The Viability of Using Recycled Rubber for Load Bearing Structures

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Abstract

The objective of this research project was to investigate the feasibility of using recycled rubber as a component of load bearing structures. There have been several studies into using recycled rubber as an aggregate in concrete, which shows promising results. Additionally, a team of students at Oakland University researched and tested if crumb rubber can be used to make a rail tie. Multiple design variations were configured with two different binder ratios (11% and 12%) and different insert shapes, which were tested to find what combination performs the best and can handle actual railway loads based on American Railway Engineering and Maintenance-of-Way Association (AREMA) standards. A variety of potential structural applications where recycled rubber can be used were investigated and a determination of best practices was recorded.

Keywords: Crumb rubber, load bearing structures, recycled rubber, engineering

Current Research

With an increasing push from the government for industries to become more environmentally friendly, new research has begun to look into how rubber can be recycled for new uses. Tires make up a large portion of the rubber that is put into landfills and with growing concerns over the effects of climate change, more must be done to engineer better products that do not have a negative impact on the environment [9]. One of the uses of recycled rubber that is emerging as a popular option is the use of recycled rubbers in load bearing structures such as concrete or rail ties. According to the Rubber Manufacturing Association (RMA), 26% of scrapped rubber tires are repurposed as crumb rubber each year [9]. Crumb rubber is scrap rubber that is ground up into uniform sizes, which can range from dust particles to half inch particles. Adding rubber to concrete mixtures improves the structural properties of the concrete [1]. This recent discovery is a promising step towards using rubber for building new structures. The recycled rubber reduces manufacturing costs, improves the performance of the concrete, and reduces the amount of rubber that is disposed of in landfills and harmful chemicals released by burning the rubber. Additionally, adding 15% crumb rubber to a concrete mix showed to increase the energy absorption of the material, proving that adding rubber improves performance and durability [2]. By confirming that the addition of the rubber improves the mechanical properties of the concrete, it can be argued that the recycled rubber should be used in future structural applications to improve the design. Furthermore, the amount of rubber used in these materials also affects the mechanical properties that are important for supporting loads; it was found that as the composition of rubber increased in various concrete mixtures, the compression toughness and deformation characteristics drastically improved [3]. Rubber has elastic properties, so the more rubber there is the more elastic the material will be; however, it is important to note that too much rubber will reduce the strength of the material

Another potential application for the use of recycled rubber is to make rail ties. Typically made of wood, rail ties are structured as standard rectangular beams that have dimensions of 7x9x96” which could easily be made by press molding rubber. For instance, patent research into the topic of rubber rail ties yields only a few results, meaning there is still much unknown for the use of rubber rail ties. For example, the US patent number 2004/0232253 held by Hansen Ties cites their own test data which states that their rubber rail tie exceeded AREMA standards for bending moments, rail seat compression, rupture moment, and spike insertion/ withdrawal [4]. The rubber rail tie produced by Hansen Ties shows an improvement from using the wooden rail ties; using these rubber rail ties instead of the wooden ties improves the mechanical properties of the railway such as by increasing the bending moment force allowed, rail seat compression force, and the impact loads while it is also better for the environment by reducing the need to cut down trees and treat the wood with harmful creosote additives. The wooden rail ties are soaked in creosote to make the wood last longer, but it has been found that the creosote-soaked rail ties can leach polyaromatic hydrocarbons and nitrogen heterocycles into the environment [10]. Both of these chemicals are harmful to both humans and the environment, so there is a major concern about the ongoing effect that the use of creosote will have. Additionally, the use of rubber in railway ties is shown to increase the impact resistance, which is important since as the train wheels pass over the rail it applies impact loads to the rail ties [5]. The rubber rail ties are better at absorbing energy from loads applied by the passing train. To add, the rubber also improves the fatigue strength and the elastic properties of the rail ties [5]. The use of recycled crumb rubber in rail ties improves the durability and elasticity of the rail ties which is attractive to railroad companies who can implement these rail ties to reduce maintenance costs on their railroads and do not need to be replaced as often.

