THE USE OF SULFUR IN FLEXIBLE PAVEMENT ROAD CONSTRUCTION OPPORTUNITIES AND CONCERNS

by

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Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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(CIVIL ENGINEERING)

Approved by,

____
(Dr. AP Salah Elias Zoorob)

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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NOOR HAZIMAH BINTI MARZUKI

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ABSTRACT

Sulfur has been incorporated into asphalt mixture for a number of years in an attempt to combat various damage and failure mechanism that occur in flexible pavements at an increasing rate such as shoving, rutting, and raveling. Furthermore, the cost of road construction materials in particular bitumen is expensive. Hence, among the alternatives is by incorporating sulfur in the asphalt bound layers of the pavement structure. Sulfur is a major waste of by-product from gas and oil production that has potential for encapsulation in civil engineering purposes.

This study will cover on the use of sulfur in road construction opportunities and concerns. The utilization of sulfur on road construction has been known as Sulfur Extended Asphalt Modifier (SEAM). Opportunity for utilization of sulfur as partial substitute for bitumen in asphalt mixtures is a great application. Sulfur may make the asphalt more economical and may improve mechanical and durability properties such as increased stiffness and reduced permanent deformation.

In the asphalt mixture, sulfur crystallization will function as a structuring agent. Sulfur and asphalt is mix together above the melting point of the modified sulfur and when the blend cools, it solidifies. Then, the crystallization result is in different level of strengthening depending on the amount of modified sulfur and asphalt is ratio. The amount of sulfur added is important as it will affect the performance of pavement structure. However, handling and safety issues need to concern due to the oxidizing of sulfur dioxide will produces the poisonous gas that was toxic.

ACKNOWLEDGEMENT

Praise to Allah for His guidance and blessings He has given me throughout this Final Year Project. It's the strength from him that it what keeps us going in everything we do. My greatest appreciation goes to my supervisor, Dr. AP Salah Elias Zoorob for helping, teaching, giving advices and opinions through completing this work. I appreciate his efforts and time he allocates for me. Million thanks to his for giving me this opportunity and his confidence in me.

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Thank you so much

CHAPTER 1

INTRODUCTION

Road or pavement is defined as an overland relationship system consisting of a fixed structure and is a form of relationship the most practical, effective and economic. It is designed to be a national network connecting up to the small towns and rural areas. Pavement 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.

Construction of the road networks is one of the main features in the development process. The perfect transport system, efficient and effective is a precondition to stimulate socio-economic growth and industrialization of the country. There are various types of pavement construction depending upon the materials used which is flexible pavements, semi rigid pavements and rigid pavements. Flexible pavements is the most convenient and simple type of pavement construction. However, the performance of conventional bitumen of flexible pavement may not be considered satisfactory for some particular reasons.

Modern road network planning began designed and expand over the time. Roadway in the colonial period was constructing to meet their needs and goals in order to facilitate the administration and exploitation of the wealth of the country. It requires an effective level of the pavement structure and efficiently so that the pavement structure is always be in a satisfactory condition. However, various damage and failure either from construction to maintenance levels can be seen on the pavement structure.

Kordi. et al (2010) stated that some of the flexible pavements for the roads in Malaysia are not able to carry the load with specified design life especially in industry areas because heavy lorries always using these road to move their goods even the pavement are designed until ten to fifteen years design life to support road. This could adversely affect the pavement where damage can occur easily and in short span of time. Among the example of failures are shoving, corrugations, rutting, depression, bleeding, raveling, fatigue, and others failure. This pavement problem is influenced by the pavement failure or failure of the pavement bearing structure including sub-grade, sub-base and road base for the pavement.

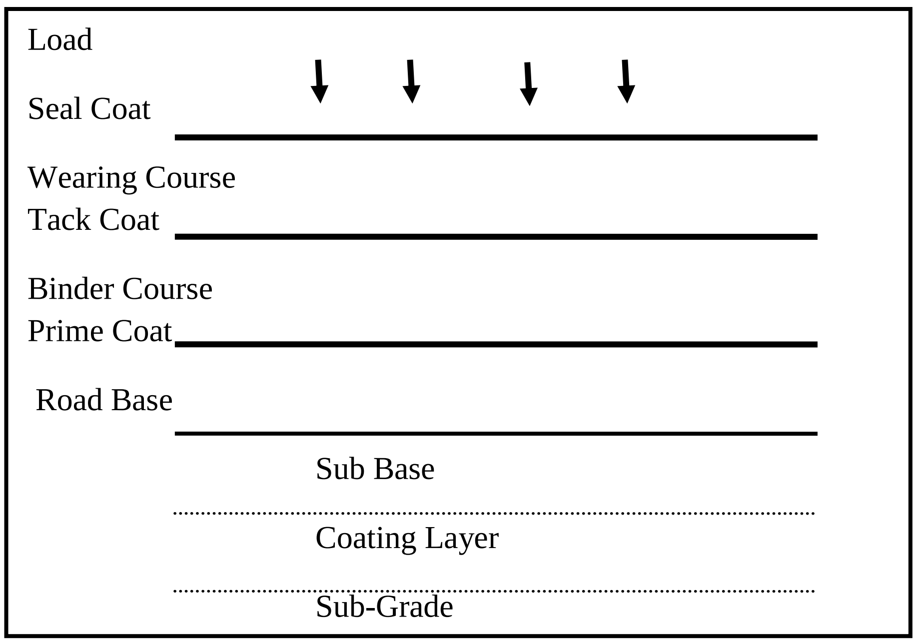


Figure 1.0 Flexible road structure

Therefore, some research has been made in order to improve the quality and strength of the existing pavement. Among the alternative is by improving the mix design of the pavement construction such as by gradation, polymer modified asphalt, filler, additives and by using sulfur. From the previous research, the use of sulfur as a partial substitute for bitumen in asphalt mixtures shows the better and effective improvement of the pavement properties. Therefore, this research will focus on the use of sulfur in the road construction that has been use based on the previous research.

1.1 Background of Sulfur in Road Construction

Road network is vital for economy growth especially in the global transportation infrastructure. More than 90% of the road network is surfaced with asphalt mixtures. Asphalt is a mixture of bitumen and mineral materials used as a paving material that is typically produced at temperature among the range of 140-160°C.However, part of the bitumen in asphalt mixtures can be substituted with sulfur. Due to the increasing of sulfur production, it is uses by many industrial and application especially in road construction and also in research.

Among the countries that produce a lot of sulfur is China, United States, Russia, Germany, Japan and India. According to Nazarbeygi A.E. et al (2012), the production of sulfur has considerably grown in Iran as a co-product resulting from the increase of the number of oil and gas industries. The table below shows the total amount of sulfur that was produced by the country that was stated.

