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Innovative Uses Of Recycled And Waste Materials In Construction Application

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Innovative uses of Recycled and Waste Materials in Construction Application

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department: Civil Engineering

Major: Civil Engineering

Major Professor: Dr. Taher Abu-Lebdeh

Greensboro, North Carolina

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School of Graduate Studies
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This is to certify that the Master's Thesis of

Johnny J. Bolden, IV

has met the thesis requirements of
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Greensboro, North Carolina
2013

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Biographical Sketch

Johnny J. Bolden, IV was born on May 27, 1987 in Charles City, VA. He graduated from Charles City High school in 2005. He obtained the Bachelor of Science degree from North Carolina Agricultural and Technical State University in December 2009 in Architectural Engineering. He is a candidate for the Masters of Science degree in Civil Engineering with an emphasis in Structures. He had an early interest in building from a young age, and a passion for drawing. After his completion of his Bachelor of Science degree, he developed skills as a designer, mechanical engineer, electrical engineer, and structural engineering. Upon completion of his Master of Science degree he has developed skills and knowledge for designing bridges, highways, and high rise building structures. Eventually, he would like to start a family business designing and constructing commercial buildings, high rise buildings, bridges, and custom-built mansions.

Dedication

I would like to take this opportunity to thank Jesus, my lord and savior, for being with me every step of the way and providing me the strength and encouragement to finish. I dedicate this thesis to my mother Tanya Lynette Johnson, father Johnny James Bolden, III, grandparents Almeda Tyler and James C. Tyler, sisters Tania Bolden and Tiffany Bolden, cousins and step father Rodney Johnson for all their love, support, wisdom, encouragement and prayers.

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Most of all, the author would like to express his dearest appreciation to his family for their patience, understanding, and support throughout the course of his studies and research work.

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Key to Abbreviations

FHWA	Federal Highway Administration
ISWM	Integrated Solid Waste Management
RCA	Recycled Concrete Aggregate
RMA	Rubber Manufactures Association
IDEM	Indian Department of Environmental Management
TDF	Tire-derived Fuel
RMC	Rubber Modified Concrete
CRC	Crumb Rubber Concrete
CRA	Crumb Rubber Additive
SAM	Stress Absorbing Membrane
SAMI	Stress Absorbing Membrane Interlayer
CRMA	Crumb Rubber-modified Asphalt
FWD	Falling Weight Deflectometer
AASHTO	American Association of State Highway and Transportation Officials
CARE	Carpet America Recovery Efforts
MSW	Municipal Solid Waste
ACRR	According to the Association of Cities and Regions for Recycling
SP	Super Plasticizer
ACAA	American Coal Ash Association
Mt	Million Metric tons
GGBFS	Ground Granulated Blast Furnace Slag
EAF	Electric Arc Furnace

CKD	Cement Kiln Dust
PI	Plastic Index
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
RAP	Recycled Asphalt Pavement
EFB	Empty Fruit Bunch
BMA	Bio Mastic Asphalt

Abstract

More production equals more waste, more waste creates environmental concerns of toxic threat. An economical viable solution to this problem should include utilization of waste materials for new products and one that minimizes the heavy burden on the nation's landfills. The importance of recycling is huge because it saves natural resources, saves energy, reduces solid waste, reduces air and water pollutants, and reduces greenhouse gases. The construction industry can start being aware of and take advantage of the benefits of using waste and recycled materials. Studies have investigated the use of acceptable waste, recycled, and reusable materials and methods. The use of swine manure, animal fat, silica fume, roofing shingles, empty palm fruit bunch, citrus peels, cement kiln dust, fly ash, foundry sand, slag, glass, plastic, carpet, tire scraps, asphalt pavement, and concrete aggregate in construction is becoming increasingly popular due to the shortage and increasing cost of raw materials. In this study a survey was conducted to find out the current practices of the uses of waste and recycled materials in the construction industry. The results proved that companies are not aware of what's available to use or the quality of the materials performance or the cost savings or any other benefits including environmental. Based from the results of the survey the following research was conducted to create better documentation for Green Building, connecting researches and contractors with an overview of what recycled materials are available for different construction applications.

CHAPTER 1

Introduction

1.1 Overview on Recycling

People in today’s world are consuming an enormous amount of raw materials. Because of this, natural resources are being quickly depleted. With the growth in the population, comes an increase of waste generated by the increasing demand for new highways, commercial buildings, housing developments, and infrastructure projects, which results in a tremendous amount of waste ending up in landfills yearly. With consumer and economic growth there will always be natural resources not only depleting eventually disappear. Awomeso et al. (2010), stated that current environmental concerns have forced developed and developing countries to reduce pollution for sustainable growth, and highlighted the use of effective waste disposal techniques that are suitable for environmental protection.

With the use of recycled materials, the environment can be saved and flourish on reusable and recycled materials. Recycling conserves natural resources, saves energy, reduces solid waste, reduces air and water pollutants, and reduces greenhouse gases. Recycling, re-use, and composting create an estimated six to ten times as many jobs as waste incineration and landfills. The Global Alliance for Incinerator Alternatives (GAIA) (2012) contends that recycling saves three to five times the energy generated by waste-to-energy plants, even without counting the wasted energy in burned materials.

In time, landfill will begin to over flow and barriers for landfills are not full proof, and many landfill liners and plastic pipes allow chemicals and gases to pass through undetected. Newer lined landfills leaks are feather thin, making leaks only detectable if they reach the landfill-monitoring wells. Both old and new landfills are usually located near large bodies of water, making detection of leaks complicated.

In the United States alone, municipal solid waste generates approximately 200 million tons of waste per year. Among these, approximately 38% are paper products, 8% plastics, and 3% carpets and textiles. In 2010, the average amount of waste generated by each person in the United States per day was 4.43 pounds per person; 1.51 pounds were recycled and composted. Figure 1.1 shows Municipal Solid Waste (MSW) generation rates compared to per capita produce. Figure 1.2 shows MSWs total recycling rates from 1960 to 2010.

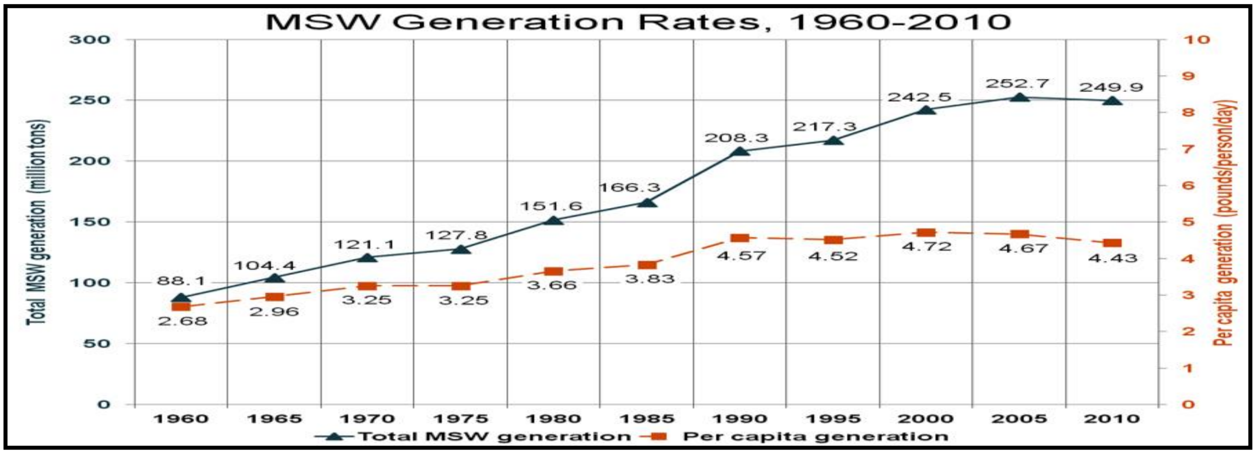


Figure 1.1. Municipal solid waste generation rates from 1960 to 2010 (EPA, 2012).

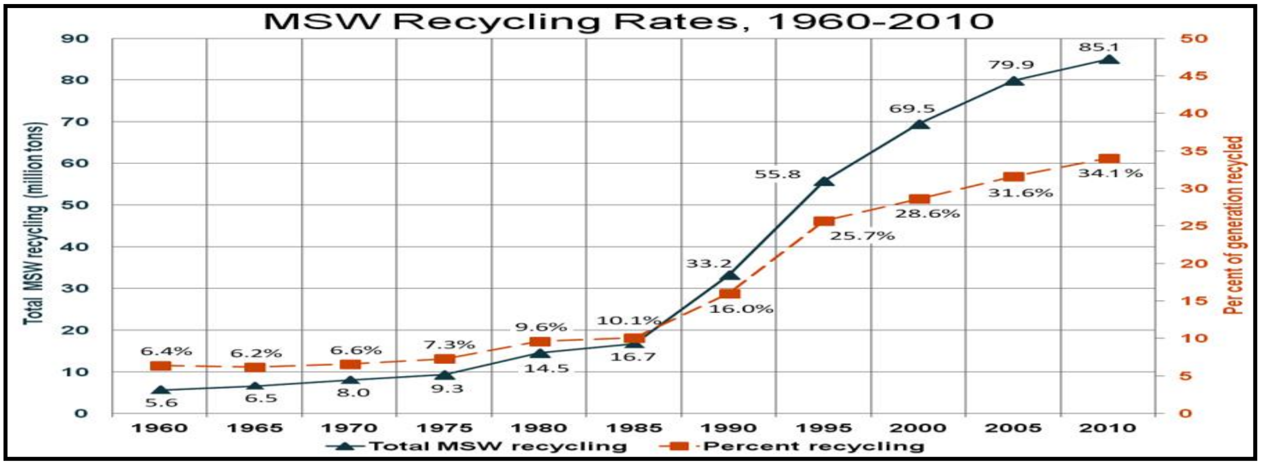


Figure 1.2. Municipal Solid Waste Total Recycling Rates from 1960 to 2010 (EPA, 2012).

1.2 Problem Statement

Research shows that there are many innovative uses of recycling and reusing waste materials in the construction industry. Currently, there is no document, which a researcher could find, that presents a collection of these materials, ready for use by contractors, and academia the like. Another problem is a lack of understanding of what constitutes as recyclable materials, and knowing their usages / alternative usages. To substantiate the researcher's claim provided are some applicable examples in regards to the construction industry (i.e., usages, sustainable materials, and pressing issues on reducing waste).

In the United States, over 7 billion pounds of polymerizing vinyl chloride (PVC) are thrown away yearly. Usages for flexible forms of PVC waste are hosepipes, insulation, and shoes. A use for rigid PVC waste is molded articles. Only 18 million pounds of that, about one quarter of 1% is recycled. Americans use approximately one billion plastic shopping bags, creating 300 thousand tons of landfill waste yearly. It should be noted that plastic is not biodegrade. Sunlight breaks plastic down into smaller and smaller particles that pollute the soil and water, which are costly and difficult to remove. In the landfills, plastic is shielded from sunlight delaying decomposing for thousands of years.

Several alternatives in many different applications can be used today utilizing waste and recycled materials, and have proved to be little or no cost while reducing extracting raw materials, often cutting transportation costs, and can be positively used in the construction industry to capitalize on.

1.2.1 Sustainable Materials. Sustainable materials are a consideration of the construction industry to help circumvent waste issues. Some recycled materials have emerged as a construction material in its own such as recycled concrete aggregate (RCA). The application of

RCA in concrete began in the United States in 1942 by using waste from construction and demolition projects for stabilizing the base materials for road construction in new highways. As highways wear out, they will need replacing; the amount of concrete reused saves on project costs, the use of raw materials, and reduces filling landfills.

For various reasons, the concrete construction industry is not sustainable. First, it consumes huge quantities of virgin materials. Second, the principal binder in concrete is Portland cement, in which the production is a major contributor to greenhouse gas emissions that implicates global warming and climate change. Third, many concrete structures lack durability, which has an adverse effect on the resource productivity of the industry. Research findings show using fly ash (FA) in concrete can address these issues.

Integrated Solid Waste Management (ISWM) systems are one of the greatest challenges and possible solution for sustainable development. ISWM is the selection and application of suitable techniques, technologies management programs to achieve specific waste management objectives and goals (Tchobanoglous et al., 1993). Malakahmad and his colleagues (2010) suggested the implementation of ISWM systems as a toll for sustainable development. They concluded that one key element of ISWM is solid waste separation, which contributes to a successful recycling program (Malakahmad et al., 2010). Meuser et al. (2011) investigated where waste is produced and found that 62-65% of the waste fine material consisted of mineral particles and biodegradable organic waste, 20-25% of the waste consisted of construction and demolition waste and the remaining 10-15% were other materials such as plastic, metals, glass and timber, and 3.4-5.7% of polyethylene. Begum et al. (2010) investigated the issue of minimizing construction waste and its significant impacts on the environment. Their study revealed that a significant amount of material wastage can be reduced by the adoption of prefabrication, and the rates of reused and recycled waste materials are relatively higher in projects that adopt prefabrication. In addition to a reduction of construction waste generation, Hassim et al. (2009) identified and discussed other advantages of applying prefabrication in the building and construction activities. This include enhance integrity on the building design and construction, reduction unskilled and foreign workers, reduce construction cost, fixed design at the early stage of design, better supervision, promote safer and more organized construction site, and improve environmental performance through waste minimization.

1.2.2 Materials.

1.2.2.1 Fly ash. Studies have shown that fly ash, a coal combustion byproduct of, poses human and ecological risks by containing significant quantities of heavy metals such as arsenic, lead, and selenium that can lead to the development of cancer and neurological problems (Ahmaruzzaman, 2010). Studies also have shown that fly ash, because of its uranium and thorium content, is more radioactive than nuclear waste. However, several researchers have found fly ash is potentially good for use in the construction industry, instead of being stockpiled at off sites or filling landfills. Figure 1.3 shows dumping of piles of fly ash at an offsite in Virginia.

Figure 1.3. Fly ash being dumped in Virginia (Collection, 2009).

Utilizations of fly ash in construction include, concrete production, structural fills, embankments, filter in asphalt mixes, and grouting.

Mehta (2004) studied concrete mixtures containing more than 50% fly ash (FA) by mass in cement. Mehta's findings showed that the high-volume of FA in concrete offers a solution to fulfilling the increasing demands for concrete in the future in a sustainable manner at a reduced or no additional cost, and at the same time reducing the environmental impact of two industries that are vital to economic development, namely, the cement industry and the coal-fired power industry. Several studies on waste and supplementary cementing materials, such as, blast furnace slag, silica fume, rice husk ash, and metkaolin can be used as partial replacements for Portland cement.

Ahmaruzzaman (2010) studied the utilization of fly ash in construction as a low-cost adsorbent for the removal of organic compounds. He found that fly ash is a promising adsorbent for the removal of various pollutants. The adsorption capacity of fly ash maybe increased after chemical and physical activation. The conversion of fly ash into zeolites has many applications, such as, ion exchange, molecular sieves, and adsorbents (Ahmaruzzaman, 2010).

1.2.2.2 Tire waste.

An estimated number of one two billion scrap tires have been disposed of in huge piles across the United States. An additional 250 million tires unaccounted for are discarded yearly (Rubber Manufacturers Association, 2011). Figure 1.4 shows a stockpile of tires illegally dumped. These stockpiles are perfect breeding grounds for mosquitoes and rats caring diseases that can be a harmful threat to society. Approximately, 30% of these scrap tires end up in overcrowded landfills, and thousands more remain in empty lots and illegal tire dumps. Illegal stockpiles are dangerous because they are a huge fire hazard. Tires retain heat that can cause these piles to ignite easily, creating toxin emitting gases and fires that can take longtime to extinguish. Figure 1.5 shows a stockpile on fire polluting the air and damaging the environment.

Figure 1.4. Stock pile of tires illegally dumped (Kinnard, 2011).

Figure 1.5. Stock pile of waste tires on fire polluting the air (Madera, 2007).

1.2.2.3 Glass. Glass is another waste product filling landfills. In 2010, the United States sent 11.5 million tons of glass to landfills. The glass process consists of the super cooling of a melted liquid consisting of sand and soda ash. Glass is harmful to our environment because is not biodegradable, it takes millions of years to decompose into the raw materials it was made from. Glass serves as containers for wine, olive oil, soda, perfume, tomato sauce, pickles, olives, peppers, candles and beer. Some other usages are in many computers and television, cups, plates, and windows. Figure 1.6 shows a pile of glass sent for recycling.

In 2010, the United States recycled and recovered about 27% of the glass for recycling. Glass is one of the easiest reusable wastes, where 90% of new containers come from recycled glass.

Figure 1.6. Glass waste waiting to be recycled (Stock, 2012).

Glass manufactures saves cost and energy from using recycled crushed glass known as "cullet." Cullet cost less than raw materials and melts at a lower temperature. According to the Plastic Packaging Institute (2012) report the energy saved by recycling one glass bottle can light a 100-watt light bulb for four hours or run a computer for 30 minutes.

In highway construction, waste glass usages are for aggregate substitute in asphalt paving. Other applications can be for bead manufacturing, decorative applications, fiberglass, fractionators (match tips), and fluxes in metal foundry work.

1.2.2.4 Carpet waste. In 2010, carpet waste dumped in landfills was 6 billion pounds (see Figure 1.7). According to Carpet America Recovery Efforts or CARE, in 2010, 338 million pounds of carpet waste was diverted from landfills, 271 million pounds of carpet were recycled; 3 million pounds were used as alternative fuel, 23 million pounds for cement kilns. Old carpet is being used in composite lumber (both decking and sheets), tile backer board, roofing shingles, rail road ties, automotive parts, carpet cushion, and stepping stones. Studies show that carpet fiber can be a useful material that strengthens concrete, asphalt, and soils.

Figure 1.7. Waste carpet adding to the volume of waste in landfills (Schwartz, 2010).

1.2.3 Issues. Several issues exist regarding reducing waste. A pressing issue in the construction industry is minimizing waste. Pereira et al. (2010) supports the adoption of prefabrication and Industrialized Building Systems (IBS) to reduce enormous waste generation and management problems. Another key environmental issue is waste incinerators, furnaces for burning trash, garbage, and ashes. These incinerators produce 210 different dioxin compounds plus mercury, cadmium, nitrous oxide, hydrogen chloride, sulfuric acid, and fluorides. Produced also in incinerators is particulate matter that is small enough to remain permanently in the lungs. Additionally, waste incinerators generate more CO2 emissions than coal, oil, or natural gas-fueled power plants. Therefore, the use of recycled materials has become a key factor in making the world sustainable in the future.

Key Definitions

Innovation - is the creation of better or more effective products, processes, services, technologies, or ideas that are readily available to markets, governments, and society. Innovation differs from invention in that innovation refers to the use of a better and, as a result, novel idea or method, whereas invention refers more directly to the creation of the idea or method itself. This document is a collection of innovative uses of waste materials to be available in one place for contractors and researchers (see Table 1.1).

1.3 Research Objective

The objective of this thesis was to survey the literature for innovative usages of waste and recycling materials in the construction industry. To accomplish this objective, better documentation for different green building benefits addressing economic and environmental concerns.

This thesis provides a survey of selected waste and recycled material currently being used in civil engineering applications by contractors, manufacturers, and construction companies.

Lastly, this thesis can also serve as a literature review for connecting researchers and contractors desiring to pursue research in the use of what waste and recycled materials are available for civil engineering applications.

Table 1.1

Introduction of Innovative Recycled Materials and Application.

Recycled Material	**Innovative Recycled Material in Construction Applications**															
	Alternative Fuel	**Asphalt Binder**	**Pavement Sealant**	**Polymer**	**Asphalt Concrete Mix Agent**	**Adhesive**	**Hot Mix Asphalt**	**Aggregate**	**Base Course**	**Mineral Filler**	**Base stabilizer**	**Adsorbent**	**Soil Stabilizer**	**Waste Water Treatment**	**Concrete Mixes**	**Embankments**
Swine Manure	x	x	x													
Animal Fat				x	x											
Soy Bean	x				x	x										
Roof Shingles		x					x	x	x	x	x					
Date & Oil Palm Tree							x									
Citrus Peels												x				
Cement Kiln Dust					x		x						x	x	x	
Fly Ash					x			x		x		x		x	x	x

Table 1.1

(cont.)

Recycled Material	**Innovative Recycled Material in Construction Applications**															
	Alternative Fuel	**Asphalt Binder**	**Pavement Sealant**	**Polymer**	**Asphalt Concrete Mix Agent**	**Adhesive**	**Hot Mix Asphalt**	**Aggregate**	**Base Course**	**Mineral Filler**	**Base stabilizer**	**Adsorbent**	**Soil Stabilizer**	**Waste Water Treatment**	**Concrete Mixes**	**Embankments**
Floundry Sand					x		x	x	x						x	x
Slag					x				x				x		x	x
Glass					x			x		x						x
Plastic							x	x								x
Carpet	x				x		x								x	x
Tire Scraps	x		x		x		x		x			x	x		x	x
Asphalt Pavement					x		x	x	x							
Concrete Aggregate					x			x	x						x	

1.4 Organization of Thesis

Chapter 2 presents a background of the literature of materials used in the construction industry involving waste and recycling materials. Chapter 3 presents results from a survey conducted to find out what recycled and waste materials are currently being used in the construction industry and areas were companies need to be informed more on a material. Chapters 4, 5, and 6 presents information on applicable waste and recycling materials within four sectors, namely, Composite Waste, Industrial Sector Waste, Municipal Sector Waste, and Transportation Sector Waste. Included is a comprehensive review of data, information, findings (including benefits / advantages) and evidences relative to recycling waste materials and construction applications. Each sector includes subsections of recyclable materials in relation to the construction industry. Chapter 7 summarizes all sections discussing cost effectiveness, advantages/disadvantages to the construction industry. Recommendations for future research are also given.

CHAPTER 2

Background: Waste Materials in Construction

For years, scientist and researchers have been searching possible solutions to environmental concerns of waste production and pollution. Many have found that replacing raw materials with recycled materials reduce our dependency on raw materials in the construction industry. The Federal Highway Administration (FHWA) estimated that building demolition in the United States alone produces 123 million tons of construction waste per year (F. H. A. FHWA, 2004).

Several researchers at NC A&T State University (James et al., (2011), Fini et al., (2011), Abu-Lebdeh et al., (2011), (2010), Fini & Abu-Lebdeh, (2011), Hamoush et al., (2010), (2011a & b), Xiu et al., (2010)) and other academia investigated several green materials technologies that reduce environmental effects, and use recycled materials in infrastructures applications. The researchers developed several green material technology programs, which maintain or improve current practices in construction engineering, and ensures green products or methods arising from these programs would be cost effective and would confer benefits on society, the economy, and the environment. In order to obtain knowledge of the most advanced use of waste and recycled materials, the author reviewed these and other studies.

A significant number of studies explored recycled concrete aggregate (RCA). The Washington State Department of Transportation (WSDOT) used recycled concrete pavements to produce aggregates for new concrete portland cement concrete (PCC) pavements. This is because recycling pavement to produce new pavement conserves natural resources, reduces the impact on dwindling landfill space, reduces disposal costs, and may reduce overall projects costs. The primary reason for considering recycling, however, is the high quality of aggregate in their existing pavements. Washington pavements contain some of the highest quality aggregates in the world, which is a fact cited as the reason for the excellent performance of not only the PCC pavements, but also hot mix asphalt (HMA) pavements. Using RCA can be successful with careful consideration given to the properties and physical characteristics of the aggregate, the physical properties of the fresh and hardened concrete and the mechanical behavior of the pavement containing RCA. WSDOT recommends the use of RCA based on their investigation on the properties and characteristics of RCA, the physical properties of fresh and hardened concrete containing RCA, the mechanical behavior of concrete containing RCA, and special considerations for concrete pavements using RCA to achieve suitable levels of workability, durability, and strength (Anderson, Uhlmeyer, & Russell, 2009). Bosquez (2009) evaluated different recycled materials and focused his study on RCA as flexible base. In his study, RCA demonstrated a decrease in permeability with an increase in moisture content. His cost analysis also showed by using RCA, savings can be expected during the construction (Bosquez, 2009).

James et al. (2011) researched the potential of using RCA and fly ash (FA) in concrete pavement. The recycled concrete came from a demolished local site. Their research revealed using RCA up to 25% and FA up to 15% will not have a significant difference (if any) in strength compared with concrete containing virgin aggregate. Thus, using RCA and FA in concrete pavement may promote economic and environmental benefit.

Roshan et al. (2010) studied a special kind of lightweight aggregate called lika. Lika is a waste product with 0-3 mm fine aggregate. Lika is a form of silica fume also known as micro silica. As a pozzolan, lika increases the long-term strength and material properties of Portland cement. The objective of their research was to achieve the best mix design of lightweight concrete and find the optimized amount of micro silica in a lightweight concrete. They compared their experimental results with theoretical viewpoints to reach the properties of the optimized concrete with lika. Their conclusion was that light aggregate of lika might produce lightweight concrete.

High Strength Concrete (HSC) normally contains high cementitous amount and low water cement ratio. However, these lead to significant volume changes to the concrete; therefore, it will affect the strength development. In addition, the brittleness of HSC increased when silica fume used as partial cement replacement to achieve high strength. Ramli and Hoe (2010) studied the effects of incorporating short discrete coconut fibers (CF), bar chip fibers (BF) and glass fibers (GF) into HSC to enhance the performance of concrete while keeping the binder content at moderate level. They found that the combinations of short discrete fibers and very coarse sand to produce HSC showed very satisfying results. The coconut fibers are relatively high in water absorption compared to Bar chip and glass fibers, hence reduced the workability of the concrete. Bar chip fibers showed the best ability to increase the compressive strength and flexural strength of HSC. For glass fibers, the flexural strength and elastic modulus was higher than coconut fibers.

Hoyos et al. (2011) investigated using reclaimed asphalt pavement (RAP) aggregate materials treated with different dosages of Portland type I and II cement and with alkali-resistant glass fibers. Their test results confirmed the potential of cement-fiber-treated RAP material as an environmentally and structurally sound alternative to non-bonded materials for base and sub base applications in pavement engineering (Laureano R. Hoyos, M.ASCE, Puppala, M.ASCE, & Ordonez, 2011).

In 2004, the use of waste glass was investigated by Shayan and Xu, (2004). They grinded the glass into a fine powder for incorporation into the concrete as a pozzolanic material.

The results showed beneficial pozzolanic reactions in the concrete, and could replace up to 30% of cement in some concrete mixes with satisfactory strength development. Ling et al. (2012) conducted a study using 100% of recycled glass in architectural cement mortars. They used fixed water to cement ratio of 0.4. The results revealed the use of recycled glass improved the fluidity, drying shrinkage, and resistance to acid attack. The flexural and compressive strength decreased with the increase in glass content (Ling, Poon, & Kou, 2011).

A well-documented fact about lead is that it is one contaminant found in industrial wastewaters, and it exists in the wastewater of several industries. However, recovering lead from wastewater is very expensive. Because of this, Alzayadien (2009) focused his research on the development of cost effective alternatives using various natural sources and industrial wastes. He explored the use of low-cost agricultural materials, waste and residues, for recovering heavy metals from contaminated industrial effluent as a potential alternative method to high cost adsorbents. Alzayadien systematically investigated the adsorption of lead (II) ions onto Orange Peels (OP), a typical agricultural byproduct, with the variation in the parameters of pH, sorbent dosage, contact time and the initial concentration of adsorbent. Alzaydien found that the sorption capacity of the orange peel is comparable to other available adsorbents, and quite cheaper.

The steel making industry produces tons of waste every year. Steel making slag from Electric Arc Furnace (EAF) is an abundant by-product in the steel making industry that has potential use for removing heavy metal from contaminated water or wastewater. Beh et al. (2010) investigated the characteristic and behavior of manganese removal by using EAF slag as an efficient metal removal. Their research found that the EAF slag can be an efficient adsorbent to remove manganese from both the solution and waste water (Beh, Chuah, Choong, Kamarudzaman, & Abdan, 2010).

Copper slag is a by-product obtained during the refining of copper. Shi and co-investigators (Shi et al. 2008) investigated the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete. Several studies have found different uses for copper slag such as roofing granules, abrasive, tiles, road-base materials, railroad ballast, and asphalt pavements. The potential use of copper slag in the construction industry as a raw material in the production of cement, concrete clinker, base coarse and fine aggregates.

Foundry is a waste product that grows (accumulates) in cast iron foundry plants. Foundries generate about 450 tons per year, which ends up in landfills. Fiore and Znetti (2007) researched the best reuse and recycled solutions for foundry. Their results showed using particles below 0.25 mm fraction made of mineral coal and bentonite, and between 0.025 and 0.1 mm fraction together with pelletized and dried mud from dust abatement on molding lines, may be recycled in Portland concrete production.

Solid waste management is one of the major environmental concerns in the United States. The United States generates over 5 billion tons of nonhazardous solid waste materials yearly. Of these, scrap-tires generate more than 270 million (approximately 3.6 million tons) yearly. In addition to this, there are about 300 million stockpiled scrap-tires. Several studies have been conducted on the reuse of scrap-tires. Siddique and Nhaik (2004) researched the use of scrap-tires in Portland cement concrete and the benefits of using magnesium oxychloride cement as a binder for rubberized concrete mixtures (Siddique & Naik, 2004).

Crumb rubber is a material produced by shredding and commutating used tires. No doubt, the increasing piles of tires create environmental concerns. Kaloush et al. (2004) conducted a study to find means to dispose of crumb rubber in Portland cement concrete and still provide a final product with good engineering properties. The results of the crumb rubber concrete (CRC) showed that as the rubber content increased, the tensile strength decreased, but the strain at failure increased. The coefficient of thermal expansion tests indicated the CRC are more resistant to thermal changes (Kaloush, Way, & Zhu, 2005).

The vast majority of building facing materials consist of cladding materials such as clay bricks, concrete blocks, vinyl siding, natural and artificial stones. Among these, natural stone is the preferred material for many reasons, including accessibility, beauty, durability, hardness, strength, and sustainability. However, the difficulty to quarry, transport, and cut natural stone has led to an undesirable effect on project schedules and costs. Hamoush et al. (2011) investigated a new improved engineered stone for better toughness, ductility, durability, and thermal resistance. In their research, the back layer of the stone utilized recycled crumb rubber, which provides a combined solution for energy saving and environmental concerns. The results of adding crumb rubber showed a reduction in the material unit weight, enhanced ductility and toughness, and improved thermal resistance. The stone's properties such as compressive strength, thermal conductivity, durability, impact resistance, and water absorption were experimentally measured and compared with natural stone specimens (Hamoush, et al., 2011).