Another topic that will need to be explored for rubber rail ties is to determine the best process for producing the molded rubber. The recycled rubber can be shredded down to various crumb sizes. The correct crumb size, temperature of the press mold, and pressure applied to the material must be found in order to produce the best-performing rubber since different processes lead to different structural properties for rubber [6]. The size of the crumb particles can affect the adhesion of the resulting composite.

There is a noticeable gap in current research into the applicability of rubber rail ties, which the team at Oakland University addressed through their research project. More research needs to be done to refine the ratios of crumb rubber to binder that can be used to produce the best-performing press molded rubber ties. Furthermore, there is some data already collected showing improved mechanical properties of rubber rail ties, but there has not been enough testing done to corroborate the existing research. The team at Oakland University will focus on the most important test requirements for rail ties which include bending strength, rupture strength, rail seat compression, and Shore hardness of the rubber.

Aims and Objectives

Introduction

The effects of climate change and its impact on the environment has led to a push to become more environmentally friendly, which includes finding ways to reuse existing materials for new products. According to the Rubber Manufacturing Association (RMA), around 300 million scrap tires are produced annually in just the United States [9]. There is a large market potential for these scrap tires since currently, 40% are used in tire-derived fuel, 26% are used in crumb rubber, 13% are dumped into landfills, and only 5.5% are used in civil engineering applications [9]. In developing countries, the issue of old tires in landfills is even worse since there are not as many defined practices for what to do with the used materials. The process for recycling used tires consists of separating the metal, textile, and rubber so that the materials can be reused [8]. Discovering useful applications for reusing the rubber from tires is an attractive opportunity for businesses to generate new profits while also providing a positive impact on the environment. It is particularly useful for developing countries, where these new practices can be adopted to provide cheaper housing or lower construction costs in general. In this thesis project, the use of recycled rubber for load bearing applications was explored by analyzing data from previous research and synthesizing it with new research conducted by a team at Oakland University. The main applications that were studied are concrete and rail ties, while the potential for new uses were also explored.

Aims

1. To investigate the viability of recycled rubber as a component of a load bearing structure such as concrete or a rail tie.

2. To analyze data from a prototype crumb rubber rail tie fabricated by a team at Oakland University.

3. To investigate the relationship between the percentage of crumb rubber in a material to the structural properties it has.

Objectives

1. Examined the accuracy and viability of previous research for the applicability of rubber in structural uses, this was then applied to find gaps in current knowledge to identify what areas need improvement. For example, the research done by the team at Oakland University was applied to gain a further understanding of how well the molded rubber works under loads and stresses. This data was used to validate the potential future production of rail ties made of molded rubber and further the industry towards using rubber in more structural applications.

2. Made determinations based on collected data of the modeled rubber rail tie which assisted in finding conclusions as to whether or not rubber can reliably be used as a load bearing structure in a railroad application. By using SOLIDWORKS to run finite element analysis (FEA) to test how the product will perform under stresses and loads, the team at Oakland University was be able to theoretically prove the viability of the rubber rail tie and which will lead Airboss to pursue further testing on full-scale physical parts after the project has concluded.

3. Identified the ideal crumb rubber ratio for a material to optimize its performance which provided the industry with a good basis to formulate new designs using crumb rubber. This research can be applied to become the new industry standard for applications where strong rubber is needed.

