CRITICAL REVIEW OF THE SUITABILITY OF SULPHUR AS A COMPONENT IN VARIOUS CIVIL ENGINEERING APPLICATIONS

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Civil Engineering
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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

SEPTEMBER 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ANAND KUMAR A/L VIJIA KOMAR

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Abstract

Sulphur Extended Asphalt (SEA) mixtures were used commercially in the 1970s and 1980s. Increases in sulphur prices, however, rendered SEA mixes uneconomical. Handling and safety issues also were of concern, as molten sulphur was difficult to use and occasionally generated H2S. Sulphur is a major waste of by-product from gas and oil production that has potential for encapsulation in civil engineering purposes mainly concentrating in road pavements.

This study will cover on the usage of sulphur in road construction opportunities and concerns for asphalt and rigid pavement. This utilization of sulfur on road construction has been known very widely over the globe. Opportunity for utilization of sulphur as partial substitute for bitumen in asphalt mixtures is a great application. Sulphur may make the asphalt more economical and may improve the properties such as increased stiffness and reduced permanent deformation.

Preliminarily, as used herein, the terms "asphalt" or "asphalt cement" shall mean any of the heavy petroleum oils or tar or pitch; "bituminous concrete" shall mean a composition of asphalt cement and aggregate (such as gravel, sand, mineral fillers, etc.); and "sulphur-extended asphalt" shall mean a mixture of sulphur and asphalt cement. Additionally, the term "binder content shall mean, depending upon the context, either the weight of the asphalt cement alone or the weight of the sulphur-extended asphalt mixture, expressed as a weight percentage of the total weight of the bituminous concrete mixture. The units of measurement for the results of the well-known Marshall Flow test noted herein are in one one-hundredths of an inch. For example, if a bituminous concrete test specimen deforms 0.15 inch, the Marshall Flow value is noted as 15.

However, handling and safety issues need to concern due to sulphur will produce the harmful effects. When it burns, the oxidizing to sulphur dioxide will occur and this will produces the poisonous gas that was toxic. Now the major concern of this research is to determine whether the usage of sulphur as an additive for road pavement which covers both asphalt road and rigid pavement is safe to the environment. Does this sulphur which is an additive will give any negative effect to the road and environment in a long run time period?

1.0 Introduction

1.1 Asphalt pavement

A road is a path, or way on land that connects between two places or more. A road is the main route for vehicles to travel and it is comprised of hard and solid materials underneath it. It is designed to be a national network connecting up to the small towns, rural areas and is the most popular mode of travelling. Road pavement structure is the structure that interacts directly with the use of vehicles on the road. It requires a level of continuous and effective maintenance of the pavement structure to always be in a satisfactory condition. There are few types of road and the most typical and popular road is the asphaltic and the rigid pavement.

Asphalt (specifically, asphalt concrete) has been widely used since the 1920s. The viscous nature of the bitumen binder allows asphalt concrete to sustain significant plastic deformation, although fatigue from repeated loading over time is the most common failure mechanism. Most asphalt surfaces are laid on a gravel base, which is generally at least as thick as the asphalt layer, although some 'full depth' asphalt surfaces are laid directly on the native subgrade. In areas with very soft or expansive subgrades such as clay or peat, thick gravel bases or stabilization of the subgrade with Portland cement or lime may be required. Polypropylene and polyester geo synthetics have also been used for this purpose and in some northern countries, a layer of polystyrene boards have been used to delay and minimize frost penetration into the subgrade. [23]

Depending on the temperature at which it is applied, asphalt is categorized as hot mix, warm mix, or cold mix. Hot mix asphalt is applied at temperatures over 300°F (150°C) with a free floating screed. Warm mix asphalt is applied at temperatures of 200–250°F (95–120°C), resulting in reduced energy usage and emissions of volatile organic compounds. Cold mix asphalt is often used on lower volume rural roads, where hot mix asphalt would cool too much on the long trip from the asphalt plant to the construction site. [15]

An asphalt concrete surface will generally be constructed for high volume primary highways having an average annual daily traffic load greater than 1200 vehicles per day. Advantages of asphalt roadways include relatively low noise, relatively low cost compared with other paving methods, and perceived ease of repair. Disadvantages include less durability than other paving methods, less tensile strength than concrete, the tendency to become slick and soft in hot weather and a certain amount of hydrocarbon pollution to soil and groundwater or waterways.

In the 1960s, rubberized asphalt was used for the first time, mixing crumb rubber from used tires with asphalt. While a potential use for tires that would otherwise fill landfills and present a fire hazard, rubberized asphalt has shown greater incidence of wear in freeze-thaw cycles in temperate zones due to non-homogeneous expansion and contraction with non-rubber components. Also, application of rubberized asphalt is more temperature-sensitive, and in many locations can only be applied at certain times of the year.

Study results of the long-term acoustic benefits of rubberized asphalt are inconclusive. Initial application of rubberized asphalt may provide 3-5 decibels (dB) reduction in tire-pavement source noise emissions; however, this translates to only 1-3 decibels (dB) in total traffic noise level reduction (due to the other components of traffic noise). Compared to traditional passive attenuating measures (e.g., noise walls and earth berms) rubberized asphalt provides shorter-lasting and lesser acoustic benefits at typically much greater expense. [23]

1.2 Rigid pavement

Concrete surfaces (specifically, Portland cement concrete) are created using a concrete mix of Portland cement, coarse aggregate, sand and water. In virtually all modern mixes there will also be various admixtures added to increase workability, reduce the required amount of water, mitigate harmful chemical reactions and for other beneficial purposes. In many cases there will also be Portland cement substitutes added, such as fly ash. This can reduce the cost of the concrete and improve its physical properties. The material is applied in a freshly mixed slurry, and worked mechanically to compact the interior and force some of the cement slurry to the surface to produce a smoother, denser surface free from honeycombing. The water allows the mix to combine molecularly in a chemical reaction called hydration.

Concrete surfaces have been refined into three common types: jointed plain (JPCP), jointed reinforced (JRCP) and continuously reinforced (CRCP). The one item that distinguishes each type is the jointing system used to control crack development. [24]

- Jointed plain concrete pavements contain enough joints to control the location of all the expected shrinkage cracks. The concrete cracks at the joints and not elsewhere in the slabs. Jointed plain pavements do not contain any steel reinforcement. However, there may be smooth steel bars at transverse joints and deformed steel bars at longitudinal joints. The spacing between transverse joints is typically about 15 feet (4.6 m) for slabs 7 to 12 inches (180 to 300 mm) thick. Today, a majority of US state agencies build jointed plain pavements.

- Jointed reinforced concrete pavements contain steel mesh reinforcement (sometimes called distributed steel). In jointed reinforced concrete pavements, designers increase the joint spacing purposely, and include reinforcing steel to hold together intermediate cracks in each slab. The spacing between transverse joints is typically 30 feet (9.1 m) or more. In the past, some agencies used a spacing as great as 100 feet (30 m).

- During construction of the interstate system, most agencies in the Eastern and Midwestern United States laid jointed-reinforced pavement. Today only a handful of agencies employ this design, and its use is generally not recommended as both of the other types offer better performance and is easier to repair.

- Continuously reinforced concrete pavements do not require any transverse contraction joints. Transverse cracks are expected in the slab, usually at intervals of 3 to 5 ft (0.91 to 1.5 m). These pavements are designed with enough steel, 0.6–0.7% by cross-sectional area, so that cracks are held together tightly. Determining an appropriate spacing between the cracks is part of the design process for this type of pavement.

Continuously reinforced designs may cost slightly more than jointed reinforced or jointed plain designs due to increased quantities of steel. Often the cost of the steel is offset by the reduced cost of concrete because a continuously reinforced design is nearly always significantly thinner than a jointed design for the same traffic loads. Properly designed, the two methods should demonstrate similar long-term performance and cost-effectiveness. A number of agencies have made policy decisions to use continuously reinforced designs in their heavy urban traffic corridors.

One of the major advantages of concrete pavements is they are typically stronger and more durable than asphalt roadways. They also can be grooved to provide a durable skid-resistant surface. A notable disadvantage is that it can typically have a higher initial cost, as well as can be more time consuming to construct. This cost can typically be offset through the long life cycle of the pavement. Concrete pavement can be maintained over time utilizing a series of methods known as concrete pavement restoration which include diamond grinding, dowel-bar retrofits, joint and crack sealing, cross-stitching, etc. Diamond grinding is also useful in reducing noise and restoring skid resistance in older concrete pavement. [24]