Lee et al. (2009) investigated shredded tires and rubber sand as a lightweight backfill. The numerical modeling results suggested tire shreds, particularly when mixed with sand might be effective when used as a backfill. Segre and Joekes (2010) studied the surface modification of powdered tire rubber to increase its adhesion to cement paste. They concluded that using treated tire rubber particles, as addition, instead of a coarse aggregate, in cement-based materials is promising for applications such as driveways or in road construction (Segre & Joekes, 2000). Toutanji (1996) investigated the effect of the replacement of mineral coarse aggregate by rubber tire aggregate. The test revealed high toughness was displayed by specimens containing rubber tire chips as compared to control specimens (Toutanji, 1996). Bosscher and Edil (1997) researched the use of shredded scrap tires as a lightweight fill material in highway construction. They concluded that tire chips can be used as an environmentally acceptable lightweight fill in highway applications if properly confined (Peter J. Bosscher & Edil, 1997).

Scrap tires cut into chips are coarse grained, free draining, and have a low compacted density; thus, offers significant advantages for using lightweight fill and retaining wall backfill. Humphrey et al. (1993) investigated shear strength and compressibility of tire chips for retaining wall backfill. The compressibility tests showed that tire chips are highly compressible on initial loading, but the compressibility on subsequent unloading and reloading cycles is less (Humphrey, Sandford, Cribbs, & Manion, 1993). Özkul and Baykal (2007) investigated drained and un-drained shear strength of mixtures of clay and tire buffing. Their results proved that the peak strength of the composite is comparable to or greater than clay alone when tested at confining stresses below 200–300 kPa (Özkul & Baykal, 2007).

Ahmed and Lovell (1993) investigated the feasibility of using rubber soils as lightweight geomaterial in highway construction. The use of shredded tires in highway construction offers technical, economic, and environmental benefits under certain conditions. Findings revealed that using shredded tires reduce weight of fill, which helps increase stability, reduce settlements, and correct or prevent slides on slopes and reduced backfill pressure on retaining structures.

Pierce and Blackwell (2003) investigated the potential of scrap tire rubber as lightweight aggregate in flowable fill. Flowable fill is a self-leveling and self-compacting material that is rapidly gaining acceptance and application in construction, particularly in transportation and utility earthworks. The study replaced sand with crumb rubber in flowable fill to produce a lightweight material. Based on the results, crumb rubber-based flowable fill is a possible use in substantial numbers of construction applications such as bridge abutment fills, trench fills, and foundation support fills.

Kahtib et al. (1999) investigated the use of recycled tire rubber in a Portland cement concrete (PCC) mixture as a possible alternative for nonconventional PCC mixtures. Their study focused on the determination of the practicality of producing such mixes and evaluating their engineering properties. They experimented with fine crumb rubber and coarse tire chips in PCC mixtures. They concluded that rubberized concrete mixes may be suitable for nonstructural purposes such as lightweight concrete walls, building facades, and architectural units (Khatib & Bayomy, 1999).

Garrick (2004) analyzed waste tire modified concrete to develop a concrete with high strength and high toughness. Waste tires used were in the form of fibers and chips in the PCC. The results showed waste tire should be used in the form of fibers instead of chips in modifying concrete to create a higher strength and stiffness in modified rubber concrete (Garrick, 2004).

Kumaran et al. (2008) researched the feasibility of using waste tires in the form of chips and fibers with different sizes in concrete to improve the strength as well as protecting the environment. They also reviewed the potential application in the field by exploiting its unique characteristics and properties. The study outlined the use of rubberized concrete in structural and non-structural members, and showed how it is suitable for the concrete, its uses, barriers and benefits. Hossain et al. (1997) researched the structural layer coefficients of crumb rubber-modified asphalt concrete mixtures. Structural layer coefficients for crumb rubber–modified (CRM) asphalt concrete mixtures developed were from back calculated module values using the falling weight deflectometer (FWD) test results on site pavements. The results indicated a lower structural layer coefficient value for the asphalt-rubber mix compared with the conventional asphalt concrete (Hossain, Habib, & Latorella, 1997).

Zhong et al. (2002) investigated the potential application of rubber-modified asphalt in railroad track beds by measuring its shear modulus and damping ratio. Findings showed that because crumb rubber is a material with high shear stiffness and damping ratio, makes it a very attractive material for vibration attenuation of railroad track beds (Zhong, Zeng, & Rose, 2002). Noise control is a major requirement in improving the living environment. One way to accomplish this is using a sound absorber. Zulkifli et al. (2010) investigated the potential of using coconut coir fiber as a sound absorber. Their results showed that the noise absorption coefficient of coconut coir fiber increased at all frequencies when there was backing with Woven Cotton Cloth (WCC). At low frequency, the NAC increased significantly (Zulkifli, Zulkarnain, & Nor, 2010).

In recent years, lightweight materials, in particular, the expanded polystyrene (EPS) block geofoams have been more widely used in the infrastructure rehabilitation and in the construction of new facilities such as roads and embankments. EPS is a waste that is widely obtained from molded sheets for building insulation and packing material for cushioning fragile items inside boxes. Yasufuku et al. (2002) investigated the compaction, direct shear, and permeability properties of a mixture of sand and heat compressed and crushed EPS (HCCE) for possible use as a lightweight fill material. The waste expanded polystyrene (EPS) is melted by 230 degrees, hot blasted and solidified. The solidified EPS was crushed by the crusher to make the crushed material used in their study called HCCE. Their results showed the HCCE material was effective in decreasing the self-weight of soil, and in increasing its shear strength and permeability. Liu, Deng et al. (2006) (Liu, Deng, & Chu, 2006) conducted a laboratory study on the formation of a lightweight fill material by blending soil with polystyrene pre-puff (PSPP) beads and other binders such as cement. The results were comparable to the expanded polystyrene (EPS) block geofoam and PSPP. The PSPP beads mixed had a higher density in lightweight fill and had higher shear strength and higher stiffness. PSPP can be used as a substitute of EPS blocks when irregular shaped volumes are to be filled or when stronger fill materials are required (Liu, et al., 2006).

Research also shows that fiber reinforcement can effectively improve the toughness and durability characteristics of concrete. The use of recycled fibers from industrial or postconsumer waste offers additional advantages of waste reduction and resources conservation. Wang et al. (2000) reviewed some of the work on concrete reinforcement using recycled fibers, including tire cords/wires, carpet fibers, feather fibers, steel shavings, wood fibers from paper waste, and high density polyethylene. Their review revealed carpet waste fibers improve, the toughness and shrinkage properties of concrete. A restrained shrinkage test for steel fibers showed about the same free shrinkage as concrete. Because different researchers did not perform the same tests, the researchers concluded that fibers could provide similar reinforcement as virgin materials, although a higher rate may be required to match the performance. Potential applications could include buildings, pavements, columns, bridge decks and barriers, and for airport construction such as runways and taxiways (Y. Wang, Wu, & Li, 2000).

Awwad and Shbeeb (2007) researched the use of polyethylene to enhance asphalt mixture properties. The results obtained from wheel track and fatigue tests revealed that using polyethylene outperformed traditional binders used in stone mastic asphalt. Their results indicated that grinded High Density Polyethylene (HDPE) polyethylene modifier provided an increase in stability, reduction in density, and slightly increased the air voids (Mohammad T.

Awwad & Lina Shbeeb, 2007).

Kaosol (2010) conducted research on reusing the water treatment sludge from a water treatment plant to make hollow concrete blocks. His objectives were to increase the value of the water treatment sludge from a water treatment plant and to make a sustainable and profitable disposal alternative for the water treatment sludge. Findings showed that the production of the hollow concrete blocks mixed with water treatment sludge could be a profitable disposal alternative in the future (Kaosol, 2010).

Siddique (2006) studied the utilization of cement kiln dust (CKD) in cement mortar and concrete. CKD is fine-grained, particulate material chiefly composed of oxidized, anhydrous, micron-sized particles collected from electrostatic precipitators during the high temperature production of clinker. Cement kiln dust is generated partly for reuse in cement plants and sent to landfills. Use of CKD in making controlled low-strength materials (CLSM), asphalt concrete, soil stabilizer, and leachate analysis. Siddique concluded that Concrete mixtures containing lower percentages of CKD (5%) can achieve almost equal compressive strength, flexural strength, toughness and freezing and thawing resistance as that of the control mixture (Siddique, 2006). Ebrahimi and co-investigators (2011) studied effectiveness of cement kiln dust (CKD) in improving the stiffness of recycled base course materials. Recycled materials included road surface gravel (RSG) and recycled pavement material (RPM). Their results showed that due to the combined effects of stiffness gain with continuing hydration and stiffness reduction with freeze thaw cycles, the final modulus of the recycled materials mixed with CKD is 2 to 5 times higher than that of untreated RPM and RSG materials (Ebrahimi, Edil, & Son, 2011).

Previous findings on the occurrence of water soluble antioxidants in palm oil has brought up the question on whether these compounds are present in other parts of the oil palm; namely its leaves. Han and May (2010) studied the determination of the water-soluble antioxidants in oil palm leaves. They concluded that the oil palm leaves contains water soluble antioxidative compounds with varying concentrations (Han & May, 2010).

A study by Muniandy et al. (2008) used the Empty Fruit Bunch (EFB) of Date and Oil Palm trees, which is a waste used to produce a fiber for additives in asphalt binder. Muniandy and co-investigators tested five blends with date palm fibers, five blends with oil palm fiber, and one with no fibers. The samples were evaluated using Dynamic Shear Rheometer (DSR) equipment, and measured for phase angle, shear strain and complex strain. Their result indicated that the date palm fiber improved the blend up to PG 76, the oil palm fiber blend showed an improvement up to PG 70, which is based on 80/100 penetration grade asphalt binder or PG58.

Due to intensive confinement of the livestock industry, an environmental problem associated with animal waste is one of the most critical environmental concerns. Because of this, there is an important and urgent need to develop an efficient way to reduce the pollution of animal waste while extracting valuable energy. Research show that the supercritical liquefaction processing of swine manure into a liquid fuel is a cost-effective approach for reducing animal waste in swine farms while simultaneously increasing farmers' income (Xiu, Shahbazi, Wang, & Wallace, 2010). Additionally, researchers at North Carolina A & T State University (Fini et al., 2009) investigated the use of by-products of bio-fuel from swine manure in construction adhesives. Their study compared the rheological characteristics of bio-based adhesives and petroleum based adhesives. Their study resulted in the development of sustainable construction adhesives such as asphalt binder and sealant used in highway and airport pavements.

Watson et al. (2007) investigated the potential use of roofing shingle waste in hot mix asphaltic concrete (HMAC). This would reduce the environmental problems related to the disposal of waste in landfills and also reduce the amount of virgin asphalt cement and fine aggregate required in hot mix asphaltic concrete (HMAC). Georgia Department of Transportation (GDOT) produced mixtures of HMAC using waste generated by roofing manufactures, consisting of discolored or damaged shingles. They tested the samples and showed that shingles performed well compared to unmodified control sections for this reason, GDOT allowed the use of recycled shingle in HMAC (Watson, Johnson, & Sharma, 2007).

CHAPTER 3

Survey of Current Recycling Practices

3.1 Introduction

The use of recycled and waste materials currently being used is a very important topic affecting the construction industry. Green building is a growing concept based on government policies and incentives to save energy, cost, and environmental concerns involving waste. In order to accomplish the growing industry of green building, the end users, including contractors, engineers, researchers and suppliers, have to be informed about what recycled and waste materials are available to use in the construction industry. To find out what companies are aware of recycled and waste materials and who are actually using them, companies have to be approached and questioned. If it is discovered some companies are not using recycled materials, what are the barriers or issues behind not using recycled materials in the construction industry?

3.2 Methodology

A survey was conducted through phone calls, visits, and email, addressing: 1) If the company uses or resells any waste or recycled materials for construction application, 2) Is the surveyor aware of other recycled materials that are being used in construction applications, and 3) Are there any recycled materials that are not recommended for use in the construction industry? All the questions ended with a yes for what application and if no, reasons for no using the material. Each survey consisted of a list of recycled and waste materials including; cement kiln dust (CKD), fly ash, foundry sand, slag, glass, plastic, carpet, tire rubber, recycled asphalt, recycled concrete, gypsum, silica fume, swine manure, animal fat, soy bean, roofing shingles, citrus peels, sewage sludge, date & oil palm tree, and a place to add additional recycled materials being used in the construction industry not listed. The last question was included to record any additional contact or references to question for more information on the topic.

3.3 Survey Results and Discussion

The survey was compiled of over 50 companies. The companies surveyed consisted of contractors, engineers, concrete, asphalt, landfills, scrap yards, steel manufactures, architects, trucker drivers, drilling, demolition, and recycling companies. Table 3.1 shows the percentage for each type of company surveyed.

Table 3.1

Percent of Company Participation.

Company	Count	Percent
Recycling	20	31%
Construction	11	17%
Concrete	9	14%
Contractors	6	9%
Asphalt	5	8%
Engineer	4	6%
Manufacture	4	6%
Architect	2	3%
Salvage	1	2%
Association	1	2%
Trucking	1	2%
Steel	1	2%
Total	65	100%

Figure 3.1 shows a complete analysis for the most common recycled materials in the construction industry. From this sample of companies, the most common recycled material was Recycled Concrete at 15%; followed by Recycled Asphalt and Wood, with 12% and 8%

respectively. Seven percent of the companies did not use recycled material at all. There were a few companies that were not included in the graph.

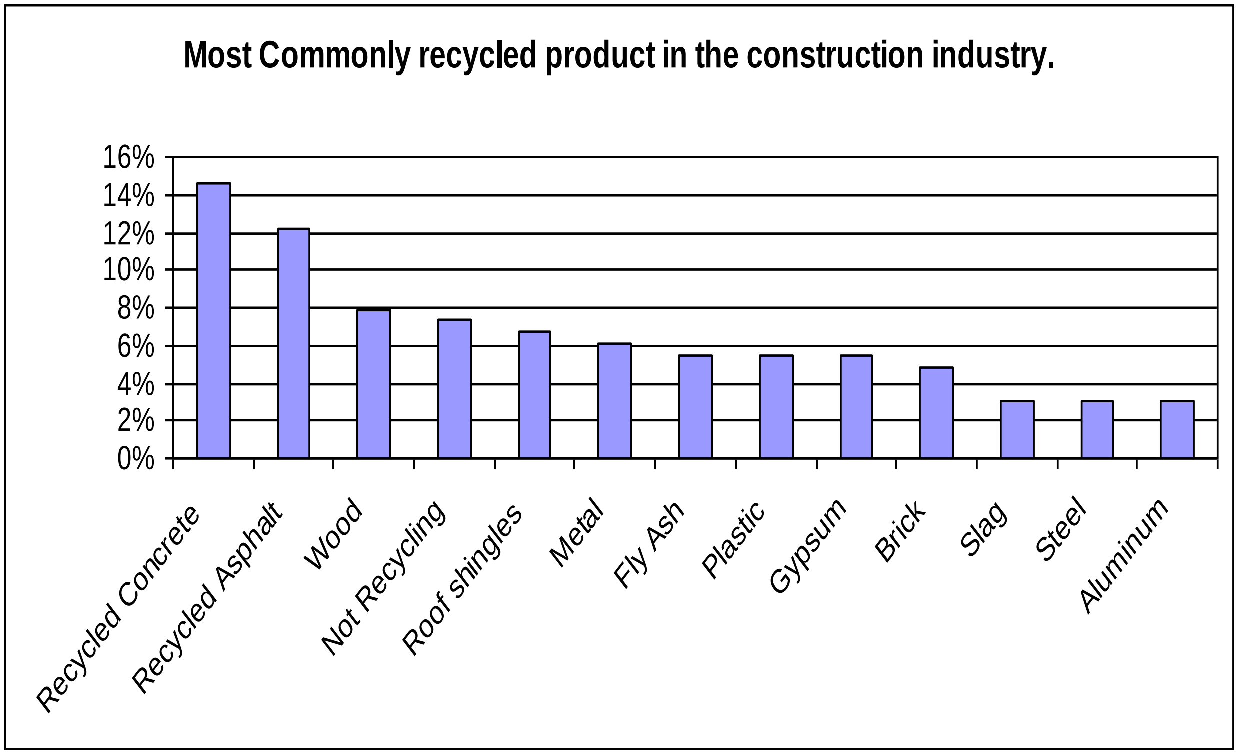


Figure 3.1. Most commonly used recycled materials for Construction applications.

These companies used less than 2% of any given recycled material including tire rubber, silica fume, glass, cement kiln dust, carpet, foundry sand, swine manure, animal fat, soy bean, citrus peels, sewage sludge and date & oil palm tree, which were listed in the survey as usable recyclable materials for construction applications. Other materials that were mentioned that had a low percentage usage were cast iron, copper, brass, and sawdust.

Figure 3.2 shows the percentages of the most commonly used materials in concrete. Recycled concrete was found to be the most popular, because it is easy to recycle back into concrete was at 54%, the cost is low compared to purchasing natural stones and aggregate, and its availability is high because of demolition of older buildings and highways. In order for concrete to be recycled and used as an aggregate, it must be cleansed and washed for DOT approval.

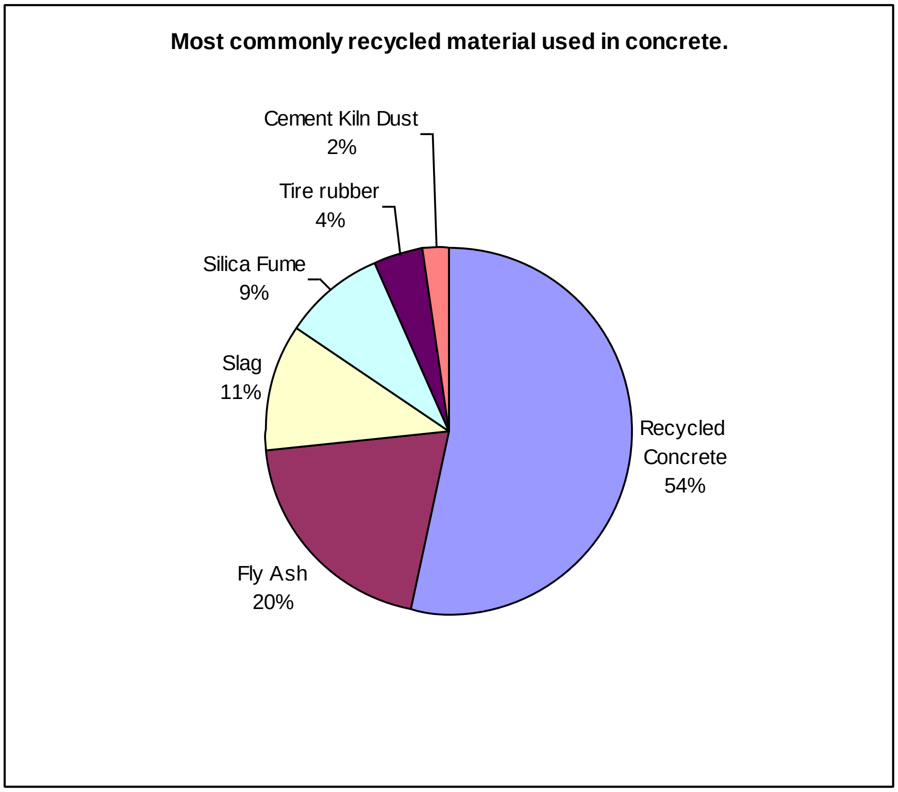


Figure 3.2. Most commonly used recycled material in concrete.

Fly ash was very popular, with 20% of companies using it in concrete. Companies mentioned it is a great substitute for natural fine aggregate and also increased concrete strength and saved cost on purchasing new materials. Some companies mentioned slag (12%) and silica fume (9%) for special projects, varying use according to the engineer from job to job bases. Tire rubber (4%) was found to be used in concrete including concrete barrier applications. One company considered using cement kiln dust and glass in their concrete, based off information provided to them by the National Ready Mix Association, but have yet to complete a testing strip. Companies using recycled asphalt (57%), grinded the old asphalt into course and fine course, then applied it to the new asphalt paving process. Another company mentioned they reuse up to 40% recycled asphalt, course and fine. Figure 3.3 shows the most commonly used material in asphalt applications. There is also a high percentage of recycling roofing shingles (36%) that asphalt companies use.

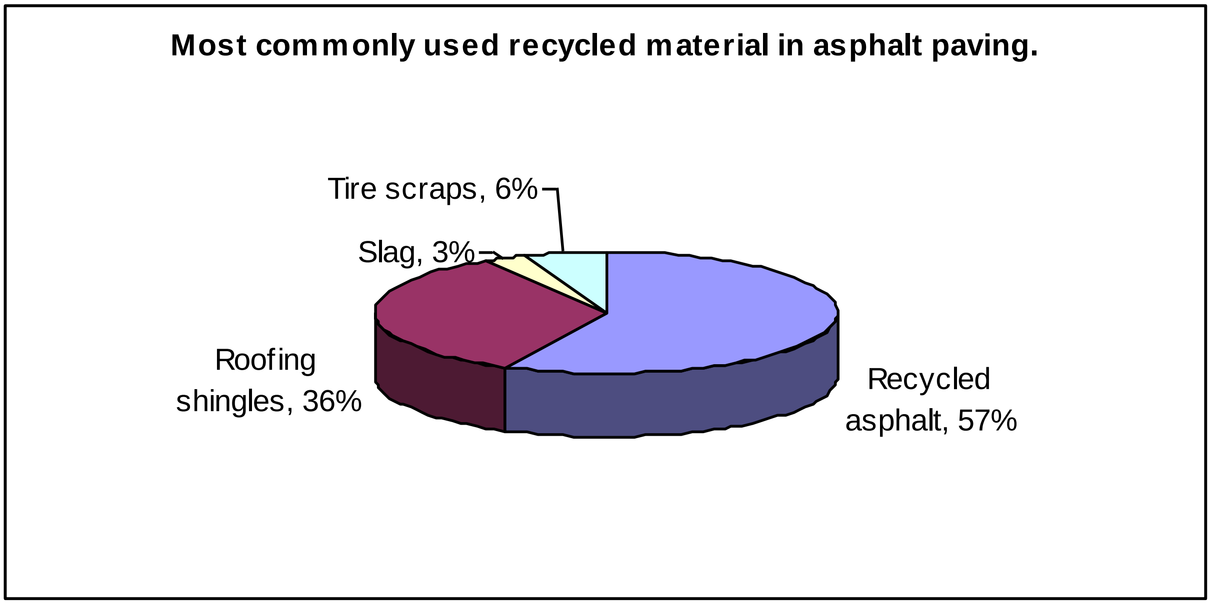


Figure 3.3. Most commonly used recycled material in asphalt paving.

Of all the companies surveyed, 7% explained they did not use recycled materials. Some reasons these companies gave not using any recycled material included cost, lack of education regarding certain materials, limited to special cases, environmental, quality of the product, contamination, permits, separation process, a market to buy the material, no equipment, storage, sent to scrap yards and landfills, and availability. Figure 3.4 is a bar chart that represents the percent of reasons why companies are not using recycled materials.

The companies surveyed, felt that cost made up 22% of the reasons why they do not use certain recycled materials in the construction industry. The cost outweighs the benefits for using certain recycled materials. Some processes are expensive to operate including glass and the recycling tire scraps. Following cost, companies claimed lack of education to be 13% of the reason why certain recycled materials aren’t being used in construction applications. Many companies are unfamiliar or not sure of what recycled materials can be used in construction applications.

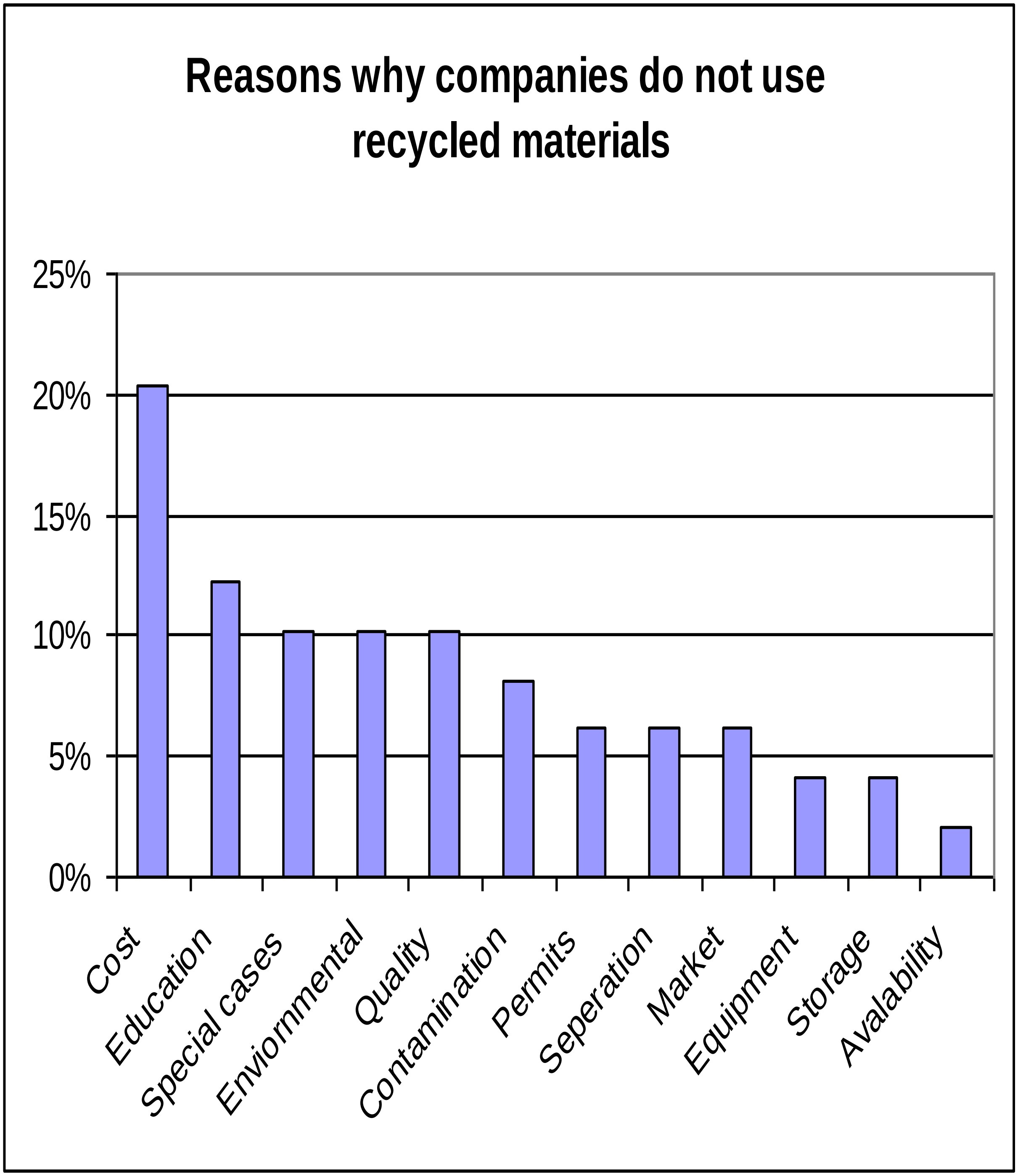


Figure 3.4. Reasons why companies do not use recycled materia**ls.**

Environmental constituted for 11% of the reasons. Environmental hazards include fly ash which contains traces of arsenic and mercury, roofing shingles containing asbestos, cementious material in silica fume, and molding issues in some gypsum. Quality represents 11% of the reasons certain materials were not used. For example, fly ash contained to much alkaline, which compromises the properties of the mix. Eleven percent of the reasons are because of limited to job to job bases including gypsum, silica fume, slag, which are left up to the engineer to decide. Contamination, making up 8% has similar reasons to that of quality reasons which reduced performance of the application. Comprising 7% each, the need to have a permit to accept certain waste, the expensiveness of the separation process, and lack of market of people to buy the recycled material, are other reasons companies choose not to recycle. This leads to education and awareness of what applications companies can use recycled materials for.

Findings show that 14% of the companies are completely unaware of other recycled materials being used in construction. Figure 3.5 analysis the percent of materials the companies are aware of in the construction industry.

There are many other materials that can be used, however due to the vast underuse (less than 1%), they were not mentioned in this survey. Some of these materials include, date & oil palm, sewage sludge, citrus peels, soy bean, animal fat, polyester lumber, rice husk, and swine manure. The majority of companies surveyed were not sure or aware of what recycled materials are accessible for construction applications. The reason for the underuse can be traced to new research and the lack of government approved regulations for these materials to be used, especially on state and government level projects. With data to support the materials performance and results proving it works, recycled and waste materials would grow much faster in the construction industry.

The reasons why companies are benefiting from recycling are cost, quality and reduce the waste sent to landfills. Figure 3.6 shows the results on why companies are recycling.

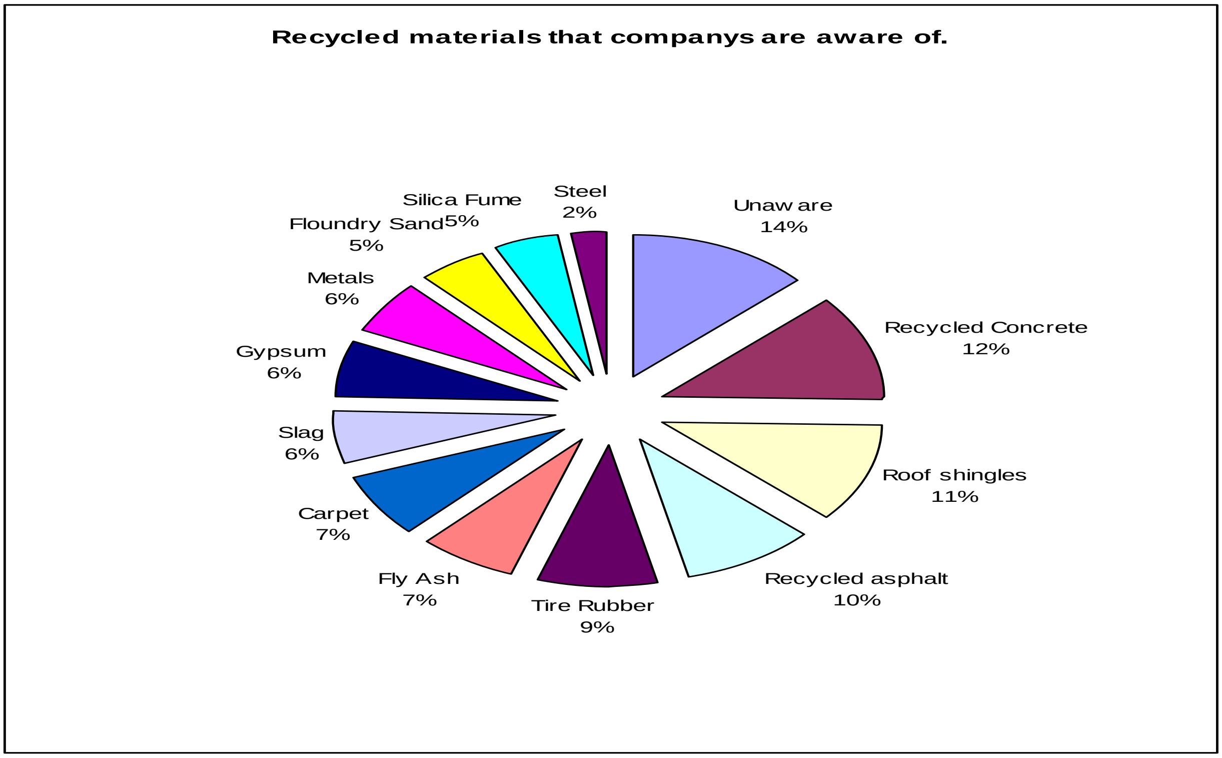


Figure 3.5. Recycled materials that companies are aware of for construction applications.

