A SPRAY BASED CRUMB RUBBER TECHNOLOGY IN HIGHWAY NOISE REDUCTION APPLICATION

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ABSTRACT

Crumb rubber is a commodity made by re-processing (shredding) disposed automobile tires. This article presents a new technology development on the application of crumb rubber in highway noise reduction systems. Advantages and disadvantages of two commonly used manufacturing processes (molding and spray) of crumb rubber panels are analyzed. It is shown that for the intended application, a spraying process is much preferable. Four types of spray devices are further examined. The bonding agent selection and the mix design are investigated. A number of crumb rubber panels are made by the spraying process, and the test of acoustic absorption (ASTM C423-90a) is performed on one type of the panels. The acoustic testing result shows that crumb rubber panels exhibit an excellent noise reduction capability. The future work to continue the current progress is also discussed. The theme of this article is to present the progress made in advancing this technology-product development as well as the feasibility and promise of what it can do for solving two environmental problems, scrap tires and traffic noise, simultaneously.

INTRODUCTION

Annually, more than a quarter billion of automobile tires are disposed in the U.S.A., and most of them are dumped in landfills[1]. What to do with the disposed tires becomes a problem for environmental protection more and more each day. It appears that the best way to solve this problem is to re-use the scrap tires in production of various products. The first step moving toward the reuse of scrap tires is to re-process (shred) them into small pieces with the fiber and metal removed, which is called crumb rubber. Crumb rubber can be used in a wide variety of rubber material applications. The industrial-scale based technology for re-processing scrap tires into crumb rubber started in the 1950's and became mature in the 1970's. At present in the U.S.A., a few dozen of re-processing plants are in operation, and they provide crumb rubber with different size gradations as a commercial commodity. Now the issue becomes how to "consume" crumb rubber.

Currently the biggest customer for consuming crumb rubber is the asphalt pavement industry. Adding crumb rubber into asphalt forms crumb rubber modified asphalt (CRMA). This rubberized asphalt then can be used as part of the hot mix asphalt (HMA) to build roads, highways, and other facilities like parking lots, etc. However, CRMA costs more as much as 30% in some cases on a ton-per-ton basis in comparison with "conventional" asphalt pavement that is without any additives. In addition, the demand for asphalt is quite flat in recent years because few new roads and highways are built, and the volume of asphalt needed in repairing roads and pavements is limited. Also, the market demand for CRMA rests solely in the hands of materials engineers in each independent state, county or municipal paving agency. If a paving agency does not use CRMA, then the market in that region would be non-existent. As such, the whole amount of crumb rubber used in CRMA can only take a small percentage out of the total stock of scrap tires under current market conditions. Currently, only about 10 percent of the scrap tires in the USA are converted into crumb [2]. A comprehensive study on the current progress of rubberized asphalt pavement can be found in the article prepared by Carlson and Zhu[3].

Other products that consume crumb rubber include garden hoses, floor mats, horse trails, playground chips, roofing materials and others. In a number of states, scrap tires are burned for generating electricity or as a fuel supplement in the place of coal or other materials. But the total quantity of scrap tires and crumb rubber these products and processes can utilize is also not enough to stem the flow of scrap tire build-up. Therefore, the current situation is that the rate of automobile tire disposition is much greater than the rate of those disposed tires being reprocessed or reused. Consequently, many tire reprocessing plants have huge stockpiles. From time to time, news reports of scrap tire piles burning can be heard/seen, and such burning causes a severe damage to the environment with respect to air pollution and ground water contamination.

Faced with the increasing pressure of this problem, many efforts have been made to find solutions. In fact, as part of these efforts, this article reflects the progress made in a project which is sponsored by Arizona Department of Environmental Quality beginning in March, 1998. The objective of this project is to research and develop new products that can use large quantities of crumb rubber. The theme is that new crumb rubber based products must be developed by using new and advanced technologies. Such technologies will make these products competitive and promising in finding markets with high demand. The crumb rubber application in highway noise barriers is one area of the progress resulting from this project.