1.3 Below are the images for asphalt road and rigid pavement by layers.

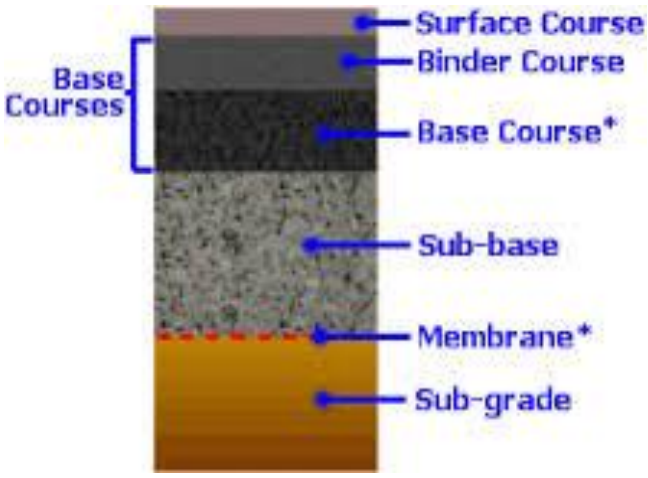
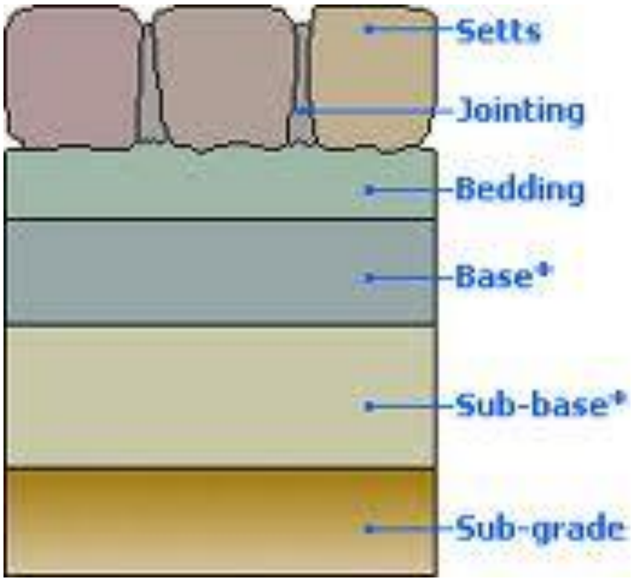


Figure 1 shows the cross sectional of asphalt pavement [2]



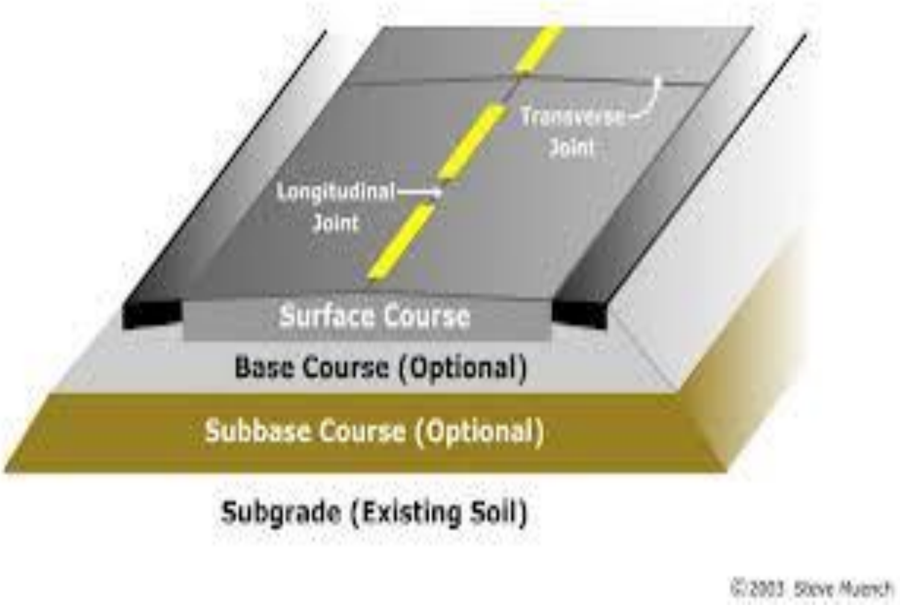


Figure 2 shows the layers of a rigid pavement [2]

2.0 Background of study

2.1 History of sulphur

Being abundantly available in native form, sulphur (Latin sulphur) was known in ancient times and is referred to in the Torah (Genesis). English translations of the Bible commonly referred to burning sulphur as "brimstone", giving rise to the name of 'fire-and-brimstone' sermons, in which listeners are reminded of the fate of eternal damnation that await the unbelieving and unrepentant. It is from this part of the Bible that Hell is implied to "smell of sulphur" (likely due to its association with volcanic activity). According to the Ebers Papyrus, a sulphur ointment was used in ancient Egypt to treat granular eyelids. Sulphur was used for fumigation in pre classical Greece.

This is mentioned in the *Odyssey*. Pliny the Elder discusses sulphur in book 35 of his *Natural History*, saying that its best-known source is the island of Melos. He mentions its use for fumigation, medicine, and bleaching cloth. A natural form of sulphur known as *shiliuhuang* was known in China since the 6th century BC and found in Han Zhong. By the 3rd century, the Chinese discovered that sulphur could be extracted from pyrite. Chinese Daoists were interested in sulphur flammability and its reactivity with certain metals, yet its earliest practical uses were found in traditional Chinese medicine. A Song Dynasty military treatise of 1044 AD described different formulas for Chinese black powder, which is a mixture of potassium nitrate (KNO) charcoal and sulphur. [19]

Indian alchemists, practitioners of "the science of mercury, wrote extensively about the use of sulphur in alchemical operations with mercury, from the eighth century AD onwards early. European alchemists gave sulphur its own alchemical symbol, a triangle at the top of a cross. In traditional skin treatment before the modern era of scientific medicine, elemental sulphur was used mainly in creams to alleviate conditions such as scabies, ringworm, psoriasis, eczema, and acne. The mechanism of action is unknown—though elemental sulphur does oxidize slowly to sulphuric acid, which in turn (through the action of sulphide) acts as a mild reducing and antibacterial agent. [25]

In 1777, Antoine Lavoisier helped convince the scientific community that sulphur was an element, not a compound. With the sulphur from Sicily being principally controlled by the French market, a debate ensued about the amount of sulphur France and Britain got. This led to a bloodless confrontation between the two sides in 1840.

In 1867, sulphur was discovered in underground deposits in Louisiana and Texas. The highly successful Frasch process was developed to extract this resource. In the late 18th century, furniture makers used molten sulphur to produce decorative inlays in their craft. Because of the sulphur dioxide produced during the process of melting sulphur, the craft of sulphur inlays was soon abandoned. Molten sulphur is sometimes still used for setting steel bolts into drilled concrete holes where high shock resistance is desired for floor-mounted equipment attachment points. Pure powdered sulphur was used as a medicinal tonic and laxative. With the advent of the contact process, the majority of sulphur today is used to make sulphuric for a wide range of uses, particularly fertilizer. [25]

2.2 Chemical properties of sulphur

Sulphur is a non-metallic chemical element identified by the letter S. This is the list of sulphur chemical properties. It has a seismic number 16 in the periodic table. Sulphur is a valuable commodity and integral component of the world economy used to manufacture numerous products including fertilizers, construction and other chemicals. Sulphur occurs naturally in the environment and is the thirteenth most abundant element in the earth's crust. It can be mined in its elemental form, though this production has increased significantly in recent years.

Sulphur forms polyatomic molecules with different chemical formulas, with the best-known allotrope being octasulphur, cyclo-S_8. Octasulphur is a soft, bright-yellow solid with only a faint odour, similar to that of matches.[4] It melts at 115.21 °C, boils at 444.6 °C and sublimes easily. At 95.2 °C, below its melting temperature, cyclo-octasulphur changes from α-octasulphur to the β-polymorph. The structure of the S_8 ring is virtually unchanged by this phase change, which affects the intermolecular interactions. Between its melting and boiling temperatures, octasulphur changes its allotrope again, turning from β-octasulphur to γ-sulphur, again accompanied by a lower density but increased viscosity due to the formation of polymers. At even higher temperatures, however, the viscosity decreases as depolymerisation occurs. Molten sulphur assumes a dark red colour above 200 °C. The density of sulphur is about 2 $g \cdot cm^{-3}$, depending on the allotrope; all of its stable allotropes are excellent electrical insulators.

Sulphur burns with a blue flame concomitant with formation of sulphur dioxide, notable for its peculiar suffocating odour. Sulphur is insoluble in water but soluble in carbon disulphide and, to a lesser extent, in other nonpolar organic solvents, such as benzene and toluene. The first and the second ionization energies of sulphur are 999.6 and 2252 $kJ \cdot mol^{-1}$, respectively. Despite such figures, the +2 oxidation state is rare, with +4 and +6 being more common. The fourth and sixth ionization energies are 4556 and 8495.8 $kJ \cdot mol^{-1}$, the magnitude of the figures caused by electron transfer between orbitals; these states are only stable with strong oxidants as fluorine, oxygen, and chlorine. [16]

Sulphur forms over 30 solid allotropes, more than any other element. Besides S_8, several other rings are known. Removing one atom from the crown gives S_7, which is more deeply yellow than S_8. HPLC analysis of "elemental sulphur" reveals an equilibrium mixture of mainly S_8, but with S_7 and small amounts of S_6. Larger rings have been prepared, including S_{12} and S_{18}. Amorphous or "plastic" sulphur is produced by rapid cooling of molten sulphur—for example, by pouring it into cold water x-ray studies show that the amorphous form may have a helical structure with eight atoms per turn. The long coiled polymeric molecules make the brownish substance elastic, and in bulk this form has the feel of crude rubber. This form is metastable at room temperature and gradually reverts to crystalline molecular allotrope, which is no longer elastic.

This process happens within a matter of hours to days, but can be rapidly catalysed. Sulphur has 25 known isotopes, four of which are stable: ^{32}S (95.02%), ^{33}S (0.75%), ^{34}S (4.21%), and ^{36}S (0.02%). Other than ^{35}S, with a half-life of 87 days and formed in cosmic ray spallation of ^{40}Ar, the radioactive isotopes of sulphur have half-lives less than 170 minutes. When sulphides minerals are precipitated, isotopic equilibration among solids and liquid may cause small differences in the δS-34 values of co-genetic minerals. The differences between minerals can be used to estimate the temperature of equilibration. The δC-13 and δS-34 of coexisting carbonate minerals and sulphides can be used to determine the pH and oxygen fugacity of the ore-bearing fluid during ore formation. [17, 18]

2.3 World contributors of sulphur

Sulphur that is mined or recovered from oil and gas production is known as brimstone, or elemental sulphur. Sulphur produced as a by-product of ferrous and non-ferrous metal smelting is produced in the form of sulphuric aside. A smaller volume is produced as sulphur dioxide, which is also emitted from petroleum products used in vehicles and at some power plants. Plants absorb sulphur from the soil in sulphate form.