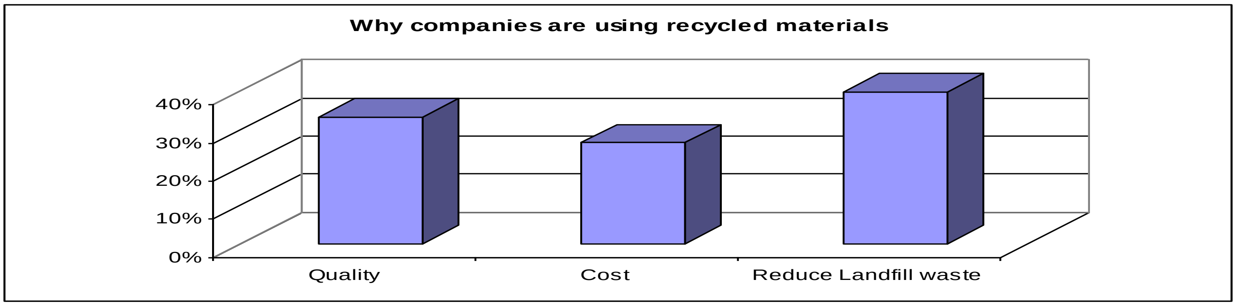


Figure 3.6. Why companies are using recycled materials.

There are plenty of benefits in using recycled materials in construction application. Quality represents 33%. Some recycled materials can improve strength in most cases, but not in large amounts. Silica fume turns the quality of concrete in to high strength concrete. Fly ash improves the workability and tire rubber improves thermal conductivity. Cost represents 27%. In most cases, recycled materials are low in cost compared to the cost of raw materials. For some materials, there is also saving in water, landfill tipping, and light weight transportation cost.

Reducing the waste sent to landfills represents the most beneficial ranking at 40%. Out of over 50 companies, the areas that need more research, analysis, and data to be used in the construction industry application is shown in Figure 3.7.

The remaining chapters of this publication provide a general overview of foundry sand, cement kiln dust, fly ash, slag, glass, plastic, carpet, tire rubber, recycled asphalt, recycled concrete, gypsum, silica fume, swine manure, and sewage slug, and their uses in various civil engineering applications. It will familiarize highway engineers and inspectors with this technology. This documentation will provide a place to find materials and application in one place. This will give companies a formal document for uses of waste and recycled materials in the construction industry. Readily at hand, without searching literature, researchers will find what is available, what is the market for conventional alternatives, what is the relative cost, what are the barriers to switching, what are the key issues to be looked at, how much to use, and the benefits of using recycled materials.

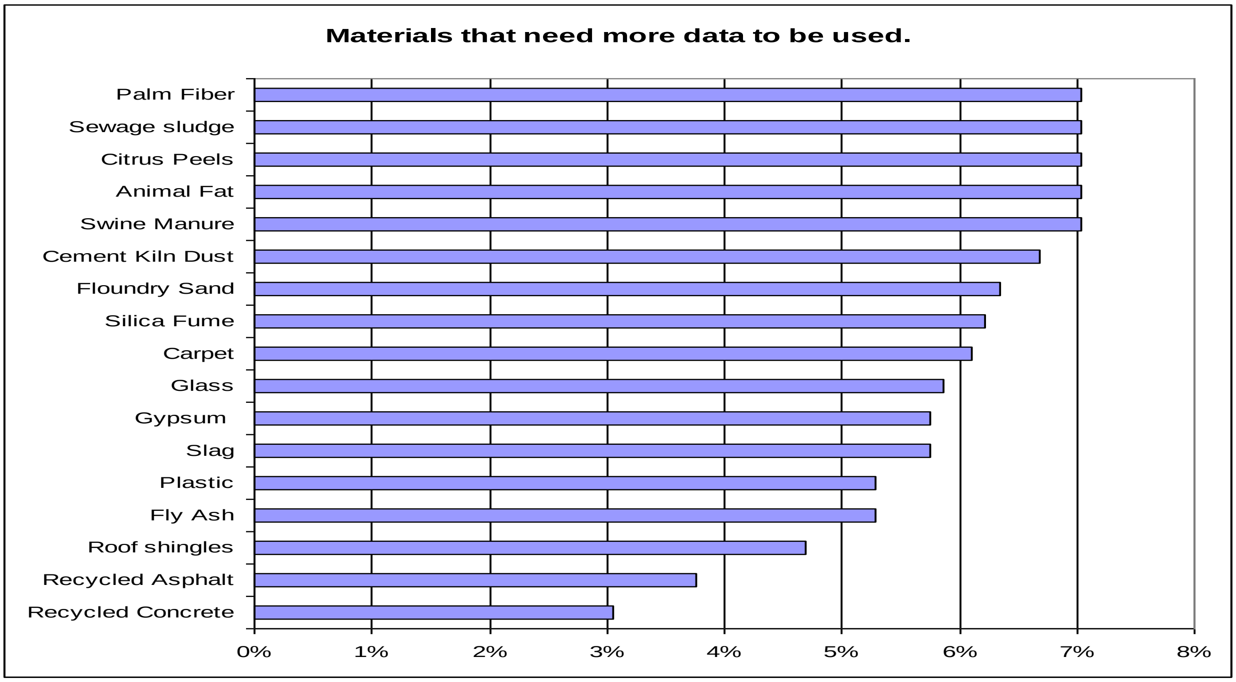


Figure 3.7. The percent of materials that need more data to be used in the construction industry.

CHAPTER 4

Composite Waste

4.1 Swine Manure

A large amount of swine manure (Figure 4.1), created by thousands of animals in giant hog farms can pollute rivers, poison groundwater and pump out clouds of methane and carbon dioxide. Manure is collected and available at livestock facilities. Manure consists of 96% – 98% water content.

Figure 4.1. Swine manure waste (http://www.sweeta.illinois.edu).

Current manure is being used to replace commercial fertilizers, such as straw made from the raw material wheat, 15 pounds of dry wheat compares to 100 pounds of fresh manure. Using fresh manure increases the fertility and water capacity of the soil improving soil tilth, bulk density, infiltration rate and permeability. Some of the barriers to switch have been odor problems and clogging equipment and piping.

The environmental effects of swine manure storage systems and application methods are a concern, mainly with respect to surface water, groundwater, and air quality as affected by odors and gaseous emissions from large-scale swine production operations. To address these concerns scientist have found ways to convert swine waste into bio-binder. Bio-binder production reduces the United States' dependence on petroleum resources by supplementing 9 million barrels of bio-oil per year reducing carbon emissions otherwise made by gasoline.

North Carolina Agricultural & Technical State University (NC A&T SU) has conducted research on the use of bio-fuel from swine manure in construction. Fini et al. (2011) investigated the replacement of petroleum-based adhesives (a non-biodegradable material) with a bio based, biodegradable adhesive from swine manure. The goals of their research were to both eliminate the need for storing swine manure and to improve the nation's sustainable infrastructural systems through appropriate usage of these by-products in construction adhesives such as asphalt binder and sealant used in highway and airport pavement. Their study produced bio-binder from manure, and analyzed its chemical composition. They added the bio-binder to PG 64-22 at 2, 5 and 10 percent by weight of the base binder, and studied the rheological properties of the bio-modified binder by conducting three tests namely Viscosity, Bending Beam Rheometer (BBR), and Dynamic Shear Rheometer (DSR). The viscosity of bio-modified binder was significantly lower than that of a non-modified binder.

Additionally, viscosity continued to decrease as the percentage of the bio-binder increased (Figure 4.2). Meaning, the reduction in the binder viscosity can improve binder wettability, which in turn return improves mixture durability. In addition, it will enables the asphalt producer to lower the mixing and compaction temperatures, which reduces binder aging and enhances pavement performance (Fini, Al-Qadi, You, Zada, & Mills-Beale, 2011).

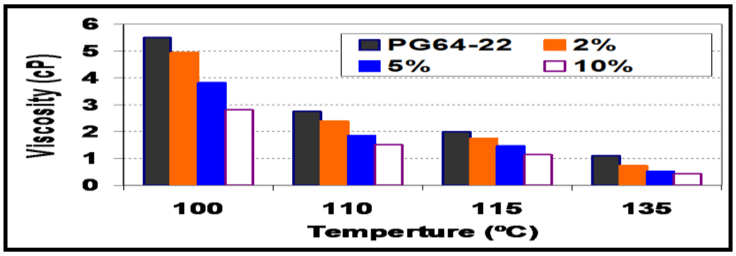


Figure 4.2. Viscosity test results (Fini, et al., 2011).

The results of the BBR test showed a significant decrease in stiffness, and an increase in relaxation capability of the binder (Figure 4.3). This implies an improvement in low temperature properties and a reduction in low temperature cracking.

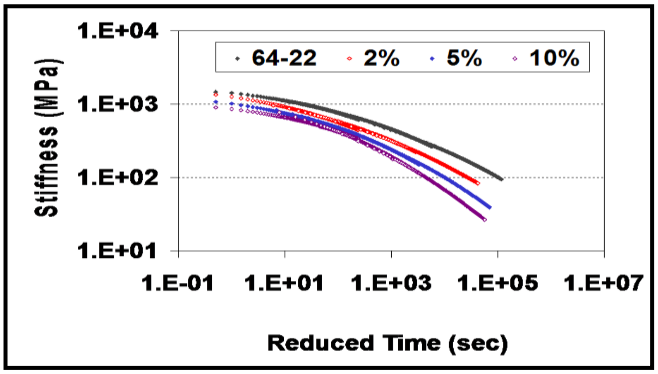


Figure 4.3. BBR test results according to ASTM D6648 (Fini, et al., 2011).

A DSR test characterized the viscoelastic behavior of the asphalt binder. The results showed that the complex modulus of modified binder decreased compared to the base binder (Figure 4.4). Noted also, although 2% addition of bio-binder did not influence the high temperature grade, addition of 5%-10% bio-binder resulted in one drop in binder’s high temperature grade. This means by adding 2% bio-binder, one can maintain high temperature grade of binder while enhancing its low temperature property and mixture workability (Fini, et al., 2011).

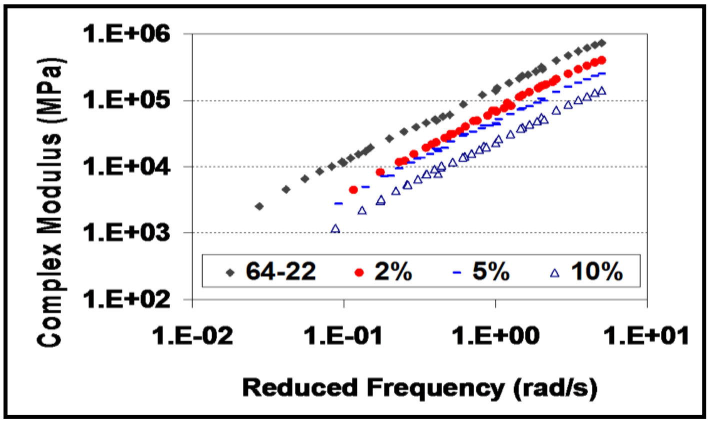


Figure 4.4. Dynamic shear rheometer (DSR) following ASTM D7175 (Fini, et al., 2011)

4.2 Animal Fat Oil

Data related to historical prices and supply and demand of waste/recycled greases and animal fats is less clear than that available for major commodity oils. Figure 4.5 is an animal fat waste.

Figure 4.5. Animal fat waste (livingthedililife.blogspot.com).

In the past much of these waste products have been used in the production of animal feeds. The use of waste fats for animal feed is not as common as it once was and this has resulted in surplus quantities becoming available. This has led to significant disposal problems. USDA yellow grease production estimates for the U.S. from 1995 to 2000 average 2.6 billion pounds, equivalent to 350 million gallons of biodiesel. Minnesota yellow grease production estimates range from 16 million to 48 million pounds equivalent to 2 to 6 million gallons of biodiesel. However, it is clear that yellow grease is about half the cost of soybean oil. Whereas soybean oil prices range from 14 to 28 cents per pound, yellow grease prices range from 7 to 16 cents per pound.

The use of animal fat has been used in the construction industry since roman times.

Animal fat also referred to as tall oil. Ahmedzade et al. (2007) investigated the properties of asphalt concrete mixtures modified with tall oil pitch (TOP) and styrene-butadiene-styrene (SBS). They prepared seven asphalt binder formulations for testing 8% of TOP; 8+3%, 8+6% and 8+9% of TOP +SBS, respectively, by total weight of binder. Then, they conducted several compression strength tests under different conditions to determine water, heat and frost resistance of the samples. Figures 4.6 and 4.7 show fatigue and life plastic deformation tests results, respectively. TOP has a strong connection with aggregate after wetting providing a chemical adsorption interaction. Calcium carboxylates of the carboxylic acids of TOP (abietic, oleic and their derivatives) cause strong adhesive connections between TOP and aggregate (Kuloglu & Akhmedzade, 2001). Their results indicated the asphalt mixture modified by 8% TOP + 6% SBS gave the best results for the tests, and found the modified binder increased the physical and mechanical properties of the asphalt binder (Ahmedzade, Tigdemir, & Kalyoncuoglu, 2007).

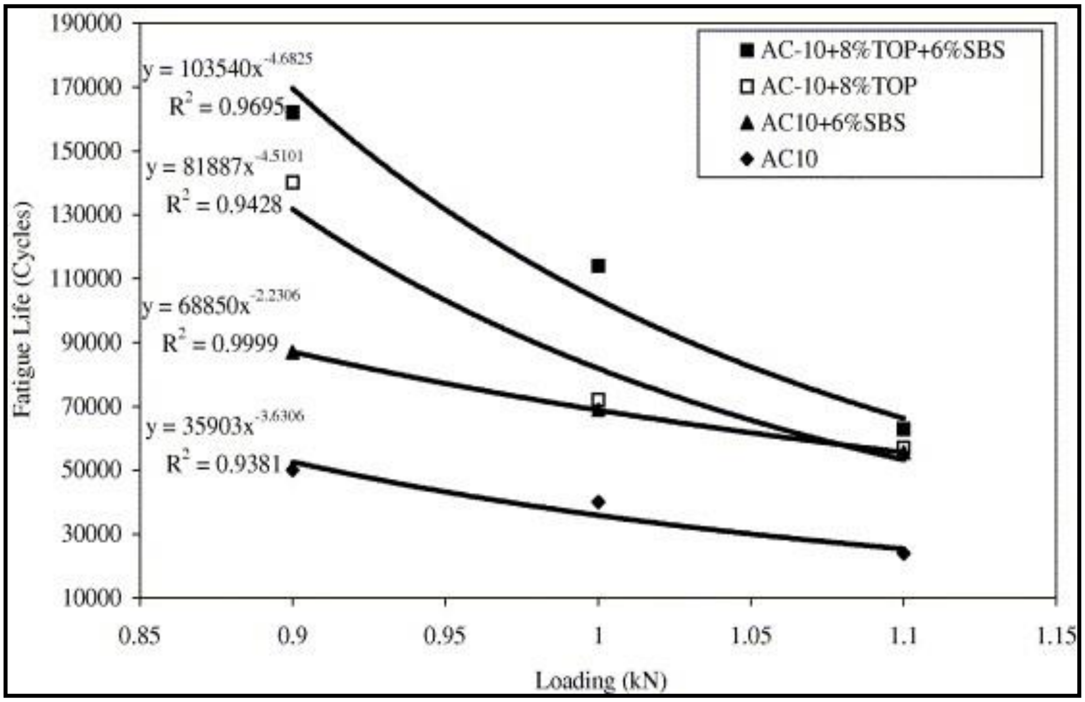


Figure 4.6. Fatigue life curve (Ahmedzade, et al., 2007).

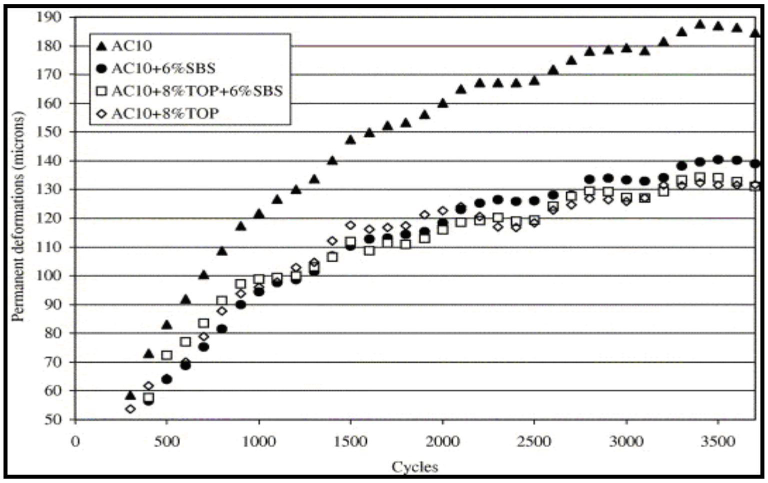


Figure 4.7. Average permanent deformations (Ahmedzade, et al., 2007).

4.3 Palm Oil Fiber

Palm oil is edible plant oil derived from the palm tree fruit. It is common in the tropical locations like Africa, Brazil and South Asia. It has a low cost and high saturation used for frying. The waste product from the empty palm tree is causing disposal problems. Figure 4.8 is a photo of empty palm bunch waste pile from a palm oil mill in Malaysia.

Figure 4.8. Empty fruit bunch from a palm oil mill in Malaysia (etawau.com).

Due to high oil prices and eventually higher asphalt cement price, and also considering the high price of polymer as a modifier, natural fibers such as date palm cellulose fiber or oil palm cellulose fiber could be used as an alternative to enhance the rheological properties of the binder (Muniandy, Jafariahangari, Yunus, & Hassim, 2008). Figure 4.9 is a close up of palm fibers.

Figure 4.9. Empty fruit bunch fibers (sonmanizales.com).

Muniandy et al. (2008) conducted a study to take advantage of the Empty Fruit Bunch (EFB) of Date and Oil Palm trees to produce cellulose fiber to use as an additive in the asphalt binder. The use of natural fibers and EFB waste would reduce the cost of asphalt for construction paving. In their study, a total of 11 blends were prepared that consisted of 5 blends with date palm fiber, 5 blends with oil palm fiber and one control sample that contained no fibers (PG58). They conducted several tests to find the optimum fiber content based on shear modulus, phase angle, shear strain, failure temperature, and performance grade for Bio Mastic Asphalt (BMA). The results indicated that fibers enhanced the rheological performance of the BMA blends (Muniandy, et al., 2008). Figures 4.10 and 4.11 show a performance increase of the date palm fiber; however, the enhancement for the oil palm fiber was not as much.

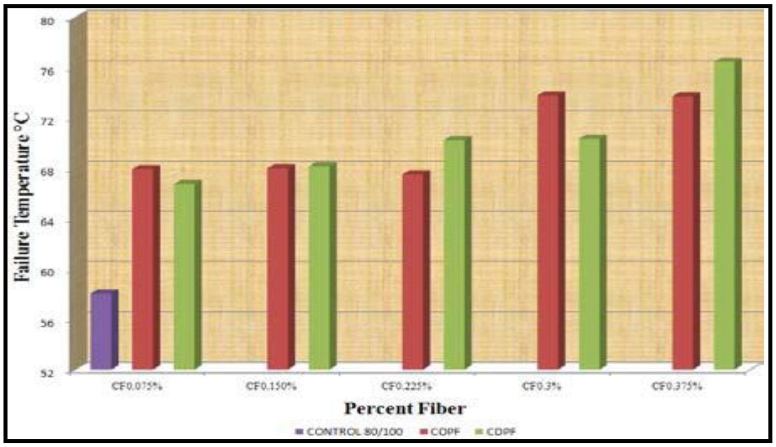


Figure 4.10. BMA failure temperature vs. percent fiber (Muniandy, et al., 2008).

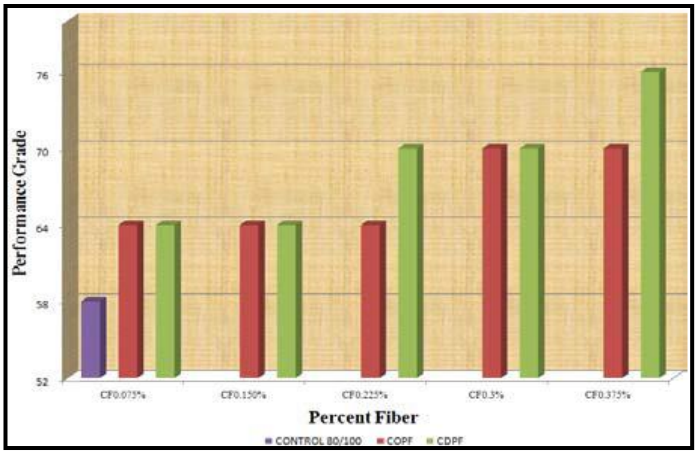


Figure 4.11 .BMA performance grade vs. percent fiber (Muniandy, et al., 2008).

Their testing revealed that optimum fiber content of 0.375% (by the weight of the total mix of the date palm fiber) improved the blend up to PG 76 and for the oil palm fiber, with fiber content of 0.3% improved to the blend up to PG 70. The date palm fiber showed a better performance rather than the oil palm fiber.

4.4 Citrus Grapefruit & Orange Peel

Citrus wastes (peel, pulp, and seeds) generated from juice production are almost 50 wt% of the original whole fruit. The US 2006/2008 seasons of citrus juice production generated 10.6

million metric tons of waste; Figure 4.12 shows a waste pile of citrus peels.

Figure 4.12. Pile of citrus waste generated by Citrus Waste Biorefinery: Biomass Characterization of Grapefruit Processing (www.tamuk.edu).

Research shows that citrus peel can be an alternative to commercial activated carbon that is high in capital and regeneration costs, which is the preferred absorbent for removal of methylene blue (MB). MB is a dye that comes from the wastewater from textile industries, and can cause severe environmental pollution if emitted to the environment without proper treatment. Among various dyes, methylene blue (MB) is the most frequently used substance for dying silk, wood and cotton. It has severe health impact on humans such as nausea, vomiting, and diarrhea.

Researchers are now developing new low-cost adsorbent from various non-conventional waste materials for an equivalent potential as the commercial activated carbon. Studies attempted to develop a low-cost adsorbent from citrus fruit peel by carbonizing it through a chemical activation method. Citrus fruit peel has no use after the extraction of juice from the fruit. Dutta et al. (2011) investigated the possibility of Charred Citrus Fruit Peel (CCFP) as an adsorbent for liquid phase removal of MB, a model dye. They conducted an experimental study using Citrus fruit (grapefruit) peel collected from a local juice maker. An activating agent such as ortho-phosphoric acid or zinc chloride or sulfuric acid was mixed with the dried powdered fruit peel of size lesser than 90 µm. The results showed that ortho-phosphoric acid was the best activating agent among others. To compare CCFP with the commercial activated carbon properties, (see Table 4.1), CCFP has a solid density, bulk density, moisture content, low ash content, SET surface area, and pore volume.

Several studies on different adsorbents for Methylene Blue (MB) are tabulated in Table 4.2. The maximum removal capacity of CCFP for MB was found to be 25 mg/g which is comparable with other adsorbents tested by other scientists. Figure 4.13 shows the actual and predicted responses.

Actual response for removal of MB for a particular run and the predicted values evaluated from the model were compared as shown in Figure 4.13. Table 4.1 gives the statistical parameters obtained from their study.

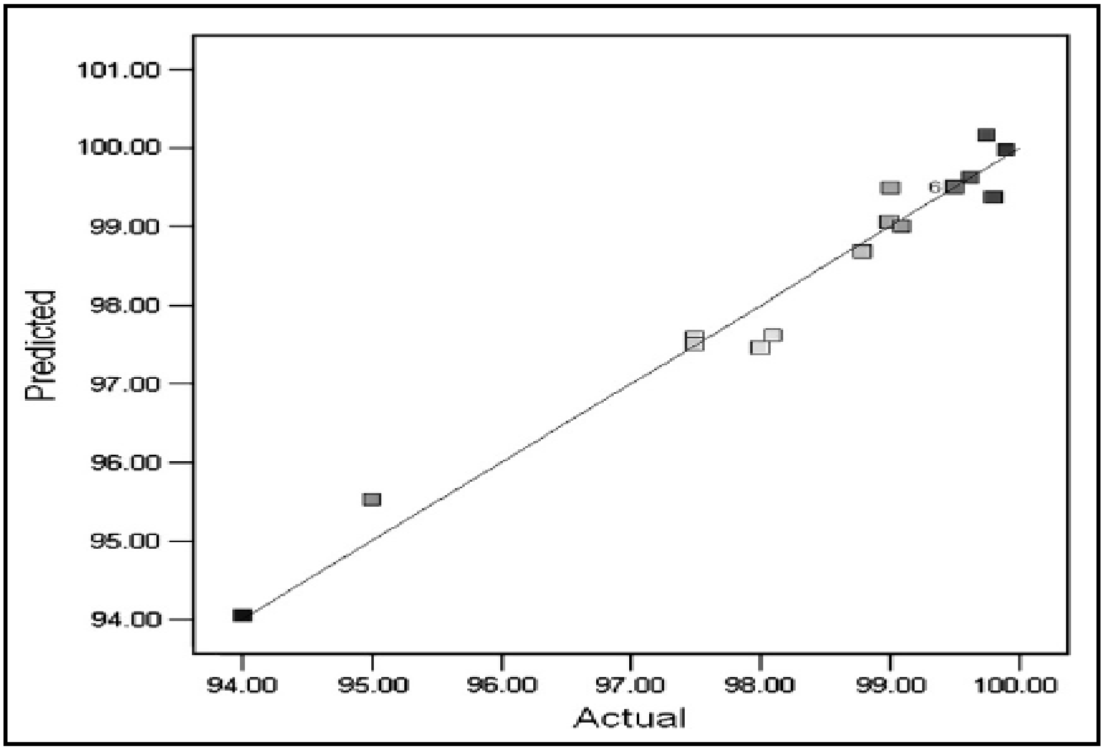


Figure 4.13. Plot of actual response vs. predicted response for removal of MB (Dutta, et al., 2011).

Table 4.1

Characterization of CCFP and commercial activated carbon (Dutta, et al., 2011).

Properties	**CCFP**	**Activated Carbon**
Bulk density (kg/m^3)	2008	2600
Solid density (kg/m^3)	1234	988.43
Moisture content (%)	17.36	12.81
Ash content (%)	10.92	7.13
BET surface area (m^2/g)	526	750
Pore volume (cc/gm)	1.3864	0.8956

Table 4.2

Removal capacity of various adsorbents for MB (Dutta, et al., 2011).

Type of adsorbents	**Adsorption capacity (mg MB/g Absorbent)**	**References**
Jordanian Tripoli	16.6	A.S Alzaydien [11]
Rice husk activated carbon	9.83	Hama et al. [12]
Activated carbon from Delonix regia pods	24.0	Ho et al. [13]
Coir pith carbon	5.87	Kavitha and Namasivayam [14]
Solid waste from leather industry	80	Oliveira et al. [5]
Rectorite	89.4	He et al. [16]
Fly ash	0.814	Khan et al. [17]
Lemon peel	29	Kumar and Porkodi [18]
Tamarind fruit shell	1.72	P. Saha [19]
Acid activated carbon	60.61	Arivoli et al. [20]

Table 4.3

Values of statistical parameter (Dutta, et al., 2011).

Statistical parameter	**Values**
R-squared	0.9704
Adj R-squared	0.9437
Pred R-squared	0.7547

The fair values of the statistical parameters are due to the selection of different variables in wide ranges with a limited number of experiments. The best condition for removal of MB was optimized using design expert software keeping pH at 7. According to the software, the optimum response can be obtained when the weight of CCFP, pH and initial concentration of MB were 0.48 g, 7 and 30mg/L, respectively. These results were also verified by experimentation. Predicted percentage removal of MB (97.5%) at the said condition matched very well with the experimental value (98.0%) (Dutta, et al., 2011).

ALzaydien (2009) investigated orange peels as an adsorbent of MB. They conducted a test for the variation in the parameters of pH, sorbent dosage, contact time, and the initial concentration of adsorbent. Langmuir and Freundlich isotherms were used to analyze the equilibrium data. To describe the adsorption mechanism, the kinetic and thermodynamic parameters also calculated. The orange peel (OP) was obtained from a local market, cut into small pieces and dried at 100°C for 24 hours using hot air oven. Biosorption experiments were carried out in a thermostatic shaker at 180 rpm, and at an ambient temperature (20±2°C) using 250 mL shaking flasks containing 100 mL of different concentrations and initial pH values of Pb(II) solutions prepared from reagent grade salt Pb(NO3)2 (Merck). The initial pH values of the solutions were previously adjusted with 0.1 M HNO3 or NaOH and measured using a hand held pH meters (315i/SET). 0.2-1.0 g of the sorbent was added to each flask; then flasks were sealed to prevent a change in the volume of the solution during the experiments. The results of the monolayer adsorption capacity were 21.1 mg g-1 at pH 6 and 20°C. The dimensionless separation factor (RL) showed that orange peel can be used for removal of lead (II) ions from aqueous solutions (ALzaydien, 2009).