HIGHWAY NOISE BARRIERS

When vehicles are in motion, friction between the vehicle's body and the air touching the vehicle will take place. Such friction renders an aerodynamics effect that noise will be generated because of the gradient in the air pressure field induced by the friction. This pressure field will propagate to generate noise that can be heard at significant distances. Additionally, the contact of grooved tires on pavement surfaces occurring at high speeds creates a substantial sound pressure field as well as engine operations and exhaust systems. This type of noise is called traffic noise since it is originated by moving vehicles. Its acoustic spectrum is of multiple frequencies. The majority of the spectrum falls within the frequency range of 250 Hertz and 4000 Hertz[4]. The noise within this frequency range can be easily heard by the human ear, and can cause great discomfort. To control the propagation of this traffic noise, common practice is to build noise barriers along highways so that noise will be contained and absorbed within barriers, and will not propagate to any significant distance.

However, most highway noise barriers are built with pre-cast concrete or concrete blocks/slabs. The study shows that these barriers are of very high acoustic reflectivity (95% and above[5]) and of low sound absorption for the frequency band of highway noise between 250 Hertz and 4000 Hertz. So the effectiveness of concrete noise barriers in controlling vehicle noise is far from being satisfactory.

With the drastic increase in highway traffic in the last two decades, the effort to develop new and better noise-reduction barriers for highways as well as airport and other applications has been intensified. It is predictable that such an intensification will continue because noise poses an increasingly environmental threat. In recent years, some notable progress has been made in this respect. It has been reported a section of polycarbonate noise wall was built in 1996 near Culver City park in Los Angeles, California. The polycarbonate noise reduction panels are developed by Quitite International, a company based in Los Angeles, California, and the panels are made by Lexan® polycarbonate plastic produced by General Electric. In addition, a jet engine testing shelter was installed also by using Lexan® polycarbonate plastic at Albany airport, Albany, New York in 1997 [6]. Another development is the noise barrier system developed by Carsonite International in Early Branch, South Carolina, and the noise barriers are lightweight hollow panels made of tongue-and-groove planks of reinforced composite material filled with crumbed tire rubber. A few sections of Carsonite noise barriers have been built in Long Beach, California. Traditional noise barrier walls have a flat surface. Now new designs are experimented with non-flat surface textures (Figure-1).

Figure-1 Grooved noise barrier walls near Highway 101 in Tempe, Arizona

These newly developed noise barriers exhibit a much better performance than concrete with respect to the capability of sound absorption and transmission loss, but the noise reduction is not the only criterion. In fact, there are other crucial criteria in constructing noise barriers. These criteria include: (1) cost effectiveness, (2) technology maturity, (3) durability, (4) low cost and convenience in installation, (5) low cost and convenience in maintenance and repair, and (6) aesthetics. The conventional concrete noise barriers meet those criteria very favorably. For example, the average cost to build one foot of concrete noise barrier (typical 6 to 8 feet tall) is about $20 ($20/ft). Polycarbonate plastic or composite noise barriers are very costly, and much less competitive in those criteria in comparison to concrete ones. This is why so far the progress made in replacing concrete noise barriers with aforementioned new noise reduction materials is very limited.

CRUMB RUBBER

From an engineering point of view, crumb rubber has a number of special thermo-mechanical and chemico-physical properties. Crumb rubber is made by shredding scrap tires and as such, it is a particulate material free of fiber and steel. It is made commercially available in 50-pound bags or 2000-pounds bulk bags. The size of the rubber particles is graded. The finest one can be as small as about 0.2mm (Mesh #80) and below, The gradation commonly used in rubberized asphalt pavement is between about 2.0 mm to 0.5 mm (Mesh #10 to Mesh #40). Crumb rubber is light in weight and is durable. It can last for a long period of time in a natural environment. From the safety consideration, crumb rubber is a non-toxic and inert material.

The idea to explore the possible application of crumb rubber in the noise reduction application merges from the fact that [7] bulk rubber panels have a much better sound absorption capability than concrete blocks/slabs do. Now, since crumb rubber is made in a state of loose granules, using crumb rubber to make panels provides the opportunity that the panels now may be fabricated in the way that they can contain a large percentage of air voids.