Elemental sulphur is produced all over the world. Largest production occurs where sour (meaning sulphur-rich) gas and oil is processed and refined: United States, Canada, the Former Soviet Union, and West Asia. Over half of elemental sulphur production is traded internationally. China is the world's largest importer, followed by Morocco and the United States. Canada is the largest exporter, followed by Russia and Saudi Arabia. The crystallography of sulphur is complex. Depending on the specific conditions, sulphur allotropes form several distinct crystal structures. [21]

The global s sulphur industry remained divided into two sectors—discretionary and nondiscretionary. In the discretionary sector, the mining of sulphur or pyrites is the sole objective; this voluntary production of native sulphur or pyrites is based on the orderly mining of discrete deposits, with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the nondiscretionary sector, sulphur or sulfuric acid is recovered as an involuntary byproduct, the quantity of output subject to demand for the primary product irrespective of sulphur demand.

Nondiscretionary sources represented nearly 87% of the sulphur in all forms produced worldwide. With the termination of Frasch production in the United States, Poland was the only country that produced more than 1 Mt of native sulphur by using either the Frasch or conventional mining methods (table 12). Small quantities of native sulphur were produced in Asia, Europe, and South America. The importance of pyrites to the world sulphur supply has significantly decreased; China was the only country in the top 15 sulphur producers whose primary sulphur source was pyrites.

About 71% of all pyrites production was in this country. Of the 25 countries listed in table 12 that produced 400,000 t or more of sulphur, 18 obtained the majority of their production as recovered elemental sulfur. These 25 countries produced 94% of the total sulphur produced worldwide. The international sulphur trade was dominated by a limited number of exporting countries, which, in descending order of importance, were Canada, Russia, Saudi Arabia, Japan, and the United Arab Emirates; these countries exported more than 1 Mt of elemental sulfur each and accounted for 64% of total sulphur trade.

Major sulphur importers, in descending order, were China, Morocco, the United States, India, Tunisia, and Brazil, all with imports of more than 1 Mt. World production of sulphur was virtually the same in 2000 as it was in 1999; consumption was believed to be slightly higher. Statistics compiled by CRU International Ltd. showed 1998 to be the seventh consecutive year in which sulphur supplies exceeded demand. Although complete data for 1999 and 2000 We're not available; it could be assumed that 2000 represented the ninth consecutive year of excess sulfur supplies (Kitto, 2000).

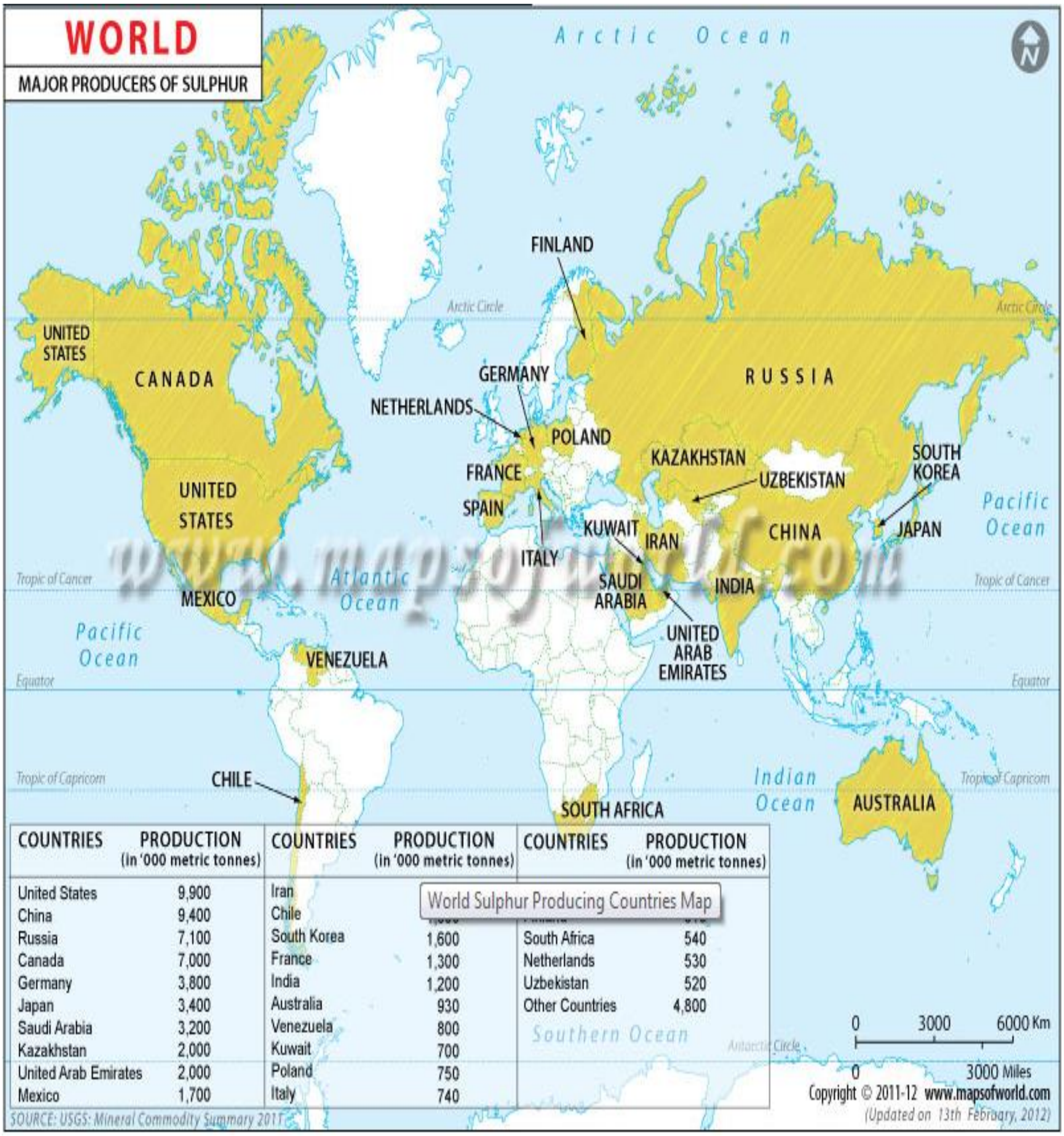


Figure 3 shows the world map where the sulphur is located [21]

Figure 4 shows the picture of sulphur in the form of powder [3]

Figure 5 shows the raw sulphur from petroleum [3]

Figure 6 shows the sulphur in rigid form [3]

Figure 7 shows the sulphur in thiopave

Figure 8 shows the proportion sulphur in thiopave

Figure 9 shows the sulphur in thiocrete blocks

2.0 Problem Statement

Therefore, several researches have been made in order to improve the quality and strength of the existing road pavement and concrete design. Many additives have been used to achieve this purpose. So for this research the main additive that is being highlighted is sulphur. From the previous research, the use of sulphur as an additive or as a substitute for bitumen and concrete technology shows the better and effective improvement of the road pavement properties and the concrete properties. Therefore, this research will focus on the usage of sulphur in rigid and asphalt pavement from the aspect of environment. Whether the usage of sulphur is safe for the environment. There also will be some consideration and comparison whether sulphur is an ideal additive or whether it has any potential disadvantage to the environment.

The modification of sulphur has many uses in construction. The main or plus point for sulphur in pavement is that it has the ability to increase strength and reduce permanent deformation. More or less this innovation still lack regarding with the use of sulphur in terms of its impact on the environment and the effects of the sulphur production such as economic effects. Sulphur usage in concrete is also popular in some Middle East country. In Qatar for example there has been a research centre for the development of sulphur to be used in construction of building. It has many advantages than the normal concrete from different and various factors. Sulphur production which is inconsistent will require a high cost of production is not in efficient manner. Then the main effect of sulphur is very important whether it is beneficial or more too harmful. Therefore, further study is needed to compare the use of sulphur on the pavement of road and concrete can be seen in more detail and much more. Consequently, the strengthening and improvement of the previous experiments is needed with the appropriate option of methodology so that the performance of sulphur can be improved in the future. There are many disadvantage of sulphur in the view of world.

The main agenda or problem been analysed in this report is whether the usage of sulphur is safe and have advantage on the environment or should it be left undisturbed. This research is to compare the advantage and disadvantage of sulphur in asphalt and pavement considering also the impact on the environment. This research will focus mainly on the comparison of the advantage and disadvantage of using sulphur as an additive in construction. The research will count on the aspect of environment mainly because it is to identify whether sulphur really do have a positive impact on construction and environment.

3.0 Aims and objectives

The main objectives of this research are to:

- To understand the characteristic of sulphur and make a comparison whether it can be used widely in construction without any side effects.
- To determine the effect of sulphur on the pavement, components and other important application that will affect the environment, life span of structure and economic.
- To determine whether to use sulphur widely in construction or whether not to use sulphur as an additive.

3.1 Scope of works

The studies will emphasis on the aspect of using sulphur in pavements and building (concrete). This research will be done to determine the effects of sulphur on the environment. The ideology is to identify the characteristics and classify the advantages and disadvantages thus also the effectiveness of the sulphur production either it is useful or not in future. Then, the limitations of this study will be based on the use of sulphur from the previous research and case studies regarding with the application of sulphur on the pavement and building. This research will come out with the solution and some recommendation evaluates the characteristic of sulphur and its long term usage without any negative impact.

