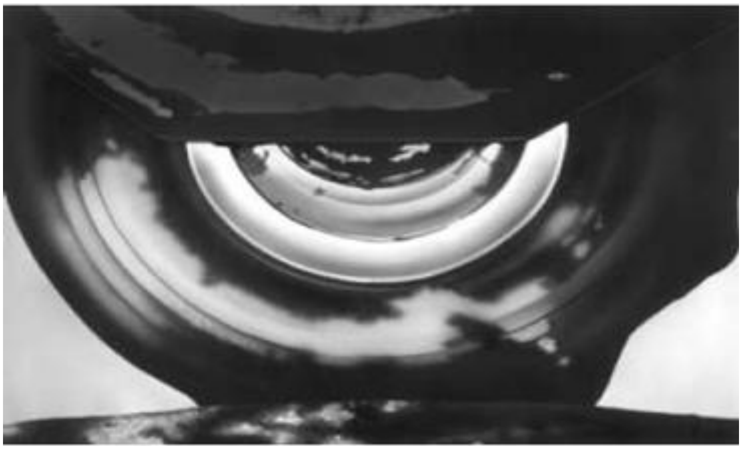

Figure 1 Traction wave in the tread surface (Source: Michelin and Goodyear)

Ozone effect on tyres

Like the other rubber products, Aircraft tyres are also somewhat affected by the extremes of weather and the sunlight. Most of the aircraft tyres are made of natural and synthetic rubber which is susceptible to ozone and will react to its presence. This will result in a degradation of the rubber which led to crack. Continued stress due to service causes the crack to grow until it is visible as a surface crack, at right angle to the direction of the applied stress.

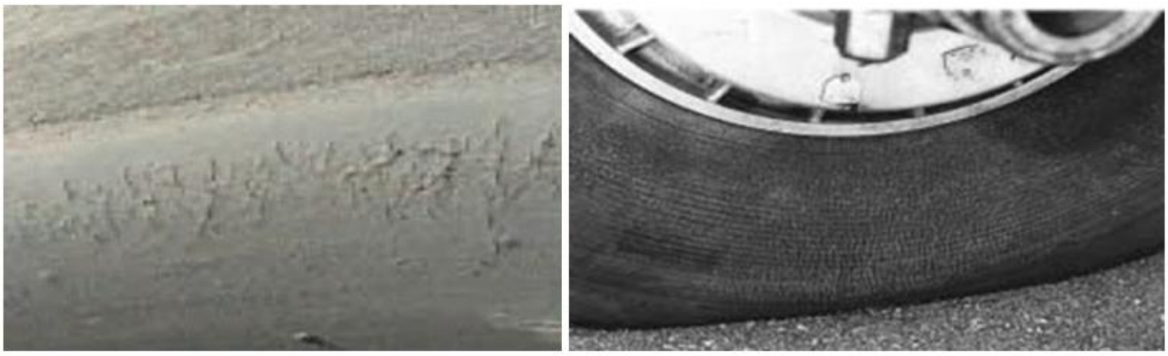

Figure 2 Surface cracks on the tyres (Source: Michelin and Goodyear)

Type of Tyre wear, Cause and Required Action

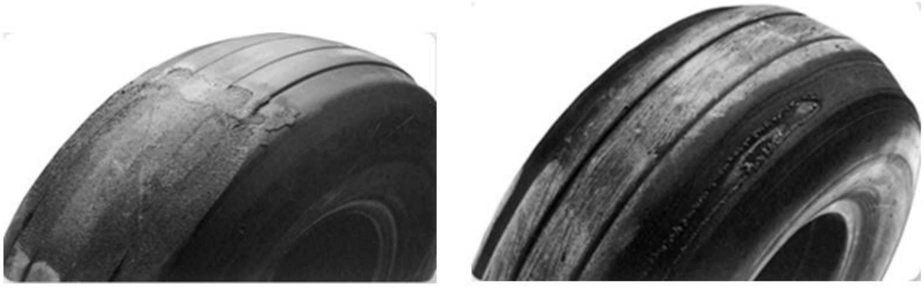

Figure 4: Shoulder wear (Source: Michelin and Goodyear)

Cause: Caused by underinflation which may lead to over stressing of the tyre. Aircraft design may also be the cause.
RequiredAction: The tyre should be removed