Rubber panels containing high air porosity will certainly increase the sound absorption capability in comparison with bulk (zero porosity) rubber panels.

More importantly, crumb rubber is a recycled material, as more is consumed, the better it will be to help reduce so-called the scrap tire pollution. Also, considering that most new noise barriers recently developed or under development are made from plastic that is a high-energy-consumption product made by chemically processing fossil oils, and the resource for fossil oils on earth is limited. Therefore, the choice is obvious that developing crumb rubber for its application in noise-reduction can lead to a win-win situation if successful.

MOLDING TECHNOLOGY

It appears that crumb rubber is a worthy material for its noise barrier applications. To achieve this noise barrier application objective, it is necessary to find out the technology to "manufacture" crumb rubber panels. Two manufacturing technologies can be used to reach this objective. One is to use the molding technology in which crumb rubber is placed in a mold mixed with a bonding agent. Then temperature and pressure will be exerted on the mold. Consolidation will take place in the mix of rubber particles with a bonding agent, and a molded solid type of panel will be made.

The molding method in making panels is a mature technology. However, it is not suitable for this application because of the following major reasons. The first reason is that the panels made by the molding technology usually are produced with a flat surface. To accomplish a better sound absorption characteristic, a flat surface is not the best choice. In fact, the recent design of noise barriers tends to have a contoured surface texture. As such, molding can not easily meet such a wavy contour requirement for the noise barrier design.

The second reason resides in the fact that making molds is time-consuming and expensive. To make a non-flat mold requires even more time and is more expensive. The design development of contoured noise-panel surfaces is still in its evolution stage, and many new contour design patterns are yet to come. Thus, the necessity in making different molds to accommodate the forthcoming plausible design changes makes the employment of the molding technology unattractive, if not impractical.

Molded panels are usually made in a solid state with low porosity because the molding process requires the exertion of high pressure. Typical molded parts with a good quality can have no higher than a few percent of air voids. For the noise reduction purpose, a higher porosity is preferable as aforementioned. This is the third reason.

The last major reason is that after almost a century's construction, there are thousands and thousands of miles of existing concrete highway noise barriers. The focus for highway noise reduction from the view of the transportation department in many states is rather on what can be done to improve the noise reduction capability for existing noise barriers than on the construction of better sound absorption new noise barriers. This is primarily because not many new highways and noise barriers are under construction or planned. It appears that the molding technology can help little in this regard.

In addition to those four major reasons, there are other factors that inhibit the use of the molding technology for the highway noise reduction application, for example, high cost in investing mold equipment, but they will not be detailed here.

SPRAY TECHNOLOGY

The alternative method to make crumb rubber panels is to employ a spray technology. Here the spray technology is referred to as using a spray or blaster device that can pressurize and disperse the mix of crumb rubber particles with a bonding agent onto a base substrate. A panel is formed after spraying enough volume of the mix on the base substrate and the solidification takes place as the bonding agent becomes dry, and a bonding strength is developed between the bonding agent and rubber particles. It can be seen that this spray process is a coating operation.

The advantages of the spray technology are as follows:

1 Easy control on the panel size and thickness
2. Easy implementation of panel surface texture/contour designs
3. Mobility of taking the spray or blaster device to highways and spraying to existing highway noise barriers.
4. Easy handling of the large volume of coatings.
5. Easy repair and maintenance of sprayed panels
6. Easy coloring of the panels

Based on those advantages, the spray technology is further investigated to “manufacture” the crumb rubber panels.

BOND AGENT SELECTION AND MIX DESIGN

The first task in investigating the spray technology is the selection of the bonding agent. The guideline in the selection is that the bonding agent should be a member of the rubber family with respect to its chemical compositions[8]. Following this guideline, two polymer compounds, one is acrylic and the other is alkyd, are selected because both acrylic and alkyd belong to the rubber family chemically and are commercially available. The acrylic-based compound is water-soluble and the alkyd-based compound is oil-based. A number of mixes of an acrylic compound with crumb rubber are made. It is shown that a strong bond is developed between the acrylic compound and crumb rubber. A number of mixes of an alkyd based compound with crumb rubber are also made, and, in comparison to the bonding strength between the acrylic compound and crumb rubber, an stronger bond between the alkyd compound and rubber particles is observed. From the bonding strength point of view, the alkyd-based compound is more preferable because it can better serve the purpose of having a strong bonding strength.