4.0 Literature review

4.1 Characteristics of Sulphur

Sulphur has been in existence since the ancient times ago and was recognized as one of the chemical elements. It is yellow in colour, odourless and brittle solid which is soft. It would soluble in carbon disulphide but insoluble in water. When it burns, the oxidizing to sulphur dioxide will occur and this will produces the poisonous gas. The use of this gas sometimes gives the good effect and it is already use began several thousand years ago through fumigation. Sulphur is a multivalent non-metal, abundant, tasteless and odourless. In its native form sulphur is a yellow crystalline solid. In nature it occurs as the pure element or as sulphide minerals.

Although sulphur is infamous for its smell, frequently compare to rotten eggs, that odour is actually characteristic of hydrogen sulphide (H2S). The crystallography of sulphur is complex. Depending on the specific conditions, sulphur allotropes form several distinct crystal structures. The major derivative of sulphur is sulphuric acid (H2SO4), one of the most important elements used as an industrial raw material. Sulphur is also used in batteries, detergents, fungicides, manufacture of fertilizers, gun powder, matches and fireworks. Other applications are making corrosion-resistant concrete which has great strength and is frost resistant, for solvents and in a host of other products of the chemical and pharmaceutical industries.

Life on Earth may have been possible because of sulphur. Conditions in the early seas were such that simple chemical reactions could have generated the range of amino acids that are the building blocks of life. Sulphur occurs naturally near volcanoes. Native sulphur occurs naturally as massive deposits in Texas and Louisiana in the USA. Many sulphide minerals are known: pyrite and marcasite are iron sulphide; stibnite is antimony sulphide; galena is lead sulphide; cinnabar is mercury sulphide. The chief source of sulphur for industry is the hydrogen sulphide of natural gas, Canada is the main producer.

4.2 Chemical properties

Sulphur burns with a blue flame concomitant with formation of sulphur dioxide, notable for its peculiar suffocating odour. Sulphur is insoluble in water but soluble in carbon disulphide and, to a lesser extent, in other nonpolar organic solvents, such as benzene and toluene. The first and the second ionization energies are 999.6 and 2252 kJ·mol−1, respectively. Despite such figures, the +2 oxidation state is rare, with +4 and +6 being more common. The fourth and sixth ionization energies are 4556 and 8495.8 kJ·mol−1, the magnitude of the figures caused by electron transfer between orbitals; these states are only stable with strong oxidants as fluorine, oxygen, and chlorine. [16]

4.3 Effects of sulphur on the environment

Sulphur can be found in the air in many different forms. It can cause irritations of the eyes and the throat with animals, when the uptake takes place through inhalation of sulphur in the gaseous phase. Sulphur is applied in industries widely and emitted to air, due to the limited possibilities of destruction of the sulphur bonds that are applied. These are some of the effects of sulphur in the form of gases.

The damaging effects of sulphur with animals are mostly brain damage, through malfunctioning of the hypothalamus, and damage to the nervous system. Laboratory tests with test animals have indicated that sulphur can cause serious vascular damage in veins of the brains, the heart and the kidneys. These tests have also indicated that certain forms of sulphur can cause foetal damage and congenital effects. Mothers can even carry sulphur poisoning over to their children through mother milk. Finally, sulphur can damage the internal enzyme systems of animals.

4.4 Effects of sulphur to construction

There is the long-term question of what ultimately happens to any products made using recovered sulphur. For example, when a sulphur-rich construction material reaches the end of its useful life what will happen to the sulphur it contains? Will these materials be allowed to degrade and release their sulphur to the geosphere? We have to take a long-term view on sulphur release when we are looking for a sustainable solution.

According to O. Abdel-Mohsen (2010) although currently not widely used, sulphur construction materials can offer improvements over more traditional materials, especially in specific applications. Sulphur construction materials include sulphur concrete and sulphur-extended asphalt pavements as well as pre-cast concrete components, extrusions, and cast-in-place forms. This one of a kind book discusses the basic properties and behaviour of sulphur cement and concrete materials and based on these properties, new sulphur market applications are evaluated and the technological aspects of material production are presented. [6]

Reviews acceptable methods of disposing of unneeded sulphur without compromising environmental protection. Reveals the advantages of using modified sulphur concrete materials for sub-ground and sub-marine structures, and immobilization of hazardous wastes. According to G. Maisa El (2010), the author describes the unique features of sulphur construction materials such as corrosion resistance, low moisture penetration, high thermal and mechanical performance, and long-term stability in various environments. Discusses sulphur concrete process design for use in waste management practices (barrier systems for waste containment; stabilization/solidification of waste; etc.) [6]

4.4 Sulphur Extended Asphalt

In the early 1970s, due to concern over asphalt cement supply issues and an anticipated overabundance of elemental sulfur, many organizations Society National des Pétroles d'Aquitaine (SNPA), Gulf Oil of Canada, Sulfur Development Institute of Canada (SUDIC), Texas Chemical Company, U.S. Bureau of Mines, and the Texas Transportation Institute) began to evaluate the potential for sulfur to substitute for asphalt as a binder extender this became known as Sulfur-Extended Asphalt (SEA). At the time, it was projected that there would be an abundant amount of sulfur from many sources pyrite processing into sulfuric acid, natural gas recovery, crude oil refining, coal usage, other chemical processes, and desulfurization from smoke stack emissions.

The results of this review indicated that sulphur could potentially be used as an asphalt extender with no significant deleterious effect on performance and durability. However, during the 1980's, increasing sulphur prices ended most of the interest in sulphur-extended asphalt. Sulphur-extended asphalt has been used in dense-graded mixtures with sulfur/asphalt binder mass ratios from 20/80 to 40/60, and at times even up to 50/50. The emulsified portion of sulfur performs as an asphalt extender while any excess sulfur performs as a mix filler or stabilizer. [31]

The allowable sulphur concentration in the binder depends on the properties of the asphalt. On a long-term basis, approximately 20 percent of the sulfur remains dissolved and/or dispersed as part of the binder. Free sulfur, above approximately 20 percent by weight, solidifies to a crystalline state. The replacement of asphalt with sulfur is made on an equivalent volume basis, and an accounting for the higher specific gravity of sulfur is needed to maintain existing standards for mix impermeability and durability. The following simplified equation can be used to convert a conventional mix design to an equivalent volume of total binder (sulphur and asphalt). [32]

Calculation based on Bureau of Mines work

$$\textbf{Total Binder mass (\%)} = A\left\{\frac{100R}{100R - P_S(R - G_{asphalt})}\right\}$$

Where:

A = Mass % asphalt binder in conventional mix design
R = Sulfur/asphalt specific gravity ratio
P_S = Mass % Sulfur in total "binder"
G = Specific gravity

Example Calculation

Assume that:

Optimum asphalt content is 5.3%
Sulfur:Asphalt mass replacement ratio is 20:80
G_{Sulfur} is 2.00
$G_{Asphalt}$ is 1.03

Therefore: R = 2.00/1.03 = 1.94

$$\textbf{Total Binder mass (\%)} = 5.3\left\{\frac{100(1.94)}{100(1.94) - (20)(1.94-1.03)}\right\} = 5.8\%$$

This total binder content is then divided accordingly:

20 x 5.8% = 1.16 % Sulfur
80 x 5.8% = 4.64 % Asphalt

How is SEA Used

SEA has been produced with minimal plant additions and modifications. Various methods such as in-line blending with liquid sulfur, direct feed with liquid sulfur, and direct feed with solid sulfur in pelletized form have been used. In the past, in-line blending with liquid sulfur was the most popular method but today solid sulfur may be much easier to handle at the mixing plant. When hot sulfur paving mixtures are kept below 300°F (149°C), evolved noxious gases and pollutants, including H2S, SO2, SO3, and organic sulfur materials, have been shown to be within safe limits. [34]

Therefore, the recommended maximum allowable upper temperature limit for continuous handling of sulfur modified paving materials is 300°F (149°C). Sulfur handling practices already established in the sulfur industry, as well as those common to the hot asphalt concrete community, are believed to provide adequate personnel safety. With the ever-growing popularity of warm-mix asphalt (WMA), these lower mixture temperatures are not unusual in current practice. However, SEA production is currently not recommended by suppliers in conjunction with any of the water foaming type of WMA technologies.

The biggest hazard is the storage area for the liquid sulfur and/or the pre-blended sulfur-asphalt blend. However, these areas are not generally accessible to most personnel and restricting access to appropriate personnel is advised. Sulfur in solid form is fairly inert, insoluble in water, and not readily dissolved by engine oil, grease, and gasoline. When constructing with SEA paving material for the first time, personnel should be given prior instruction on the nature of the material as well as techniques for handling it safely. [34]

Engineering Properties of SEA

FHWA Turner-Fairbank Laboratory, reported in 1990, on cores taken from 18 of the original SEA field projects and the associated AC control sections. He noted some minimal benefit and some potential areas of concern with the SEA. However, there were also some compositional issues with these cores which could explain the less than optimal results. Based on indirect tensile (IDT) resilient modulus (MrR) testing at 77°F (25°C), the impact of SEA on modulus was project specific and "sulfur had no effect on temperature susceptibility". Based on IDT incremental creep testing, the impact of SEA on permanent deformation was project specific and "usually relatively better at 77°F (25°C) compared to 41°F (5°C)".