Country & Year	**2008 (Thousand metric tons)**	**2009 (Thousand metric tons)**	**2010 (Thousand metric tons)**
China	8610	9370	9600
United states	9300	8940	9080
Russia	7170	7070	7070
Germany	4167	3760	3905
Japan	3334	3214	3292
India	1170	1150	1170

Table 1.1: Total amount of sulfur production for 2008, 2009 and 2010[22]

An innovative use of sulfur has become something that was important nowadays where it has been the subject of experiments and research. This innovation of sulfur has been used as a partial replacement of bitumen in an asphalt mixture during the production process resulting in a pavement that has enhanced mechanical properties such as increased stiffness and reduced permanent deformation.

The innovative use of this sulfur has proven to have a better effect and improve the functioning of the existing structure pavement. Among the factors to be considered is the most efficient amount of sulfur to be used in the pavement structure and the optimum temperature during the production process.

This factor is very important in ensuring the performance of pavement is always at a satisfactory level. If the amount of sulfur ratio is not enough or less in the modified asphalt mixtures, this may reduce the hot mix production such as during the laying process of the pavement structure to function properly. This paper will cover further on the use of sulfur in various aspects, such as the mechanical properties, durability, environmental, economic and operational. Comparison between the results of some research is also implementing to prove the feasibility of this research.

1.2 Problem Statement

The innovation of the sulfur has a many uses in road construction industry. Its ability is now on the pavement structure increasingly known as capable to increase strength and reduce permanent deformation of the pavement. For example, surface layer significantly more resistant to rutting, deformation and fuel spill damage after using sulfur in asphalt mixture and this is better effect especially for airports and container ports. However, this innovation still lack regarding with the use of sulfur in terms of its impact on the environment and the effects of the sulfur uses such as economic, durability, and health and safety effects.

Then, the effect of sulfur is very important whether it is beneficial or more too harmful. For example, the sulfur will emits sulfur dioxide (SO_2) gas and as result it would be a harmful to workers during the process of pavement construction which is production, transportation, laying and compaction process. Therefore, further study is needed to compare the use of sulfur on the pavement structure that can be seen in more detail and much more. Consequently, the strengthening and improvement based on the literature review is needed with the appropriate option of methodology so that the performance of sulfur can be improved in the future.

1.3 Aims and Objectives

The objectives of this research are:

- To determine and analyze the use of sulfur as a constituent in asphalt wearing and base course of the pavement structure.

- To investigate the effect of sulfur in road construction in relation to :
  - Mechanical properties
  - Durability
  - Environmental
  - Economic
  - Operational and health & safety
- To give some recommendations to be implemented in futures to increase the performance of the innovation of sulfur in flexible pavements.

1.4 Scope of Works

The study will be focus on the use of sulfur in road pavements and effect on the mechanical properties, durability, environment, economic and operational and health and safety. The aims are to identify the characteristics and problems that occur during the application of the sulfur in road construction and also the effectiveness of the innovation sulfur either it is useful or not in future.

Then, the limitations of this study are based on the use of sulfur from the previous research and case studies regarding with the application of sulfur on the pavement only. This research will come out with some recommendation from the authors in other to increase the performance of the innovation of sulfur in roads pavements.

CHAPTER 2

LITERATURE REVIEW

2.1 Properties of Sulfur in Chemistry

Sulfur is a yellow crystalline solid in its native form and it can be found as the pure element or as sulfide and sulfate minerals in nature. It is a multivalent nonmetallic element that is abundant, odorless, tasteless and multivalent non-metal. Sulfur burns with a blue flame concomitant with formation of sulfur dioxide (SO_2) and it can form polyatomic molecules with different allotropes.When it melts, sufur can forms blood-red liquids. Then, it is soluble in carbon disulfide but in soluble in water. [7]

Figure 2.1.1: Various of sulfur forms [7]

Sulfur has been existence since the ancient times ago and was recognized as one of the chemical element. Sulfur has 21 known isotopes and naturally occurring of its four stable isotopes which are S-32, S-33, S-34 and S-36. Sulfur exists in several crystalline and amorphous allotropes contains cyclic crown-shaped S8 molecules which form several distinct crystal structures. It is complex crystallography element with rhombic and monoclinic of S8 cyclic crown-shaped molecules. Melting point of sulfur is 119.0°C (monoclinic) or 112.8°C (rhombic), the boiling point is 444.674°C and relative density is 2.07. [7]

The viscosity of molten sulfur can be produces by increases the temperature and it can produces amorphous or "plastic" form. Amorphous means an elastic variety of sulfur obtained through the rapid cooling process of molten sulfur. However, by standing this form at room temperature, it can gradually passes back to crystalline form due to it is metastable at this temperature.[18]

Figure 2.1.2: cyclic crown-shaped S8 molecules of sulfur[7]

2.2 Sulfur Extended Asphalt Modifier (SEAM)

Among the innovation of sulfur on the road construction is Sulfur Extended Asphalt Modifier (SEAM). According to Strickland D. et al (2008), Sulfur Extended Asphalt Modifier (SEAM) mixtures were used commercially in the 1970s and 1980s by the US Bureau of Mines and Federal Highways. This indicate the innovation of sulfur has started early long times ago and certainly many studies have been done before it can be used widely.[15]

However, problems with storing hot sulfur is among issue that was highlighted since sulfur is approximately twice as dense as bitumen. Besides that, other important issue is related with health and safety concerns during the production process due to exceeds the temperature limit can release the toxic gas such as hydrogen sulfide (H_2S). Hence, to overcome this problems, some solution have been studied with over 100 test roads which then led SEA to commercialization. Solid sulfur pellets is among the solution and this development has started in the late 1990s. This solution able to decrease the emission of fumes and odors during the utilization sulfur mix process which particularly more economic and eliminate hazards related with hot liquid sulfur.