Methodology

The team at Oakland University first produced a variety of rubber samples in order to test the properties of the crumb rubber composites and determine the right ratio of rubber to binder. The properties found in these tests were then used to conduct FEA on a variety of different design options to find the best performing model. Variations of the percentage of binder in the crumb rubber, the insert shape, the insert material, and the placement of the insert were analyzed by testing the positive bending moment, negative bending moment, and the rail seat compression. The stresses and deformations were compared to determine which model performed the best. These specific tests were chosen since they are specified by AREMA as standards for rail ties. A few different insert options were explored such as a hollow steel tube, an I beam (steel or aluminum), and steel rods. After FEA was conducted on each design variation, it was decided that the insert will be the steel W6x25 I beam insert. An insert was used in this design to improve the stiffness of the rail tie. With the insert, the rubber rail tie will be able to hold more weight and have less deformation under loads. The addition of the insert complicates the rail tie product but is necessary for providing the needed properties to make the rail tie competitive in the market and safe for railway passengers. The FEA tested the bending strength, rupture strength, and rail seat deformation. The data from these tests will be compared against the AREMA standards to determine whether or not the designs met the level needed to safely replace wooden rail ties. If the test data meets or exceeds the AREMA standards, then it can be concluded that the rubber rail tie design has potential, leading AirBoss Flexible Products to pursue further testing on prototype parts and eventually bring the product to the market.

Concurrently, a literature review of current research was conducted to gain a better understanding of the background of recycled rubbers used in load bearing structures. Emphasis was placed on the use of recycled rubber as an aggregate in concrete and the use of crumb rubber to press mold structural supports. This research was conducted to find consistencies in different research to make a better determination of if recycled rubbers can be reliable in load bearing applications.

Outcomes

The engineering field is always looking to innovate and find best practices, especially those that can benefit the environment while also improving the design of a product. This thesis further investigated the use of recycled rubbers in structural applications in order to validate the claims that recycled rubber is a sustainable alternative that exceeds the performance of existing materials in use. One major goal of this study was to provide AirBoss Flexible Products with a modeled rubber rail tie and reliable test data that proves they can pursue bringing this product to market through mass production. An additional goal was to further study existing research that has been conducted on the use of recycled rubber in various construction applications such as concrete, road materials, and manhole covers.

One goal of this research was to prove that crumb rubber is a useful material for use in load bearing structures. The test data found in this study was used to justify that the company sponsor, AirBoss Flexible Products, can potentially bring the full-scale product to production and successfully sell the improved rubber rail ties to railroad companies to improve their railways both mechanically and environmentally. An aspiration of this study was to prove the usefulness of recycled rubber so that the rubber waste can be reduced, which would have a positive impact on the environment. It is expected that further research will build upon this study to further the understanding of using recycled rubbers in load bearing applications and lead to the development of new products that use more sustainable materials.

This research project furthered my own understanding of academic research and the process of developing a new product from the initial stages. This benefits me both academically and professionally since it gave me the opportunity to gain experience working in a research group. This is so beneficial for me as I move into the workforce since a lot of the processes that I worked through in this project I will have to also do as an engineer such as research and development, working with a team, weekly presentations, patent research, answering to customer expectations, etc.

Results

Crumb rubber rail ties

First, rubber samples were fabricated to determine the best percentage of binder to add to the rubber samples to yield the highest Shore hardness along with testing different pressures for molding the rubber during the curing process. The team determined that the best practice was to use 11% binder with 6kN pressure on the rubber, which yielded a Shore hardness of 60, a Young's Modulus of 29.59 MPa, Shear Modulus of 11.07 MPa, and a Poisson's ratio of 3.10. This sample test data was then used to conduct accurate FEA by using the exact rubber values from the rubber that was fabricated. This way we were able to directly model the rubber-binder specimens made in the lab through SOLIDWORKS. Models of the rubber rail tie and inserts were made in SOLIDWORKS and FEA was conducted to test the rail seat compression, positive bending, and negative bending. The rail seat compression test was especially useful in modeling how the rail tie would behave under the load of a train car.