Overall, sulfur had little effect on creep moduli but, there may be an overall trend for the SEA sections to have lower permanent deformations. Based on ASTM D 4867 moisture susceptibility testing (using tensile strength ratio, TSR, and resilient modulus ratio, (MrR) at the varying core air voids,"sulphur decreased both ratios". Based on the visual observations of stripping, it was concluded that the lower ratios were related to a loss of cohesion rather than a loss of adhesion. The SEA binders were weakened by the conditioning processes. Sulphur decreased both the dry and wet tensile strengths but did not lead to visual stripping. Wet strengths were more affected than dry strengths and sulphur increased the dry of the soft mixtures. [36]

Based on stress-controlled IDT fatigue testing conducted at 77°F (25°C), "when considering all projects, sulphur decreased the fatigue life". The SEA binders in approximately 17 of the 29 field projects were designed on an equal volume of total binder (sulphur + asphalt) basis; however, the method of sulphur substitution in the mix design "was not consistent". In most projects, the sulphur was simply substituted by mass for asphalt and the same design for the asphalt control mixture was used; with the higher specific gravity of sulphur, this would lead to drier mixes.

The percent total sulfur by total binder weight was obtained by high temperature combustion and an IR absorption detector (ASTM D 4239). Most projects contained less sulfur than intended and some were significantly low in sulfur content. Some of the sulfur contents were so low compared to the target values that they were obviously deficient. Regarding fatigue life, the fatigue curve of SEA mixtures typically indicate less cycles to failure at equal high strain values compared with similar AC mixtures; however, the level of strain occurring in the pavement used to determine pavement life from the fatigue curve tends to be lower because of the higher modulus of SEA mixtures, resulting in longer life overall. [37]

As points out, lower flexibility can be tolerated in SEA materials as the tensile stresses and strains developed at the underside of the pavement are lower than for an AC pavement of equivalent thickness and subjected to the same loading also found that flexibility should not be confused with fatigue resistance, which reduces the ability of a pavement to sustain repeated bending. This has been found to be satisfactory for a moderate range of sulfur-extended binder formulations. If required for certain applications, fatigue resistance, flexibility, and fracture resistance of SEA mixtures can be improved using higher binder contents and softer binder grades because these mixtures are also typically stiffer and more resistant to rutting.

The National Center for Asphalt Technology (NCAT) recently completed a study of a standard 19 mm test track mixture made with various SEA mixtures. This investigated alternative base asphalt binder grades (PG 67-22 and PG 58-28), percent sulfur (30 and 40 percent of total binder), and total binder contents (mix designed at 3.5 and 2 percent air voids). Figure 1 shows an example comparison of the dynamic modulus (E*) measured with the Asphalt Mixture Performance Tester (AMPT) for these various sulfur mixtures at a frequency of 10 Hz and a temperature of 70°F (21°C) along with two control mixes designed at 4 percent air voids. The figure also illustrates the effect of curing time (14 days), during which the un-dissolved sulfur can crystallize in the matrix of the mixture. [38]

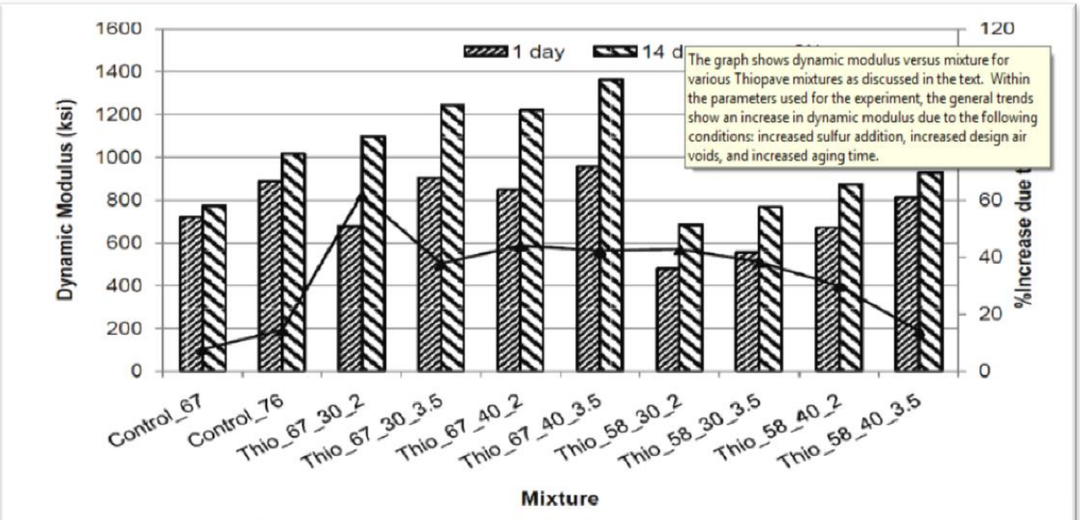


Figure 1: Average E* Results at 10 Hz, 70°F (21°C) for All NCAT Mixtures after 1 and 14 Days.

Figure 10 shows the average E* results at 10 Hz for all NCAT mixtures after 14 days

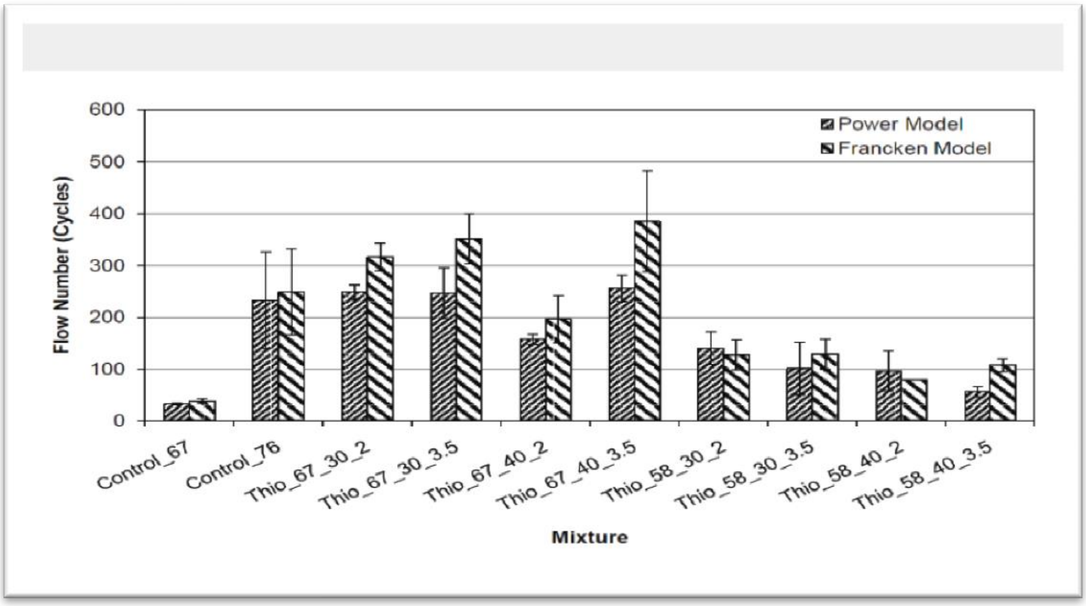


Figure 11 shows the average Fh results at 70 psi for all NCAT mixtures after 14 days

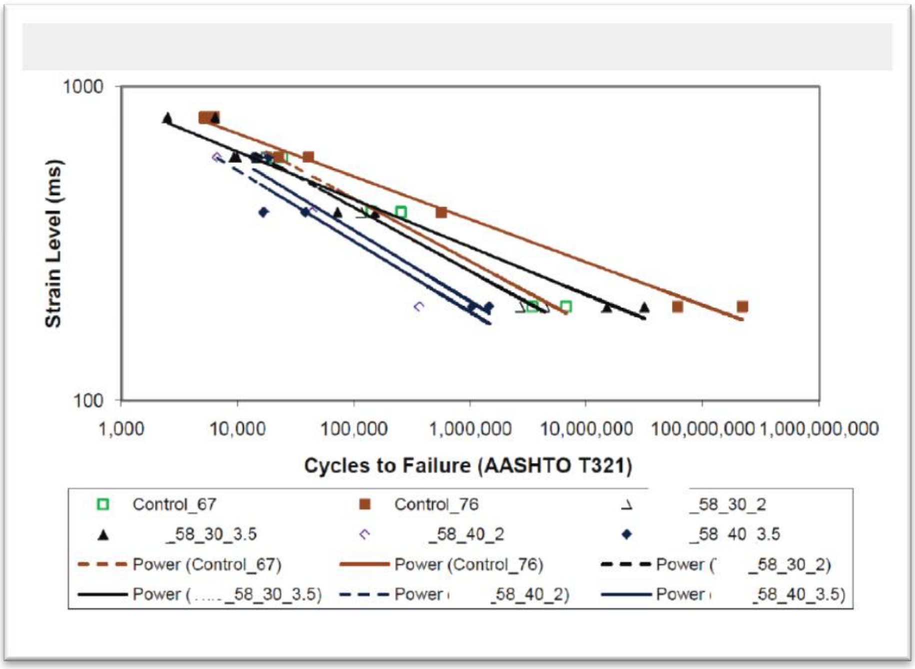


Figure 12 shows the graph of strain levels against cycles of failure

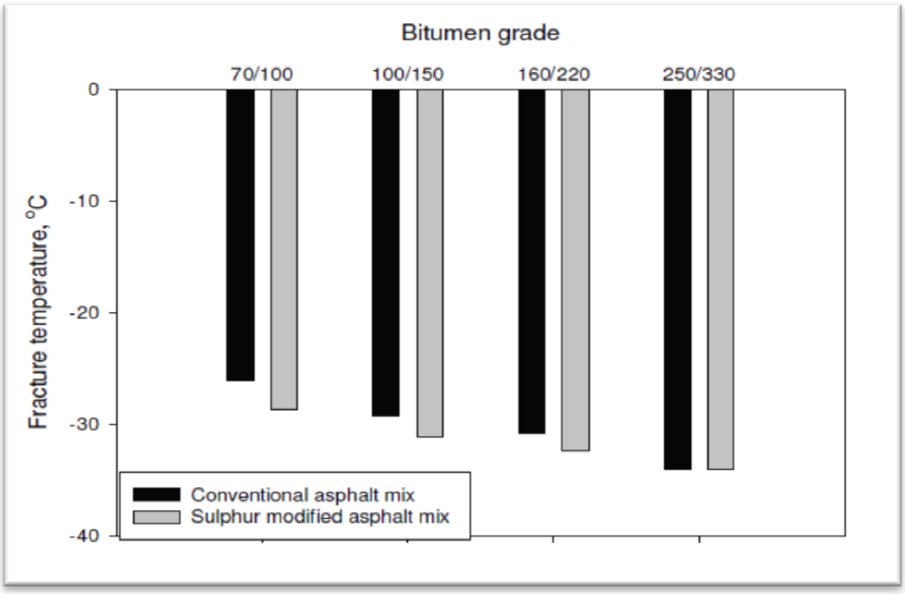


Figure 13 shows the Low-Temperature Properties of Sulphur Extended Asphalt Mixtures