Strickland D. et al (2008) also claimed that, from the laboratory and field test indicated that the performance of these utilization of sulfur mix are suitable especially for high stress applications for example heavy duty pavement and container terminals due to the deformation resistance, stability, stiffness and fatigue resistance show the enhance performance.[15]

2.3 Source of Sulfur

Sulfur is found naturally and meteorites in areas of volcanic regions and around hot springs. For example, it can be occur especially along the Pacific Ring of Fire like Japan, Indonesia, and Chile. Besides that, it is generally found in nature, including gypsum, galena, iron pyrite, sphalerite, stibnite, cinnabar, Epsom salts, barite and many others minerals.[16]

However, nowadays sulfur is obtaining from the petroleum crude oil and natural gas process and the amount of sulfur from this process is high. According to Al-Mehthel M. et al (2010), the production of sulfur as a co-product has increased due to the increase in number of oil and gas industries in Gulf region, particularly in Saudi Arabia. This become among the big source in supplying of sulfur which is through oil and gas industries especially for the future usage of sulfur. [2]

Figure 2.3.1: Sulfur from Natural Gas and Oil Petroleum Refining[2]

In these oil refining processes, the changes process to elemental of sulfur is occurs due to it often become as undesired or detrimental compounds. Al-Ansary M. (2010) claimed in the Pearl GTL (Gas-to-Liquids) projects, the catalyst that are use together with chemical conversion to converts the natural gas into a range of products such as naptha, kerosene and others products is very sensitive to sulfur poisoning and virtually all sulfur needs to be removed in the gas treating process. [3]

Therefore, in other to avoid this undesired or detrimental compounds as the materials to removed without any function or recycling, it is better to produce some beneficial co-product from sulfur that will increase the performance of others industries for example in road construction.

2.4Uses of Sulfur in industry

In chemical industry, sulfur has many applications and is essential in our life. Among the application is as a component of gunpowder, fumigant, fungicide, matches, fireworks, in the making of fertilizers and in the vulcanization of natural rubber. Besides that, sulfur also use in other important compound includes sulfur dioxide used as a bleaching agent, disinfectant, and refrigerant. [19]

Then, sulfur is needed in the making of sulfuric acid (H_2SO_4) which is the main commercial use of sulfur product. As known, sulfuric acid is produced by dissolving sulfur trioxide in water resulting as the strong acid and become the number one industrialized agent world is production. This indicated that sulfur not use only in road construction but also in other industries.

According to Al-Ansary M. (2010), Shell sulfur concrete has been used where it completely replaces the cement and water in concrete. This technology resultant gives the relatively low cost and lower carbon footprint compared to the Portland cement concrete.

2.5 Composition of Sulfur

The composition of sulfur based aggregate asphalt mixes was obtained by a process comprising mixing aggregate with asphalt, molten sulfur and asbestos fibers wherein the asbestos fibers include 20 to 80 weight percent amphibole and 20 to 80 weight percent chrysotile. The molten sulfur is made by a method comprising heating a mixture of sulfur and a sulfur plasticizer. Sulfur plasticizer will further treated with amyl acetate. Then, sulfur plasticizer able to reduces the crystalline of sulfur which resulting in a generally stronger and less brittle material. [6]

2.6 Density of Sulfur Extended Asphalt Modifier (SEAM)

Density is defined as mass per unit volume. The greater the density, the more mass per unit volume.

Density Formula :

$$\text{Density} = \text{mass} \div \text{volume}$$

Solid sulfur has a density of 2.07 grams per cubic centimeter at temperature of 25ºC. In general, sulfur in solids form are more dense than in the liquid form. Then, the density of bitumen is 1.01 grams per cubic centimeter at temperature of 25ºC. Hence :

1 grams of bitumen = 1 cm^3

1 grams of sulfur = 0.5 cm^3

According to Nicholls J.C. (2012), the utilization of sulfur pellets in SEAM binders does not give effect to the compaction process with the bulk density being marginally greater. Then, the equivalent of volume basis for the replacement of sulfur in asphalt mixtures is needed to maintain the existing standards so that the better performance of pavement can achieved. The below equation can be used to get the equivalent volume of total binder (sulfur and asphalt) based on the Bureau of Mines work :

$$\text{Total Binder Mass (\%)} = A \frac{(100R)}{100R - P_S (R - G_{asphalt})} \quad [5]$$

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 [5]

In the SEAM mixes, the mass ratios from 20/80 to 40/60 has been used for sulfur/asphalt binders and at times even up to 50/50. However, approximately 20% of the sulfur dissolved into the bitumen and 20% becomes free sulfur which solidifies into crystalline form.

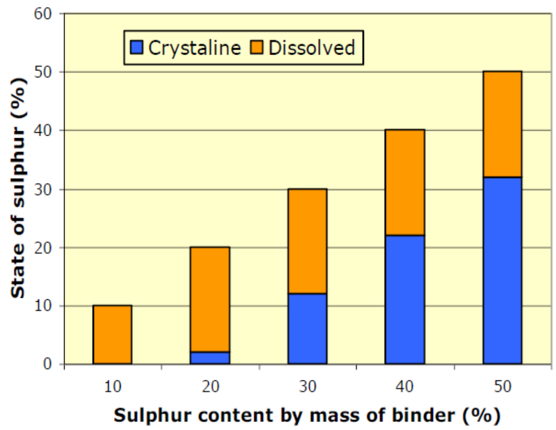


Figure 2.6.1 : State of sulfur when added to bitumen [12]

2.7Sulfur in Asphalt Production

In road construction, sulfur also use in many application such as by substitute some of the asphalt mixture with the sulfur due to the sulfur can give the better performance of pavement properties. According to Al-Mehthel, M. (2010), the process incorporating of sulfur extended asphalt begins with the preparation process of modified asphalt blends for any asphalt layer. Then, the elemental of sulfur is mix together with the local asphalt with a ratio of 40/60 (sulfur/asphalt).This ratio is important in order it can affect the performance and effectiveness of the pavement structure.[2]

After that, the blend is prepare by heating the plain asphalt to maximum 145°C and the required amount of sulfur as per weight ratios is adding slowly by using a shear-blender before the compaction process is carried out. During the compaction process, the temperature should not to be exceeding 145°C temperature limits for sulfur asphalt mix due to it can give harmful effect.[2]

Figure 2.7.1: Sulfur-modified asphalt application during the mix lay down process (Ras Laftan Industrial City (RLIC), Qatar in October 2007) [3]

2.8Performance of sulfur in permanent deformation

According to Saylak D. et.al (1988) the sulfur are actually performed well in the case of rutting and the performance of the result within 3 years post-construction evaluation shows that the sand - asphalt - sulfur pavement have been better than originally anticipated. Rutting is one of the pavement failures as a result of compaction or mix design problem and occur when sub grade does not rut yet the pavement surface exhibits wheel path depressions.

Figure 2.8.1: Rutting problem occurred on the pavement

Nazarbeygi, A.E., (2012) also agree that by incorporating sulfur in the asphalt mixture, it give the best performance to overcome the rutting problems based on the test result. This rut resistance result of mixes is shows in the below table and graph that was determined using wheel-tracking machine according to BS 598 test method.