III. APPLICATIONS OF RECYCLED RUBBER: A REVIEW

Disposal of waste tyres from airfield runway is a challenging task because tyres have a long life and are non-biodegradable. Hence, it is necessary to utilize the waste rubber effectively with technical development. There are many different uses for waste rubber that is beneficial in helping to reduce the amount of waste rubber. The waste rubber can be used for the production of new tyres, to produce the tyre-derived fuel, for making the moulded rubber products, agricultural uses, recreational and sports applications, in Geotechnical and asphalt applications, in civil engineering applications and products like rubberized concrete, in **Automotive Industry, as Shock absorption and Safety Products.**

Recycled Rubber for Pavement Asphalt Mixtures

Niraj D. Baraiya (July 2013) reported that the waste rubber can be used as well sized aggregates in the bitumen mix which is called rubber aggregate. The research mentioned that the waste rubber that can be used is between the ranges of 5% to 20% for the additional flexibility of surface layer. The results reveal that by using the rubber aggregate, the problem like thermal cracking and permanent deformation are reduced in hot temperature. Further the experimental results confirms that by using the rubber aggregate, the conventional stone aggregate can be saved to a certain quantity and their use ultimately improves the quality and performance of road with the ability to absorb the sound which helps in reducing the sound pollution. The flexural strength of the layer increased with the heavy load bearing characteristics. On the other side of the experimental investigation done by **Davide Lo Presti (September 2013)**, that the use of rubber modified asphalts enhances the performance of the pavement in the form of a superior cracking performance at the reduced thickness. The rubber contents that can be used should be as low as 5% and as high as 25% depending on the application. The mixing, laying and compaction temperatures are comparable to standard mix. The research challenged the need for suitable blending and mixing equipment, cost of that equipment and the degree of difficulty in preparing the asphalt mix design. The experimental results clearly reveals that the initial costs are an issue but the rapid cost increase of bitumen and results of lifecycle cost analysis indicated that modified bitumen is economically convenient option in many cases. **Harpalsinh Raol et al (January 2014)** studied the use of crumb rubber in bitumen modification which helps in achieving lower susceptibility to daily and seasonal temperature variations, better age resistance properties, higher fatigue life of mixes, higher resistance to deformation at elevated pavement temperatures, prevention of cracking and overall improved performance in extreme climatic conditions and under heavy traffic conditions. This paper concludes that crumb rubber gives the satisfactory results by using it in 15% of proportion to replace the bitumen for various tests and bitumen mixes. The results showed that the Marshal Stability values of crumb rubber bitumen are 1.6 times greater than the Marshal Stability values of conventional bitumen mix. The research is done for the use of crumb rubber modified bitumen in paving applications for economizing the bitumen cost by **Foad Ali Zolfaghari et al (September 2014).** The research showed that the flexural range of Crumb rubber modified bitumen offers binders which are stable and easy to handle with enhanced performances and mentioned that using the rubber is the durable and economical solution for new construction and maintenance of wearing courses. The tests are performed by varying the percentages of rubber ranging from 5% to 25% with the increment of 5% in each test. The paper concluded that the use of crumb rubber as high as 15% had increased the stability value which is increased by 5.25% than the unmodified bitumen. The unit weight was found to be more at 15% with the values of 2.275gm/cc than the other percentages of crumb rubber. Hence it is clear that for the best results the crumb rubber content that can be used is 15% by weight of bitumen.