SEA Safety Practices

The second volume of the report prepared by the Texas Transportation Institute discusses methods and equipment for monitoring potential emissions and pollutants and recommends safety practices for the handling of sulfur and sulfur-modified asphalt mixtures and pavements. In general, the equipment used for the preparation and placement of the sulphur modified pavement mixtures has been the same as those used for asphalt hot-mix. Laboratory measurements of organic emissions under conditions intended to maximize emissions have shown that the amounts are negligible.

Short term exposure samples taken in the breathing zone of the laboratory worker during sample preparation showed peak levels of about 0.2 ppm H2S and 0.1 ppm SO2. Ample ventilation in the laboratory will control these exposures adequately. Toxic and explosive quantities of H2S can collect in the domes of transports and in the domes of tanks containing liquid sulphur. No sparks, smoking, open flames, or welding should be permitted near any opening to a liquid sulphur container. In continuous drum mixing plants, sulphur must be injected at a point downstream, where direct contact with the burner flame is avoided.

Dispersion of the emissions after release from the stack prevents exposure of personnel to levels in excess of the maximum allowable concentration from this source, and these stack gases do not constitute a significant exposure to the personnel in the plant. However, monitoring stack emissions to determine compliance with appropriate laws, and installation of appropriate control devices is recommended, as the utilization of sulphur at the plant may raise the concentration of pollutants in the stack. Care should be taken in maintaining screed temperature control. It is not necessary to excessively heat the screed to obtain good paving results because of the reduced viscosity of the mix obtained with SEA. In addition, higher screed temperatures also increase the level of undesirable emissions (SO2).

Surface heating of in-place pavement is sometimes employed for the maintenance and rehabilitation of asphalt pavements. Temperatures in excess of 400°F are likely at the pavement surface, indicating that H_2S and SO_2 emissions may be significant, but elevated temperatures are held over a specific pavement spot for only a short time, so H_2S and SO_2 emissions decrease rapidly. Wind and distance from the source will dilute the H_2S and SO_2 concentrations before it can reach the workers' breathing zone. Although exposures may be expected to be minimal, these direct heat application methods, used with planning, scarifying, and hot surface recycling, should be avoided with SEA pavement surfaces when possible.

Cold milling, diamond grinding, and grooving of pavement surfaces are being increasingly used. The process of crushing, grinding, or pulverizing may cause sulphur odours and sulphur gases to be present as well as dust particles with trace quantities of sulphur. After dispersion due to wind and distance, H_2S and SO_2 levels should be insignificant. Safety procedures followed in the asphalt industry are recommended. The redesign of driers and drum mixers for the handling of reclaimed asphalt pavement (RAP) have virtually eliminated gaseous emissions from recycle mixes within the plant operations. The worker exposure to H_2S, SO_2, and particulate sulphur is expected to be the same as is common to the asphalt paving operation (hauling and placing), which has been shown to be minimal.

Mix temperature in excess of 300°F will result in sharply increased H_2S and SO_2 emissions and should be avoided. Dispersion due to wind and distance from the source keeps H_2S and SO_2 emissions at low levels in the general area. However, recycling of SEA RAP at normal hot mix temperatures with superheated virgin aggregate should be avoided because of these increased emissions. Although most of these gases will be mitigated through the dryer drum heating and mixing process, some may escape to the stack or to the immediate area around the plant. Recycling of SEA RAP at warm mix temperatures (275°F ± 10°F) has been shown to result in non-hazardous levels of emissions around the plant and paver. SEA RAP can be easily identified with either a calcium chloride precipitate lab test or a simple blowing heater field test.

4.6 A high performance alternative

The goal has been to enable manufacturers to produce sulphur concrete with specific performance benefits:

- High resistance to acids and salts
- High compressive and flexural strength
- Excellent freeze thaw performance
- Easily pigmented to create a wide colour range, including natural and vibrant tones
- Readily moulded to create a wide range of surface textures and finishes.

These performance characteristics create huge potential for use in the following concrete applications:

- Marine applications
- Paving slabs and curbs
- Road barriers and bollards
- Retaining walls
- Garden products

Shell Thiocrete also offers process efficiencies at the precast concrete plant:

- Reduced waste – through reheating and remoulding
- Faster setting time for many product types – improving mould utilisation

Research and Development is on-going to identify further concrete applications where Shell Thiocrete can deliver benefits to the market.[6]

Shell Thiocrete cobblestones in Abu Dhabi

Initial studies indicate that concrete products manufactured with Shell Thiocrete have a lower carbon footprint than Portland cement. Switching to Shell Thiocrete can therefore help specifies meet their environmental targets:

- Although Shell Thiocrete, together with aggregates, needs to be mixed at 135°C when making sulphur-enhanced concrete, this process uses less energy than conventional cold concrete mixing processes because it avoids the energy needed to heat limestone to 1450°C to manufacture Portland cement.
- The CO2 released when limestone is heated in the cement production process is avoided.

Shell Thiocrete also offers resource savings and enhanced recyclability compared to traditional concrete:

- Shell Thiocrete does not require water, removing the energy and infrastructure costs associated with water supply. This is of particular benefit in locations where fresh water is scarce and desalination is necessary.
- Shell Thiocrete products can be recycled by crushing, reheating and remoulding with no significant loss of performance.
- Shell Thiocrete products can be made with a range of low quality aggregates.

Patented Shell Thiopave technologies have been developed to help improve road performance and deliver environmental benefits through the innovative use of sulphur in asphalt.

Why sulphur?

Shell Thiopave technologies enable a proportion of the bitumen in the asphalt mixture to be replaced with sulphur and special additives. Shell Thiopave has the potential to significantly increase road life and to deliver meaningful energy savings through lower temperature production. At the same time, Shell Thiopave reduces the amount of bitumen needed for road construction, by replacing a proportion of the bitumen in the asphalt mixture; therefore helping to alleviate industry concerns about bitumen supply demand imbalances. The evolution of sulphur asphalt technology. The potential of sulphur to improve asphalt performance has long been recognized.

However, early sulphur asphalts in the 1970s proved difficult to transport, store and use safely. Shell technologists have been addressing these challenges. The goal has been to develop a sulphur in asphalt technology that meets twenty first century industrial hygiene and worker safety standards in a way which is practical to manage at the asphalt plant and paving site. Shell Thiopave technologies are the outcome of this extensive and persistent process of research and development. Special additives have been combined with the sulphur to minimize the creation of fumes during mixing, transportation and paving. These technological innovations mean that the latest workplace health and safety standards in North America, Europe, India and China can now be met and the benefits of sulphur in asphalt can be accessed on a significant scale around the world.

A high performance alternative to conventional paving Shell Thiopave improves road performance in several ways. Substituting a proportion of the bitumen in asphalt with Shell Thiopave improves its structural rigidity due to the crystallization of elemental sulphur throughout the mixture. When used in the structural layers, this increased strength provides higher traffic carrying capacity in the finished road, making Shell Thiopave ideal for heavy duty applications such as bus lanes, intersections and truck terminal yards. In surface layers, Shell Thiopave makes pavements significantly more resistant to rutting, deformation and fuel spill damage, opening up the opportunity to use asphalt pavement where it has previously been ineffective to do so, for example airports and container ports. Benefits across a range of climatic condition In cold and seasonal climates where thermal cracking is an issue, Shell Thiopave allows the use of softer bitumen's with improved low temperature properties without sacrificing high temperature performance. In hot climates, where conventional bitumen's often do not deliver the high level of stiffness required, Shell Thiopave improves anti-rutting performance while still allowing the effective use of locally-available bitumen's. Sections on roads in the diverse climates of the USA, Canada, China, Saudi Arabia and Qatar have already been successfully paved using Shell Thiopave.

A flexible technology

Varying the proportion of Shell Thiopave to bitumen changes the characteristics of the resulting asphalt mixture. This flexibility allows customers to use Shell Thiopave to optimise their mixture designs taking into account the characteristics of their locally available bitumen and aggregates. Shell's technical experts have conducted extensive research on using Shell Thiopave with a wide range of bitumen and aggregate types and can advise customers on the best binder proportions for a given set of circumstances. Straightforward storage and handling Shell Thiopave is supplied as a solid pellet, added at the mix plant towards the end of the asphalt manufacturing process.