No.	Binder Type (Bitumen/Sulfur Ratio)	Temperature °C	Density g/cm^3	Rut depth mm	Rut rate mm/hr
1	100/0	45	2.340	1.12	0.46
2	75/25	45	2.386	0.96	0.48
3	65/35	45	2.390	0.82	0.38
4	55/45	45	2.392	0.4	-0.04

Figure 2.8.2: Wheel-tracking test results[11]

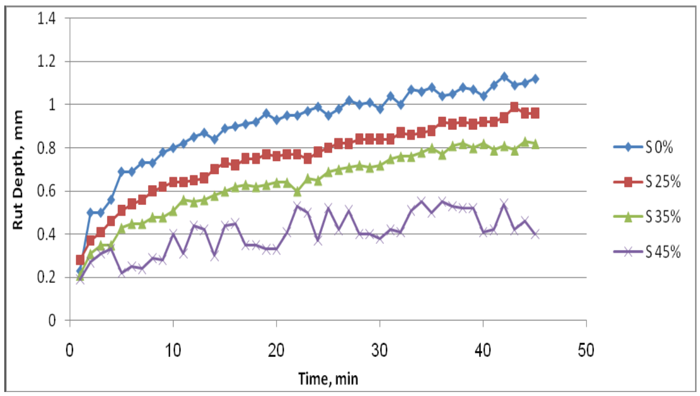


Figure 2.8.3: Influence of Sulfur on rut depth[11]

According to Al-Ansary M. (2010) some of the added sulfur modified asphalt act as a bitumen extender and improved the mechanical properties which is reduced the permanent deformation in the asphalt layer. The following graph shows the permanent deformation test result based on load repetitions to the mixtures. The performance of permanent deformation shows the better result by 40% addition of sulfur in asphalt mixture than 10% addition of sulfur.

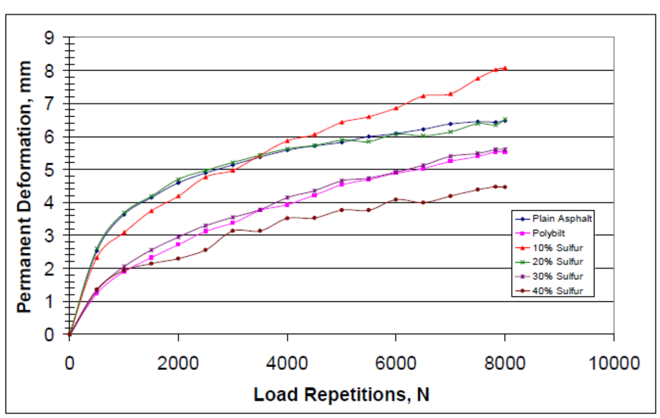


Figure 2.8.4: Result of permanent deformation test[2]

The below figure shows the typical profiles of the tested mix samples for different ratio of sulfur in asphalt mixes.

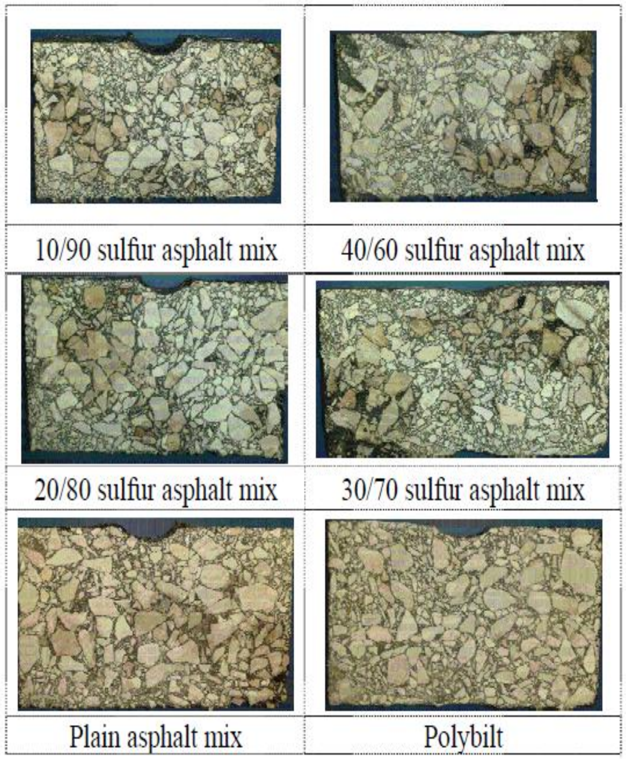


Figure 2.8.5: Result of the permanent deformation resistance of different sulfur ratio in asphalt mixtures[2]

2.9 Stiffness Modulus of SEAM

Stiffness means the rigidity of the pavement structure which it resists deformation in response to an applied force. This force normally comes from the traffic loading of transportation. Nicholls J.C. (2012) agreed that asphalt mixtures that was adding with sulfur pellets proven have higher stiffness moduli than normal bitumen mixtures. The utilization of sulfur in asphalt mixtures have shows the improvement performance of stiffness effect without changing the overall mechanical properties of the mixture. The following figure shows that the stiffness modulus is increases with the 40% addition rate of sulfur pellets.[12]

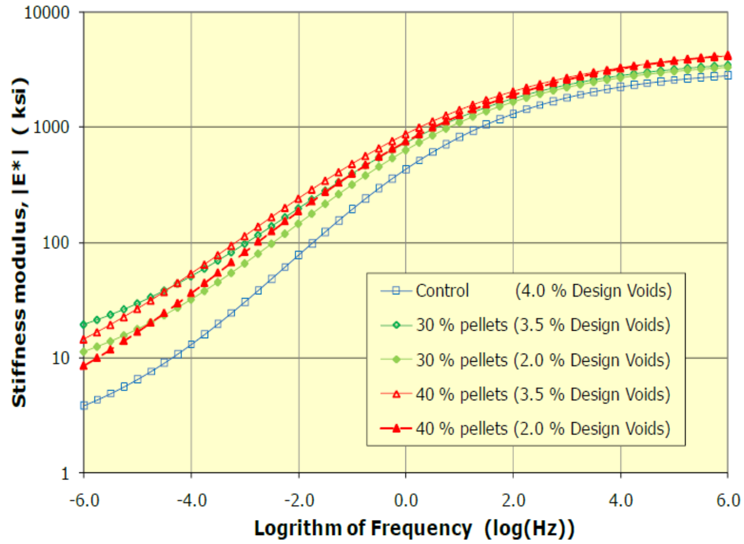


Figure 2.9.1: Stiffness Modulus graph[2]