4.5 Sewage Sludge Ash

Coarse solids and biosolids accumulated in a wastewater treatment process must be treated and disposed of in a safe and effective manner creating sewage sludge. This material may be inadvertently contaminated with toxic organic and inorganic compounds like heavy metals. The negative is that sewage waste contains harmful containments such as heavy metals, organic carcinogens, and photogenes (Morse, 1989). Since sewage slag is full of nutrients like nitrogen and phosphorus, it is good for fertilizer in landscaping for highways and farmers. In South Africa the sludge is dried and given always to reduce land fill waste. Figure 4.13 is a photo of sewage slag ash and clay to make cement piping.

Figure 4.14. Sewage slag ash being used in cement piping (sewerhistory.org).

Sewage sludge ash has been investigated to be use in concrete applications. A study in Iran by M. Jamshidi et al. (2011) used dry sludge of a domestic/industrial water treatment plant in concrete. They investigated at water to cement ratios of 0.45 and 0.55. By increasing in dry sludge content to 20% in concrete samples, a decrease about 20% in compressive and flexural strengths was obtained. Concretes containing 20% dry sludge showed acceptable results at w/c ratio of 0.45, considering economical and technical reasons and environmental issues.

Sewage sludge ash can be used as a mineral filler substitute or as a portion of the fine aggregate in hot mix asphalt paving. The introduction of sewage sludge ash at levels of approximately 2% to 5% by weight of aggregate has been shown to produce mix design properties that are comparable to those of mixes containing conventional fillers such as hydrated lime and stone dust (FHAW, 2004). Research shows several benefits of sewage slag ash, namely, compaction, compressive strength, freeze thaw resistance, and has hardening properties, which may be used for the production of concrete. The former Metropolitan Waste Control Commission (MWCC) of Minneapolis, Minnesota, undertook an extensive investigation on the use of sludge ash in hot mix asphalt production. The results of their demonstrations reportedly revealed no visible difference between the pavement sections containing sludge ash and adjacent sections containing conventional materials ("Sewage Sludge Ash Use in Bituminous Paving," 1990)

The properties of an asphalt paving mix containing sludge ash that are of particular interest include stability, mix density, air voids, asphalt demand, durability, and asphalt cement viscosity. Stability: The addition of sludge ash in paving mixes up to approximately 5 to 6 percent by weight of aggregate reportedly increases the stability of the mix (Khanbiluardi, 1994). Mix Density: The addition of sludge ash can decrease the density of the mix (Khanbiluardi, 1994). Air Voids and Asphalt Demand: An increase in sludge ash concentration can be expected to result in an increase in air voids and a corresponding increase in the asphalt cement demand of the mix (Khanbiluardi, 1994). Durability: Mix durability (measured in the laboratory) may be slightly improved by the addition of sludge ash (Khanbiluardi, 1994).

Viscosity: The addition of sludge ash to asphalt cement reduces the ductility of the binder and its penetration values and increases the corresponding viscosity of the binder, producing a high consistency binder (Khanbiluardi, 1994).

CHAPTER 5

Industrial Sector Waste

5.1 Cement Kiln Dust

Cement kiln dust (CKD) is a by-product from the manufacturing of Portland cement. CKD is a fine grained, highly alkaline waste, removed from cement kiln exhaust-gas using air-pollution control devices and collected in a particulate matter control devices such as bag houses or dust bins. In 2006, US cement plants produced 99.8 million metric tons of cement (Adaska & Taubert, 2008).

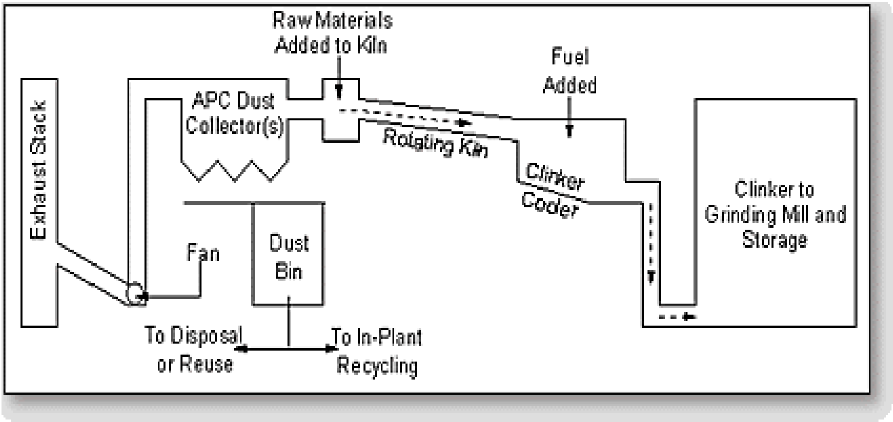


Figure 5.1. Portland cement manufacturing operation producing CKD (RMRC, 2008).

Each year nearly eight million tons of CKD is recycled directly back into the cement kiln as raw material (Figure 5.1). By doing so, manufacturers conserve energy and reduce use of limestone and other virgin raw materials (Portland Cement Association, 2012). CKD is similar to raw feed, but the amount of alkalis, chloride and sulfate is usually considerably higher in dust. This reduces the dependency of land filled CKD disposal to 47% (Adaska & Taubert, 2008). In 1993 the EPA issued a report to congress which concluded CKD generally posed little if any, risk to human health and the environment, but could if mismanaged. In 2006, 1.16 million tons of CKD was removed from cement manufacturing process.

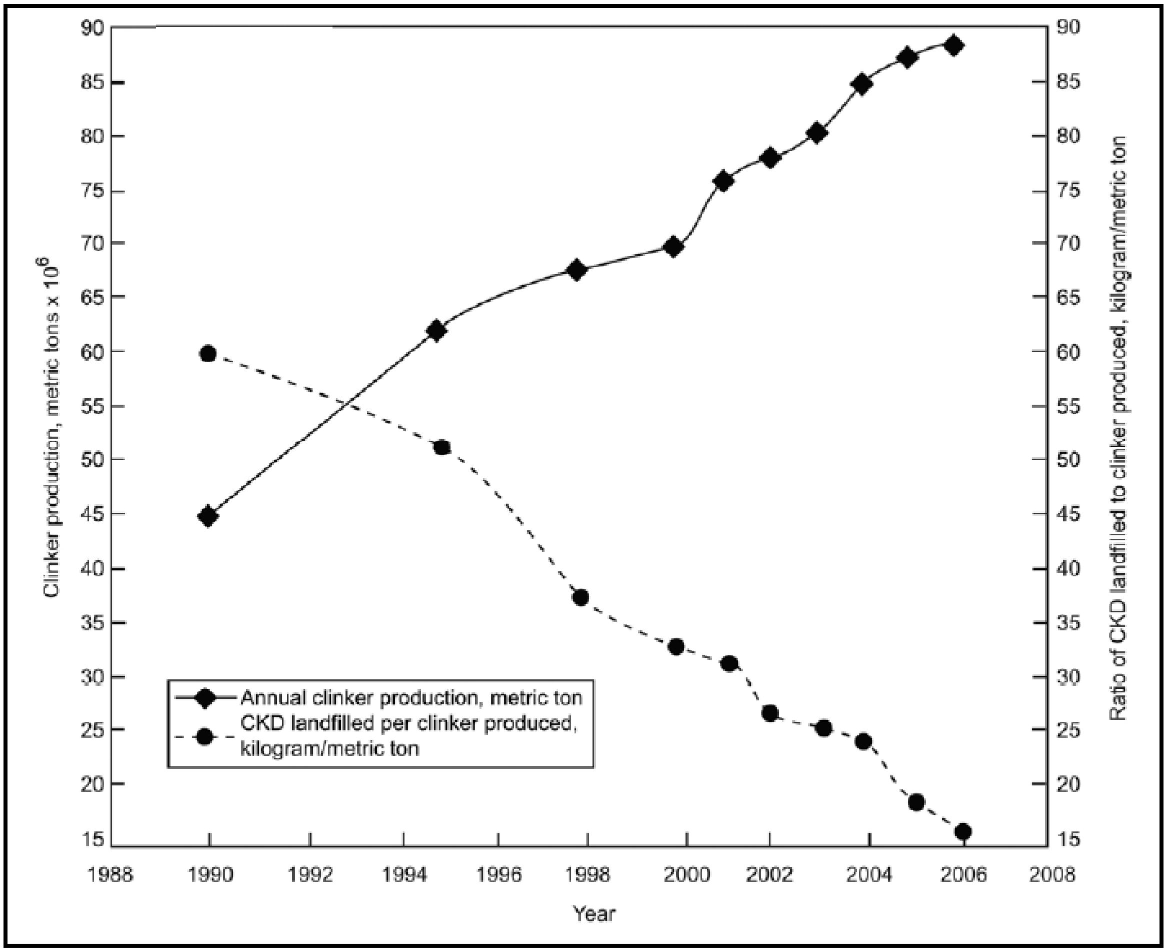


Figure 5.2. Clinker Production and Ratio of CKD Landfilled/Clinker Produced (From PCA member company surveys).

The amount of CKD removed from onsite landfills has grown from just over 13,400 metric tons in 1998 to more than 261,000 metric tons in 2006 (Figure 5.2). The CKD not returned to production is disposed in landfills, waste spills, or surface impoundments. The most common beneficial uses of CKD in the construction industry are soil enhancement, base stabilization for pavement, waste treatment, cement replacement, asphalt pavement, low strength back fill and municipal land fill cover (Adaska & Taubert, 2008). Table 5.1 shows the Beneficial Uses of Cement Kiln Removed from the Cement Manufacturing Process. The lack of substantial scientific proof of its effectiveness limits its use.

Table 5.1

Beneficial Uses of Cement Kiln in construction applications (PCA member company survey for 2006).

Uses of CKD	**Quantity of CKD beneficially reused, metric tons**
Soil / Clay Stabilization / Consolidation	533,365
Waste Stabilization / Solidification	213,675
Cement Additive / Blending	183,228
Mine Reclamation	152,756
Agricultural Soil Amendment	33,546
Sanitary Landfill Liner / Cover Material	15,042
Waste Neutralization / Stabilization	12,302
Pavement Manufacturing	12,066
Concrete Products	374
Beneficial Use Not Provided	3,657
Total	1,160,011

In the United States, 10% of CKD is used as a soil stabilizer (Corish and Coleman, 1995). Instead of using lime, a finer more expensive stabilizer, CKD is preferred to for improve soils strength and minimize and cost. Miller & Zaman (2000) indicated that CKD can be used as an alternative to quick lime for sub grade stabilization in highway construction.

Figure 5.3. Constructing a pavement base using CKD (Courtesy of Lafarge North America**).**

The use of CKD as an addition to Portland cement has been evaluated by a number of researchers. A summary can be found in Detweiler et al. (1996) of some examples. Bhatty (1953, 1984a-c, and 1986) reported the use of CKD in Portland cement. The study found that cement containing only CKD had reduce workability, setting times, and strengths. The loss of strength was attributed to the alkalis in the dust. Abo-el-enein et al. (1994) studied the mechanical properties of cement and CKD. They found blended cement with up to 15% kiln dust had increased strengths and accelerated hydration.

Research shows that CKD is useful as a solidification of waste. CKD is a quality adsorbent and a natural alkaline that makes it an effective waste treatment. CKD is an inexpensive material that is as effective in waste treatment as commercial cement or lime. CKD has been successfully used in coal miner's effluents, industrial waste water, sewage, and oil sludge (Siddique, 2006). Research also shows that CKD has a high absorptive capacity and alkaline properties, which reduce the moisture content. As a stabilizing agent for wastes, CKD increases the bearing capacity and provides an alkaline environment for waste materials. Other studies show CKD mixed with sand increase compressive strength. According to Siddique (2006), concrete mixtures containing lower percentages of CKD, more specifically 5%, can achieve almost equal compressive strength, flexural strength, toughness, and freezing- thawing resistance as the control mixture. Addition of CKD to soils can substantially improve the unconfined compressive strength. The improvement is more significant for soils with low PI (Siddique, 2006).

According to Emery (1981), CKD mixed with asphalt, as mineral filler, significantly reduces asphalt cement requirements between 15% and 25% by volume. CKD added to the asphalt binder produces low ductile mastic asphalt. It provides stripping resistance for pavement. The investigation of Emery (1981) revealed that slurry seal mixed with 2% CKD and stripping fine aggregate showed excellent results in abrasion testing.

Ebrahimi et al. (2011) conducted a study on the use of CKD in recycled materials; including road surface gravel (RSG) and recycled pavement material (RPM). Their results showed an increase in modulus of 5 – 30 times compared to untreated specimens. The results were not as high as cement stabilization. However, with the increase of CKD of 15% in RPM the modules decreased with potential of swelling. The lower rate of modulus was due to the free lime and sulfate contents. They also conducted freeze - thaw testing, which resulted in a modulus reduction in the order of 0.5 to 0.8 for CKD mixtures and 0.5 for cement mixtures, which was due to the combined effects of stiffness gain with continuing hydration and stiffness reduction with freeze - thaw cycles. As, shown in Figure 5.4, the final modulus of the recycled materials mixed with CKD is 2 to 5 times higher than that of the untreated RPM and RSG materials (Ebrahimi, et al., 2011).

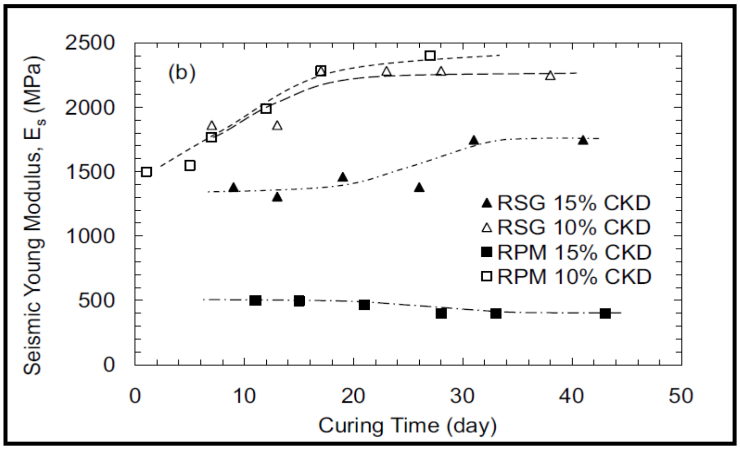


Figure 5.4. Seismic young modulus as a function of curing time and CKD mixtures for RSG and RPM (Ebrahimi, et al., 2011).

Advantages of using cement kiln dust in concrete materials; Opens a value added use option for utilization of CKD; Helps in sustainable development by reducing demand of new landfills; Uniform finer particle size is useful in manufacturing of self-consolidating concrete and high-performance concrete; Improves corrosion resistance of reinforcing steel in concrete; Manufacturing of blended cement.

5.2 Fly Ash

Fly ash (FA) is the by-product of coal combustion in power generation. Coal provides more than half of the nation's electricity, and continues to be the fuel of choice for generating power. Fly Ash is a powdery substance laced with heavy metals such as arsenic, mercury, and lead. Fly ash is generally grey in color, abrasive, mostly alkaline, and refractory in nature. According to US Energy Information Association, the US burns one billion short tons after china at about four billion followed by Europe and then India at 800 million tons. In 2010, the US alone mad about 130 million tons of “coal combustion products” or leftovers, about half of that is fly ash (Transportation Department Foundation, 2011).

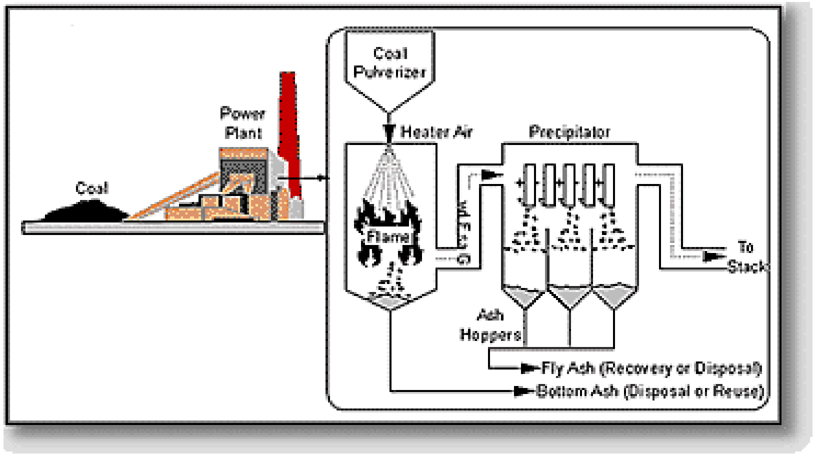


Figure 5.5. Production of fly ash in a dry-bottom utility boiler with electrostatic precipitator (RMRC, 2008).

Figure 5.5 is a diagram of the production of fly ash. The amount of fly ash released by factories and thermal power plants has been increasing throughout the world, and the disposal of large amounts of fly ash has become a serious environmental problem. For power companies, disposal options are costly because the fly ash is potentially toxic waste and must be treated as such. Fly ash is highly contaminated due to their enrichment and the potential toxin trace elements condensing from the flue gas. Considerable research has been conducted on this waste material to prevent the toxin threat in the environment or to stream line waste disposal technique making waste material affordable and used in new products instead of disposed in landfills.

The worldwide utilization of fly ash ranges from 5% to 57%. The chemical composition of fly ash consist of a high percentage of silica (60– 65%), alumina (25–30%), magnetite, Fe2O3 (6–15%) makes it a good candidate for the synthesis of zeolite, alum, and precipitated silica. The other important physicochemical characteristics of fly ash, such as bulk density, particle size, porosity, water holding capacity, and surface area makes it suitable for use as an adsorbent. The American Coal Ash Association writes most fly ash end up in dumps and about and about 40% is reused, primarily in the construction industry as concrete filler. Several studies have been conducted on the utilization of fly ash in construction, as a low-cost adsorbent for the removal of organic compounds, flue gas and metals, light weight aggregate, mine back fill, road sub-base, zeolite synthesis, concrete production, structural fills, embankments, filter in asphalt mixes, and grouting. Figure 5.6 shows common applications for fly ash.

There are many reasons to increase the utilization amount of fly ash. To name a few, it replaces some scarce or expensive natural resources, minimization of disposal costs, reservation of less area for disposal; thus, enabling other uses of the land and decreasing disposal-permitting requirements. There also may be financial returns from the sale of the by-product or at least an offset of processing and disposal cost. Fly ash can be an alternative to another industrial resource, process, or application. These processes and application include, but are not limited to, cement and concrete products, structural fill and cover material, roadway and pavement utilization, addition to construction materials as a lightweight aggregate, infiltration barrier and underground void filling, and water and environmental improvement. The geotechnical properties of fly ash (e.g., specific gravity, permeability, internal angular friction, and consolidation characteristics) make it suitable for use in construction of roads and embankments, structural fill, and concrete.

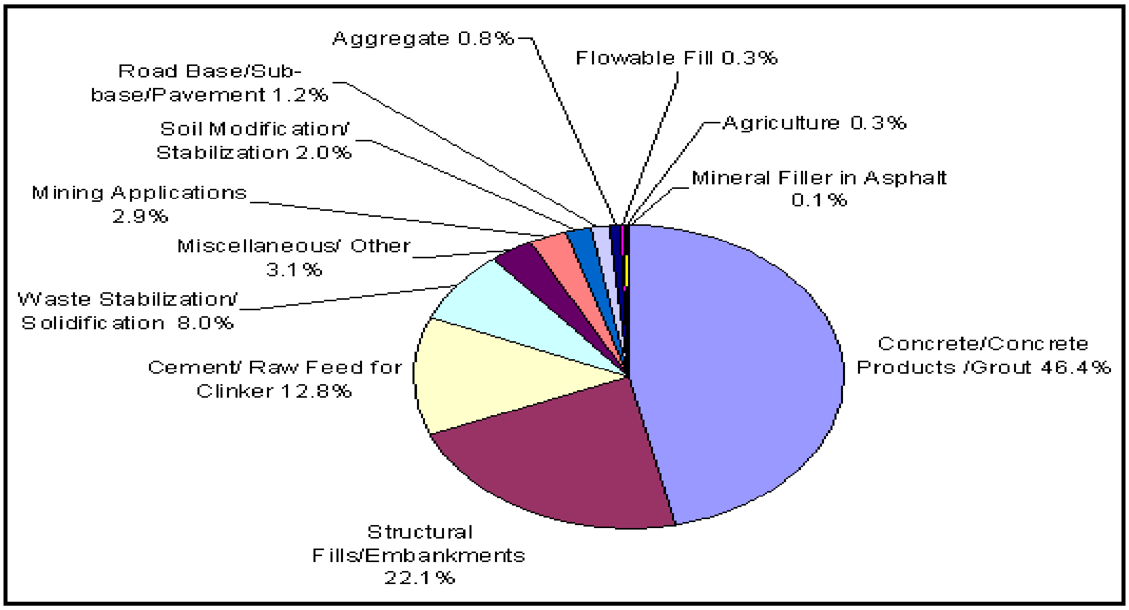


Figure 5.6. Common applications of fly ash (RMRC, 2008).

The pozzolanic properties of the ash, including its lime binding capacity makes it useful for manufacturing cement, concrete building materials, and concrete-admixed products (Ahmaruzzaman, 2010).

Utilization of fly ash appears to be technically feasible in the cement industry. There are essentially three applications for fly ash in cement, including (1) replacement of cement in Portland cement concrete (2) pozzolanic material in the production of pozzolanic cements, and (3) set retardant ingredients with cement as a replacement of gypsum (Ahmaruzzaman, 2010).

Cement is the most costly and energy intensive component of concrete. The cost of a ton of ASTM C618 compliant fly ash is often half the price of Portland cement. Using fly ash instead of Portland cement can reduce the cost of concrete projects while improving its overall performance and durability (ACAA, 2009). Unlike cement, the major cost of fly ash is in transportation which could be double or triple fly ash prices. According to data from the U.S. Geological Survey the average price of cement in 2010 was $92 per ton, or five cents per pound. A survey of fly ash providers nationwide found the average price of a ton of fly ash is $40 or tow cents per pound. A typical mix of fly ash concrete will include approximately 390 pounds of Portland cement and 150 pounds of fly ash. This is compared to pure Portland cement concrete, which contains about 564 pounds of pure cement.

The utilization of fly ash is partly based on economic grounds as pozzolana for partial replacement of cement, and partly because of its beneficial effects such as lower water demand for similar workability, reduced bleeding, and lower evolution of heat. Particularly, its uses are in massive concrete applications and large volume placement to control expansion due to heat hydration, and helps in reducing cracking at early ages. The major drawback of fiber reinforced concrete is its low workability. To overcome this shortcoming, a material is needed that can improve the workability without compromising strength. Fly ash used in concrete enhances the workability of the concrete (Ahmaruzzaman, 2010). Further, fly ash is widely recommended as a partial replacement for cement that provides much stronger and stable protective cover to steel against weathering action. The utilization of fly ash in concrete produces less permeability because of the spherical particles; therefore, improved packing, i.e. more dense paste and pozzolanic reaction.

5.2.1 Class F and Class C fly ash. In mass concrete, with high-percentage replacement of cement with fly ash, there is a lower heat of hydration compared to straight Portland cement concrete, particularly when using Class F fly ash. Class F fly ash is produced from the burning of bituminous coals, commonly available in central and eastern parts of the country. They are harder, older anthracite coals, which consist of low lime content making it have little or no cementious value. While Class C fly ash is produced from the burning of younger lignite or sub bituminous coal from western sources and has higher lime content that Class F ash. Its cementious qualities of its own means it will chemically react with water, even if cement is not present. Setting times and early strengths are affected far less. Ravina and Mehta (1986) reported that by replacing 35–50% of cement with fly ash, there was 5–7% reduction in water requirement for the designated slump. Also the rate and volume of bleeding water was either higher or about the same compared with the control mixture. Abrasion resistance increased with an increase in Class F fly ash content as replacement of fine aggregates (Siddique, 2003). Abrasion resistance of concrete made with Class C fly ash was better than both concretes without fly ash and concretes containing Class F fly ash (Tikalsky, Carrasquillo, & Carrasquillo, 1988). In addition to having pozzolanic properties, fly ash also has some self-cementing properties. Naik and Ramme (1987) researched high early strength concrete counting large quantities of Class C fly ash. The test clearly established that cement replacement of up to 30% with fly ash increases early strength compared to the concrete made with no fly ash. Therefore, concrete mixed with Class C fly ash can be used with confidence to produce high early strength concrete for precast/pre-stressed products. Traditionally, with bituminous-type fly ash, 15-25% of the cement may be replaced with fly ash. High lime fly ash has permitted normal replacements of 25-40% and up to 75% for parking lots, driveways, and streets. The utilization of fly ash in the construction of concrete dams was investigated by Gao and co-investigators (2007). The 90 days compressive strength of dam concrete was higher when 50% fly ash was used rather than 30% fly ash or without fly ash. Fly ash may decrease the deformation of dam concrete with 50% of fly ash, and the shrinkage and expansive strain was reduced significantly, about 33% and 40% less than the specimens without fly ash, respectively. Lupu and co-workers (2006) investigated the use of chemically modified fly ash to control the setting of cement. The chemical treatment of Class C fly ash with a 0.2 wt. percentage of CaCO3 solution results in dramatic increase in setting time, and superior stability during the induction period for cement slurries.

By incorporating super plasticizer (SPs) accelerates the early strength development of fly ash concrete to achieve the desired performance. Generally, the long-term ultimate mechanical properties of fly ash concretes are higher than plain Portland cement concretes. The setting and hardening rates of fly ash concrete at early ages are slower, especially under cold-water condition. An extended hydration period makes the material more sensitive to curing conditions. These problems may be solved using various methods such as steam curing. There has been much concern about sulphate resistance of concrete containing high-lime fly ash. Dunstan et al. (1980) proposed a sulphate resistance factor R of less than 1.5 to improve fly ash. Research has shown that fly ash used in Portland cement has a number of positive effects on the resulting concrete. A decrease in water demand decreases the water to cement ratio. An improvement of the packing of particle size decreases air entrainment in the concrete (James, Choi, & Abu-Lebdeh, 2011).

James et al. (2011) conducted research on the use of RCA and fly ash. They compared the flexural strength prediction by ACI 318 (2008). The experimental results showed an underestimate of the flexural (Figure 5.7). Their results determined that concretes containing RCA and FA had the same strength after 112 days of cure duration as the control mix at 0.55:0.45, water: cement ratio. With the use of RCA up to 25% and FA up to 15%, there was no significant difference (if any) in strength compared to concrete containing virgin aggregate .

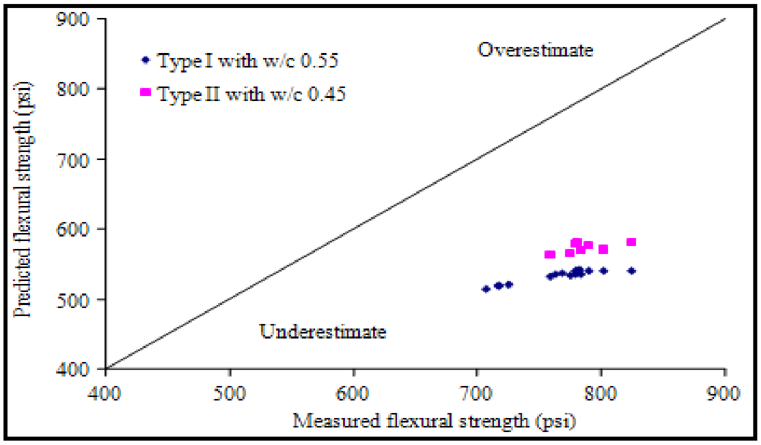


Figure 5.7. Measured versus predicted flexural strength (James, et al., 2011).

In conclusion, high-volume concrete offers a holistic solution to the problem of meeting the increasing demands for concrete in the future in a sustainable manner and at a reduced or no additional cost. At the same time, reducing the environmental impact of two industries that are vital to economic development, namely the cement industry and the coal-fired power industry (Mehta, 2004). Concrete mixes workability improving by reducing water requirements. Resulting in lower bleeding and provide a more durable surface and reduced heat of hydration, increased resistance against alkali aggregates, resistance to sulfate attack by combing fly ash with lime, reduced permeability; and cost (Boles, 1986). However, benefits depend on the type of cement, fly ash, and mix design. Fly ash also is used in other non critical structures and cement treated base like sidewalks, curbs, and barriers (Ahmed, 1993).

5.2.2 Asphalt Concrete Mix. For many years, asphalt-paving mixtures have consisted of substitute mineral filler. Mineral filler in asphalt paving mixtures consists of particles, less than 0.075 mm (No. 200 sieve) in size that fill the voids in a paving mix, and serve to improve the cohesion of the binder (asphalt cement), and the stability of the mixtures. Some sources of fly ash that contains a high lime (CaO) content such as Class C fly ash, may also be useful as an anti-stripping agent in asphalt paving mixes ((FHWA) & (ACAA), 2003).

5.2.3 Light Weight Aggregate. Lightweight construction products use fly ash as a by-product aggregate in bricks. Fly ash bricks weigh on an average a third or less than commercial clay-fired bricks. A mixture of 20% fly ash and 50% clay, makes bricks that have high strength and absorb less water than fly ash bricks. Cicek and Tanriverdi (2007) observed the positive effect of the addition of fly ash, sand and hydrated lime in the compressive strength of the bricks. The use of fly ash brick provides lower requirement of mortar in construction, plastering over brick can be avoided, cost effective, energy efficient and avoids the use of fertile clay. In addition to fly ash bricks, another usage includes lightweight rigid roofing tiles. The roof tiles are lighter in weight (reducing dead weight and transportation cost) and have a Class-A fire rating for high fire, danger areas.

5.2.4 Embankments. For several decades, the usage of fly ash can be used as embankment or structural fill material, sub grade base coarse material, aggregate filler, bituminous pavement additive, and mineral filler for bituminous concrete. The shear strength of fly ash in soils typically equals or exceeds the strength of soils usually used in embankments (Lin, 1971). The strength is partially due to the fly ash having self-hardening or pozzolanic characteristics typically found in Class C fly ash, and because an activator is not required for stabilization. The most commonly used activators or chemical binders in pozzolan-stabilized base (PSB) mixtures are lime and Portland cement, although cement kiln dusts and limekiln dusts were recent usages. When pozzolanic-type Class F fly ash is used, adding an activator is necessary to initiate the pozzolanic reaction. Fly ash dose not posses properties required for base coarse or select fills for slab on grade. Ahmed (1993) recommends the use of fly ash as a common fill to raise and or level grades. The utilization of fly ash has demonstrated to be useful as grout to fill open cast mines. This process would reduce acid mine drainage (AMD), which can affect both water and atmospheric influences.