After conducting extensive finite element analysis on the crumb rubber rail tie, along with several different design variations that consisted of different insert shapes and materials, it was found that the rubber rail tie with the W6x25 I beam made of A992 steel performed the best. This design was found to have several test specifications that beat the AREMA standards. For instance, the design was found to have a deformation of only 0.142 inches whereas the pass criteria for the rail seat compression test was that under 100 kips of force, the area of the rail seat should not compress more than 0.25 inches. Additionally, the Modulus of Elasticity (MOE) was tested in the center negative bending test which AREMA's standard lists 170,000 psi, while the rubber rail tie design has an MOE of 2,615,000 psi. Furthermore, the Modulus of Rupture (MOR) was found to be 6,770 psi. This test data confirms that the rubber rail tie with the steel I beam insert developed by the team at Oakland University is a feasible design to be used in a railroad since it meets or exceeds the AREMA standards; however, the test data does not beat the specifications of a comparable rubber tue made by a competitor. A rubber with a higher Shore hardness should be used to fabricate the crumb rubber rail tie.

The compressive strength of the rubber-binder specimen was also tested using an Instron Testing Machine to conduct compression tests. The initial tests carried out at rates of 5, 3, and 2 mm/min on the sample resulted in no formation of visible cracks. The rubber specimen resumed its original position after being fully compressed. Subsequent testing at 1 mm/min on the specimen resulted in an extremely small, but observable crack near the center of the specimen. This test was carried out on two specimens, the first at 5 mm total compression (5 min), the second at 7.5 mm (7.5 min), with the observed crack only appearing during the compression of the latter test. After the compression plates were removed, the specimen once again resumed its initial dimensions, and the crack was no longer observable. A compressive stress-strain curve of the specimen is shown below in figure 1, based on the data for the specimen that was compressed 7.5 mm. This test was halted after a crack was observed at 4.76 MPa.

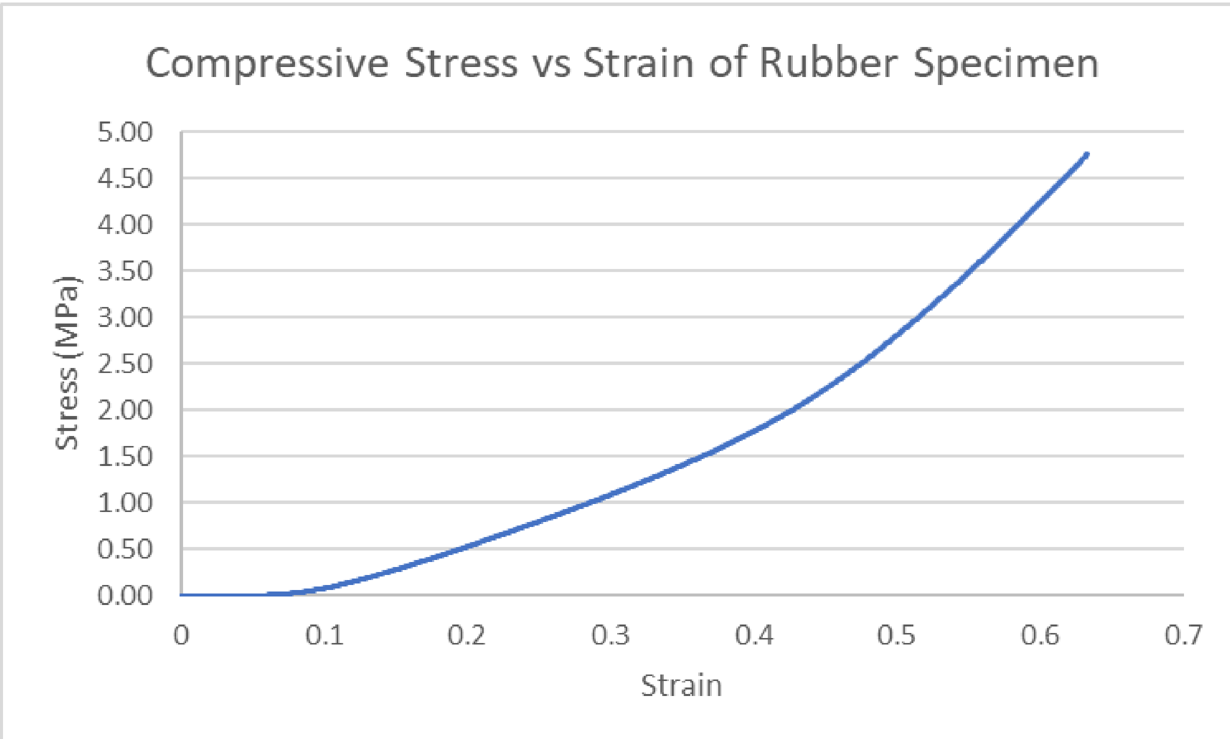

Figure 1: Compressive Stress vs Strain of Rubber Specimen, 1 mm/min Compression Rate, 68° F, 7.5 mm Total Compression (7.5 min)