The following figure shows the stiffness ratio results of two mixes by using indirect tensile stiffness (ITMS) test. This field trial test was laid at Pearl Village for the Pearl GTL project in RLIC, Qatar. The stiffness ratio was increased particularly at high temperatures with the addition of 40% by mass sulfur modified asphalt pellets.[3]

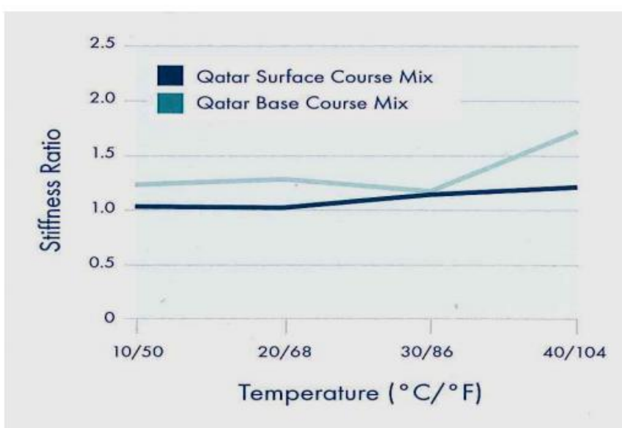


Figure 2.9.2: Stiffness ratio result with 40% addition of mass Shell sulfur modified asphalt. [3]

2.10 Moisture Sensitivity of SEAM

According to "An Alternative Asphalt Binder, Sulfur-Extended Asphalt (SEA)", sulfur decreased both ratio of tensile strength ratio, TSR, and resilient modulus ratio, MrR at the varying core air voids based on ASTM D 4867 moisture susceptibility testing. Then, the more affected is wet strengths than dry strengths. "An Alternative Asphalt Binder, Sulfur-Extended Asphalt (SEA)" also indicate that the moisture susceptibility of SEA mixtures was increased by incorporating sulfur in asphalt mixtures which has increased the percent of air void level. [5]

The following figure shows a dynamic modulus versus mixture graph result. The study has been done by The National Center for Asphalt Technology (NCAT) for various Thiopave mixtures by using a standard 19 mm test track mixture. By adjusting the binder content, base asphalt grade, and sulfur content in the mix design, the specific desired properties can be obtained through this comparison figure for the various sulfur mixtures at a temperature of 70°F (21°C) along with two control mixes designed at 4 percent air voids.

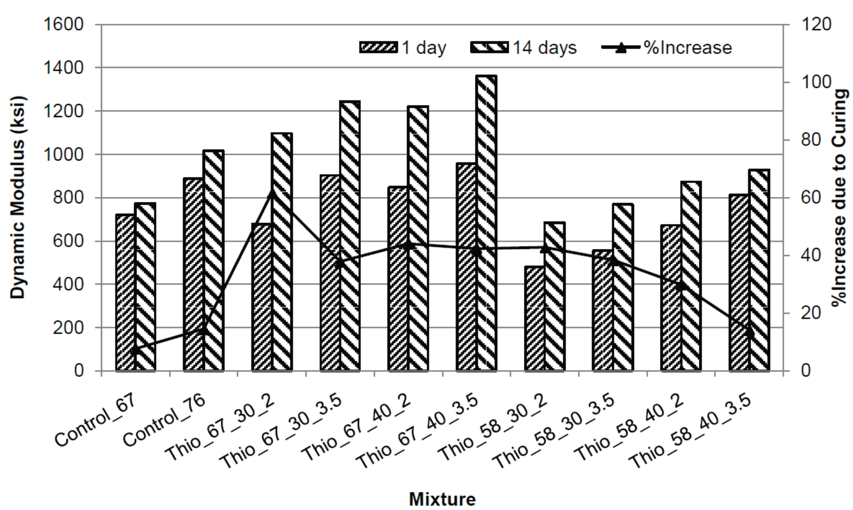


Figure 2.10.1: Average E* Results at 10 Hz, 70°F (21°C) for All NCAT Mixtures after 1 and 14 Days [5]

The below figure shows how based on the flow number (FN) able to improve the rutting resistance of Thiopave mixes with no confining stress. As shown, the trends for the PG 67 minus 22 binder shows an increase in flow number due to increased design air voids and increased aging time. [5]

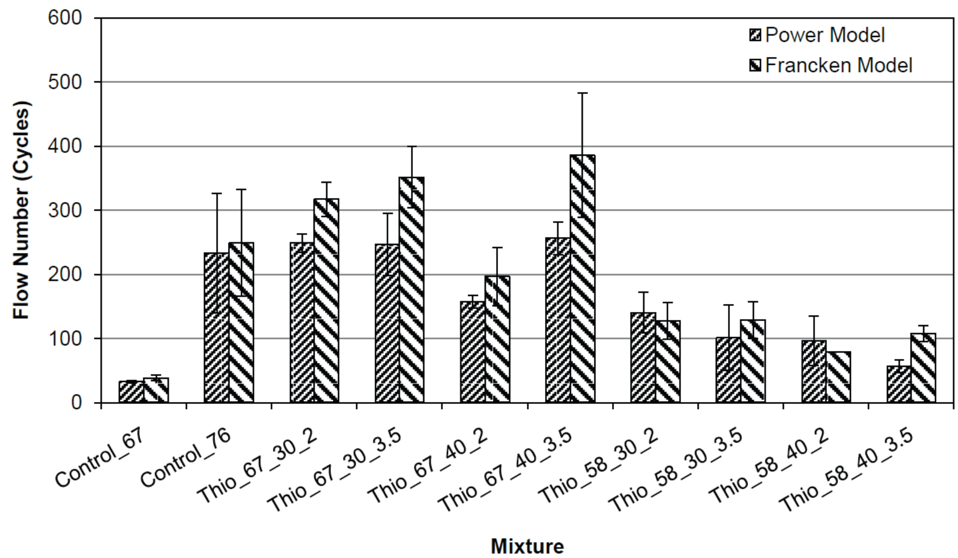


Figure 2.10.2: Average FN Results at 70 psi (480 kPa) for All NCAT Mixtures after 14 Days. [5]

2.11 Fatigue Cracking

Fatigue is a common type of distress in asphalt pavement which generally due to overloading failures. This is because the sub base or base was weakened causes base or sub base inadequately support the surface layer. In SEAM mixtures, the fatigue problem is very important in order to maintain the quality of production.