5.2.5 Removal of Pollutants. Another interesting possible use for fly ash is a low-cost adsorbent for gas and water treatment. A considerable amount of research has been conducted on the absorption and removal of various pollutants such as nitrogen oxides (NOx) (Rubio, Izquierdo, Mayoral, Bona, & Andres, 2007), sulphur oxide compounds (SOx), organic compounds, and mercury (Masaki, Nobuo, & Takeshi, 2000) in air, dyes, and other organic compounds in waters. Findings on NOx suggested the efficient removal of mineral matter from unburnt carbon of fly ash before activation. Thus obtain more suitable activated carbon for environmental applications in the gas phase. The removal of mercury affected the temperature, if the activated carbon content was very small. Rubio and co-researchers (2007) assumed that the complex chemical action with activated carbon and calcium chloride is the most significant factor for metallic mercury removal by actual fly ash. Peloso, et al. (1983) investigated the adsorption of toluene vapors on fly ash. Their findings revealed that fly ash product obtained after particle aggregation and thermal activation showed satisfactory adsorption performance for toluene vapours. The adsorption kinetics of representative aromatic hydrocarbon and mxylene, on fly ash has also been studied (Rotenberg et al., 1991). The results indicated that kinetics of mxylene adsorption of fly ash resembled the kinetics reported for penetration of adsorbents into porous adsorbents. Fly ash has been widely used as a low-cost adsorbent for the removal of heavy metal. Tables 5.2 and 5.3 summarize absorbent capacity of metals and organic compounds investigated on fly ash.

Fly ash has also been investigated for the removal of other inorganic components from wastewater, including phosphate (Chen et al., 2007), fluoride (Chaturvedi, Yadava, Pathak, & Singh, 1990), and boron (Ozturk & Kavak, 2005). Fly ash was investigated in the removal of organic compounds from waste water, including phenolic compounds (Daifullah & Gad, 1998) and pesticides (Kumari & Saxena, 1988).

Table 5.2

Summary of metal absorbents (Ahmaruzzaman, 2010).

Metals	**Absorbent**	**Adsorption Capacity (mg/g)**	**Temperature (^{o}C)**
Zn^{2+}	Coal fly ash	6.5-13.3	30-60
	Fe impregnated fly ash	7.5-15.5	30-60
	Al impregnated fly ash	7.0-15.4	30-60
	Coal fly ash	0.25-2.8	20
	Coal fly ash (I)	0.25-1.19	20
	Coal fly ash (II)	0.07-1.30	20
	Bagasse fly ash	2.34-2.54	30-50
	Bagasse fly ash	13.21	30
	Fly ash	4.64	23
	Fly ash	0.27	25
	Fly ash	0.068-0.75	0-55
	Fly ash	3.4	-
	Rice husk ash	5.88	
	Bagasse fly ash	7.03	
	Fly ash	11.11	
	Rice husk ash	14.30	
	Fly ash	7.84	
Cd^{2+}	Fly ash	198.2	25
	Fly ash-washed	195.5	25
	Fly ash-acid	180.4	25
	Fly ash	1.6-8.0	-
	Fly ash zeolite	95.6	20
	Fly ash (I)	0.08-0.29	20
	Fly ash (II)	0.0077-0.22	20
	Bagasse fly ash	1.24-2.0	30-50
	Fly ash	0.05	25
	Coal fly ash	18.98	25
	Rice husk ash	3.04	
	Afsin-Elbistan fly ash	0.29	
	Seyimoter fly ash	0.21	
	Bagasse fly ash	6.19	
	Fly ash	207.3	
	Fly ash	1.38	
Pb^{2+}	Fly ash	444.7	25
	Fly ash-washed	483.4	25
	Fly ash-acid	437.0	25

Table 5.2

(cont.)

Metals	Absorbent	Adsorption Capacity (mg/g)	Temperature (^{o}C)
Pb^{2+}	Bagasse fly ash	285-566	30-50
	Fly ash	18.8	
	Fly ash	18.0	
	Treated rice husk ash	12.61	30

The use of fly ash for the removal of dyes from waste water has also been investigated, including azo (Kara, Aydiner, Demirbas, Kobya, & Dizge, 2007), thiazine (S. Wang, Boyjoo, Choueib, & Zhu, 2005), xanthene (Yamad, Haraguchi, Gacho, Bussakorn, & Pena, 2003), and arlmethane dyes (Gupta, Prasad, & Singh, 1990). Table 5.4 shows a comparison of dye adsorptioin on fly ash. It is evident that fly ash has a great potential in environmental applications. Fly ash is an interesting alternative to replace activated carbon or zeolites for adsorption in the water pollution treatment.

Table 5.3

Organic compound absorbents (Ahmaruzzaman 2010).

Organic compounds	Absorbent	Adsorption Capacity (mg/g)
Phenol	Coal	13.23
	Residual coal	45.45
	Residual coal treated with $H_3 PO_4$	142.8
	Rice husk	4.508
	Coke breeze	0.172
	Rice husk	4.508
	Rice husk char	7.91
	Petroleum coke	6.01
	Lignite	10.0
	Neutralized red mud	4.127
	Sewage sludge	94.0
Dye	Waste news paper	390
(Basic blue 9)	Coal	250
	Sewage sludge	114.94
	Rice husk	19.83
	Straw	19.82

Table 5.3

(cont.)

Organic compounds	**Absorbent**	**Adsorption Capacity (mg/g)**
Dye	Hazelnut shell	8.82
(Basic blue 9)	Coir pith	120.43
	Banana peel	20.2
	Orange peel	18.6
Metal (Zn^{2+})	Blast furnace slag	103.3
	Lignin	95
	Lignin	73
	Acid washed-tea industry waste	12
	Tea industry waste	11
	Powered waste sludge	168
	Sugar beet pulp	35.6
	Lignin	11.24
	Solid residue of olive mill products	5.40
	Red mud	12.59
	Blast furnace slag	17.65
	Coffee husk	5.57
	Clarified sludge	15.53

There are several drawbacks of the adsorption of organic compounds (i) fly ash low-cost depends on its origin. The unburned carbon content in fly ash varies with region and adsorption capacity; (ii) the effectiveness of the adsorption process depends on variables used for the process such as pH, ionic strength and temperature, existence of competing organic or inorganic compounds, initial adsorbent concentration, contact time, and speed of rotation.

Table 5.4

Comparison of dye adsorption on fly ash (Ahmaruzzaman, 2010).

Metals	**Absorbent**	**Adsorption Capacity (mg/g)**	**Temperature (oC)**
Cr^{6+}	Fly ash + wollastonite	2.92	-
	Fly ash + China clay	0.31	-
	Fly ash	23.86	-
	Rice husk aash	25.64	-

Table 5.4

(cont).

Metals	Absorbent	Adsorption Capacity (mg/g)	Temperature (oC)
	Fe impregnated fly ash	1.82	30-60
	Al impregnated fly ash	1.67	30-60
	Fly ash (I)	0.55	20
	Fly ash (II)	0.82	20
	Bagasse fly ash	4.25-4.35	30-50
Hg^{2+}	Fly ash	2.82	30
	Fly ash	11.0	30-60
	Fe impregnated fly ash	12.5	30-60
	Al impregnated fly ash	13.4	30-60
	Sulfo-calcic	5	30
	Silica-aluminous ashes	3.2	30
	Fly ash-C	0.63-0.73	21-May
	Treated rice coal-char	6.72	30
As3+	Fly ash coal-char	3.7-89.2	25
As5+	Fly ash	7.7-27.8	20
	Fly ash coal-char	0.02-34.5	25

Coal fly ash is an inexpensive absorbent for dry-type flue gas desulphurization (FGD). Fly ash recycling in the FGD process has shown promising results. Fly ash treated with calcium hydroxide has been tested as a reactive adsorbent for SO2 removal (Al-Shawabkeh, Matsuda, & Hasatani, 1995). For wet-type FGD, the process requires wastewater treatment and high water consumption. However, during the FGD process, if fly ash is used, there will be no need for wastewater treatment or gas reheating; thus an ideal choice for controlling the emission of sulfur dioxide, and an environmentally friendly method for reuse of coal ash.

5.2.6 Plant Growth. Although this application is off topic, it is worth noting that plant growth is one of many applications of fly ash. Several studies proposed that fly ash can be used as a soil ameliorate that may improve physical, chemical and biological properties of the degraded soils and is a source of readily available plant micro-and macro-nutrients (Ahmaruzzaman, 2010). Fly ash in agriculture as an eco-friendly and economic fertilizer or soil amendments, which is established after repeated field experiments for each type of soil to confirm its quality and safety. Fly ash has a lot of potential in agriculture due to its efficiency in modification of soil health and crop performance. Fly ash contains different essential elements including both macronutrients P, K, Ca, Mg and micronutrients Zn, Fe, Cu, Mn, B, and Mo to help plant growth. Agricultural lime application also contributes to global warming, according to the Intergovernmental Panel on Climate Change (IPCC) assuming that all the carbon in agricultural lime finally is released as CO2 in the atmosphere. Ahmaruzzman (2010) postulates the use of fly ash instead of lime in agriculture can reduce net CO2 emission, and reduce global warming.

5.3 Foundry Sand

Foundry sand is a by-product of ferrous and nonferrous metal casting. It is high quality silica sand with uniform physical characteristics. Foundry facilities operate by purchasing high quality silica sand to make casting molds and reuse the sand numerous times within the foundry. Eventually, the sand becomes unsuitable for use in casting molds, due to heat and mechanical form erosion. The waste or unsuitable sand is continuously removed and replaced with high quality silica sand. Figure 5.8 shows waste foundry sand has been removed from the process and either recycled into a non-foundry application or land filled. In the United States alone, 100 million tons of sand is used in production annually. Foundry sand production is nearly 6 to 10 million tons annually available to be recycled into other products. (American Foundry Society, 2012).

Recycling used foundry sand can save energy, reduces the need to mine virgin materials, and may reduce costs for both producers and end users. EPA has found that used foundry sands produced by iron, steel, and aluminum foundries are rarely hazardous. Despite the support from the EPA, only about 15% of used foundry sands are recycled.

Figure 5.8. Foundry sand making plant (www.foundryrecycling.org).

This is mainly due to the lack of information on its potential beneficial uses. Beneficial reuse of foundry sand continues to become a more accepted practice as more end-users are introduced to the concept. Beneficial applications of foundry sand include aggregate replacement in asphalt mixtures, Portland cement concrete, source material for Portland cement, sand used in masonry mortar mixes, embankments, retaining walls, subbase, flowable fills, barrier layers, and HMA mixtures. According to the FHWA in 2004, engineering applications uses approximately 500,000 to 700,000 tons of foundry sand annually.

There are two types available foundry sand green sand, that uses clay as a binder consist of 85% -95% silica, 0-12% clay, 2-10% carbonaceous additive, such as seacoal, and 2-5% water.

The other is chemically bonded sand that use polymers to bind brains together consists of 93-99% silica and 1% - 3% chemical binder. Foundry sand has nearly all the properties of natural or manufactured sands and can normally be used as a sand replacement. Studies have shown that foundry sand can be used to replace between 8% and 25% of fine aggregate content (FHWA, 2004).

When mixes are properly designed using Superpave, Marshall, or Hveem techniques, foundry sand can be an effective sand alternative. After cleaning off all clay, dust, and other deleterious materials and metals removed magnetically. The use in HMA, foundry sand once cleaned can replace 8% - 25% of fine aggregate. In Portland cement concrete the mixture of 25% fine aggregate, 45% course aggregate, 20% cement and 10% water. Foundry sand can be used as a fine aggregate replacement. Generally fly ash is too fine to permit full substitution. Fine aggregates consist of natural sand and crushed stone with particles smaller than 3/8 inch. Course aggregate is 3/8 into to 2 inches. The smaller size of foundry sand effects cement water requirement, as well as concrete workability, economy, porosity, shrinkage, and durability (FHWA, 2004). Too many fine particles can lower the strength and durability. Large dust content can interfere with bonding of cement to the aggregate surface, and can increase water demand. Dust factors reduce the durability of hardening concrete.

According to the FHWA (2004), founder sand performed well retaining walls, embankments and backfill structures. As well as in bases and sub bases under roadways and paved surfaces. Foundry sand performed extremely well in flowable fill. In soils it performed well because of its composition, color, and consistency. Table 5.5 is the top application being used with foundry sand.

Table 5.5

The top applications being used for foundry sand ((FIRST), 2004).

Ranking	**Application**
1	Embankments / Structural Fills
2	Road base / Subbase
3	Hot Mix Asphalt (HMA)
4	Flowable Fills
5	Soil / Horticultural
6	Cement and Concrete Products
7	Traction Control
8	Other Applications

Siddique et al. (2011) investigated the effects of used-foundry sand (UFS) on the mechanical properties of concrete. They replaced regular sand with UFS with three different percentages (10%, 20%, and 30%) by weight. They performed several tests on the properties of concrete including compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity. Their test results showed a marginal increase in the compressive strength of concrete mixtures with the addition of UFS as a partial replacement of regular sand. The increase in compressive strength with the inclusion of UFS could probably be due to the fact that UFS was finer than regular sand which resulted in denser concrete matrix, and also due to the silica content present in the UFS (Siddique, Schutter, & Noumowe, 2009). Figure 5.11 shows the graph from their compressive strength test.

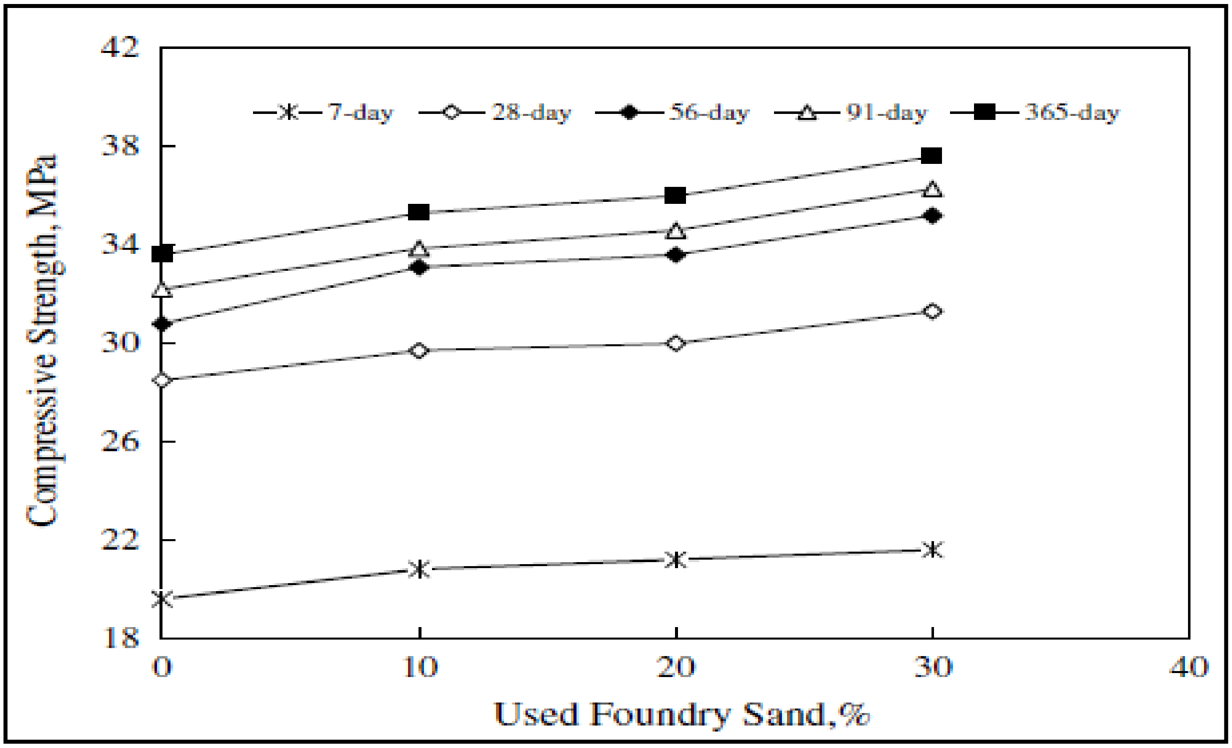


Figure 5.9. Compressive strength in relation to UFS content and curing age (Siddique, et al., 2009).

The following conclusions were drawn from their investigation: (i) compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with the increase in foundry sand content and increased with age, (ii) increase in compressive strength varied between 8% to 19% depending upon UFS percentage and testing age, whereas it was between 6.5% to 14.5% for splitting-tensile strength, 7% to 12% for flexural strength, and 5% to 12% for modulus of elasticity. Results of their investigation suggest that using UFS conveniently can make good quality concrete and construction materials.

Fiore and Znetti (2007) researched the reuse and recycling solutions for foundry sand. Their results showed that particles below 0.25 mm fraction (made of mineral coal and bentonite) may be reused in molding operations, while particles between 0.025 and 0.1 mm fraction together with the pelletized, and dried mud (from dust abatement on molding lines) may be recycled in Portland concrete production (Fiore & Zanetti, 2007).

5.4 Slag

Slag is a by-product of iron and steel making and is marketed primarily to the construction industry. There are over 140 processors of iron and steel slag in the U.S. Data on slag the U.S. in 2011 was between 16 to 21 million tons. An estimated 17 million tons of iron and steel slag, valued at about $290 million, was sold in 2011 (Oss, 2012). Normally, slag is returned to the blast and steel furnaces as ferrous and flux feed, but data on these returns are also incomplete. Iron and steel slag is used for construction purposes, especially, for road surfaces since roman times. By the mid-19th century, new uses for slag emerged as an aggregate in hydraulic cement concrete, and for some slag cementious material in its on right. In the 20th century, slag was an excellent aggregate for asphalt road paving. Dumping or disposal of this slag causes wastage of metal values and leads to environmental problems and filling the landfills. Rather than disposing these slags, take full advantage of its mechanical properties. Therefore, its use has been explored by several investigators and they have utilized the slag in diversified ways like recovery of metal values, preparation of value added product like cement replacement in concrete, embankment fills, ballast, abrasive, aggregate, glass, and tiles (Gorai, Jana, & Premchand, 2003). It can be used as roofing granules, abrasive tiles, road-base material, rail road ballast, and asphalt pavement (Collins & Cielieski, 1994).

5.4.1 Blast Furnace Slag. Slag, when used as a by-product of iron in a blast furnace consists mainly of silicates and aluminosilicates of lime (R.L. Schroeder, 1994). According to the American Iron and Steel Institute recovered and reuse of slag’s conserves tens of millions of tons per year of other natural resources. Relatively small percentage (less than 10%) of the blast furnace slag generated is disposed of in landfills. There are four types of blast furnace slag, which depends on the cooling methods: air-cooled, granulated, expanded, and rip rip. Blast furnace (BF) slag is a high quality material suitable for production of Portland cement concrete and offers higher compressive strengths than natural aggregates like limestone. Due to its increased cement paste bond because of the angularity and vesicular surface area characteristics of slag. BF has a sulfar component that allows water to dissolve the sulfar into a basic material such as calcium. This may cause a rotten egg smell. That rate of leaching diminishes with time as the chemical nature changes from sulfide to sulfate through oxidation. BF can also can be added to cement kilns to replace other raw materials I the clinkering process. BF is versatile being light weight, durability, and attractive color. BF provides more surface and greater volume per ton, than natural aggregates, with no sacrifice in strength or durability, this means greater yield per ton. High ways built with slag in place of natural stone, resist wear and superior protection against skidding, also provides durability, fire resistance, strength and quality control. When slag is processed with a quality control program by the manufacture slag aggregates generally meet federal, state and local specifications. Course size BF may have 20% less density than natural aggregates, this is an advantage because the lighter weight makes it easier to handle and lower transportation cost. The lighter aggregate also reduces dead load, allowing for important savings in supporting structures. BF is also found to have longer life in asphalt paving. Priced to be competitive with natural aggregates in the local markets, more information can be obtained form the producers in the individual project area. BF slag base and sub base aggregates are available in areas around steel producing centers. Not all types are available in all areas. Air cooled slag is used in highway construction, as shown in Figure 5.10.

Figure 5.10. Air cooled coarse aggregate ((NSA), 2009).

Air-cooled slag is cooled slowly by ambient air and is processed at plants for sizing for uses in construction. The slag can be used in concrete and asphalt mix, fill material in embankments, road base material, and as treatments for the improvement of soils (Ahmed, 1993). Cervantes and Roesler (2007) reported that air-cooled slag binds well with Portland cement and asphalt mixtures due to the slag's rough finish, and larger surface area in comparison to other aggregates. Granulated slag that is rapidly cooled by large quantities of water to produce sand like granule that is primarily ground into a cement commonly known as ground granulated blast furnace slag (GGBFS), or Type S slag cement, as shown in Figure 5.11.

Figure 5.11. Ground Granulated Blast Furnace Slag (GGBFS) ((NSA), 2009).

They also noted that GGBFS has a positive effect on the flexural and compressive strength of concrete. The increase in strength was most notable after 28 days. Replacing Portland cement with GGBS in concrete mixtures will also help reduce greenhouse gas emissions because the manufacture of Portland cement emits large amounts of CO_2. Figure 5.12 shows expanded slag with low density, and allows for good mechanical binding with hydraulic cement paste.

Figure 5.12. Expanded slag ((NSA), 2009).

Expanded slag is quickly cooled or steamed and is light in weight. It can be used as a lightweight fill and high-fire rated concrete masonry. The largest of the slag is the air-cooled rip rip, shown in Figure 5.13, used to stabilize shorelines and stream banks, and prevent erosion along slopes and embankments.

Figure 5.13. Air cooled blast furnace slag rip rip ((NSA), 2009).

5.4.2 Steel Slag. Steel slag is a by-product of making steel, the process of collecting the steel slag as shown in Figure 4.12. 50 million tons per year of steel slag are produced as a residue in the world (Altun & Yilmaz, 2002).

Today, about 65% (7.7 to 8.3 million tons) of steel slag is used each year in the United States as an aggregate (Motz & Geiseler, 2001). While most of the furnace slag is recycled for use as an aggregate, the excess 35% from other operations (raker, ladle, clean out, or pit slag) is usually sent to landfills for disposal. Steel slag has a significant amount of iron, which makes it a very dense and hard material.

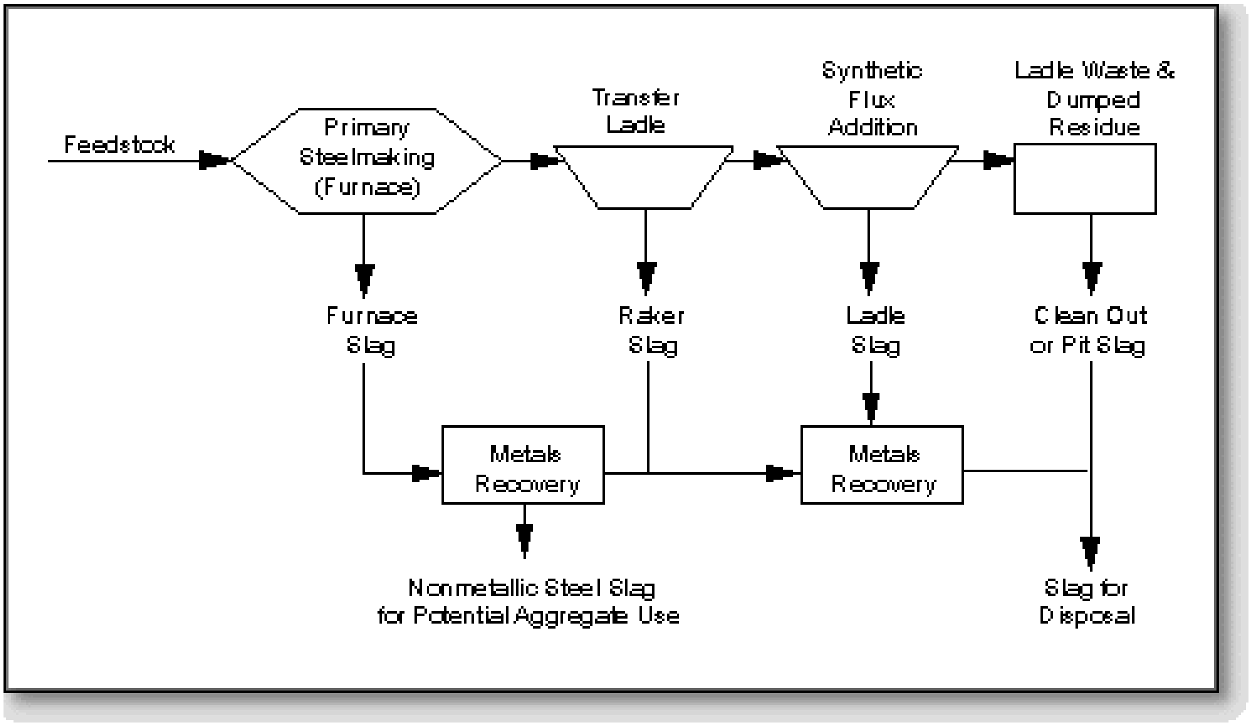


Figure 5.14. Steel slag collection process (FHWA, 2012).

Steel slag has several uses in highway construction similar to those in blast furnace. Most of its uses have been concentrated as road base material and fill material. Steel slag contain free lime, thus causes the material volume to increase and swelling to occur that causes the top layer to lift when it hydrates. Therefore, proper selection is required in its application.

Usages of steel slags consist of an additive in concrete, asphalt, base material, and fill material in embankments. NSA does not recommend the use of steel slag aggregate in concrete failure. Steel slag creates a weak cement like matrix after compaction and water saturation because it contains free lime. Benefits of adding steel slag to cement are lower energy cost, higher abrasion resistance, lower hydration heat evolution and higher later strength development, but have disadvantages of longer setting time and lower early strength when compared with normal Portland cement concrete. Huang et al. (2007) studied the use of steel slag as a substitute for coarse aggregates in asphalt mixes, and found that steel slag provides an improved resistance to rutting and skid resistance. They also concluded that the high specific gravity of steel can increase the density of the asphalt mix and cause an increase in the cost of transportation (Huang, Bird, & Heidrich, 2007). Tsakiridis et al. (2008) studied the addition of steel slag in the raw mix for production of Portland cement clinker. They concluded that 10.5% steel slag did not affect either the sintering or the hydration process during Portland cement production (Tsakiridis, Papadimitriou, Tsivilis, & Koroneos, 2008). A study by Beh et al. (2010) on Electric Arc Furnace (EAF) slag as an efficient removal of heavy metal from contaminated water or wastewater found that EAF is an efficient absorbent to remove manganese from water (Beh, et al., 2010).

5.4.3 Copper Slag. Copper slag is a by-product from refining copper. Figure 5.15 is a diagram of the production process of copper slag. Copper slag is the glassy material left over from melting and converting step of producing copper. Every ton of copper produced generates an estimated 2.2 tons of slag in each year, approximately 24.6 million tons of slag is generated from world copper production.

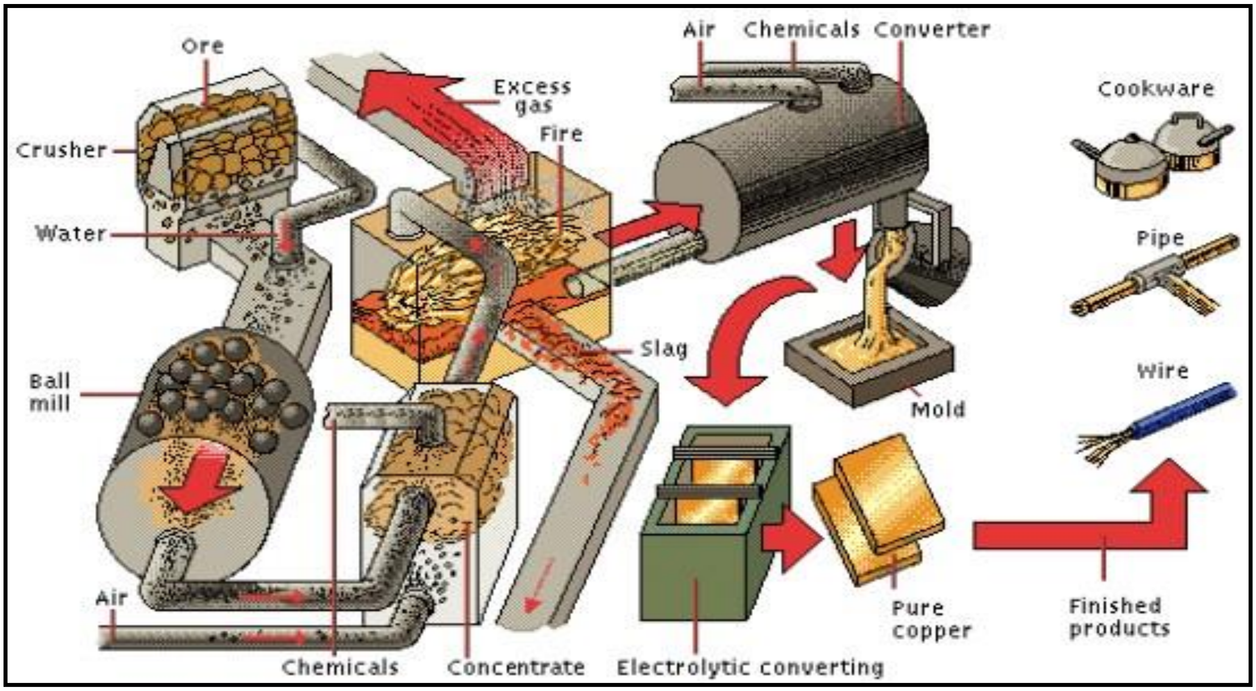


Figure 5.15. The production process of copper slag (A/Prof Wee Tiong Huan, 2012).

Copper slag was used as fine aggregate for concrete by (Toshiki, Osamu, & Kenji, 2000). The use of copper slag (15% mass) as a Portland cement replacement was reported by (Arino-Moreno & Mobasher, 1999) and found that it affected the strength and toughness of the mixture.

5.5 Silica Fume

Silicon metal and alloys are produced in electric furnaces. The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than being landfilled (Figure 5.17).

Prior to mid-1970, nearly all silica fume discharged into the atmosphere. After environmental concerns necessitated, the collection and landfilling of silica fume became mandatory.