Environmental testing was also conducted to ensure that the rubber rail ties would not provide a risk to the environment or easily degrade while being exposed to the elements. A leaching test found that after 48 hours submerged in water, the rubber leached Cyanuric Acid. The water went from ~100 PPM of Cyanuric Acid at hour 0 to >300 PPM after 48 hours. Cyanuric acid is classified as “essentially non toxic;” however, it can be dangerous to wildlife in higher concentrations which is possible if an entire track were to be converted to the rubber rail ties. The water leaching tests pose a concern to how the rubber rail ties could affect the surrounding ecosystems. Additionally, a UV degradation test was completed and found no noticeable cracks or deformation after 1 week of exposure to sunlight and UV. Additional testing during other seasons may be done to further validate this testing and an additive such as Avobenzone or Benzophenone can be considered to prevent any UV degradation. Furthermore, a temperature test was performed on the rubber-binder composite samples, with pieces being left in a heat oven/ freezer at temperatures of -4°F and 250°F. Two samples were hot/ cold soaked then tension tested. It was found that the sample exposed to 250°F had no noticeable change in comparison to samples at room temperature's tensile stress-strain curve, while the sample at -4°F showed a slight decrease in Young's Modulus. Longer exposure tests with more samples must be completed to gain a better understanding of the full scope of the effect temperature will have on the rubber.

Crumb rubber as a concrete additive

A literature review was conducted to investigate the viability of crumb rubber as an ingredient in concrete used for structural applications. It was found that adding the recycled rubber into the mix in a range of 10% to 20% crumb rubber of the was most effective in maximizing the positive mechanical properties of the crumb rubber such as elasticity and durability. Most crumb rubber volume totals in aggregate concrete mixes were found most effective around 15%, with improvements in resistance to cracking under impact loads by 80-100%, improved elastic properties, 40-60% higher impact resistance, and better fatigue strength [2]. Further results have shown that fatigue failure and impact resistance were improved when compared to ordinary concrete [6]. The rubberized concrete is more durable than regular concrete, leading to a longer lifespan which will reduce maintenance costs. To add, the impact strength was increased by 60% from the ordinary concrete design [6]. The rubberized concrete can absorb more energy leading to a higher impact strength due to the rubber's elastic properties. The crumb rubber when added to concrete mix ranging in volume from 10-20% improves the durability and strength of the concrete [6]. Over 20% crumb rubber added to the concrete mix leads to large decreases in strength characteristics, making the rubberized concrete over 20% rubber not useful for structural applications. An increase in the percentage of crumb rubber in a concrete mix directly increased the material's ability to absorb compression energy, also known as compression toughness [3]. Compression toughness is important for structural building materials because it is a measure of how well the material will be able to withstand heavy variable loads over long periods of time. A material that deforms elastically will return to its original shape after the stress has been removed, which is vital for structural materials. Maintaining high strength, toughness, and durability in building materials is important for the safety and durability of the project application, otherwise it is not reasonable to use that construction material. It is important to get the correct percentage of crumb rubber in the concrete mix so that the material has the necessary specifications to maintain a safe design. A review of studies conducted on rubberized concrete concluded that the addition of rubber in concrete mixes improves the energy absorption and ductility of the concrete [9]. Rubberized concrete could be useful in the construction of earthquake resistant structures since it can better absorb the shock waves.