But, the drawback is that the spray device is filled with the residual of rubber particles “glued” with the oil based compound like alkyd after application and is problematic with respect to the cleaning which will require the use of a large quantity of chemical thinners, and take a quite amount of time. As a consequence, it is quite costly both in time and money to maintain and clean the spray devices dispersing alkyd compounds. On the other hand, only water is needed to wash the spray device after it is used in dispersing the acrylic based soluble compound. In addition, the cost for alkyd based compounds is more expensive than that of acrylic based compounds.

Therefore, the choice is made to select the acrylic-based compounds as the bonding agent. But, a thin layer of alkyd polymer will be sprayed to the panels made by the mix of the acrylic-based agent with rubber particles as a finishing coat. This thin layer will sever the purpose of coloring panels and at the same time provide a protective coating for the panel to increase the panel durability (it is typical that an acrylic based paint can last 10 years to15 years, but an alkyd based paint can last 15 years to 20 years or longer). Therefore, such a selection to have the acrylic compound as the bonding agent, and the alkyd compound used as the protective coating reflects an optimum approach in utilizing the two polymers for their contribution to serve the spraying technology.

The next task is to determine the mix ratio of crumb rubber to the bonding agent. For better sound absorption, a higher percent of crumb rubber in the mix is desirable. However, too much rubber particles in the mix will make the mix very “sticky” or “dry”. As such, the flowability of the mix will be reduced so that the spraying process can become non-operable. So a balanced ratio is needed in the mix design. Based on a number of tried mixes with different ratios, it is shown that the percent of crumb rubber may vary from 50% to 80% in weight for every 100% of the bonding agent also in weight. Such a mixing ratio can generally make the spraying process workable. It is also noticed that the mixing ratio selection depends on the particle size of crumb rubber. Because the bonding agent “coats” rubber particles, when larger sized rubber particles are used, lesser amount of the bonding agent is needed to coat those rubber particles. Thus the ratio of higher percent of crumb rubber can be reached by using larger rubber particles. The size of crumb rubber used in this study varies between 0.25 mm to 4.0 mm.

SPRAYING DEVICES AND PROCESSES

Four types of spray systems are tested in making crumb rubber based panels. The first one is a Binks gun system, a traditional spray device. Binks spray systems are designed for spraying paint or a liquid with very fine particles. The test shows that the gun is workable only with Mesh #40 crumb rubber. Spraying the mix with rubber particles larger than Mesh #40 will cause the “clogging” problem because of the Binks’s nozzle is very small. Therefore, Binks guns can play a minor rule for the current application without modification to the nozzle.

The second one is a hopper type of spray gun (Wal Board). The feature of this spray device is that it has a large spray tip so coarse rubber particles can easily be “pushed” through the nozzle. The testing results show that this device can work well with the mix of crumb rubber up to 4.0 mm in a laboratory environment. Most of these spray devices have a small capacity, and the future task is to develop a device that can handle a large volume of the mix.

As aforementioned, increasing the rubber ratio in the mix is favorable to enhance the acoustic absorption capability. For this purpose the third spray device, a protocol of a spray system is designed and manufactured as part of the task implemented in the current study that can spray dry rubber particles. A wet-dry spray process is then planned that this spray gun disperses dry rubber particles along with another gun spraying the mix (wet), so a high rubber content can be achieved. The wet-dry process is in its infant stage, and more tests are needed to further characterize and quantify this process.