Sari W. Abusharar and Mustafa Al-Tayeb (March 2016) experimented on the mechanical properties of the waste rubber modified bitumen and indicated the optimum rubber that can be used for the modification is up to 5% by weight of the mix. The paper showed considerable improvement in various mechanical properties with the results of the maximum level of stability. With the introduction of more rubber into the mixture, the Marshall Stability first started to increase but then slumped after 5%. The Marshall flow started with an initial increase which was followed by a decrease with the introduction of more rubber into the mixture. Adding the rubber to the mixture decreases the air voids of the mixture and its bulk specific gravity. The appropriate amount of the added rubber was found to be 5% by weight of aggregate. This percentage results in the maximum level of stability. The study concluded that the effects of rubber on air voids, bulk specific gravity and Marshall Stability of the mixture are significant. **Yazan Issa (May 2016)** studied the change in asphalt mixture properties after adding the waste rubber. The samples are prepared by adding rubber to bitumen in the wet process with 5%, 10% and 20% by bitumen weight. The results showed that the properties of rubber-asphalt mixture are improved in comparison with normal asphalt pavement. The paper concluded that the amount of 10% of rubber by bitumen weight in asphalt pavement is desirable. The average stability increased with rubber addition up to 10% and decreases at higher percentages. At low percentages of bitumen, the average stability of asphalt without rubber is low compared to asphalt with 10% rubber. The results showed that the flow values increases with an increase in the bitumen content. The flow value of asphalt with rubber is lower in comparison with the asphalt with 5% and 20% rubber but higher than 10% rubber. The finding of this study agreed with other international studies. The study of Mashaan et.al (2013) indicated that replacing 12% of bitumen weight by rubber gave the higher asphalt stability. Several studies showed the rubber asphalt is high cost but is more accurate to consider the design life cost of pavement not the initial construction cost. Hicks and Epps (2000) concluded that the asphalt rubber pavement could be more cost-effective than conventional pavement. **Prakash Somani et al (May 2016)** examined the bitumen mix at various proportions of 2% to 8% of waste rubber. The results showed that 8% of crumb rubber in the mix gives the higher Marshall Test values. The results are increased as compared to conventional mix and proved that by adding certain amount of waste in the bitumen, it gains strength and thus become more durable and impact resistive with an eco- friendly process. **Nicola Fiore et al (June 2017)** reviewed on the Impact of bitumen modification using crumb rubber material which is obtained from a high pressure water jet (HPWJ) technique. In this they mentioned the two main techniques to use recycled rubber in fabrication of hot mix asphalt. The results should that bitumen modification using the HPWJ material results in binders that are less susceptible to changes in temperature and with high storage stability properties. In summary these experimental results suggest that new HPWJ is a promising material for the production of high quality asphalt.

Rubberized Concrete Mix Design

H.A.Toutanji (January 1996) investigated by taking four different volume contents of rubber tyre chips of 25,50,75 and 100% which resulted in the reduction of compressive and flexural strength, the compressive strength was twice the reduction of flexural strength. Specimens which contained rubber aggregates exhibited ductile failure. The toughness of the flexural specimens was evaluated for plain and rubber concrete and the results of the test showed high toughness displayed by specimens containing rubber chips. Toughness increased when rubber is incorporated into concrete. Specimens with 50 and 100% rubber aggregates exhibit equal toughness values. Rubber concrete has a reduction in strength due to the incorporation of rubber. **H.E.M Sallam et.al (July 2008)** taken three different volume ratios of crumb rubber with 10%, 20% and 30% are used in partial replacement of sand. Two different sizes of cylinders were tested as indirect tension test. In result, fine aggregate by 10% crumb rubber caused a decrease in concrete compressive strength. Crumb rubber small size used in concrete can be increased its resistance to an impact load, bridging effect is not seen in the small size of rubber hence mode of failure in rubberized concrete under static and impact compression was same as that of plain concrete. **Trilok Gupta et.al (July 2015)** studied the replacement of waste tyre rubber as fine aggregate to evaluate the density, compressive strength, water permeability, dynamic modulus of elasticity and chloride diffusion. Rubber is mixed in three different water-cement ratios 0.35, 0.45 and 0.55 with the rubber percentages of 0 to 25%. Results showed that dynamic and static modulus of elasticity, compressive strength of rubber concrete decreases with increase in the replacement level of fine aggregate by rubber. The next research is done by **Parul Mangal (September 2015)** for the replacement of coarse aggregate with rubber and studied the compressive strength, flexural strength, split tensile strength by using the different proportions as 15%, 25% and 35%. Concluded that rubberized concrete is affordable to withstand more pressure and cost-effective, can withstand impact and temperature when compare it with conventional concrete. The compressive strength of rubberized concrete is approximately 42% lower than the conventional concrete and split tensile strength is higher than the conventional concrete by approximately 35%. **Afia S. Hameed and A.P. Shashikala (February 2016)** done an experimental investigation on crumb rubber by replacing 15% volume fraction of fine aggregate to find the fatigue failure load and impact resistance. Achieved design strength is of 50Mpa and 55Mpa. Test results indicated that there was a reduction in compressive strength and modulus values. Impact resistance and fatigue failure were high for rubber concrete as compared with ordinary high strength concrete. As compared to pre-stressed concrete sleeper, the impact strength of crumb rubber concrete showed an increase of about 60%. **A.Sofi (June 2016)** tested for the compressive strength, flexural tensile strength, water penetration and water absorption of rubber concrete when the natural aggregate is partially replaced with rubber. Compressive and flexural strength values get gradually decreased in the presence of waste tyre rubber in concrete. Abrasion resistance was observed better in rubberized concrete in comparison with the conventional concrete. Scrap tyre rubber is used in the preparation of concrete by **Mohammed Mudabheer Ahmed Siddiqui (December 2016)**. Conventional coarse aggregate is replaced by scrap rubber with the percentages from 0 to 15%. Also confirmed the decrease in compressive strength for increasing rubber content. **Giedrius Girskas. and Dzigita Nagrockiene (February 2017)** mentioned that sand is replaced with rubber in concrete with the various proportions from 5% to 20%. Ultrasonic pulse velocity in concrete is modified with crumb rubber were measured in the test. Structural performance indicators of concrete specimens were calculated. Results revealed that compressive strength dropped 68-61.3%. Higher content of rubber in the specimen the spatial inhomogeneity indicator gradually increased because the greater amount of coarse rubber granule causes are always unevenly distributed of pores and capillaries. An analysis is done by **Nelson Flores Medina et.al (March 2017)** to check the mechanical and thermal properties of sustainable incorporating concrete crumb rubber. Usually, the compressive strength and bending strengths are less than 20% when compared to conventional concrete. The toughness is increased. Moreover, when rubber concrete is exposed to impact in rough surface design, the resistance of concrete is ever greater. Results mentioned that the rubberized concrete can be used as the pre-cast concrete because of the considerable bending strength and the lower thermal conductivity.