"An Alternative Asphalt Binder, Sulfur-Extended Asphalt (SEA)" proves that at equal high strain values, the fatigue curve of SEA indicate less cycles to failure. However, the level of strain tends to be lower due to the higher modulus of SEA mixtures. The lower flexibility can be tolerated in SEAM materials. By using higher binder contents and softer binder grades, the fatigue resistance, flexibility, and fracture resistance of SEAM mixtures can be improved.[5]

The following figure shows comparison of the fatigue lines of asphalt control mixtures and SEA mixtures which indicate less cycles to failure for SEA mixtures.

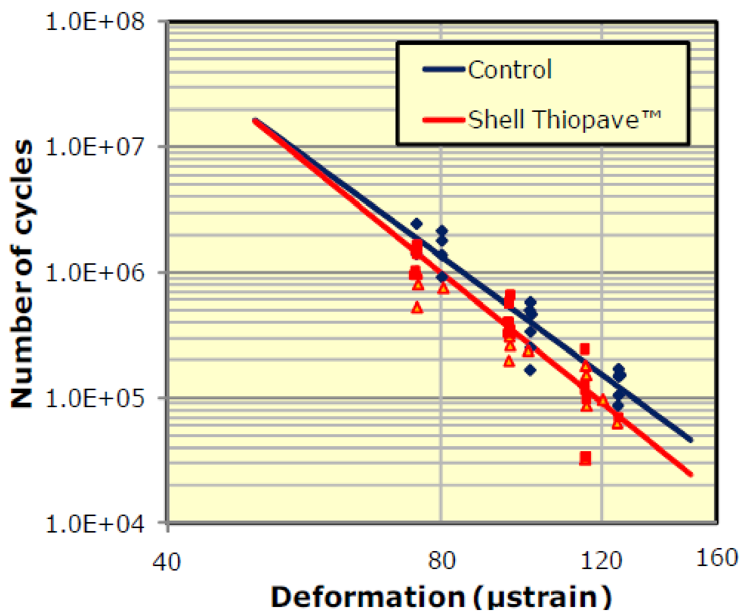


Figure 2.11.1: Number of cycles versus deformation graph for fatigue lines of asphalt mixtures [12]

2.12 Socio Economic Factor

Market cost and availability of the utilization sulfur in asphalt mixtures is very important to ensure it is practical to be continued and maintain the economic cycle of road construction. In 2011, more than 15 countries contributing more than 1Mt each of sulfur. Then, the total amounted world production of sulfur was 69 million tons (Mt) which China, Canada and Russia are among the countries that produces more than 5 Mt sulfur. [20]

However, Nicholls J.C. (2012) claimed that the cost of the development of SEAM around 1970 is uneconomical due to the availability of sulfur decreases causes increasing the cost of sulfur during that time. However, the cost has been reduced after the sulfur pellet was produced which given more profitable to use in road paving and in the same time reduced bitumen consumption and reduced pavement thicknesses.[12]

Nazarbeygi, A.E.et al (2012) also indicated that the potential of sulfur in terms of availability and cost in Iran able to decreases paving binder cost. The cost of paving binder which able to decreases is up to 25%.[11]

According to Al-Mehthel, M. (2010), the market prices of sulfur has drop due to the increasing amount of sulfur produced from oil and gas industry which grown in many countries. The petroleum and gas refining processes has limit the amount of sulfur present in fossil fuel resulting the amount of removed sulfur increased. Hence, the price of sulfur become more lower thus causes the sulfur becomes fundamental in other applications due to the availability and cost of sulfur increase.[11]

Takasawa. R. et.al (2001) indicated that the costs of producing sulfur composite material is calculated first in the evaluation of the economical feasibility of sulfur composite material equipment which allowances were made for the unit prices of raw material sulfur. The result of a roughly evaluation of this economical feasibility can be seen in the following figure. This figure proven how the development of producing and selling sulfur as composite material is very difficult and uneconomical due to the profitability result shows very bad. Then, Takasawa. R. et.al (2001)claims that it is better if sulfur can be seen as a waste material to address the sulfur surpluses. [21]

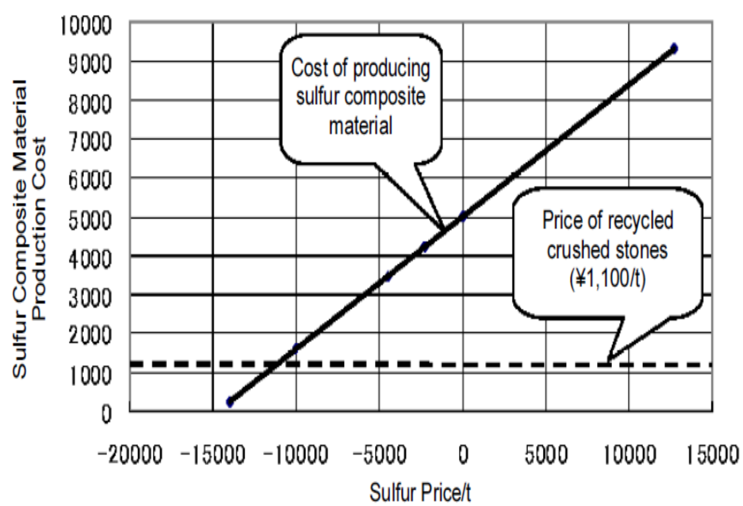


Figure 2.12.1: The result of a roughly evaluation of economical feasibility in producing sulfur composite material [21]

Then, not all customers will pay the same price of sulfur due to there are no reference price comparable and no terminal exchanges on which it is traded. Hence, this resulting unstable price of sulfur. The following table shows the price rate in US dollars per ton (1,000 kg) of sulfur in certain area of the world.

International price indications $/t*

	Feb 2008	March 2008	Aprill 2008	May 2008	June 2008
Dry bulk sulfur					
Fob Vancouver	420-450	460-480	460-480	650-660	650-660
Fob Middle East	650	642-666	650-666	745-747	805-806
Cfr India	676-679	690-700	680-700	745-750	850-852
Cfr North Africa	420-445	420-445	420-445	420-445	420-445
Cfr Med Europe	110-378	110-378	110-435	110-435	110-435
Liquid Sulfur					
NW Europe (cpt)	260-305	260-305	260-305	260-305	260-305
Sulfuric acid					
Cfr W Mediterranean**	95-145	95-145	95-145	95-145	95-145
Ex-term Tampa, FL ($/st)	170-200	170-200	170-200	180-230	180-230
*End of month price **€/t cfr Benelux source: Fertilizer Week					

Figure 2.12.2 : International price of sulfur for some countries[17]