The fourth spray device tested is a new technology called Convergent Spray Technology^{TM}. This technology was originally developed in National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center, Alabama to apply heat-resistant coatings to the Space Shuttle's solid rocket boosters. The feature of this spray device is that crumb rubber and the bonding agent are mixed at the time they are sprayed. That is the mix is not “pre-mixed”. Conventional spray devices require that the fluid or the mix are blended first, then flow within the spray system during spraying. As such, the parameter of viscosity for the fluid or the mix is introduced and is measured to make sure that the flowability is appropriate. A fluid/mix too thick or “high viscosity” will make the fluid/mix non-workable for the spray process. But for this Convergent Spray technology, this is no longer a problem, and the consequence is that now the crumb rubber ratio can be further increased. A number of specimens are made by this technology with a 1 to 1 ratio in weight between crumb rubber and the bonding agent, and they appear of good quality. This technology really shows a promising future.

ACOUSTIC ABSORPTION TEST (ASTM C423-90a)

The most critical parameter in characterizing the capability of a material of how well it can absorb sound or noise is called the acoustical absorption coefficient (AAC). A sound wave carries certain amount of the energy called sound energy. When a sound wave hit a material, portion of the sound energy will be reflected or “bounced” back. Simplistically speaking, from the noise reduction point of view, the lesser sound energy being bounced back, the better the effect of noise reduction. A value AAC=0 means sound energy being reflected completely, and a value AAC=1 means that all the sound energy is absorbed by the material, which is the best in noise reduction. American Society of Testing and Materials (ASTM) issued a standard in how to conduct the test of acoustical absorption coefficient on a specimen made by a specified material and how to determine the value of AAC based on the test result. The standard is ASTM C423-90a.

As part of this study, a testing specimen for ASTM C423-90a is fabricated (Figure-2). The mix design is 0.8 (crumb rubber) to 1 (bonding agent) with a mixed size of rubber particles using the second and third spray devices referred in above. The dimension of the specimen is quite large. It consists of four panels and each panel is 48 inches by 48 inches by 1 inch. Then, the specimen is shipped to Riverbank Acoustical Laboratories (RAL) at Geneva, Illinois, and the test is performed there in September, 1999. RAL is a highly reputable laboratory in conducting acoustic related tests. The testing result of the acoustical absorption coefficient versus frequency is obtained and is plotted in Figure-3. For the comparison purpose, also displayed in Figure-3 are the same coefficient for concrete and the aforementioned Carsonite noise barriers. It can be seen that the crumb rubber based specimen shows superiority in acoustical absorption.