Shell Thiopave is delivered in bulk or sacks, and can be stored at ambient temperature Shell Thiopave is non-toxic, does not react with water and is insensitive to UV radiation. Shell will provide full training to customers on all aspects of working with Shell Thiopave prior to first use, to help ensure the product is used effectively and safely. Environmental benefits Shell Thiopave offers a variety of environmental benefits compared to conventional asphalt, including:
Reducing the resource requirements of road building By increasing the load bearing capacity of asphalt, Shell Thiopave offers the potential for increased road life or thinner pavements. This opens up the possibility of using less energy, aggregate and bitumen in road building Energy savings at the mix plant and paving site1 Shell Thiopave asphalt is typically manufactured and laid at temperatures 20-50°C lower than the equivalent hot mix asphalt it replaces. Pavement containing Shell Thiopave is also recycled at lower temperatures Potential for CO2 reductions Scenarios run by Shell to date suggest that Shell Thiopave roads have the same or better CO2 footprint than those constructed with 100% bitumen, even before the savings associated with longer road life or thinner pavement, are taken into account. Once these additional savings are factored into the model on an individual application basis, Shell Thiopave offers the potential for significant CO2 reductions over conventional asphalt mixtures2.

<u>Recyclability</u>

Recycling trials have shown that up to 30% Shell Thiopave RAP can be recycled effectively and conventional RAP is compatible with the manufacture of Shell Thiopave mixtures. Innovative solutions for the future Shell Thiopave technologies already offer road owners and contractors the opportunity to improve the mechanical and environmental performance of the roads they build: Extended road life or thinner pavements reduced rutting, superior fuel resistance, improved extreme temperature performance, reduced CO2 emissions, reduced bitumen requirements. Shell is committed to the further development of these technologies, so that the performance and the environmental profile of asphalt pavements continue to improve to meet the needs of road authorities and road users into the future.[6]

What are the benefits of sulphur concrete as compared to normal concrete?

Sulphur concrete is made without water and cement. As a result, the costs and energy for water supply becomes obsolete. Moreover, the carbon footprint of the product is reduced. Regular concrete leaves a large carbon footprint because the production of cement requires very high (1450oC) temperatures and the process itself is responsible for 5% of all CO2 emission worldwide. In regular concrete, the cement forms "tubes" inside the material which can take in water. Upon freezing, this water expands and the inner pressure can become so high that the concrete cracks. Sulphur concrete does not have these tubes, and therefore performs better in freeze-thaw cycles. As sulphur concrete is made by heating the components, it can also be recycled by crushing, reheating and remoulding, reducing the waste associated with regular concrete construction. If you've made regular concrete before, you've seen that at first it is almost liquid, and then it starts building up its strength over time (we typically test it after 28 days to see how strong it is). Sulphur concrete gains it strength right when it is made – upon cooling down the product has its final strength.

Unlocking the potential of sulphur concrete

Sulphur has been used as a binder in specialist concrete applications such as chemical factory floors, for more than 30 years. Its properties gave it an advantage over Portland cement. However, because of the high cost of modifying sulphur with traditional technology for use as a concrete binder, it has been limited to specialist applications where its performance properties could justify a higher price than Portland cement. Shell has developed a new technology that can bring the cost of sulphur modification down. This means that instead of being limited to niche applications, concrete manufacturers can now offer the advantages of sulphur concrete in a much wider range of products than before.

The science of sulphur concrete

Unlike traditional cementitious binders that rely on chemical bonds being formed when they react with water, Shell Thiocrete uses modified heated liquid sulphur to 'glue' the aggregate together and form a stable, hard concrete product. The resulting concrete offers a range of performance benefits without the need for special admixtures:

- ✓ Significantly improved resistance to acid, salt and water
- ✓ Greater compressive (up to 70MPa) and flexural strength (up to 14MPa)
- ✓ Easily pigmented to produce a variety of colour's, from subtle neutrals to vibrant tones
- ✓ Readily molded to create a wide range of surface textures and finishes.

Making concrete with sulphur

The process for making concrete with Shell Thiocrete is similar to hot asphalt production. A hot mixture of aggregate and modified sulphur is produced and then cast into mold's to create concrete products. Depending on the products being made, customers can choose to install a dedicated production line for sulphur concrete or arrange to use an existing asphalt mixing plant. As well as improving the performance of concrete products, Shell Thiocrete also offers potential process efficiencies at the plant:

- ✓ There is no 'curing period' when making Shell Thiocrete concrete – the product gains its final strength on cooling – offering the potential for improved mold utilization

- ✓ Shell Thiocrete broadens the range of materials that can be used in concrete production compared to Portland cement thanks to its better resistance to leaching and the fact that it does not involve hydration processes that are sensitive to chemical conditions.

Recommended concrete applications

To maintain its high performance, Shell Thiocrete concrete needs to be kept below 100˚C. Above this point the bond between Shell Thiocrete and the aggregates in the concrete begins to weaken. From a recycling perspective, this is a positive benefit, as Shell Thiocrete concrete products can be recycled by crushing, reheating and recasting. It does, however, restrict the use of Shell Thiocrete to applications where heat resistance is not required.

Environmental benefits

Shell Thiocrete concrete offers a range of environmental benefits compared to Portland cement concrete:

- ✓ There are clear indications from Lifecycle Analysis conducted by Shell that concrete products manufactured with Shell Thiocrete have a significantly lower carbon footprint than those manufactured with Portland cement
- ✓ Shell Thiocrete does not require water, removing the energy and infrastructure costs associated with water supply. This is of particular benefit in locations where fresh water is scarce and desalination is necessary
- ✓ Shell Thiocrete's products can be recycled by crushing, reheating and remolding with no significant loss of performance.
- ✓ Less CO_2 released compared to conventional concrete mixing

Environmental, Health, and Safety

An FHWA sponsored study considered the safety and environmental aspects of storage and handling, formulation, construction, operation and maintenance of highway pavements containing sulfur. Airborne fumes and particulate (colloidal) elemental sulfur can be irritating to the eyes and throat but are not currently regulated as an emission health hazard. The primary hazards due to the presence of sulfur in pavement operations and handling situations are gaseous emissions of hydrogen sulfide (H2S) and sulfur dioxide (SO2). These primary hazards can usually be gauged in terms of temperature, time-duration under temperature, and dispersion factors. H2S is the most critical concern as this gas can be readily detected at concentrations as low as 0.02 ppm (parts per million) by its "rotten egg" odor; but, at high concentrations (above 100 ppm) the smell cannot be detected.

On the basis of the list of toxicity effects of the American Conference of Governmental Industrial Hygienists (ACGIH), a maximum allowable concentration (MAC) value of 5 ppm is normally specified as the upper threshold limit for continuous exposure to H2S emissions in areas normally expected to be occupied by construction or plant personnel. In 2010, the ACGIH lowered their H2S recommended threshold limit value short term exposure limit (TLV-STEL) for 15 minutes to 5 PPM and their TLV time-weighted average (TWA) over an 8-hour shift to 1 PPM. The current Occupational and Safety Health Administration (OSHA) permissible exposure limit (PEL) for TWA over an 8-hour shift for the construction industry is 10 ppm for H2S. [39]

Sulphur Dioxide (SO2) is a colourless gas with a pungent odour, which unlike H2S, gives ample warning of its presence. The MAC of 5 ppm is specified as the upper threshold limit concentration for SO2 emissions in areas normally expected to be occupied by construction or plant personnel. This same level of SO2 is the current OSHA PEL for TWA over an 8-hour shift for the construction industry. Vapor given off during mixing and dumping operations contain a certain amount of un-dissolved elemental sulfur. As the vapors come in contact with air and cool, the sulfur vapor crystallizes into small particles which are carried by the wind in a manner similar to dust and fine sands. Since there is no practical way to eliminate these emissions, the effects on both environment and personnel need to be considered.

Assessments of the environmental impact of this emission in SEA pavement construction do not exist. The principal problem associated with sulfur dust lies in its contact with eyes. This can be minimized by wearing safety goggles while working in close proximity (2 feet (0.6 meter)) to the paver hopper. Relatively little data is available regarding particulate sulfur and efforts to establish amounts of sulfur dust may be interfered with by asphalt fumes, showing a misleadingly high amount of particulates

Concentrations of H2S and SO2 emitted in drawn air samples during the laboratory preparation of seven mix designs at 250°F, 300°F, and 350°F were measured. Both H2S and SO2 emissions increased with temperature and the rate of evolution increased greatly beyond 300°F, exceeding MAC values. Producing and paving at the lowest practical temperatures will reduce the potential of any adverse impact. In addition, storage time of hot sulfur-asphalt mixes in silos should be limited to a maximum of four hours. Overnight silo storage is not advised. Today, the emissions of H2S are further diminished by the use of degassed sulfur in the pelletized solid form. [35]

"Degassed" sulfur is sulfur that has been processed to remove most of the H2S that is entrained within the elemental sulfur. Weathering of in-service pavements by naturally occurring conditions, as assessed by simulated laboratory and relatively short term outdoor exposure studies (including UV-light, freeze-thaw cycles, tire interaction, spills, and soil microbial activity), showed no measurable impact on the environment. Although the SEA pavement surface would not readily ignite, in direct flame burn tests, black smoke and H2S and SO2 gases evolved while in direct contact with the flame; however, six seconds after the flame was removed, the smoke abated, the gases reduced to trace levels after 10 seconds, and the material self-extinguished.

To simulate the impact of contaminated spills, saturated NaCl leach solution tests were conducted and it was concluded that the brine of saturated deicing salts would have a minimal impact on run-off waters emanating from sulfur-asphalt or asphalt pavements. Practice has shown that personnel working around open ports or sulfur discharge valves of storage tanks for prolonged time periods should be equipped with a respirator. Aside from eye or skin irritation from sulfur dust, discomfort can also arise from odor.