Rubber as Tyre – Derived Fuel

Ewa Rostek and Krzysztof Biernat (2013) have done an investigation on the method for the transformation processes of waste rubber for Energy Carriers. The study illustrated the complexity of the decomposition of changes as a result of the size of the energy and type of chemical bonds. The paper described there are many problems regarding the possibility of using waste tyre rubber as raw the material for the preparation of liquid energy carriers for transport or directly to energy use. **M. R. Islam et al (2013)** mentioned that the liquids produced from the waste tyre have been found to have a high gross calorific value (GCV) of around 44 MJ/kg, which would encourage their use as replacements for conventional liquid fuels. The contained concentration of Pyrolysis gas was mostly of methane, ethane, butadiene and other hydrocarbon gases with a GCV. Pyrolytic char may be used as a solid fuel, activated carbon, printers ink etc. The higher sulphur content and lower flash point are problematic properties of tyre-derived fuel but density, viscosity, GCV, carbon and hydrogen contents are found almost comparable to those of the commercial diesel fuels. The liquid may be used as diesel fuel by blending them with petroleum refinery streams.

Amir Rowhani and Thomas J. Rainey (October 2016) documented that the conversion of tyre rubber components into bio-oil is one of the most important methods for sustainable environmental stewardship. This paper is focused on the combustion of waste tyres to produce biofuel to recover the energy in the furnaces, boilers, and burners. The paper concluded that hydrothermal liquefaction is not the very applicable method for scrap tyres. Further the discussions reveal that the oil yield is predominantly dependent on temperature, heating rate, and reactor type after reviewed waste tyre pyrolysis. **Dilan Irmak Aslan et al (June 2017)** mentioned the Pyrolysis process of combustion for the potential waste management solution for waste tyres. Pyrolysis process produces liquid, gaseous fuels, and a solid char in the absence of oxygen. The paper stated that the full understanding of the reaction of kinetics and mechanisms are necessary to perform the experiments. Concluded that the paper is the first study that performed the research for the applicability of various reaction models to pyrolytic decomposition of the waste tyre. The Pyrolysis process is conducted by **Saddiq H.A et al (August 2017)** in the absence or with limited oxygen for the combustion of rubber material to obtain a solid product called char, the liquid product called tyre pyrolysis oil and the gaseous product called pyro-gas. In a laboratory tyre pyrolysis oil was produced in a simple distillation setup and obtained product from the pyrolysis is found to be 55% Tyre Pyrolysis Oil, 35% solid char and 10% pyro-gas. It is recommended that the sulphur has to be reduced using desulphurisers if the oil is to be used as fuel in internal combustion engines. It is therefore recommended that pyrolysis oil cannot be used alone as fuel in internal combustion engine but can be blended with diesel to obtain a right quality of fuel for use in internal combustion engine.