2.13 Health and Safety Issues of SEAM

Safety and health procedures are very necessary of the well being especially to workers. The procedures of safety and health should be implemented at the workplace to avoid the potential hazards become bad accident. According to "An Alternative Asphalt Binder, Sulfur-Extended Asphalt (SEA)", from the laboratory measurements of gas emissions in the breathing zone of the laboratory worker showed the peak level still does not exceed the danger limit which is 0.2 ppm (H_2S) and 0.1 ppm (SO_2). However, adequate ventilation is required as control. Besides that, no relevant elements such as smoking, sparks and open flames are allowed around the containers that contain liquid sulfur. [5]

"An Alternative Asphalt Binder, Sulfur-Extended Asphalt (SEA)" indicated that there was some element of insoluble sulfur in the vapor produced during the process of mixing and dumping of the asphalt mixture which could give bad effects to the safety workers, particularly the effect on the eye. This is because, these sulfur vapor can crystallize into small particles similarly like fine sand. Hence, the safety measure towards sulfur vapor must be considered. [5]

Another alternative that could be implemented as a safety precaution of workers which working around the sulfur storage tanks or during the production process for a prolonged period of time is to wear respiratory protection because of the discomfort caused by the odor of sulfur. In addition, skin and eye protection should also be used to prevent irritation to eyes and skin.[5]

The potential problems that may arise is related with safety for storage of sulfur and transportation from the plant to the site project, particularly in the form of liquid sulfur. Based on "Quantification Protocol for the Substitution of Bitumen Binder in Hot Mix Asphalt Production and Usage", liquid sulfur used in the production of sulfur extender can be transported to the project site by trucks or trains of gas processing facilities from which it was obtained. However, employees need to maintain the save temperature limit of asphalt mixture during the process of transportation of mixtures to the site and this may adversely affect in terms of safety for workers and the environment. Therefore, by using sulfur pellets it can facilitate the transportation process and reduce the risk of toxic gas emissions.[22]

2.14 Environmental Issues of Sulfur in Road Construction

The innovation of sulfur in roads is one of the achievements that were developed before this which produce the better product. However according to Al-Ansary M. (2010), the sulfur extended asphalt (SEA) became an unattractive option due to the environmental concerns related to the handling and safety of molten sulfur but it was solved by innovation in sulfur technology in early 2000s. [3]

This is due sulfur can become highly toxic with the higher concentrations of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) which it can quickly cause death from respiratory paralysis. Hydrogen sulfide is a toxic gas that smells like rotten eggs. Sulfur dioxide is a colorless gas with a pungent odor which produces dangerous corrosive that irritates eyes, nose and lungs. Therefore, the further test and experiment need to be done in order to eliminate hazards as well to make the innovation use of sulfur on the road construction is commercial and safe co-product in future.

Based on Nicholls J.C. (2012), to prevent the emissions of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) gas, the temperature of asphalt mixture containing sulfur pellets must not exceed 145ºC during production, laying and compaction work. Then, the maximum allowable concentration is 5ppm for continuous exposure to hydrogen sulfide (H_2S) emissions based on the basis of the list of toxicity effects of the American Conference of Governmental Industrial Hygienists (ACGIH).This is because at levels of 50-100 ppm, it may cause the human sense of smell to fail. Hence, temperature plays an important role which should be monitored and control under the safe limit especially during the production process is done to avoid the emission of toxic gas.[12]

Another field trial test shows the result of the air quality monitoring test at Khursaniyah construction site which indicates that all measured concentrations are within the acceptable limits during the application of 30/70 asphalt sulfur mix was conducted (Al-Mehthel M. (2010)). The construction quality for this project was met for the constructed test sections but must use the appropriate amount of sulfur in bitumen. The importance of the experiments that consider with the environment and human during the production of any product like sulfur mix bitumen should to be emphasized so that no accidents or harmful effects.[2]

Then, in terms of effect that relating ecosystem of the surrounding area, Nazarbeygi, A.E., (2012) claims that there are no changes on soil or runoff water quality (pH and sulfur content) occur based on the field trial test conducted in Iran. These measurements prove that SEAM mixture did not cause any danger that affecting the surrounding soil and percolation of water.[11]

The following figure shows the results of the gas emission of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2)at some position which the construction temperature is between 124-147ºC. It was found that all the measured gases emission are within the acceptable limits.

a. Probe at source (20-40 cm over auger)						
SO_2 (ppm)			H_2S (ppm)			Remarks
Maximum	Mean	Minimum	Maximum	Mean	Minimum	
30/70 Asphalt Sulfur Mix						
3.118	0.56	0.156	3.17	2.00	0.26	450C H_2S/SO_2 analyzer
8.0	1.89	0.0	-	-	-	S710 analyzer

b. Probe at elevated levels,		
30/70 Asphalt Sulfur Mix		
SO_2 (ppm)	H_2S (ppm)	Probe Position
0.39	0.47	At Operator (driver) level (2.5 m)
0.404	0.51	At foreman level (1.8 m)

Figure 2.14.1: Result of the concentration of gases at construction site

[2]

CHAPTER 3METHODOLOGY

3.1 Research Methodology

3.1.1Planning

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.

3.1.2 Gathering and analyze the information

Information has been collected from various sources which are web site, book, books-electronic version, conference proceedings, and previous compiled research journal. The information is focusing on use and method of the innovation of sulfur on the road construction as well as suitable and useful for this study option. Then, all the information that need will use to analyze about this research with more detail.

3.1.3 Mechanism analysis of different variable data

The comparison of the variable information and data that need are implementing by using the framework or other methodology option that suitable with the research. The framework will cover all the aspects that in relations with the objective of this research which is use of sulfur in road construction and effect on the mechanical properties, durability, environment, economic and health and safety.