Besides the mechanical advantages, adding rubber to the concrete also provides some additional benefits. For instance, it was found that the rubberized concrete has better thermal, water, and noise insulation when compared to typical concrete [8]. Furthermore it was observed that sound waves measured over rubberized concrete reduced in velocity by 20-30% compared to just 14-21% in standard concrete [8]. Sound does not travel as well over the rubberized concrete, which makes it useful in applications that could benefit from the noise reduction such as tunnels. Another study concluded that rubber-modified concrete reduces noise transmission and thermal conductivity, which improves the energy efficiency of the building [9]. Several studies have found that rubberized concrete improves thermal insulation and noise reduction, with the benefit of improved energy efficiency as a notable selling point. These results show that the rubberized concrete would work well in applications where it may be useful as a non-primary structure as well, such as a shock absorber in a sound buffer, roadblock, on the outer surface of tunnels, highway embankments, or retaining walls.

Additional Applications for Crumb Rubber

While the use of crumb rubber in rail ties and as a concrete aggregate can be effective, there are also other applications where crumb rubber can be useful. Based on the data found that supports the use of rubberized concrete, it can be reasoned that rubber can also be used for asphalt, culverts, retaining walls, crash barriers, highway embankments, bricks, mortar, steel-concrete beams, and other similar applications. The use of scrap tires as construction materials in civil engineering is gaining interest in recent years due to the increasing availability, low weight of the material, compressibility, and low thermal conductivity [9]. Rubber is an attractive material for construction due to its appealing characteristics and low cost. It is especially gaining the attention of developing nations that have an abundance of scrap tires and lack proper construction materials. The use of recycled rubber to build improved infrastructure in these developing countries could lead to more economic development.

Another example of an effective use for scrap tire material would be manhole covers. It was found that manholes constructed from scrap tires performed better in load-bearing tests and had a higher load capacity, improving the load- bearing capacity by 5-14 kN [9]. Furthermore, the 75mm thick conventional manhole cover has a load-bearing capacity of 11.3 kN, while the 75 mm thick manhole cover made from recycled rubber was found to have a load-bearing capacity of 12.75-16.6 kN [9]. Additionally, a 100 mm thick manhole cover made from the scrap tire was determined to have a load-bearing capacity of 17.0- 25.5 kN, proving that in each case the manhole cover made from scrap rubber performed better than the conventional manhole cover [9]. The 100 mm thick rubber manhole cover performed better than the 75mm thickness, as expected, but both variations of the rubber manhole cover performed better than the conventional cover. This verifies that the rubber manhole cover can be reliable since it can withstand the loads it will bear from vehicles and pedestrian traffic on the road.

Discussion

The results from this study are important in laying the foundation for future methods of developing sustainable alternatives for structural designs. This study used recycled crumb rubber to prove that it is a viable material to be used in both rail ties and concrete mixtures. The properties of the rubber enhance the mechanical performance of both the rail tie and the concrete due to its deformation and elastic properties allowing for better energy absorption. These characteristics allow the rubber structures to withstand more compressive stresses without cracking.

The steel I beam insert was added to the rail tie to provide added stiffness and strength to the overall tie. As the rail tie undergoes loading the insert will aid in reducing and responding accordingly to bending, buckling, and torsion that occurs with the movement and load of a locomotive car. The I beam also improved the way the rails are connected to the rail ties since the spikes are inserted into the steel to make a more secure fastening point. Pre-drilled holes will need to be machined into the steel to allow for the spikes to be inserted. The steel I beam improves the other functionality of the crumb rubber rail tie.

Recycled crumb rubber was also found to be a viable ingredient in concrete mixtures for structural applications. The crumb rubber improves the concrete with better durability, higher ductility, and better functional properties, which is better for load bearing applications because the concrete is able to handle larger loads for longer periods of time. It was also observed that rubberized concrete did not have any sudden failures when being tested under variable compressive loading conditions, which is desirable in many constructional applications. Furthermore, rubberized concrete can be utilized in tunnels to reduce excess noise due to its better sound absorption qualities as rubber rail ties have already been proven to be effective at reducing railway noise due to the rubber’s dampening characteristics.