Other Applications

Das Tapas and Singh Baleshwar (March 2013) worked out on benefits and impacts of scrap tyre use in geotechnical engineering and stated that the shredded rubber can be used for the applications in geotechnical field as embankment fill, retaining wall and bridge abutment backfill, insulation layer to limit frost penetration, vibration damping layer and drainage layer. The paper mentioned that Carbon black is added to strengthen the rubber and increase abrasion resistance and the extender oil used in fabrication is a mixture of aromatic hydrocarbons that acts to soften the rubber and increase its workability. To prevent high- temperature deformation, Sulphur is employed to harden the rubber by cross-linking the polymer chains. To prevent deterioration of the rubber complex, antioxidant and other additives are also added. Concluded that the adsorptive properties of tyre rubber for retaining nitrogen and phosphorus can be beneficially used beneath sand-based root zones of athletic fields and golf courses. **Daniel Kyser and Nadarajah Ravichandran (May 2016)** has proven that the rubber waste is used for the roofing membranes are now being disposed of by chipping the waste sheets into uniform, angular chips roughly 1–2 mm in nominal diameter. Tests were performed on sand mixtures in ratios by weight of 100%, 75%, 50%, and25%. The paper mentioned that the shredded roofing membrane is fire resistant. The results show that the new composite material is lightweight but has high permeability and friction angle that are comparable to a granular soil. Based on these properties it is believed that the new material can be used as light-weight retaining wall backfill, drainage layer in landfills, as the insulator in roadway subgrade sand embankment fill because of low dry unit weight, be resists against shearing, and be porous. **Preeti Sharma et.al (April 2016)** mentioned various methods for the management of waste rubber by Landfill, Crumbing, DE vulcanization, Remould, Incineration, Tyre Derived Fuel and Pyrolysis. The paper mentioned that pyrolysis is a process of converting waste rubber into Pyrolysis oil, Carbon black and hydrocarbon gas. It is stated that Heat and catalyst are required for the reaction of molecular breakdown where larger molecules are broken down into smaller molecules.

IV. EFFECTIVENESS IN THE FORM OF COST AND HANDLING

The percentage savings represent the percentage of the total cost saving over conventional hot mix asphalt by using rubberized hot mix asphalt. The cost-effectiveness of using asphalt rubber depends on the location of the project and functional class of the road. In many types of researches, it is concluded that by using the waste rubber in asphalt mixes, the initial costs are an issue but the rapid cost increase of bitumen and results of lifecycle cost analysis indicated that modified bitumen is the economical convenient option. The handling of rubberized asphalt is easy because of the low weight and softer binders that are produced. The storage stability is considered as one of the main concerns related to the use of asphalt rubber in the fabrication of rubberized asphalt and it can be overcome by incorporating the additive dosages to provide the required storage stability. Moving to the rubberized concrete, the flexibility for handling is easy compared to conventional concrete because of the incorporation of the lightweight material like rubber in the place of natural aggregates. The workability of the rubberized concrete is also high compared to normal concrete. It also stated that it is economical because of the replacement of the high-cost natural aggregates like sand and also the transportation costs of the mineral aggregates reduce. In the production of fuel by using the rubber, it is costly including the transport of the waste rubber to the refinery plants and the studies showed the handling of these fuels shows complexity because of decomposition changes and as a result of the size of the energy and type of chemical bonds.

V. CONCLUSION

From the experimental investigation carried out by various researchers on the reuse of waste rubber deposits, it is evident that the use of waste rubber for the production of modified asphalt and rubberized concrete is the cost-effective and ultimate solution for recycling and reusing of rubber waste. Though the rubberized concrete compressive strength decreases with the increase in the replacement level of fine aggregate by rubber, many research papers concluded that rubberized concrete is affordable to withstand more pressure, impact load and temperature when compared to conventional concrete. It is advised to use the waste tyre rubber powder for the preparation of Activated Carbon for the waste water treatment to remove heavy metals like lead and cadmium.

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