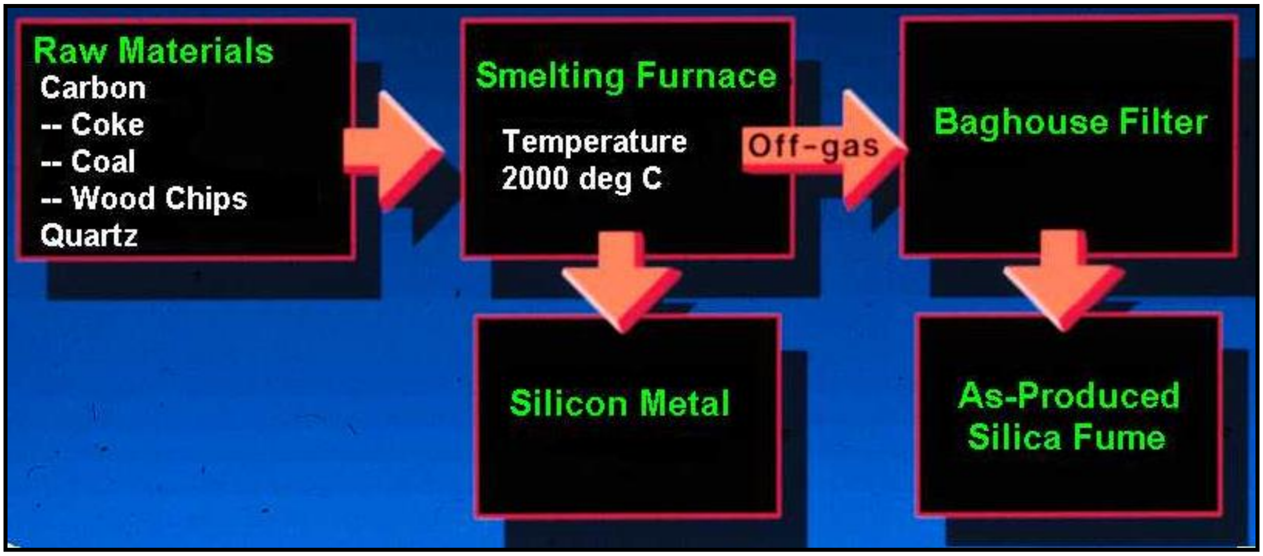


Figure 5.16. The production process of silica fume (silicafume.org).

Perhaps the most important use of this material is as a mineral admixture in concrete. Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stem from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Silica fume is extremely small 1/100th the size of average cement particles including fly ash (Figure 5.17).

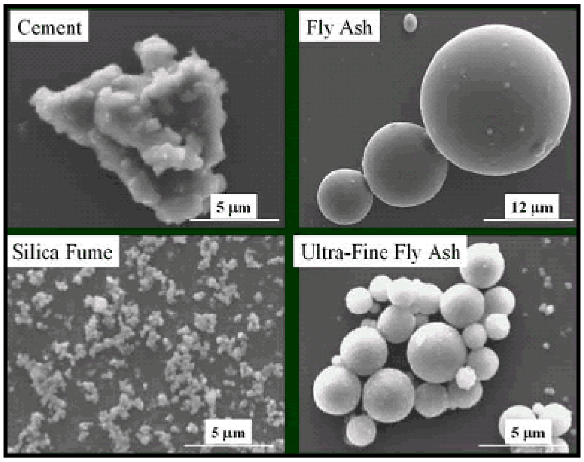


Figure 5.17. Silica fume particles viewed in a transmission electron microscope (fhwa.dot.gov).

Silica fume is used in various construction applications including parking garages, bridge decks, marine structures, slabs, roadways, and precast concrete. In 2011, the average cost of silica fume is $600 to $4,500 ton. The increased cost of silica fume compared with Portland cement and other pozzolans or slag have been barriers to its wider use in routine concrete jobs. Different portions are added to cement between 5% and 15% of silica and its compressive strength as shown in Figure 5.18. To avoid cracking from insufficiently moist cured, given 7 days of continuous moist curing.

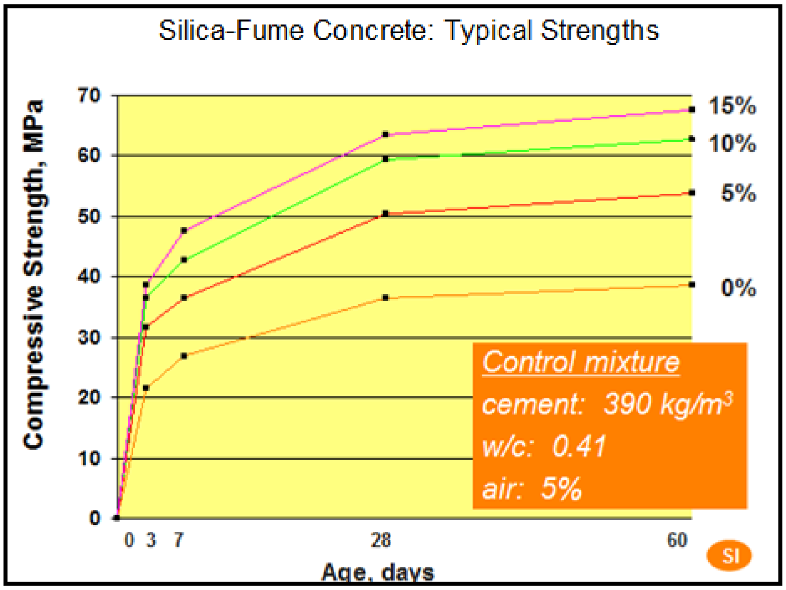


Figure 5.18. Silica fume concrete strength (silicafume.org).

5.6 Bottom Ash

Bottom ash is a material collected from burning coal for electricity. Bottom ash is collected in a hopper below the heat-absorbing furnace. It is coarser than fly ash with grain sizes ranging of fine sand and fine gravel. According to American Coal Ash Association (ACAA) 18.4 million tons were generated in 2008. Approximately, 10.4 million tons were disposed in landfills. Usages include embankments, sub grades, sub-bases, and even bases from a study by C. W. Lowell at Purdue University. They concluded bottom ash has a non-hazardous nature, with minimum effects on ground water quality, and low radioactivity. However, with its high corrosiveness, it is not recommended near metal structures (Ahmed, 1993). Figure 5.19 is a chart of different applications for bottom ash.

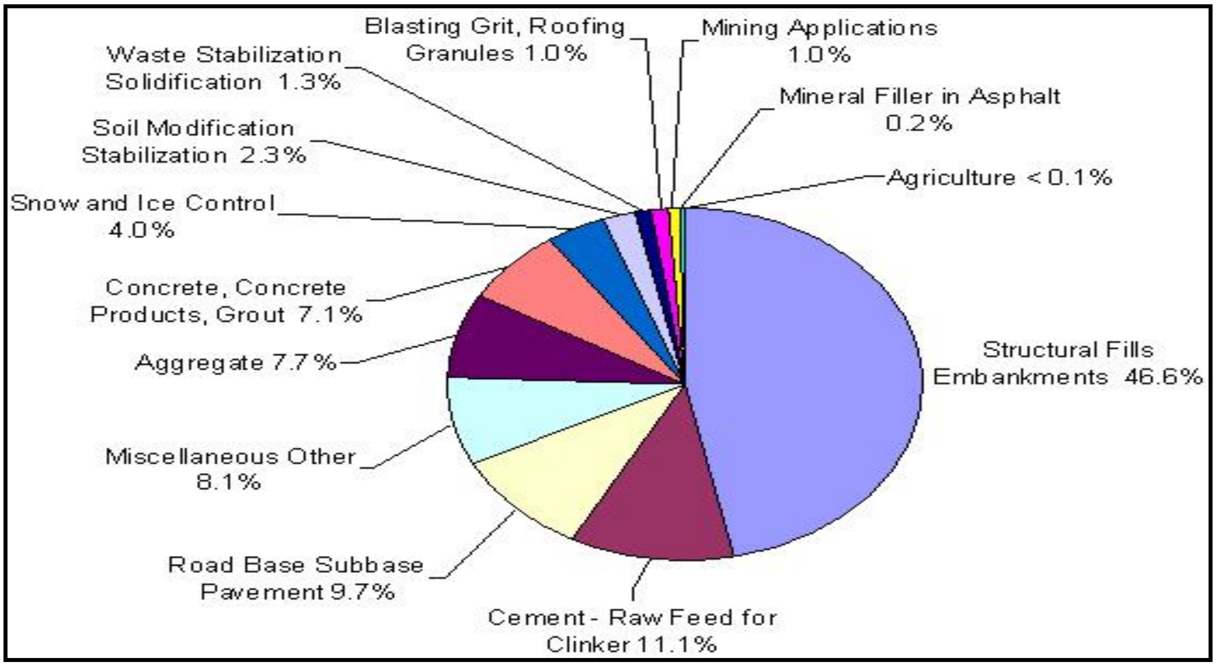


Figure 5.19. Applications of bottom ash as a total reuse (RMRC, 2008).

5.7 Other Ashes

Many kinds of biomass ash have similar pozzolanic properties as coal fly ash, such as those from rice husk, wood, wheat straw, and sugar cane straw (Martirena et al., 2006) (Yu, Sawayama, Sugita, Shoya, & Isojima, 1999) among which have been added in concrete as mineral admixtures, improving the performance of concrete. Rice husk with its high silica content has been used as an insulator, adsorbent, cement and concrete additive, and as a substitute for silica (Grammelis, Skodras, & Kakaras, 2006).

CHAPTER 6

Municipal Sector Waste

6.1 Roofing Shingles

Each year the U.S. generates approximately 11 million tons of asphalt roofing shingle scrap (Cal Recycling, 2006). Use of recycled asphalt shingles (both manufacturer's waste and tear-offs) increased from 702,000 tons to 1.10 million tons from 2009 to 2010, which represents a 57% increase. Assuming conservative asphalt content of 20% for shingles, this represents 234,000 tons (1.5 million barrels) of asphalt binder conserved. Shingle waste represents approximately one-third the waste stream from construction that is land filled each year (Figure 6.1).

Figure 6.1. Roof shingle waste recycled and grinded (Asplat Shingle Grinding Service, 2012).

Cost estimates for disposing shingles in landfills is from \$18 to \$60 per ton. Data has shown information about the inclusion of asbestos in roofing shingles is inconsistent in quantifying its use. The Department of Health and Human Services indentified asbestos as a known human carcinogen, and inhalation of asbestos may cause a number of deleterious health conditions, including lung cancer, asbestosis, and mesothelioma. Iowa Central Recycling, Inc. also conducted a study from 1999 to 2001 on the asbestos content of roofing shingles. They sampled 1,791 shingles and analyzed 0% containing asbestos. Massachusetts Recycle America Enterprises, LLC sampled 16,154 from 2004 to 2007 and analyzed 401 containing asbestos, which represents 2.5 %. Asbestos used to be and is no longer used in manufacturing of asphalt roofing shingles. Due to the practice of covering worn out roof with new shingles, there may continue to be a very small amount of asbestos in the shingle waste stream until about 2016 (Can Recycling, 2006).

There are two categories of roofing shingle scrapes: (1) post-manufacture or tear-off roofing shingles, which are generally off-spec materials generated by the manufacturer and (2) post-consumer or roofing shingle tabs, which are generated from construction waste. Tear-off roofing shingles generated during the demolition or replacement of existing roof shingles. Roofing shingle tabs are generated when new asphalt shingles are trimmed during production or "out of spec" shingles. Estimates indicate that the percentage of roofing scraps generated by manufacturing scrap is 87.5% and 12.5% from tear-off roofing scrap. Benefits of recycling asphalt shingles include conservation of landfill space, potentially lower disposal costs for shingle scrap manufactures, reduced cost in the production of HMA and conservation of raw materials. Recycling roofing shingles shaves $2.80 per ton off the cost of HMA, shingles contain bitumen, the binding agent in asphalt pavement, its oil, and its oil is expensive.

Saving landfill space economic saving, improved pavement performance because the asphalt used in shingles is harder than pavement asphalt. Over one million tons of reclaimed asphalt shingles went into HMA in 2010, less than 10% of total waste stream, according to the National Asphalt paving Association. Roofing shingles have various applications for the construction industry. For instance asphalt pavement, aggregate base and sub base, cold patch (for pot hole, sidewalks, utility cuts, driveways, ramps, bridges & parking lots), road and ground cover, new roofing and fuel oil.

Currently, HMA is the largest recycling market for waste asphalt shingles. Figure 6.2

shows scrap roof shingles waste, and a pile of grinded recycled shingles.

Figure 6.2. Roofing shingle grinding process in Texas (petersoncorp.com).

Asphalt shingles are utilized two ways in HMA production: as a binder and as an aggregate, because of its adhesive characteristics, flexibility, and ability to form strong cohesive mixtures with mineral aggregates. Asphalt shingles contain approximately 19% to 36% asphalt by weight. In addition, the ceramics in the shingles (approximately 20-38% by weight) are a source of aggregate used in HMA. A fact sheet distributed by the Northeast Recycling Council says that using HMA with 5% of recycled shingle content can shave as much as $2.80 per ton off the cost of HMA while improving the quality of the paving. One North Carolina paving company stopped using shingles for two reasons. The shingle manufacturer they had been getting virgin scrap from for free started charging. Bits of fiber glass from ground shingles would stick up in the road when mixing with fresh asphalt. Some disadvantages to using roofing shingles after a while sitting they can become dusty and become brittle. Most companies find it more advantages to scrap off the top layer of asphalt on existing roads and use that to supplement new asphalt rather than use old shingles.

Foo et al. (1999) evaluated the properties for the HMA mixture with shingles compared to conventional HMA mixture. They concluded that recycled shingles in HMA mixture improved rutting resistance in the mix. The mix, however, may have lower fatigue resistance and a lower low temperature cracking resistance. With the use of a softer virgin binder the fatigue and low temperature performance challenges of the mix can be improved (Foo, Hanson, & Lynn, 1999).

Sengoz and Topal (2005) conducted a study to evaluate the effect of shingle waste addition to the performance of HMA in terms of stability and resistance to permanent deformation. They also investigated the rutting property of asphalt concrete that contains shingle waste. Figure 6.3 shows the results from their rutting tests.

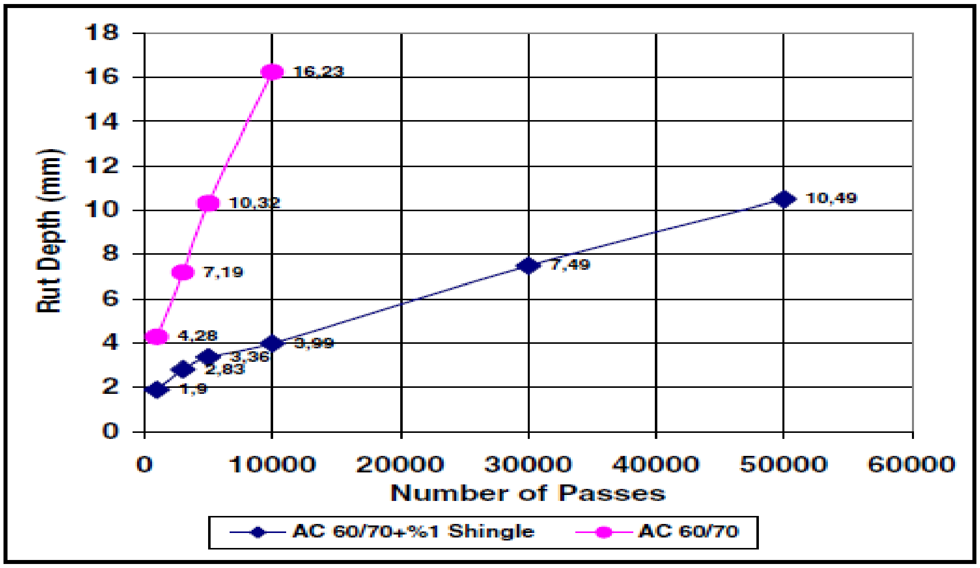


Figure 6.3. Rutting test results (Sengoz & Topal, 2005).

Their tests show that, the rut depth for the mixture with 1 % shingle waste was about 4 mm, at the end of 10,000 wheel load cycles, while the mixture prepared without shingle was about 16 mm. In addition, the rut depth value after 30000 cycles was 7.5 mm for the mixture containing shingle which is under the specification limit of 10 mm. Their results showed the addition of roofing shingle waste improved the rutting resistance of the mixtures considerably, which was due to a combination of the fibers and harder asphalt (10/20 penetration at 25 °C) (Sengoz & Topal, 2005). Other benefits include improved resistance to pavement cracking, reduced demand on virgin asphalt cement and aggregate and reduced production cost of HMA.

Researchers have investigated the use of cold patch mix asphalt with asphalt shingles. To activate the air-blown and possibly aged asphalt in roofing shingles into cold patch mix, it may be necessary to shear the mix, add solvents, such as diesel, kerosene, or asphalt rejuvenating agents. The combination of the hard asphalt, angular aggregate, and the entrained cellulose or fiber glass make a quality product that is comparable with other "high performance" cold patch mixes.

Roofing shingles incorporated into asphalt paving mixes not only modify the binder, but also function like aggregate or mineral filler (depending on the size of the shredded material). Solar heat and the weight from traffic help to melt the shingles into a single mass. Possible uses for this type surface are equipment yards and parking lots. Asphalt roofing shingles can be reduced to small pieces, about 2.5" or smaller, and then added to the mixture of a base coarse. This mixture has the potential to compete effectively with rock and gravel as a substitute ground cover or used as a stabilizer in wet and muddy areas.

Watson et al. (2007) investigated the reuse of roofing shingle waste concrete. Their results showed that the inclusion of shingle waste would reduce the environmental problems related to the disposal of waste in landfills and also reduce the amount of virgin asphalt cement and fine aggregate required in hot mix asphaltic concrete (HMAC). The Georgia Department of Transportation (GDOT) produced mixtures using waste generated by roofing manufactures, consisting of discolored or damaged shingles. The results of the rested samples revealed that shingles performed well compared with unmodified control sections and allowed as a recycling material in HMAC (Watson, et al., 2007).

6.2 Glass Waste

Americans generated 11.5 million tons of glass in the municipal solid waste (MSW) stream in 2010. Glass is composed of silica or sand and contains some amounts of limestone and soda ash used to produce uniform quality and color. According to the Association of Cities and Regions for Recycling (ACRR), people around the world send 1.5 million tons of glass to landfills each year. According to Cleanup Australia, glass that ends up in the landfill will not break down for over a million years. Out of the amount of glass that ends up in the landfill, recovered for recycling was about 27%. 90% of the recycled glass was manufactured glass containers. Cleanup Australia estimates that it takes about 60% less energy to produce glass from recycled materials than to produce glass from virgin materials. Glass recycling offers a number of benefits to consumers and the environment, including reduced emissions and lower prices on popular products.

Crushed recycled glass forms a material called cullet. The quality of the cullet is determined by how fine the cullet is. High-quality cullet can be used for abrasives, aggregate substitute, bead manufacturing, decorative applications, fiberglass, fractionators (match tips), and fluxes in metal foundry work. Increasingly, uses for lower-quality cullet are in secondary applications, such as in the manufacture of fiberglass insulation, roadbed aggregate, driving safety reflective beads, and decorative tile. Glass is useful for its high density but not so good in the fact that it is expensive and has limited processes for sorting colors. Since glass has a high density, the transportation costs are also high. Because of this, studies in construction concentrate on other uses of glass.Generally, using crushed glass cullet in asphalt pavement ensures that 100% passes for size quality (Figure 6.4).

Figure 6.4. Glass for use in asphalt pavement (Schroeder, 2011).

Most specification will allow limited amount of contaminants. A study on the use of glass in Portland cement reported by the American Society of Testing and Material (ASTM, Johnston, 1974) indicated that glass is highly susceptible to alkaki-aggregate reaction, the reaction between glass and cement causes expansion of glass and thus reduction in the strength of the concrete. The elongated particles in glass cullet create workability problems in concrete mix. Due to the likely hood of alkali-silica reaction, Caltrans prohibits use of glass as an aggregate in Portland cement concrete, cement treated base, lean concrete base and cement treated permeable base (Caltrans, 1990). The use of glass cullet as fill only seems economical if crushed, contamination free, and in reasonable travel distance.

Researchers at the Texas Department of Transportation (TxDOT) have evaluated different test for blends of glass and soils. The studies concluded that glass cullet, up to 20% by weight can be used with granular material in structural fills without compromising the strength of the material. In addition, glass cullet blended with limestone can be filter material.

In other studies by Huang, Bird, and Heidrick (2007) investigated the use of glass cullet as an aggregate in asphalt. Their findings showed that asphalt surface pavement containing 10-15% of glass with a graduation of less than 4.75mm resulted in satisfactory performance. The cost of glass in pavement is uneconomical at least 10-20% higher than conventional materials (Huang, et al., 2007). Unbound base layers and embankments may be economically justified.

6.3 Plastic Waste

Plastic also referred to as polyethylene exists in many forms. High-density polyethylene (HDPE) is more frequently used for the storage of various liquids. Many of these liquids are major household products. In 2010, plastic waste generated approximately 31 million tons, representing 12.4% of total Municipal Solid Waste. Out of the 31 tons of plastic waste, over 8% was recycling. Recycling programs have had limited success due to involved process of cleansing contaminated plastic waste, uses of recycled plastic in the construction industry include plastic strips to add to soil embankments, which has positive results of increasing the measured strength in reinforcement of soils.

Casey and co-investigators (2007) studied the use of recycled polyethylene in stone mastic asphalt. The researchers used polyethylene to enhance the mixture properties of asphalt. They added two types of polyethylene to coat the aggregate High Density Polyethylen (HDPE) and Low Density Polyethylene (LDPE). They compared three types of binders, traditional pin and fiber, a Polymer Modified Bitumens (PMB), and the developed Recycled HDPE modified binder (RP). PMB if formed by introducing virgin polymer into straight run bitumen. The quantities of virgin polymer can be up to 5%. PMP provides roads with a long service life, because it is designed to resist deformation and fatigue cracking. They developed recycled polymer (RP) was developed including PVC mulch, Isotactic PP mulch, LDPE mulch, HDPE mulch, ABS chips, Isotactic PP powder, MDPE mulch, and PET chips. Each sample started with 2% RP and results showed that LDPE, HDPE, PP powder and PP mulch was determined successfully blinded in the bitumen. Thus, an increase ranging from 2% to 5% by mass of bitumen were produced and tested. They performed standard performance test including a wheel track test and an Indirect Tensile Fatigue Test (ITFT). In the wheel track test, they found the recycled polymer performed well. However, there was a notable difference between RP and PMP. The results from the ITCT showed the PMB performed better than RP and PMP binders, which was due to a slight lack of elasticity by RP as shown in Figure 6.5. They found that LDPE and HDPE to offer the best results using RP and a blend of 4% HDPE was optimal.

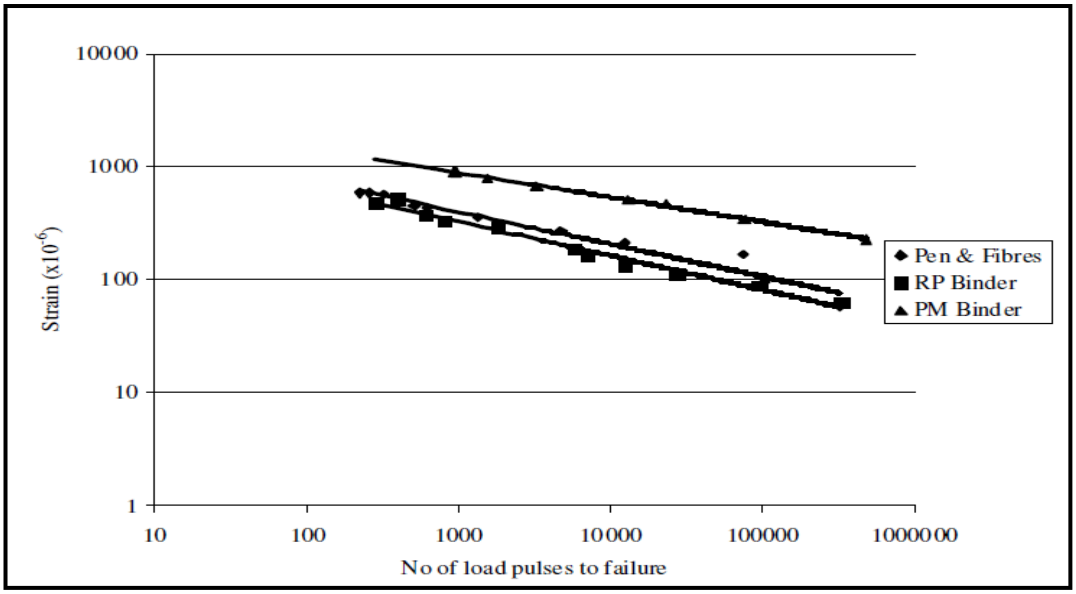


Figure 6.5. Results of the ITFT test (M.T. Awwad & L. Shbeeb, 2007).

Awwad and Shbeeb (2007) studied the use of Polyethylene in Hot Asphalt Mixtures. The researchers used polyethylene to enhance the mixture properties of asphalt. They concluded that grinded polyethylene provides better coating or attached easier to the aggregate as the surface area of the polymer increases. They recommended proportion of the modifier of 12% by the weight of bitumen content. Their results also indicated that the modified mixture has a higher stability, reduced pavement deformation; increased fatigue resistance and provided better adhesion between the asphalt and the aggregate (M.T. Awwad & L. Shbeeb, 2007).

6.4 Carpet Waste

According to Carpet America Recovery Efforts (CARE) in 2010, carpet waste diverted from landfills was 338 million pounds, 271 million pounds were recycled, 3 million pounds used for alternative fuel, and 23 million pounds for cement kilns. Figure 6.6 shows a chart of waste carpet destinations of post-consumer carpet. Old carpet is being recycled, and used in composite lumber (both decking and sheets), tile backer board, roofing shingles, rail road ties, automotive parts, carpet cushion, and stepping stones. Since CARE began in 2002, over 2 billion pounds of carpet waste was diverted from landfills in the United States. Studies have shown that carpet fiber can be a useful material in strengthening concrete, asphalt, and soils.

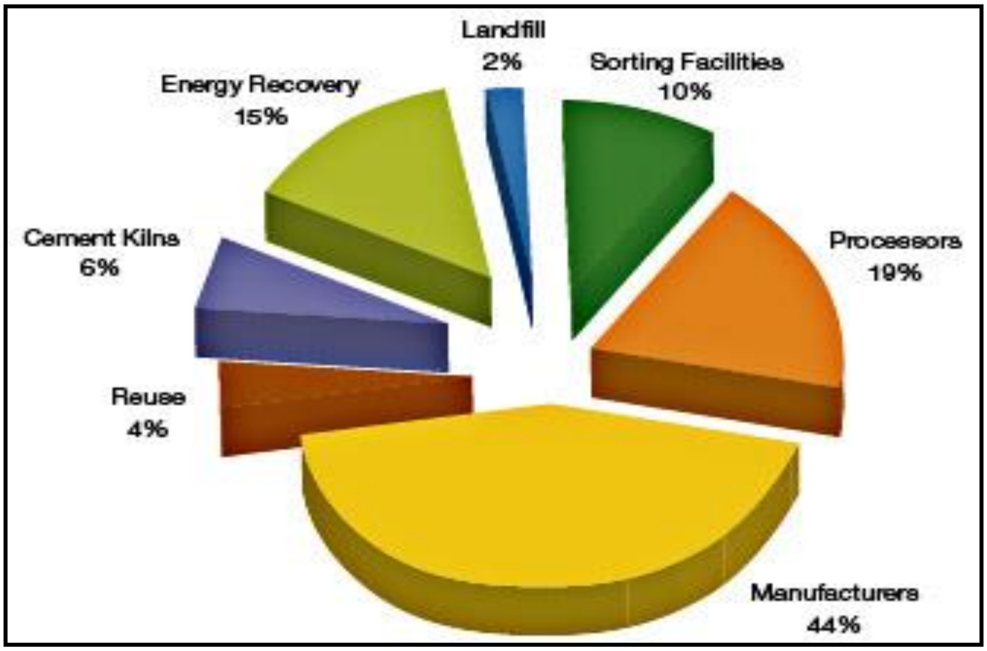


Figure 6.6. Destination of post-consumer carpet (Effort, 2009).

A study by Wang, Wu, and Li (2000) proved that by adding fibers to concrete, both toughness and tensile properties increased. Other benefits in adding carpet fiber to concrete include reduction of shrinkage, and improved fatigue strength, wear resistance, and durability. Carpet fiber may be used in asphalt to increase its toughness and fracture resistance in asphalt.

Another benefit found is a stabilizer in preventing drain down of the asphalt binder. In soil, the addition of carpet fiber increased the shear strength of sand (L.R. Hoyos, Puppala, & Ordonez, 2011).

CHAPTER 7

Transportation Sector Waste

7.1 Reclaimed Asphalt Pavement

The transportation sector has used Reclaimed Asphalt Pavement (RAP) for many years. Asphalt pavement is being recycled and re-used at a rate over 99%. In 2009, the amount of RAP used in asphalt pavements was 56.0 million tons, and in 2010, 62.1 million tons. This represents over 3 million tons (19 million barrels) of asphalt binder conserved. There are several ways to produce RAP, namely, rotomilling (milled asphalt from roadways before overlays applied) or removal or reconstruction of existing asphalt pavement. In the state of Texas, rotomilling is widely used in construction as shown in Figure 7.1.

Figure 7.1. The rotomilling process (Co., 2012).

Since Texas has mostly strict environmental regulations on disposal of solid wastes, recycling of asphalt pavements is a more feasible option. In 2007, data showed TxDOT produced approximately 15 million tons of HMA. Approximately, 3.2 million tons were recovered from which 13% was reused in Hot Mix Asphalt HMA, 24% was donated to Texas County governments, 6% was used to backfill pavement edges, 9% was used to rework base and 4% was used as a base coarse. There are three major categories of asphalt recycling. The first is hot-mix recycling, were reclaimed materials are combined with new materials in a central plant to produce hot-mix paving mixtures. The second is cold-mix recycling, were reclaiming materials are combined with new materials either onsite or at a central plant to produce cold-mix base materials. The third is surface recycling, a process in which the old asphalt surface pavement is heated in place, scraped down or “scarified”, remixed, re-laid, and rolled. Another use for RAP is in temporary driveways. Rathje, Trejo, and Folliard (2006) evaluated the used of RAP as a backfill for stabilized earth walls. They concluded that RAP has to have favorable gradation, strength, and drainage properties (Ahmed, 1993). However, Ahmed, (1993) do not recommend the use of RAP as stable back fill material because of a potential for corrosion and creep deformation.