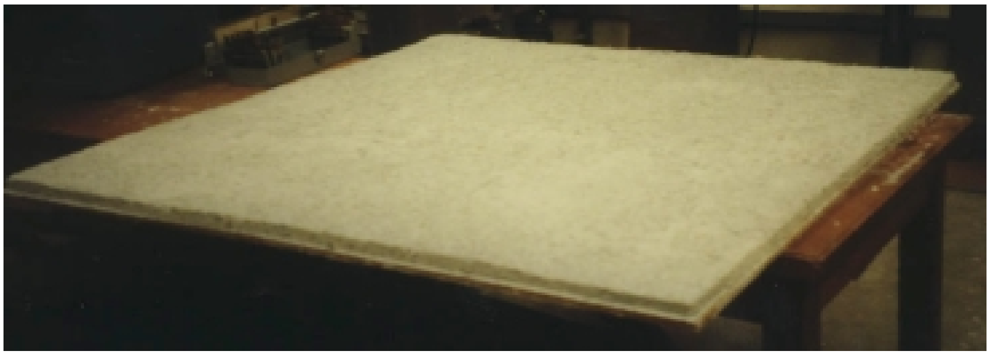

Figure-2 Crumb rubber based test specimen for ASTM C423-90a

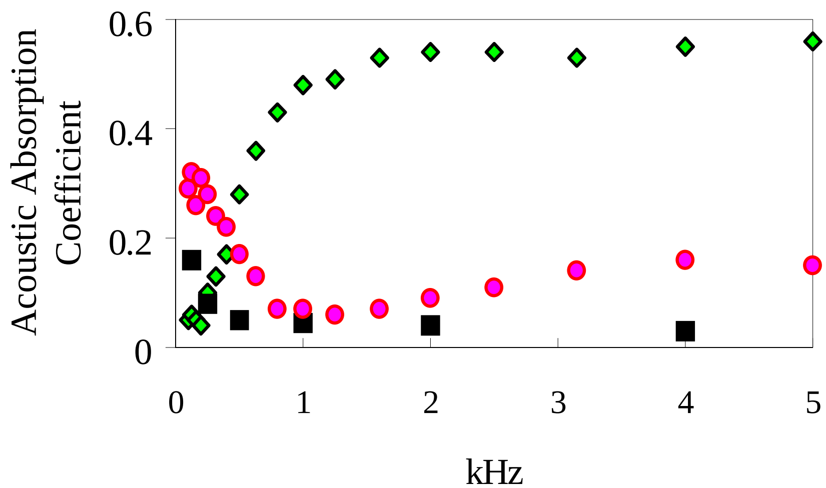

Figure-3 Acoustic absorption coefficient versus frequency. Square symbols represent for concrete noise barriers, circular symbols for Carsonite noise barriers, and diamond symbols for the crumb rubber mix.

FURTHER WORK AND DISCUSSIONS

Introducing and developing the spray technology in manufacturing crumb rubber panels for the application in highway noise reduction is one major area of the progress made in this study. This article devotes most of its analyses to address the technical aspect of the necessity and feasibility in developing such a technology. Although much progress has been made in this respect, a few tasks are needed to further advance this technology.

The first one is the panel design. Current specimens are made all with a flat surface and an about 0.4 acoustical absorption can be expectedly achieved for such a flat-surface design. The effort is needed to continue to improve the acoustical absorption. Two possibilities may be tried. One is the surface design with a rough surface texture, for example, a popcorn type of surface texture. The other one is a contoured surfacing design. In addition, from what Figure-3 shows is that the flat rubber panel can do better in the range of high frequencies with respect to acoustical absorption, now the focus will be placed to the low end of the frequency band. Hopefully, these two surface configurations will help to improve the noise reduction capability, particularly with the low band frequencies. Both analytical and experimental methods will be used in the two types of new surface design. The experimental method is conducting the tests of ASTM C423-90a on the panel specimens. However, because the testing fee for ASTM C423-90a is quite high, the analytical method will be more emphasized to evaluate the acoustical absorption nature of the two surface textures so only a limited number of and well defined ASTM C423-90a tests will be needed to achieve the goal.

The second task is to develop a mix design with respect to the size distribution of rubber particles. Though the idea is known that using multi-sized rubber particles in the panels can achieve a better sound absorption effect, the quantification of such size gradation is still not clear. Particularly, the question is unanswered whether or not if more large rubber particles are used, the acoustical absorption at the low band frequencies will be improved. The information obtained from the current study is inadequate in this respect, and more investigations are needed to develop an adequate understanding and quantification with the size gradation versus absorption.

The third task is to continue to “maturate” the development of the spray device and process technology. One element in the task is to establish a guidance of the spray process so the reliable and repeatable spray operation can be achieved. The other element is to integrate the four spray devices so far studied and to select/develop a spray device that can best accommodate the need for the current application. The third element is to develop a mobile spray unit that can be taken to highway locations. It is seen that most work done so far in this study is basically research and development (R&D) oriented. To move from R&D to the industrial application is both a quantum leap and a big challenge. In this respect, though we have a good knowledge on four spray devices tested in this study, there is much work to be done in designing and building a spray unit that can handle a large volume of the mix. This is the last element in this task.

The current study mainly focuses on the subjects that are related to the crumb rubber technology in its highway noise reduction application. However, any serious technology and product development must contain a cost analysis, and here a brief cost analysis is given. As a commodity, crumb rubber is about $0.2 to $0.3 per pound, and acrylic polymer is also at this price range, or a little bit higher. Regular spray devices do not require millions of dollars of investment. A typical industrial capacity spray gun costs $100k level or less. Therefore, though these cost estimates do not constitute a complete cost analysis, they may provide an overall sketch of what might be expected for financing this technology-product development.

This article presents a quite detailed study on the recent development of the crumb rubber technology in its highway noise reduction application. It can be seen that developing such a technology requires the effort in many different issues and subjects. Based on what is presented in this article, though facing many challenges, it appears that the future of this technology is promising and significant, because the demand for this technology will be high and it can address two environmental problems simultaneously.

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