Manhole covers are another useful application for scrap rubber from tires. It was found that the load-bearing capacity of the rubber manhole covers is better than conventional manhole covers. One major issue with conventional manhole covers is that most are made from steel, which causes the manhole covers to be stolen and sold as scrap for money. By replacing these expensive steel manhole covers with cheaper, rubber covers it will eliminate the issue of stolen manhole covers while also providing a more economical option for manhole covers. Reducing the theft of these manhole covers will also improve the safety of cities since missing manhole covers can cause injuries from pedestrians falling into the open hole or a driver not seeing the gap in the road. Manhole covers made from recycled rubber are an effective alternative to steel covers since they reduce cost, deter theft, and perform better under loads.

Conclusion and Future Directions

The results from this study demonstrate that a rail tie made from recycled crumb rubber with a steel insert has the potential to be used on railroads and that rubber is an effective material to be used in structural applications such as concrete or manhole covers. The rail tie would perform better if made from a rubber with a higher Shore hardness. The crumb rubber rail tie meets the AREMA standards, but is not competitive with the rubber rail ties produced by Hansen's Ties. Increasing the Shore hardness of the rubber could prove effective in not only improving the specifications of the rail tie, but could also eliminate the need for the steel I beam insert, or potentially allow for a cheaper insert material to be used successfully.

Further studies are needed to fully understand the safety, durability, and effectiveness of the crumb rubber rail tie. Full-scale prototype parts are necessary to properly test the rail ties to see how they compare to the AREMA standards and verify that the FEA taken in this study aligns with a real life model. Durability tests are an important part of the testing process which will need to be done to determine the life cycle of the crumb rubber rail tie. It is expected for the rubber rail tie to last longer than the wooden rail tie along with requiring much less maintenance, which is another strong advantage for the marketability of the crumb rubber rail tie.

It was found that concrete mixes using a percentage of crumb rubber mix ranging from 15% to 20% performed the best while minimizing any potential downsides. For example, it is best that the crumb rubber does not exceed over 20% of the total aggregate to avoid large reductions in compressive strength. More research must be done to investigate other potential uses for recycled rubber in load bearing applications such as using crumb rubber as an ingredient in bricks, to make manhole covers, or in various load bearing composites/ polymers. Through extensive research in this study, the results can be used to determine that crumb rubber is an effective material to be used as an ingredient in load bearing materials while also reducing the impact of rubber on the environment by finding new applications for recycled rubber.

In addition to rail ties and concrete, the use of crumb rubber in construction applications such as manhole covers, asphalt, culverts, retaining walls, crash barriers, and highway embankments has great potential. Research has confirmed that all of these applications could be supplemented by crumb rubber due to the rubber's damping characteristics, light weight, and compressibility. The rubber manhole covers had better performance in a load-bearing capacity test and were less than a third of the cost of the conventional manhole covers. It is clear that the rubber manhole covers are an improvement to the current design and should be widely adopted after further testing is done on the durability and lifespan of the product. Rubberized asphalt is a good option for road surfaces due to the wide availability of scrap rubber and its damping characteristics which can reduce road noise. Additional research should be completed to ensure the durability of each application due to how new these rubberized products are. It can be reasonably determined that there is great potential for the use of recycled rubber as reinforcement in structures, which has a profound impact on improving sustainable construction practices around the world.

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Biographical Note

John Chippi is an Honors College student at Oakland University studying Mechanical Engineering in his Senior year. He has a professional background in the automotive industry with 3 years of experience, dealing with product design for closure systems. He also has 4 years of engineering experience prior to College from his High School's engineering program. Upon graduation, he plans to work full time starting this summer and pursue a Masters of Engineering Management from Oakland University in the fall. Completion of this Masters program will allow him to pursue leadership roles in his respective field and have a greater impact on the industry. He is interested in a career in the automotive field but also looking to expand his experience into other industries as well to become a more well-rounded engineer.

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Citation Style: APA

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