7.2 Concrete Aggregate

According to the World Business Council for Sustainable Development, manufactures around the world produce more than 25 billion tons of concrete yearly. The Federal Highway Administration (FHWA) projected an increase in aggregates to over 2.5 billion tons per year. In 2008, the United States generated 143.5 million tons of building demolition debris, but only reused, recycled or convert waste-to-energy about 28% (40.2 million tons).

Recycling helps construction crews divert waste from landfills, which can save a company as much as $100 per ton on disposal fees, according to the Concrete Network. Incorporating recycled aggregates into the pavement-structure reduces the demand on the natural aggregate supply. The reduction on the demand of natural aggregates has many indirect benefits. The cost benefits of using recycled concrete aggregates from demolished concrete may materialize into a savings of at least 20% to 30% less than natural aggregates. Other benefits include a reduction of landfill space occupied by demolished concrete, the lessening of environmental impacts associated with the operation of a quarry, and the effects of transportation on costs and reduction of carbon dioxide emissions. Mandatory recycling or higher disposal fees may encourage builders to recycle concrete.

With the use of natural aggregates being limited in many states, this drives cost of the natural aggregates up. Further natural aggregate is obtained by quarrying. Quarrying is a process that effects the environment with noise pollution, dust pollution, and affects the water supply and run off management. As cities grow, the sites to quarry have to relocate farther; this causes an increase in cost for natural aggregate. The market for recycling concrete is not as high as it could be, with only about 140 million tons recycled each year in the United States, according to the Construction Materials Recycling Association. This low market can be attributed to the low toxicity of concrete, which lowers the urgency to recycle, compared to other hazardous waste materials. Some say recycling concrete is more time consuming in the process of sorting concrete and steel.

With new technology and engineering, some sites can be provided with machines to crush and sort concrete for reuse, producing Recycled Concrete Aggregate (RCA). By having a mobile concrete plants set up on sites or near sites that are removing concrete. The removed concrete can be crushed and recycled for later applications, reducing filling of landfills and the use of raw materials like stone used in construction (Figures 7.2 a&b).

Figure 7.2 Mobile crushing plant (www.txlsm.com).

Figure 7.3 Portable crushing plant (www.txlsm.com).

Mobile concrete rubble machine allows crushing the concrete to particular sizes and proper screening similar to natural aggregates. The machines have magnets that separate the steel from the concrete. In most cases, the steel is saved and recycled at a steel plant. Therefore, demolition waste from buildings, roads, and sidewalks could be reused back into the new application.

In most cases, concrete debris is sent to landfills, but by recycling concrete, the aggregate can effectively and efficiently be used in construction. The recycled aggregate has high water absorption, which is due to the cement paste from old concrete.

7.2.1 Use of Recycled Aggregates as a Base Course. A base course or granular base uses crushed aggregate in highway construction. Its primary function is to increase the load capacity of the pavement and to distribute the applied load to avoid damage to the sub grade (Chini & Monteiro, 1999).

Using RCA as a base course reduces the high cost of transportation, and the need of landfill space is eliminated. Many states like Virginia, Texas, Minnesota, and California have produced excellent results from the use of RCA. They show an improvement in strength verses the virgin aggregate normally used. Table 7.1 shows the specification requirements for flexible base.

Table 7.1

Aggregate Specification Requirements for Flexible Base (TxDOT, 2004).

Property	**Test Method**	**Grade 1**	**Grade 2**	**Grade 3**
Master gradation sieve size (% retained)	Tex-110-E			
2-1/2 in.		-	0	0
1-3/4 in.		-	0-10	0-10
7/8 in.		10-35	-	-
3/8 in.		30-50	-	-
No. 4		45-65	45-75	45-75
No. 40		70-85	60-85	50-85
Liquid limit. % max.[1]	Tex-104-E	35	40	40
Plasticity index, max.[1]	Tex-106-E	10	12	12
Plasticity index, max.[1]		As shown on the plans		
Wet ball mill, % max.[2]	Tex-116-E	40	45	-
Wet ball mill,% max. increase passing the No. 40 sieve		20	20	-
Classification[3]	Tex-117-E	1.0	1.1-2.3	-
Min. compressive strength[3] . psi Lateral pressure 0 psi Lateral pressure 15 psi	Tex-117-E	45 175	35 175	- -

Poon and Chan (2006) compared granite a natural aggregate with recycled concrete aggregates, as shown in Tables 7.2 and 7.3, the reliability test on both materials shows they have similar properties.

Table 7.2

Properties of Natural Aggregate (Poon & Chan, 2006).

Properties	**Aggregate size**				**Test method**
	40 mm	**20 mm**	**10 mm**	**< 5mm**	
Density-SSD (kg/m^3)	2622	2660	2577	2579	BS 812 Part 2
Density-oven-dry (kg/m^3)	2594	2644	2562	2492	
Water absorption (%)	1.06	0.57	0.59	3.51	
Ten percent fines – dry (kN)	-	190	-	-	BS 812 Part 111
Ten percent fines – soaked (kN)	-	190	-	-	
Water-soluble sulphate content (g/L	-	-	-	0.025	BS 1377 Part 3
Soundness (%)	-	97.5	-	-	BS 812 Part 121
Particle size distribution (mm)	% passing (5)		-	-	
50.0	100	-	-	-	BS 812 103.1
37.5	96.9	100	-	-	
20	2.09	92.1	-	-	
14	0.1	36	100	-	
10	-	8.35	95.9	-	
5	-	0.41	13.5	97.3	
2.36	-	-	1.18	77.7	
1.18	-	-	-	58	
0.6	-	-	-	41.9	
0.3	-	-	-	19.2	

Table 7.3

Properties of Recycled Concrete Aggregates (Poon & Chan, 2006).

Properties	**Aggregate size**				**Test method**
	40 mm	**20 mm**	**10 mm**	**< 5mm**	
Density-SSD (kg/m^3)	2487	2546	2580	2310	BS 812 Part 2
Density-oven-dry (kg/m^3)	2411	2493	2523	2093	
Water absorption (%)	3.17	2.17	2.29	10.3	

Table 7.3

(cont.)

Properties	Aggregate size				Test method
	40 mm	**20 mm**	**10 mm**	**< 5mm**	
Ten percent fines – dry (kN)	-	146	-	-	BS 812 Part 111
Ten percent fines – soaked (kN)	-	106	-	-	
Water-soluble sulphate content (g/L	-	-	-	0.032	BS 1377 Part 3
Soundness (%)	-	96.3	-	-	BS 812 Part 121
Particle size distribution (mm)	Percent passing (5)		-	-	
50.0	100	-	-	-	BS 812 103.1
37.5	96.4	100	-	-	
20.0	3.98	98.4	-	-	
14.0	0.23	31.4	100	-	
10.0	-	4.73	93.8	-	
5.0	-	0.18	7.6	100	
2.36	-	-	1.6	73.6	
1.18	-	-	-	48.3	
0.6	-	-	-	31.1	
0.3	-	-	-	17.7	

7.2.2 Use of recycled aggregates in Portland cement concrete. Studies on the RCA show that RCA can be used as a coarse aggregate in concrete mix designs. Test results provided by TxDOT (FHWA, 2004) did not show much success when RCA's were used in concrete due to an increase in creep and shrinkage. Because of this, a recommended use for RCA is in non-structural applications, such as sidewalks, highway and wall barriers, bench's, and parking slabs.

The FHWA has provided information on the effects of RCA on the mechanical properties (Table 7.4), fresh concrete properties of hardened (Table 7.5), and concrete durability (Table 7.6).

Table 7.4

Effect of RCA on Mechanical Properties of Concrete ((FHWA), 2007).

Property	**Range of expected changes from similar mixtures using virgin aggregates. (ACI 555R)**	
	Coarse RCA Only	**Coarse and Fine RCA**
Compressive Strength	5% to 24% less	15% to 40% less
Strength Variation	Slightly greater	Slightly greater
Modulus of Elasticity	10% to 33% less	25% to 40% less
Creep	30% to 60% greater	30% to60% greater
Tensile Strength	10% less	10% to 20% less
Permeability	200% to 500% greater	200% to 500% greater
Thermal Expansion	Somewhat less than expected for coarse aggregate used	Somewhat less than expected for coarse aggregate used
Specific Gravity	5% to 10% lower	5% to 10% lower

Table 7.5

Effect of RCA on Fresh Concrete Properties ((FHWA), 2007).

Property	**Range of expected changes from similar mixtures using virgin aggregates. (ACI 555R)**	
	Coarse RCA Only	**Coarse and Fine RCA**
Water Demand	Greater	Much greater
Drying Shrinkage	20% to 50% more	70% to 100 more
Finishability	More difficult	More difficult

Table 7.6

Effect of RCA on Concrete Durability ((FHWA), 2007).

Property	**Range of expected changes from similar mixtures using virgin aggregates. (ACI 555R)**	
	Coarse RCA Only	**Coarse and Fine RCA**
Corrosion Rate	May be faster	May be faster
Freeze-thaw Durability	Dependent on air void system	Dependent on air void system

Table 7.6

(cont.)

Property	Range of expected changes from similar mixtures using virgin aggregates. (ACI 555R)	
	Coarse RCA Only	**Coarse and Fine RCA**
Carbonization	65% greater	65% greater
Sulfate Resistance	Dependent on mixture	Dependent on mixture

7.2.3 Recycled Concrete Pavement. Ravindrarajah et al. (1987) studied the use of recycled concrete as a coarse and fine aggregate in concrete mixes at National University, Singapore. The study concluded that properties of natural aggregate had better attachment to portions of mortar as well as loose mortar compared to the recycled. Modulus of elasticity and strength reduced 10% and 30%, respectively. The amount of cracking was higher but not major failure compared to new pavement. Shrinkage doubled after 90 days. Such expansion is tolerable in Portland cement. Recycled concrete pavement bases and shoulders, fills, asphalt mixes, and ice control grit performance is promising due to its excellent skid resistance qualities. The use or recycled pavement is generally economical, technically feasible, and environmentally acceptable (Ahmed, 1993).

7.2.4 Building Rubble. Building rubble is a mixture of concrete, plaster, steel, wood, brick, piping, asphalt cement, glass, etc. Additionally, building rubble may be used as an additive to base and sub base course, fill, and embankments.

7.3 Tire Waste

According to the Rubber Manufactures Association (RMA) in 2009, scrap tires generated 291.8 million of waste, resulting in 132.6 thousand tons of waste. The Indiana Department of Environmental Management (IDEM) estimates 6 million waste tires are generated per year with about 6.5 million waste tires inventoried at illegal stock piles. There is a calculated 800 million scrap tires in the United States' landfills and stockpile. Annually 280 million tires discared, approximately one tire for every person in the US; 30 million are retreaded or reused, leaving 250 million scrap tires annually (45%); 7 % is exported; 8% new products; 40% used to provide fuel for power plants, cement plant, industrial boilers. The use of waste tires as a valuable raw material is high. The factors that favor recycling include their high physical and chemical durability, high tensile strength, elasticity, and high caloric value, and low unit weight, low cost and positive impact of recycling on the environment. Some factors that are impediments for recycling include the complex chemical composition, which makes them potentially combustible and leachates possibly generated under adverse environment conditions (Bernal, Lovell, & Salgado, 1996). Waste tire fields have caused fires that are hard to control, almost impossible to extinguish, and emits harmful pollution the atmosphere. There is 3 cases of embankment fires caused by the use of scrap tires. In May 1989, a tire store in Chicago burned for 6 weeks before extinguishing the fire. Tire scraps dumped in landfills adds to the enormous overflow of waste. Tires are produced in large volumes and are durable. They have 17% void space. This space traps methane gases, causing a bubble effect damaging liners. This could lead to a break in the seal causing poisons and gases leaks. Other concerns with stockpiles include becoming breeding grounds for rats and mosquitoes that can possibly carry deadly diseases. With these issues, scientists and researchers have discovered new ways of using waste tires as shown in Figure 7.4.

Figure 7.5 provided by Rubber Manufactures Association, shows the 2009 United States scrap tire deposition as percent of tons generated annually, as shown, scrap tires represent 26.2%. In the United States, in 2007, 89% of tires generated were also recovered, and reused. About 54% of the recovered tires were converted to tire derived fuel (TDF), and consumed by power plants, industrial builders, and cement kilns as a fuel supplement; 12% of the recovered tires went to Civil Engineering applications, and 17% to crumb rubber producers, the remaining 17% went to landfills.

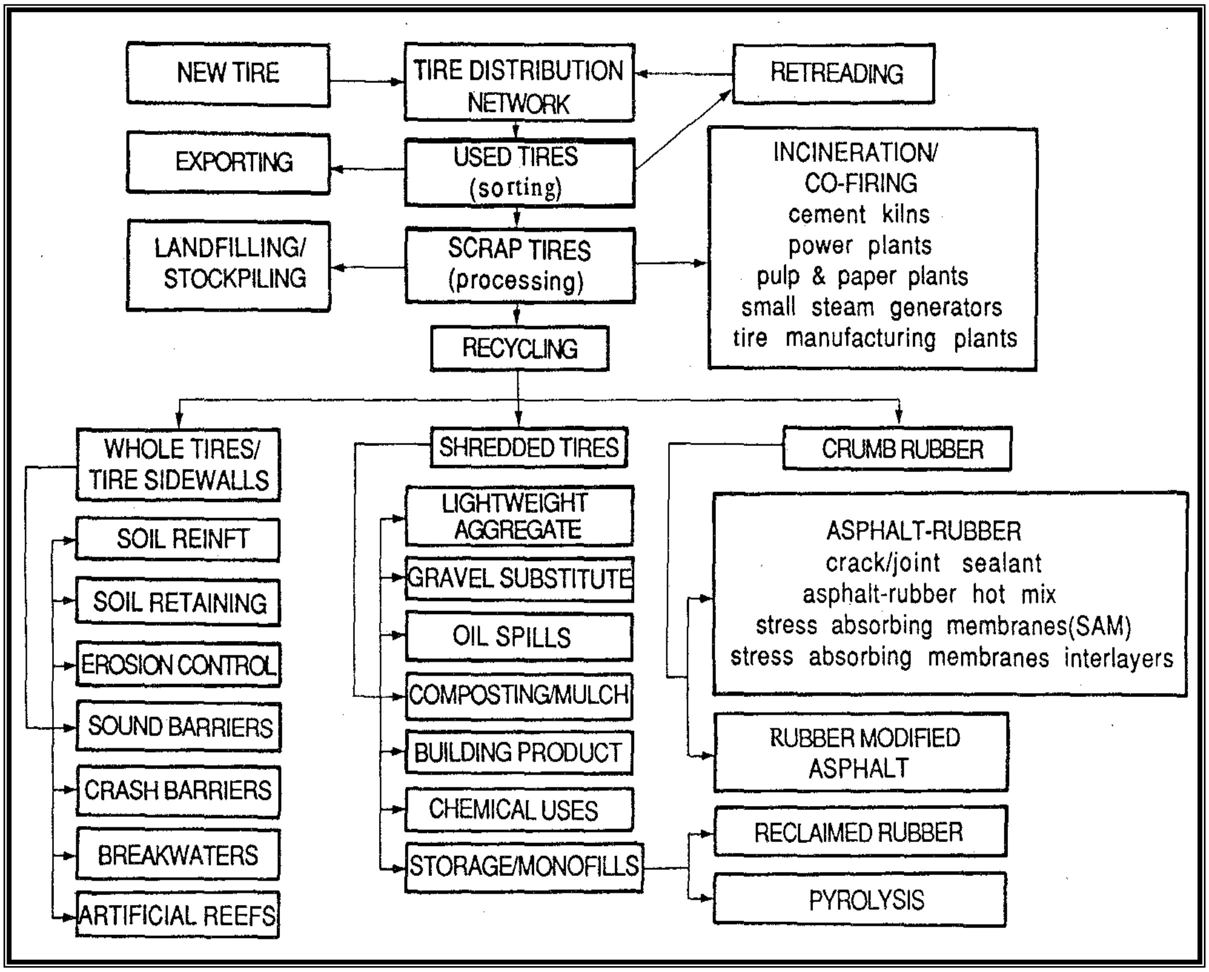
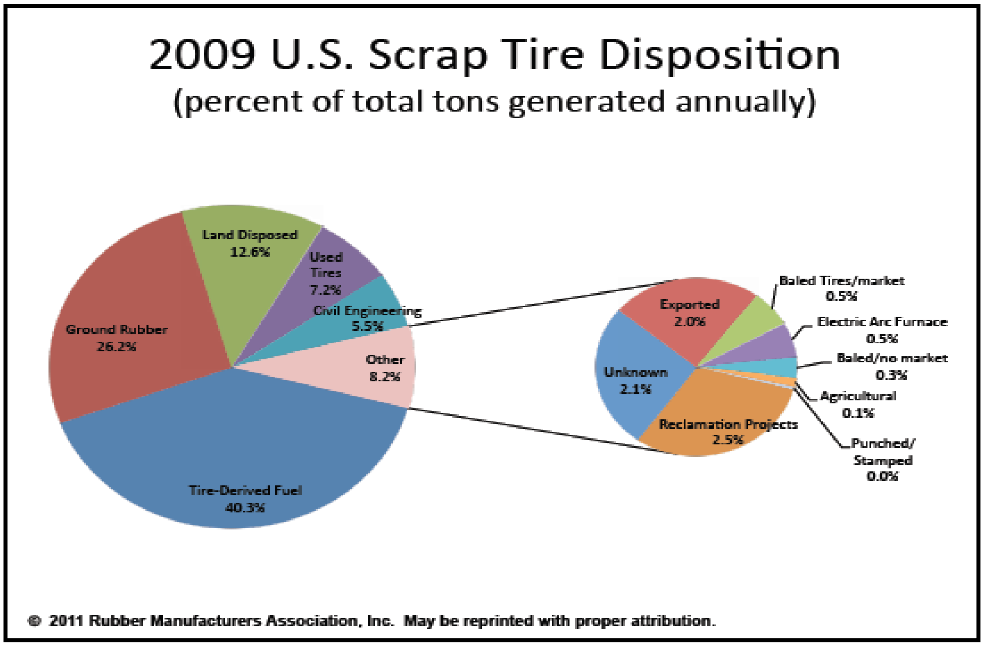


Figure 7.4. Summary of recycling and disposal options for scrap tires (Bosquez, 2009).

The Civil Engineering market ranked the second largest market for use of waste tires in the United States. Uses in construction include base for roadways, surface lots, and drainage lines. In 2009, Civil Engineering market increased using 257.2 million waste tires (RMA, 2009).

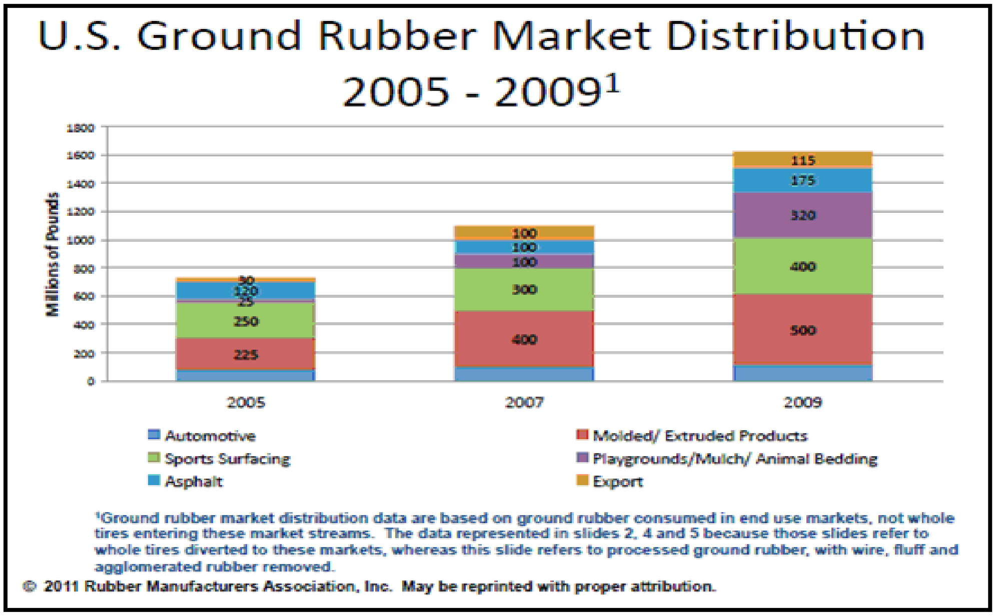
Figure 7.6 shows data from 2005 – 2009 of the ground rubber applications. Studies have investigated the use of tire waste as acceptable recycled and reusable material in the construction industry.



2009 U.S. Scrap Tire Disposition

(percent of total tons generated annually)

Figure 7.5. 2009 U.S. Scrap tire disposition (Rubber Manufacturers Association, 2011).



U.S. Ground Rubber Market Distribution 2005 - 2009[1]

[1] Ground rubber market distribution data are based on ground rubber consumed in end use markets, not whole tires entering these market streams. The data represented in slides 2, 4 and 5 because those slides refer to whole tires diverted to these markets, whereas this slide refers to processed ground rubber, with wire, fluff and agglomerated rubber removed.

Figure 7.6. U.S. ground rubber market distribution (Rubber Manufacturers Association, 2011).

The raw material of tire waste is recycled into many useful applications such as fuel, ground rubber uses, civil engineering applications, basketball courts and new shoe products. The tire clips can be used in mulch to absorbs moisture and prevent weeds from growing. Due to heavy metals and other pollutants there is a potential risk for leaching of toxins in the round water when placed in wet soils. Usages of whole tires are in artificial reefs, breakwaters, dock bumpers, soil erosion control mats, and playground equipment. Studies supporting using tire waste in stone cladding, concrete, asphalt mix, embankments, and flowable fill are discussed further.

7.3.1 Stone Cladding. Hammoush et al. (2011), conducted research at North Carolina Agricultural and Technical State University on the design of an artificial stone. The face layer of the stone was made strong, durable, and with color. The back layer utilizes recycled crumb rubber, as shown in Figure 7.7, which also shows a cross section of the stone exposing the rubber chips in layer 2. The use of crumb rubber provides a combined solution for energy saving and environmental concerns.

Figure 7.7. Cross section of stone cladding mixed with crumb rubber (Hamoush, et al., 2011).

The first layer (face layer) is solid, voids free, and contains durable materials to resist environmental contamination beside the natural look of stones, while the second layer (back layer) contains rubber chips as a light weight material that reduces the total weight of the stone, and works as thermal insulation. Researchers tested several mixtures to find the best design. Table 7.7 shows the mix proportion for the back layer.

Table 7.7

Mix proportion of the back layer of the two layer stone (Hamoush, et al., 2011).

Material	**Density (g/cc)**	**Volume (cc) (% by volume)**			**Weight (g)**		
		Mix 8	**Mix 9**	**Mix 10**	**Mix 8**	**Mix 9**	**Mix 10**
Polyester	1.1	150 (3)	100 (25)	50 (25)	165	110	55
Coarse agg.	2.7	100 (20)	80 (20)		270	216	
Sand	2.6	100 (20)	60 (15)		260	156	
Perlite	0.11	150 (30)	120 (30)	30 (15)	16.5	13	3
Fine agg.	2.7		40 (10)			108	
Rubber	1.5			120 (60)			180
Total		**500**	**400**	**200**	**711.5**	**603**	**238**
Material	**Density (g/cc)**	**Volume (cc) (% by volume)**			**Weight (g)**		
		Mix 11	**Mix 12**	**Mix13**	**Mix 11**	**Mix 12**	**Mix 13**
Polyester	1.1	70 (21)	70 (23.3)	105 (35)	77	77	15.5
Coarse agg.	2.7						
Sand	2.6		20 (6.7)			52	
Perlite	0.11	60 (18)	30 (10)	90 (30)	7	3	10
Fine agg.	2.7			30 (10)			81
Rubber	1.5	200 (61)	180 (60)	75 (25)	200	270	112.5
Total		**330**	**300**	**300**	**384**	**402**	**319**

The researchers performed several test including compression, absorption, thermal conductivity, impact, and durability. For the compression, lime stone performed better but was very brittle compared to engineered stone as shown in (Figure 7.8). However, the engineered stone had higher ductility compared to the hard limestone. (Figure 7.9) shows the results for the absorption, which shows the engineering stone to be very low with 0.21% compared to clay brick with 8.15%. The results of the thermal conductivity test showed the engineered stone was almost half (57%) of the conductivity of natural sandstone. (Table 7.8) shows thermal conductivity results of the engineered stone. The crumb rubber reduced the material unit weight, enhanced ductility and toughness, and improved thermal resistance. Facing the building with the proposed engineered stone may obtain considerable energy savings. Using the back layer as a heat insulation material may result in a 50% reduction in thermal conductivity compared to natural stone. The impact test results of the two-layer stone showed significant improvement in total absorbed energy, 75%, increase from the natural stone as shown in (Table 7.9). The increase in ductility and toughness enhances the stone's property to resist impact loading, and reduce fragments of debris (Hamoush, et al., 2011).

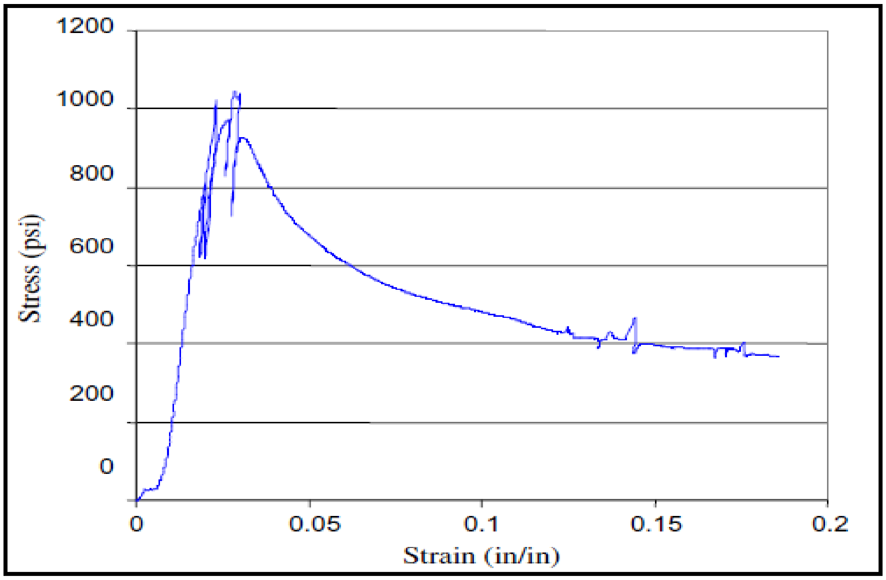


Figure 7.8. Strain of back layer (Hamoush, et al., 2011).

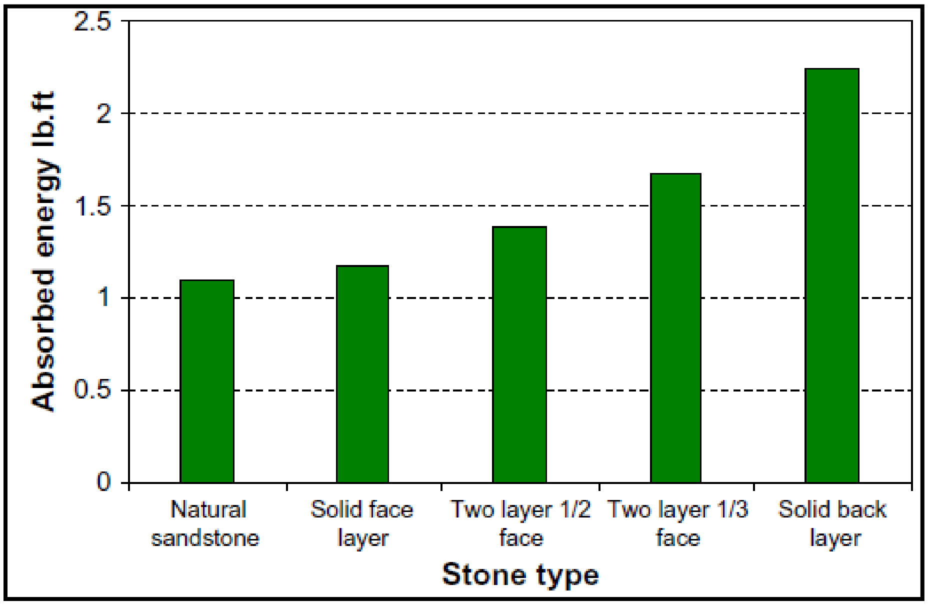


Figure 7.9. Absorbed energy for different stones (Hamoush, et al., 2011).

Table 7.8

Thermal Conductivity Results (Hamoush, et al., 2011).

Specimen		**T_{hot} (^oC)**	**T_{cold} (^oC)**	**ΔT (^oC)**	**Thick, (t) (10^{-3} m)**	**k (W/m ^oC)**	**Average (k)**	**%**
Natural	1	83.15	24.3	58.85	9.7	4.80		
	2	81.7	23.9	57.80	9.8	4.94	4.81	100
	3	82.55	24.25	58.30	9.4	4.70		
Face	1	96.2	19.5	76.65	9.3	3.53		
	2	92.85	19.5	73.35	9.0	3.58	3.54	73.6
	3	92.7	19.7	73.00	8.8	3.51		
Back	1	121.3	19.2	102.1	8.7	2.48		
	2	120.6	19.1	101.5	8.5	2.44	2.49	51.8
	3	121.3	19.5	101.8	8.9	2.55		
Two-layer	1	116.8	19.1	97.75	9.0	2.68		
	2	117.5	20.4	97.1	9.5	2.85	2.72	56.5
	3	121.3	20.9	100.4	9.1	2.64		

Table 7.9

Impact Results (Hamoush, et al., 2011).

Specimen	**Peak load**		**Deflection at peak load (mm)**	**Total energy**	
	kN	**Lb**		**Joule**	**ft-lb**
Back layer	0.50	112.7	61.10	4.20	3.11
Face layer	0.80	180.1	1.62	1.60	1.18
Two-layer, ½" back	0.76	171.2	1.81	1.88	1.39
Two-layer 2/3" back	0.97	218.7	1.87	2.28	1.68
Natural stone	1.70	381.4	0.29	1.30	0.96

7.3.2 Tire Chips in Concrete. Shredded tires into different size chips or fibers are useful in different concrete applications. Tire chips in concrete have allowed concrete to be lightweight and less in the thermal conductivity. Toutanji (1996) conducted research on the use of rubber tire particles in concrete to replace mineral aggregates. His results showed a reduction in both compressive and flexural strengths. The reduction in compressive strength was greater than that for the flexural strength. He concluded that the reduction in both strengths increased with increasing the rubber aggregate volume content (Toutanji, 1996).