The extent of this discomfort is dependent on the specific sensitivity of each person. Based on limited field studies, exposures to SO_2, SO_3, and H_2S are anticipated to be at levels considerably below the maximum allowable concentration (MAC) considered acceptable for continuous exposure during an 8-hour working day (5 ppm, 2 mg/m3, and 5 ppm, respectively) when mixtures have been produced at less than 300°F. It has been established that the bulk of sulfur released from the construction of sulfur-asphalt pavement materials is inorganic sulfur in free elemental form. [35]

Due to its mass, elemental sulfur is usually only transported short distances via wind currents. H_2S, at the concentrations potentially emitted during the paving operation, are reduced with distance by dilution. The environmental impacts on soils, flora, and fauna are diminished by attenuation with distance, absorption, and short duration of exposure during paving.

Several field studies were also evaluated in the FHWA sponsored investigation by the Texas Transportation Institute. At the Lufkin and Kennedy County Texas sulfur-asphalt trials, with the exception of the area inside the liquid sulfur storage tank, all H_2S concentrations were well below MAC values (0.2 to 0.5 ppm in the paver area). The Bureau of Mines and the Texas Air Control Board (TACB) did extensive monitoring at the Kennedy County field trials in 1977. Probes were placed at distances which ranged from 1 to 12 inches from the surface of the material for “source data”. [40]

These distances are much closer than that normally occupied by personnel, which normally range from 2 to 6 feet, the “normal data”. As long as the temperature of sulfur-asphalt systems were maintained below a maximum of 300°F, H_2S emissions were found to be well below the suggested MAC value of 5 ppm. Source type emissions appeared to be excessively high; however, in an open-air environment these concentrations are rapidly reduced with distance. The paver screed, without suitable temperature controls, would appear to be the main source of potentially high H_2S and SO_2 emissions. [40]

5.0 Methodology

To begin this project a proper research methodology has to be carried out on each criterion which is required by the project. The most important element of this research is to accumulate findings on the sufficiency of sulphur in construction through literature review. Because this research has no prototype and fully based on reading, discussion and test results.

- Planning of the feasibility of project

Once the project title has been assigned, planning of the whole project is started. The planning stage was implemented early to synchronize all tasks along the project. There were a few matters that had been taken into consideration in the planning stage of the project; tasks, date line, and, source of information and data.

- Gathering the information from various sources

Information has been collected from various sources which are web site, book, books-electronic version, conference proceedings, and previous compiled report. The information is focusing on use and method of the sulphur production that can be applied to pavement and concrete as well as suitable and useful for this study option.

- Discussing on findings and preparing basis for the alternatives method

The gathered information was then presented and discussed with the supervisor. This level is very important because the information will be briefly discussed and filtered so that all the information is valid and useful for the project.

- Implement the research method and preparing report

All the data of the sulphur product on pavement and concrete such as the reliability and considering the advantage together with its disadvantages in into the report and then come out with the preferable methodology option. Then the result will be analysed with some recommendation.

6.0 Conclusion and recommendation

From this research and all the data gathering that have been done the author have find that there are positive and negative impact of using sulphur as an additive for road pavement. More research has to be done to ensure this case study. Hence, for the improvement of this research, a few matters are recommended for the next progress of this research. The recommendations are as follow:

- The durability of utilization for sulphur on road construction needs to be investigated more.
- Implement the safety practices for the handling of sulphur in modified pavement mixture.
- Whether sulphur can still be widely used in construction of pavement or not to use sulphur as an additive.
- The impacts of sulphur to the environment for a long run time of period if been used as an additive for road pavement.

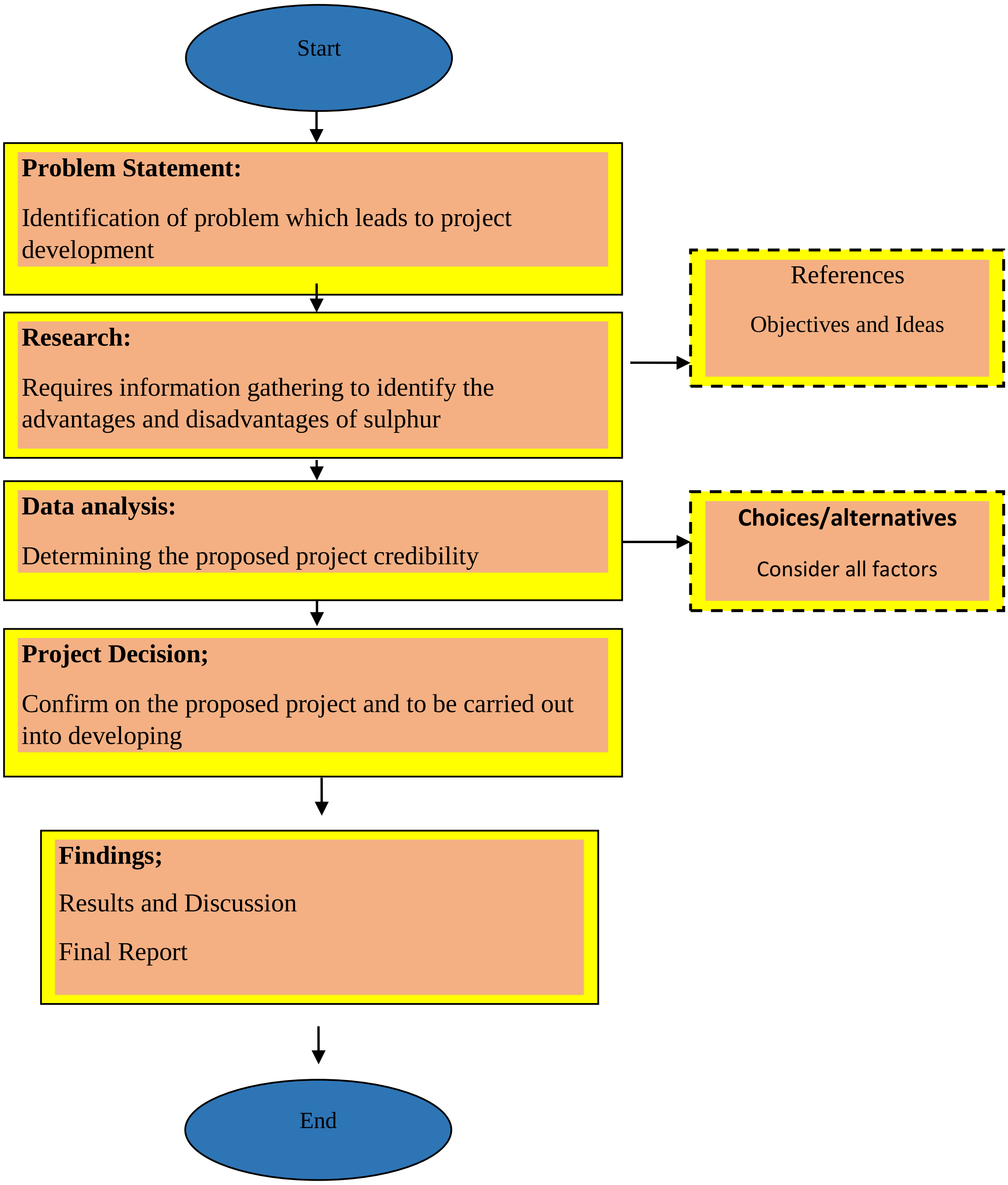
After 4 months of research on the critical review of the suitability of sulphur as a component in various civil engineering applications the author has decided that sulphur has the best potential to be an ideal additive to civil engineering application. After reviewing all the test and laboratory results from all the research paper about sulphur, it has much positive feedback and has less effect or impact on the environment. From the results and research above the author has already mention the positive side of sulphur.

The use of sulphur in asphalt has a long history, but has been tainted by the potential threat of hydrogen sulphide and sulphur dioxide emissions during mixing and paving that could be hazardous. The pelletisation of the sulphur appears to have overcome many of those fears, although strict control of temperature still needs to be maintained, making its use more practical. The practicality is demonstrated by its use on several sites, some of which have been reported.

The primary advantages of sulphur-modified asphalt are an increase of strength, stability and, possibly, durability. The resulting economic advantages of reduced bitumen consumption, reduced pavement thicknesses and lower energy consumption should be the driver for its use on commercial projects. There is a marginal increase in the carbon footprint with the inclusion of sulphur pellets in each tons of asphalt when the pellets are produced in Canada, but this disadvantage negated when the pellets come from the Netherlands. However, if the use of sulphur pellets allows a thinner base layer to be used, the carbon footprint is reduced, even with pellet production in Canada.

Recommendations also must be made on sulphur because the volume of sulphur is increasing by the time from oil recovery. The availability is increasing thus the price will fall down. From this I hope that more applications on civil engineering should be researched to prevent from environment headache.

7.0 General Procedure of Project



8.0 Gantt chart for Final Year Report 1

No	Detail/Week – FYP I	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic							Mid-Semester Break								
2	Literature Review and Research on Topic Selected															
3	Scope and Methodology Analysis															
4	Submission of Extended Proposal															
5	Starting on the findings of project															
6	Proposal defence															
7	Research and discussion															
8	Interim Report Submission															

9.0 Gantt chart for Final Year Report 2

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Continuing Progress															
2	Progress Advancement															
3	Submission of Progress Report															
4	Data Analysis								**MID SEM BREAK**							
5	Pre-SEDEX															
6	Submission of Draft Report															
7	Submission of Dissertation															
8	Submission of Technical Paper															
9	Oral Presentation (VIVA)															

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