Garrick (2004) investigated waste tire modified concrete by replacing 15% (by volume) of coarse aggregate by waste tire. He used waste tire as tire fiber and chips dispersed in the concrete mix. His results showed an increase in toughness, plastic deformation, impact resistance and cracking resistance (Garrick, 2004). He also found a reduction in the strength and stiffness of the rubberized sample. The control concrete disintegrated at the peaked load; while the rubberized concrete had considerable deformation without disintegration, which was due to the bridging caused by the tires fibers.

Rubberized concrete has many advantages in its use in the construction industry. It is affordable, cost effective, able to withstand more pressure, and more impact and temperature when comparing to conventional concrete. Rubber Modified Concrete (RMC) is weak in compressive and tensile strength, but has good water resistance with low absorption, improved acid resistance, low shrinkage, high impact resistance, and excellent sound and thermal insulation. From a different experiment, Crumb Rubber Concrete (CRC) did not shatter after failure compared to a conventional concrete mix. Such behavior may be beneficial for a structure that requires good impact resistance properties. The impact resistance of rubberized concrete was higher, and it was particularly evident in concrete specimens made with thick rubber (Kaloush, et al., 2005).

Based on the unique qualities of the rubberized concrete, it may find new areas of usage in highway constructions such as shock absorber, sound barriers, and sound absorber, and in buildings as an earthquake shock-wave absorber. It reduces plastic shrinkage cracking, and reduces the vulnerability of concrete to catastrophic failure. RMC is used in a precast sidewalk panel, non-load bearing walls in buildings, and precast roof for green buildings (Tomosawa, Noguchi, & Tamura, 2005). It can be widely used for development related projects, such as roadways or road intersections, recreational courts and pathways, and skid resistant ramps (Kaloush, et al., 2005). With this new property, it is projected that these concretes can be used in architectural applications such as nailing concrete, where high strength is not necessary, in wall panels that require low unit weight, in construction elements and barriers that are subject to impact, and in railroads to fix rails to the ground (Topçu, 1995). Rubberized concrete can also be used in non-load bearing members such as lightweight concrete walls, building facades, or other light architectural units; thus, the waste tire modified concrete mixes could give a viable alternative to the normal weight concrete (Khatib & Bayomy, 1999). Rubberized mixes are alternative uses in places where cement needs stabilized aggregate bases; particularly under flexible pavements. The other viable applications well suited for use in areas where repeated freezing and thawing occur can be poured in larger sheets than conventional concrete. Now, tennis courts can be poured in a single slab, eliminating ‘section’ lines, which must be smoothed after curing. Roofing tiles and other concrete products can now be made lighter with Rubberized concrete (Allen, 2004). Other possible uses for tire chips in concrete are in runways and taxiways in the airport, industrial floorings, and even as a structural member.

7.3.3 Asphalt Mix. Ground rubber applications consumed over 28 million tires in 2003, or nearly 10% of the scrap tires generated were used as playground surfaces, sports surfaces, and rubber modified asphalt. According to the Recycling Research Institute, the U.S. used 200 million pounds of crumb rubber (CR) in asphalt. Tire sheds and chips would be available from tire shedder operations. Ground rubber or CR would normally be available from scrap tire processors. There are probably 100 or more tire shedders in the U.S, but on about 15-20 scrap tire processors. There are 3 methods to crumb rubber, the crackmill process, granulator process, and the micro mill process. The crackmill process has larger size crumb rubber at sizes of 5mm to 0.5mm. The granulator process has medium size particles at 9.5mm (3/8 in) to 0.5mm (No. 40 sieve). The micromill process has the smallest particle size range from 0.5mm to as small as 0.075mm (No. 200 sieve).

There are two different blends for processing asphalt mixed with a crumb rubber additive (CRA), a wet and dry process. The wet process blends CRA with hot asphalt cement contain as much as 30% CRA. The wet process acts as an asphalt cement modifier. Asphalt-rubber binders are used in chop-seal as well as hot asphalt paving. Chip seal coat application using asphalt rubber binders have become known as stress-absorbing membranes (SAM). SAM is usually used in the pavement structure. The cost of using SAM is twice as much as conventional chip-seal. However, the life cycle of SAM may be 10-12 years maintenance free compared to 6-8 years, with some maintenance for conventional chip seal. The cost factors include: cost of the granulated rubber, the need for more costly aggregate (stone) as filler gradation, increased energy to heat the asphalt mix to the required temperature, mixing time, increased plant labor to handle rubber additive, and increased labor and equipment cost at site. Research shows that rubber asphalt mix was also more “sticky”, sticking to equipment which cause the release from the truck bed difficult. Stickiness increased with rubber content. Other environmental issues with rubber asphalt are increase in air pollution caused by the high temperatures to mix the asphalt rubber binder.

When as asphalt-rubber chip seal or SAM is overlaid with HMA, the chip seal is referred to as a stress-absorbing membrane interlayer (SAMI). The amount of asphalt-rubber binder suggested for use in chip seals is about 15 to 20% higher that they required for a typical asphalt cement binder without a temp correction. The amount of asphalt rubber binder suggested for use in interlayer is about 45% higher than that typically used in asphalt cement without a temperature correction. The dry process mixes at the facility with hot aggregate, before adding the asphalt cement at the site. The dry process crumb rubber is used as a portion of the fine aggregate. It is used for HMA paving in dense-graded, open graded or gap-graded mixtures, not used in cold mix and chip seals or surface treatment. For 10-20 percent GR the mixing temperature should be at 149°C to 204°C (300-400°F). The lay down temperature should at least be 121 °C (250 °F). A finishing roller must continue to compact the mixture until it is cooled below 60 °C (140 °F). That will take between 45 minutes to a hour otherwise, the continued reaction between the asphalt and the crumb rubber at elevated temperatures will cause the mixtures to swell (FHWA, 1997).

Elmore Road Construction conducted a cost overview and analysis in 2007. They found out the cost of Normal HMA made from local aggregates unmodified asphalt cement = $65/ton, for 5 years. Super pave designed HMA, local aggregates, polymer modified asphalt cement = $75/ton, 8 year life. Super pave with “Hard Aggregate” and polymer modified asphalt cement = $106/ton, for 12-15 years. HMA with CR, polymer modified asphalt cement = $106/ton, 20 years of life. Their analysis assumed a project with 10,000 tons HMA & HMA surface course = 38% of project cost. Normal HMA = $1.7 million project / 5 years =$340,000 / year. Superpave HMA = $2.0 million / 8 years = $249,000 / year. Hard Aggregate HMA = $2.8 million / 15 year = $185,000 / year. CR HMA = $2.8 million / 20 year = $138,000 / year.

Rubber modified asphalt (RMA) goes back to the late 1960 in Sweden. Later, McQuillen and Hicks (1984) produced Plus Rider. Their reports showed that RMA has higher viscosity than conventional asphalt at 60°C (140°F), tougher in surface wear, more elastic, and greater resistance to aging. They also found that thermal pavement cracking was greatly reduced, skid resistance increased, resistance to sturdy tire wear increased, and the ability to shed an ice cover more quickly than conventional pavement. Decreased maintenance cost, lasting more than 40 years, and no additional capital investment by using the same equipment as traditional paving and a consistent supply of materials. Reduced noise levels by upwards of 5 decibels and using between 500 and 2,000 scrap tires per lane mile of pavement (Liberty Tire Recycling, 2012). With the increase in oil prices, CR is a high performance alternative to traditional paving materials. CR is longer lasting, safer, less costly, and friendlier to the environment. CR asphalt reduces the occurrences of cracking with superior elasticity. It is stiffer than conventional paving, which resists rutting and increases pavement life. It also exhibits greater skid resistance and decrease splash and spray in wet conditions.

A study by Zhong et al. (2002) investigated the potential application of crumb rubber-modified asphalt (CRMA) in railroad track beds by measuring its shear modulus and damping ratio. The results of several tests showed an increase in the damping ratio and stiffness due to adding crumb rubber to asphalt. CRMA is very attractive material to use to achieve vibration attenuation of railway track beds. The stiffness characteristics of CRMA are adequate for use in railroad track structures (Zhong, et al., 2002). Their results indicated lower structural layer coefficient value for the CRMA mix compared with the conventional asphalt concrete (Zhong, et al., 2002). Successful asphalt mix in an open graded friction course meant reduced cracking, improved durability, and reduced noise.

7.3.4 Highway Embankments. Shredded tires have been used as a light weight fill material for construction of embankments. Engineers and researchers are constantly trying to develop civil engineering materials that are more durable, more economical, and lighter to replace conventional materials that will enhance the stability of slopes, foundations, and reduce settlements in problem areas. Field and laboratories indicated that these apparently contradictory requirements could potentially reconcile the use of rubber soil.

Organ uses 580,000 scrap tires, which is the largest amount in the country. They have successfully conducted more than 70 projects on the state, local, and private roads. Whole tires have been used to stabilize roadside shoulder area and provide channel slope protection. A tire chip to soil ratio of 50:50 is satisfactory for more compatibility use 10-20 percent of tire chips. Tire chips used as a fill material in sub grade applications, reduce depth of frost penetration compared with that of granular soil (FHWA, 1997). The use of tire chips benefits soils with its permeability and insulating properties. Table 7.10 shows lightweight materials that successfully use in highway embankments. These materials include: sawdust, dried peat, fly ash, slag's, cinders, cellular concrete, expanded clay or shale, expanded polystyrene, and oyster and clam shells (Ahmed & Lovell, 1993). These types of materials can be costly; especially, manufacturing costs and transportation costs for the distance to the site.

Table 7.10

Lightweight Embankment Fill Materials (Bosquez, 2009).

Material	**Unit Weight (pcf)**	**Comments**
Bark (Pine & Fir)	35-64	Waste material used relatively rarely as it is difficult to compact and requires pre-treatment to prevent groundwater pollution. Long-term settlement of bark fill may amount to 10% of compacted thickness.
Sawdust (Pine & Fir)	50-64	Usually used below permanent groundwater level. May be used in embankments, if property encapsuled.
Peat	19-64	Long term large settlement is a major concern.

Table 7.10

(cont.)

Material	**Unit Weight (pcf)**	**Comments**
Fuel ash, slag, cinders, etc.	64-100	Such materials may: possess cementing properties; absorb water with time, which may increase density; and leach substance, which may adversely affect adjacent structures and groundwater quality.
Scrap cellular concrete	64	Significant volume decrease results when the material is compacted. Excessive compaction reduces the material to a powder.
Expanded clay or shale	20-64	Possesses good engineering properties for use as lightweight fill; is relatively expensive; and should be encased in minimum of 20 in. soil cover.
Shell (oyster, clam, etc.)	70	Commercially mined or dredged shell available mainly off Gulf and Atlantic coasts. Sizes 0.5 to 13 in. (12 to 75 mm). When loosely dumped, shells have a low density and high bearing capacity because of interlock.
Expanded polystyrene	1.3-6	A super light material. The material is very expensive, but the very low density may make it economical in certain circumstances.
Low-density cellular concrete, Elastize11:		This is a lightweight fill material manufactured from Portland cement, water, and foaming agent with the trade name "Elastize11 EF" and is produced by Elastize11 Corporation of America, Ann Arbor, Michigan. Six different categories of engineered fill are produced. The material is cast in situ and has been used as lightweight fills in a variety of geotechnical applications, such as highway embankments, bridge approaches, foundations, etc.
Class I	24	
Class II	30	
Class III	36	
Class IV	42	
Class V	50	
Class VI	80	

Several states have used shredded tires as lightweight fill material, namely, Colorado, Minnesota, North Carolina, Oregon, Vermont, Washington, and Wisconsin. Laboratories and theoretical studies of Caltrans (Forsyth and Egan, 1976) indicated that tire sidewalls could possibly benefit a fill and thus permit steeper side slopes and increase resistance to earthquake loading. Minnesota Department of Natural Resources used whole tire mats and tire chunks as a material to replace corduroy logs in logging road embankments over swamps. Whole tires in backfill can help anchor wall heights up to 10 feet. Applications that use the sidewalls of whole tires as a soil reinforcement in embankments construction can enhance the stability of steep slopes along the highway (TNR, 1985). Other research findings showed temporary protection of slopes (Caltrans, 1990), retaining of forest roads with tire-faced walls (Keller, 1990), and scrap tires filled with concrete, could control erosion by the sea without destroying the character of the natural coastline protection of coastal roads from erosion (Kilpatrick, 1985). Tire shreds in embankments solve stability problems for construction in soft soil roads by reducing the weight of highways, wood chips and saw dust has replaced conventional materials. Wood is biodegradable and lack durability, conversely rubber is not and is more durable. The Oregon DOT says shredded tires are a success, using about 52,000 shredded tires as light weight fill material in a 250-ft section of road. Metals are leached from tire materials in highest concentrations under acid condition, concerns are balium, cadmium, chromium, lead, selfnium, and zinc. Research show shredded tires in sub-grade/embankments concerns needs further research (ODOT, 1990).

Some potential problems associated with the use of shredded tires in highway embankments include long-term impacts of leachates from tires; fire risk; and large compressibility of tire chips. Field tests have shown that shredded tires show no likelihood of having adverse effects on groundwater quality (P.J. Bosscher, 1997). However, long-term concerns under adverse environmental conditions persist. Proper soil cover is required on top and side slopes of shredded tire embankments for safety against fire. Normal caution is required during construction to safeguard against fire in stockpiled tires or embankment tires not yet capped with soil. Potentially, to reduce large settlements, provide a thicker soil cap and use a rubber-soil mix instead of chips alone.

To reduce the effects of post-construction settlements, only use tires under flexible pavements, and let the chips settle under traffic for some time before laying a final surface coarse. Use rubber soils with chip/mix at ratios of 38% (referred to as the optimum ratio) or less in embankments where large settlements are unacceptable (e.g., near bridge abutments). Rubber-sand at optimum chip/mix ratios possesses excellent engineering properties such as easy to compact and yield low dry density; low compressibility; high strength; and excellent drainage characteristics. The free draining characteristics of rubber-sand also reduced the possibility of undesirable leachates form tires, since water does not stagnate in fills.

7.3.5 Flowable Fill. Findings suggest that crumb rubber is an ideal aggregate for flowable fill; otherwise, known as controlled low-strength material. Pierce and Blackwell (2003) studied crumb rubber use as a complete replacement for concrete sand in flowable fill. They found that crumb rubber content in as high as 38% by weight can be mixed in flowable fill without noticeable segregation of the rubber, although there may be measurable bleeding in some cases. Achieving flowability is reasonable, and satisfying the requirements of mixing speed, mixing time. It should be noted that, addition of fly ash to the mix help control bleeding.

In summary, lightweight flowable fill produced with crumb rubber, provides material for the construction industry that imparts less stress on the soil beneath it. Thus, mitigating the potential for soil settlement, especially, when constructing on soft and compressible soils (Pierce & Blackwell, 2003). The reduction in bulk density dose not effect the impact strength of the flowable fill. Crumb rubber is strong enough to meet strength requirements but not so strong to avoid excavation in the future.

The high tensile strength, durability, and availability of scrap tires have prompted their use as lightweight aggregate in geo-engineering applications. Ozkul and Baykal (2007) conducted a study on the shear behavior of compacted rubber firer-clay composite in drained and un-drained loading. They found that the peak unconfined strength of silty clay increased due to the addition of nylon fibers and fibrillated fibers. Their findings also showed an increase in ductility, toughness, and residual strength. In addition, it has been shown that the deformation behavior of the clay has significantly changed (Özkul & Baykal, 2007).

CHAPTER 8

Conclusion

8.1 Summary of Key Points by Waste Materials

An observations made from the review of several studies suggest that the use of recycled materials has a positive impact through several different aspects. The benefit can be reflected in enhancing sustainability of the construction industry while reducing cost and environmental pollution as well as the use of natural resources. Accordingly following points are made from this research. Table 8.1 (appendix) summarizes the main findings and key points for this research.

8.1.2 Composite Sector.

Key Points for Swine Manure:

- Replacement of petroleum-based adhesives with biodegradable adhesive.
- Asphalt binder and sealant used in highway and airport pavement.
- The viscosity of bio-modified binder will be significantly lower than that of a non-modified binder.
- Reduction in the binder viscosity can improve binder wettability, which in return may improve mixture durability.
- Decrease in stiffness and increase in relaxation capability of the binder implies improvement in low temperature properties, and a reduction in low temperature cracking.
- By adding 2% bio-binder, one can maintain a high temperature grade of the binder.

Key Points for Animal Fat:

- Obtained higher overall polymer yields.
- Asphalt concrete mixtures modified with tall oil pitch (TOP) and styrene-butadiene-

styrene (SBS).

- TOP has a strong connection with aggregate after wetting providing a chemical adsorption interaction.

Key Points for Palm Oil Fibers:

- Date palm fiber improved the blend up to PG 76 and for the oil palm fiber, with fiber content of 0.3% improved to the blend up to PG 70.
- Enhanced the rheological performance of BMA blends (Muniandy, et al., 2008).

Key Points for Citrus Peel:

- CCFP has a solid density, bulk density, moisture content, low ash content, SET surface area, and pore volume.
- The maximum removal capacity of CCFP for MB was 25 mg/g comparable with other adsorbents.
- 98.0% removal of MB using CCFP (Dutta, et al., 2011).

8.1.3 Industrial Sector Waste.

Key Points for Cement Kiln Dust:

- Uses of CKD are soil stabilization, waste treatment, cement replacement, asphalt pavement.
- CKD is appropriate for soil stabilization, improving soil strengths, and minimizing work and cost.
- Siddique (2006) concrete mixtures containing lower percentages of CKD (5%) can achieve similar compressive strength, flexural strength, toughness, freezing, and thawing resistance as the control mixture.
- CKD is a quality adsorbent and a natural alkaline, which that makes it an effective waste

treatment.

- Emery (1981) mixed CKD with asphalt as mineral filler, and found it significantly reduced asphalt cement requirements between 15% and 25% by volume. CKD added to the asphalt binder produces low ductile mastic asphalt. CKD provides stripping resistance for the pavement.

Key Points for Fly Ash:

- Bulk density, particle size, porosity, water holding capacity, and surface area makes it suitable for use as an adsorbent.
- Utilization of fly ash in construction, as a low-cost adsorbent for the removal of organic compounds, flue gas and metals, light weight aggregate, mine back fill, road sub-base, zeolite synthesis, concrete production, structural fills, embankments, filter in asphalt mixes, and grouting.
- Addition to cement and concrete products, structural fill and cover material, roadway and pavement utilization, addition to construction materials as a light weight aggregate, infiltration barrier and underground void filling and soil, water and environmental improvement.
- As pozzolana for a partial replacement of cement, and partly because of its beneficial effects such as lower water demand for similar workability, reduced bleeding, cracking at an early age, and lowered evolution of heat.
- Fly ash in concrete produces less permeability because of the spherical particles, and therefore improved packing.
- Abrasion resistance of concrete made with Class C fly ash was better than both concrete without fly ash and concrete containing Class F fly ash (Tikalsky, et al., 1988). Class C

fly ash is produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties.

- Class C fly ash can be used to produce high early strength concrete for precast/pre-stressed products, with bituminous-type fly ash, 15-25% of the cement was replaced. High-lime fly ash has permitted normal replacements of 25-40% and up to 75% for parking lots, driveways, and streets. Fly ash used in the construction of concrete dams.
- Fly ash used in concrete has decreased water demand. This resulting in lower bleeding and provide a more durable surface and reduced heat of hydration, increased resistance against alkali aggregates, resistance to sulfate attack by combing fly ash with lime, reduced permeability; and economy (Boles, 1986).
- Fly ash is used in other non-critical structures and cement treated base like sidewalks, curbs, and barriers (Ahmed, 1993).
- Substitute mineral filler in asphalt paving mixtures.
- Grout to fill open cast mines. This process would reduce acid mine drainage.
- Absorption and removal of various pollutants, such as NOx (Rubio, et al., 2007), sox, organic compounds and mercury (Masaki, et al., 2000) in air, dyes and other organic compounds in waters.
- Fly ash recycling in the FGD process has shown promising results.
- Applications for example plant growth as a soil ameliorate that may improve physical, chemical and biological properties of the degraded soils, and is a source of readily available plant micro-and macro-nutrients (Ahmaruzzaman, 2010).
- The use of fly ash instead of lime in agriculture can reduce net CO2 emission, and reduce global warming.

Key Points for Foundry Sand:

- Aggregate replacement in asphalt mixtures, Portland cement concrete, source material for Portland cement sand used in masonry mortar mixes, embankments, retaining walls, sub base, flowable fills, barrier layers, and HMA mixtures.
- Marginal increase in the compressive strength of concrete mixtures with the addition of UFS as a partial replacement of regular sand.
- Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with the increase in foundry sand content and increased with age.

Key Points for Slag:

- Air cooled slag - Be used as an additive in concrete and asphalt mix, fill material in embankments, road base material, and as treatments for the improvement of soils (Ahmed, 1993).
- Cervantes and Roesler (2007) describe that air-cooled slag binds well with Portland cement and asphalt mixtures due to the slag’s rough finish and larger surface area in comparison to other aggregates.
- GGBFS has a positive effect on the flexural and compressive strength of concrete.
- Expanded slag has low density and allows for good mechanical binding with hydraulic cement paste.
- Rip rip can be used to stabilize shorelines and stream banks, and prevent erosion along slopes and embankments.
- Application of steel slag can be used as an additive in concrete, asphalt, base material and fill material in embankments.

- Adding steel slag to cement advantages include: lower energy cost, higher abrasion resistance, lower hydration heat evolution and higher later strength development. The disadvantages include longer setting time and lower early strength when compared with Portland cement.
- Huang et al. (2007) used steel slag as a substitute for coarse aggregates in asphalt mixes and found it to improve resistance to rutting and skid resistance.
- EAF as an efficient absorbent to remove manganese from water (Beh, et al., 2010).

8.1.4 Municipal Sector Waste.

Key Points for Roofing Shingles:

- Applications include but are not limited to hot mix asphalt (HMA), cold patch mix asphalt, aggregate substitute, base coarse, mineral filler, and granular base stabilizer.
- Lower disposal costs for shingle scrap manufactures, reduced cost in the production of HMA.
- Roofing shingles have adhesive characteristics, flexibility, and ability to form strong cohesive mixtures with mineral aggregates.
- Improve the rutting resistance of the mixtures considerably, due to a combination of the fibers and harder asphalt.
- Improve resistance to pavement cracking.
- Used for equipment yards and parking lots.
- Compete with rock and gravel as a substitute ground cover or used as a stabilizer in wet and muddy areas.

Key Points for Glass Waste:

- High-quality cullet can be used for abrasives, aggregate substitute, bead manufacturing, decorative applications, fiberglass, fractionators (match tips), and fluxes in metal foundry work. Increasingly, use of lower quality cullet is in secondary applications, such as the manufacture of fiberglass insulation, roadbed aggregate, driving safety reflective beads, and decorative tile.

- Due to the likely hood of alkali-silica reaction, glass cullet creates workability problems in concrete mix.
- Used with granular material in structural fills.
- Cullet blended with limestone can be filter material.
- Asphalt surface pavement containing 10-15% of glass with a graduation of less than 4.75mm resulted in satisfactory performance.

Key Points for Plastic Waste:

- Plastic strips added to soil embankments to increase the strength in reinforcement of soils.
- Grinded polyethylene provide better coating to the aggregate because of the high surface area of the polymer.
- Plastic modified mixture has a higher stability, reduced pavement deformation; increased fatigue resistance and provided better adhesion between the asphalt and the aggregate (M.T. Awwad & L. Shbeeb, 2007).

Key Points for Carpet Waste:

- An alternative fuel.
- Carpet is being used in composite lumber (both decking and sheets), tile backer board, roofing shingles, rail road ties, automotive parts, carpet cushion, and stepping stones.
- Carpet fiber can be a useful material in strengthening concrete, asphalt, and soils.

- Adding carpet fiber to concrete causes a reduction of shrinkage, and an improvement in fatigue strength, wear resistance and durability.
- Carpet fiber is used in asphalt to increase the toughness and fracture resistance.
- In soil, the addition of carpet fiber increased the shear strength of sand (L.R. Hoyos, et al., 2011).

8.1.5 Transportation Sector Waste.

Key Points for Reclaimed Asphalt Pavement:

- Used to backfill pavement edges rework base and base coarse.

Key Points for Recycled Concrete Pavement:

- Crushed aggregate as a base course or granular base in highway construction. Its primary function is to increase the load capacity of the pavement and to distribute the applied load to avoid damage to the sub grade.
- Non-structural applications, such as sidewalks, highway and wall barriers, benches, and parking slabs.
- The properties of natural aggregate had better attachment to portions of mortar as well as loose mortar compared to the recycled.
- Recycled concrete pavement bases and shoulders, fills, asphalt mixes, and ice control grit performance is promising due to its excellent skid resistance qualities (F. H. A. FHWA, 2004).

Key Points for Waste Tire Rubber:

- Waste tires in the United States, provide construction base for roadways, surface lots, and drainage lines.
- Whole tires have been used in artificial reefs, break waters, dock bumpers, soil erosion

control mats, and playground equipment. Studies and research show the using of tire waste in concrete, grass turf, asphalt mix, embankments, stone cladding, flowable fill, and clay composite.

- Rubberized concrete has many advantages in its use in construction industry being affordable, cost effective, able to withstand more pressure, and impact temperature.
- RMC has good water resistance with low absorption, improved acid resistance, low shrinkage, high impact resistance, and excellent sound and thermal insulation.
- Usages in highway construction are as a shock absorber, in sound barriers as a sound absorber, and buildings as an earthquake shock-wave absorber.
- RMC is used in precast sidewalk panel, non-load bearing walls in buildings and precast roof for green buildings (Tomosawa, et al., 2005). It can be widely used for development related projects such as roadways or road intersections, recreational courts and pathways, and skid resistant ramps (Kaloush, et al., 2005).
- Rubberized concrete has many advantages and usages in non-load bearing members, such as lightweight concrete walls, building facades or other light architectural units.
- Scrap tires can be used in playground surfaces, sports surfaces, and rubber modified asphalt.
- Crack and joint sealant and asphalt binder.
- The sidewalls of whole tires were researched in soil reinforcement in embankments construction and found to enhance the stability of steep slopes along the highway (TNR, 1985).

8.2 Recommendations for Future Research

According to worldwide state of the art studies reviewed on construction such materials. I suggest future work be extended to include the cost and LCA analysis of recycled materials as well as their carbon foot print. Future research should address other recycled material, new applications, and technology to facilitate applications of waste. Survey's should target engineers and architect and find more detailed reasons why companies are not using a recycled material for different construction applications. This will help with the process of overcoming any boundaries and concerns companies have using recycled and waste materials.

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Appendix

Table 8.1

Summary of Waste Material Uses.

Waste Material Uses				
Subject	**By-Product**	**Construction Use**	**Benefits**	**Disadvantages**
Rubber Concrete	Tire Rubber	Rubber chips and Fibers mixed with concrete	Less fires, diseased mosquitoes, adding super plasterizers will increase compression and tension strength	Reduction in tension and compression
Grass Turf	Tire Rubber	Jogging tracks, athletic fields, golf course	Resiliency and durability, removes organic compounds from leachate in landfills, absorb metal contaminants from ground water	Zinc from toxin from rubber kills vegetation
Highway Embankments	Tire Rubber	Fill under roadways, light weight fill, chip/sand ratio 38%, correction of slides on slopes, drainage medium, reduce backfill pressures on retaining structures, provide separation to prevent underlying weak/ problem soils from mixing with sub grade/ base materials	Smaller chips to have lower porosity, uses large quantities of tires, easy to compact, low dry density, low compressibility, high strength, excellent drainage characteristics, increase stability, reduce settlement	Stock piles on site may be dangerous due to fire risk
Asphalt	Tire Rubber	Bituminous construction, crack sealer, asphalt mix	Increase in damping ratio, increase in stiffness, increase confining pressure, positive influence on unsaturated sub grade soil	Decrease with shear strain, unknown health effects on construction works who inhale fumes

Table 8.1

(cont.)

Waste Material Uses				
Subject	**By-Product**	**Construction Use**	**Benefits**	**Disadvantages**
Asphalt	Fly Ash	Parking lots, driveways, streets	Reduce bleeding, lower evaluation of heat, helps reduce cracking at early ages, improve packing, decrease air entrainment	Sulphate resistance
Flowable Fill	Tire Rubber	Mixed in mortar or concrete, ideal aggregate, complete replacement for concrete sand in flowable fill	Light weight, reduction in bulk density	
Concrete	Fly Ash	Parking lots, driveways, streets, Portland cement substitute 30%,	Improves workability of mix, decrease in the amount of water used, water to cementitous ratio decreased,	Hardening rates are slower, especially under cold water, sulphate resistance
Asphalt	Carpet Fiber	Asphalt mixtures, stabilizer in preventing drain down off asphalt binder	Increase toughness and fracture resistance	
Soil	Carpet Fiber	Sand	Improves shear strength of sand	
Construction	Glass Cullet	20% by weight mixed with granular material in fills, blended with limestone to provide a filter material, 10-15% in Asphalt Mix with a gradation of 4.75 mm		

Table 8.1

(cont.)

Waste Material Uses				
Subject	**By-Product**	**Construction Use**	**Benefits**	**Disadvantages**
Soil	High Density Polyethylene	Soil embankments	Improve soil strength, resistance to deformation in sand, increases sand resilient modulus and shear strength	
Soil	Asphalt pavement	Hot mix asphalt, backfill pavement edges, rework base, base course		Corrosion and potential creep deformation as a material for backfill
Asphalt	Steel Slag	Road base material, fill material, course aggregate in asphalt	Improves resistance to rutting and skidding	High specific gravity increase the density of asphalt
Concrete	Blast Furnace Slag	Concrete mixtures	Positive effect on the flexural and compressive strength of concrete	
Asphalt	Swine Manure	Petroleum based adhesive, binder and sealant		
Asphalt	Oil Palm	Additive in asphalt binder	Reduce the cost of asphalt, enhanced Rheological performance of bio mastic asphalt blends	
Concrete	Cement Kiln Dust	concrete mixtures	Increased sand compression strength, increase in dry density, filling in voids in sand	Health hazards