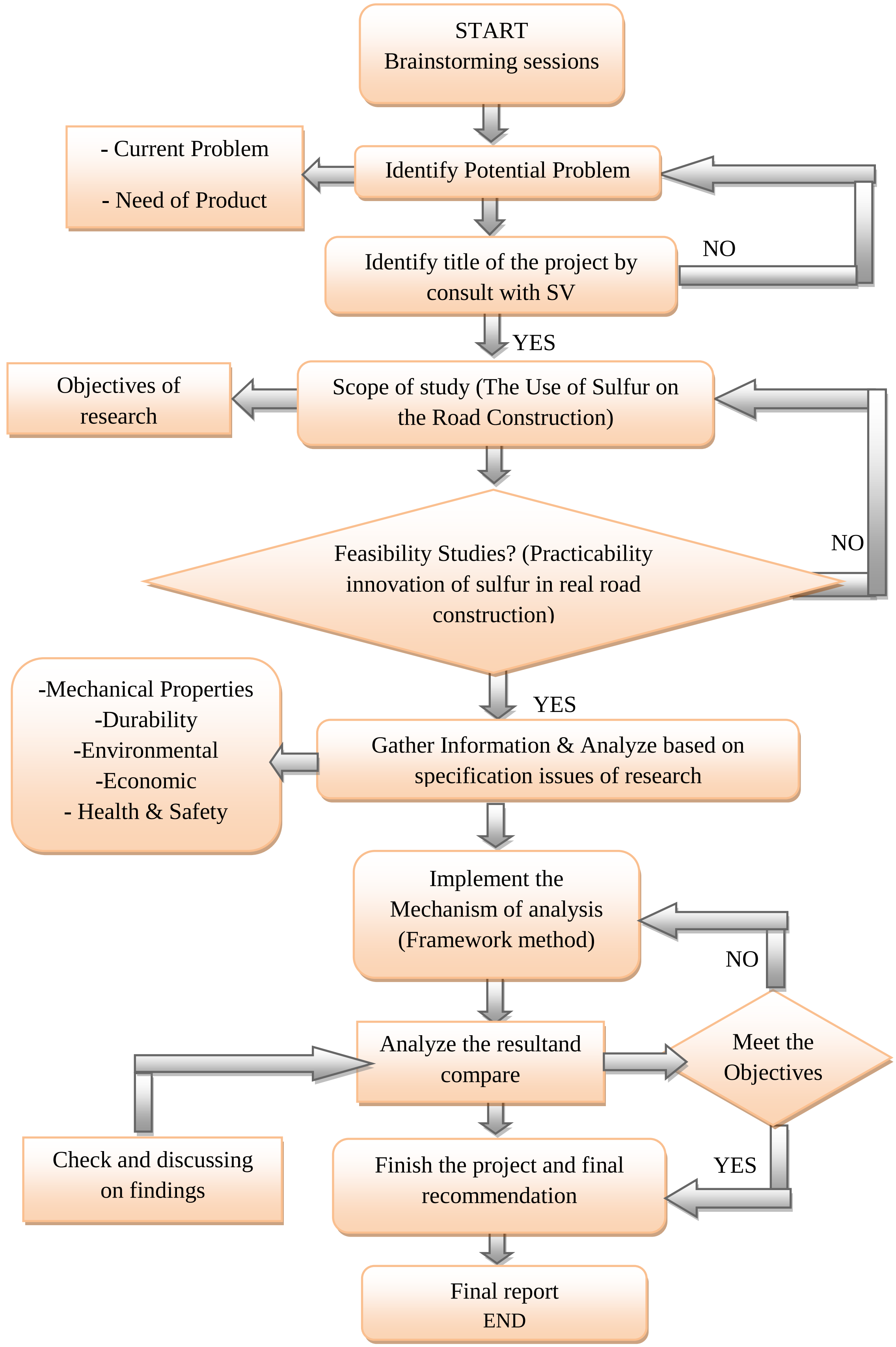
3.1.4 Discussing on findings and preparing basis for final recommendation

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 in order to finalize the recommendations.

3.1.5 Recommendations on Sulfur utilization in roads construction and preparing report

All data about the use of sulfur for the roads construction will be keyed in into the report. Then the result will be analyzed again with final recommendations to increase the performance of the use of sulfur for the roads construction in future.

3.2 Activities and Schematic Flow Process of the Research



3.3 Gantt Chart for FYP I : May 2013

	Month	**May**		**June**				**July**					**August**			
No	**Detail/week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	**Selection of Project Topic**															
	-Brainstorming Period	■	■													
	-Identify Title & Define problem		■													
2	**Preliminary Research Work**															
	-Gather Information of research		■	■	■											
	-Define problem statement & literature review		■	■	■											
	-Preparation of Extended Proposal Defence			■	■											
3	**Submissions of Extended Proposal Defence**						●									
4	**Proposal Defence**															
	-Gather information based on the scope of studies								**Mid-Semester Break**	■	■					
	-Finalize the proposal defence									■	■					
	-Feasibility of studies									■	■					
5	**Project Work Continues**															
	-Gather the data & information											■	■			
	-Preparation of mechanism of research (by Framework method)											■	■	■		
	-Preparation of Interim Report												■	■		
6	**Submission of Interim Draft Report**														●	
7	**Submission of Interim Report**															●

Process ■ Milestone ●

Gantt Chart for FYP II : September 2013

	Month	Sept		Oct				Nov					Dec			
No	**Detail/week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	**Project Work Continues**															
	-Comparison with other research															
	-Gather more information															
	-Implementation of mechanism of research (framework)															
	-Preparation of progress report															
2	**Submission of Progress Report**															
3	**Project Work Continues**															
	-Analysis the mechanism result															
	-Comparison of results															
	- Propose the recommendation								**Mid-Semester Break**							
	-Preparation of report & Presentation															
4	**Pre-SEDEX**															
5	**Preparation & Submission of Draft Report**															
6	**Submission of Dissertation (soft bound)**															
7	**Submission of Technical Paper**															
8	**Oral Presentation**															
9	**Submission of Project Dissertation (Hard Bound)**															

Process Milestone

CHAPTER 4
RESULT & DISCUSSION

4.1 Findings

Based on literature review, the utilization of sulfur in asphalt mixtures given the better performance especially in relation to mechanical properties of pavement such as increase stiffness and permanent deformation. However, some precautions need to be consider during the production process in order to ensure the pavement performance is in good condition like the normal asphalt mixtures. For example, the temperature of SEAM mixture must ensure not to exceed 145°C during the production process to avoid the emission of toxic gas which is hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) due to it can produce harmful effect especially to human.

Hence, for this project there are five aspects of the utilization of sulfur in asphalt mixtures that was emphasized in relation to the objectives of this project which is mechanical properties, durability, environmental, economic and health and safety. Then, there are few key findings that has been found based on literature review from several sources obtained on the past research to support this studies of the use of sulfur in flexible road construction opportunities and concerns. The evaluation of this study was conducted through the assessment form of critical thinking framework method of author which is within the scope of this studies and supported with past research findings.

Hence, figure 4.1.1 shows the summary graph of the framework method assessment form result of the utilization of sulfur in asphalt mixtures based on the category in this studies which evaluated by the author.

Throughout the result, it can be seen that the health and safety is the highest marks following with the mechanical properties, environmental, and economic effects. Then, the lowest result of this evaluation is durability effect. Due to these findings, it indicate that health and safety effect of the utilization of sulfur in asphalt mixtures is within the safe limit and under control.

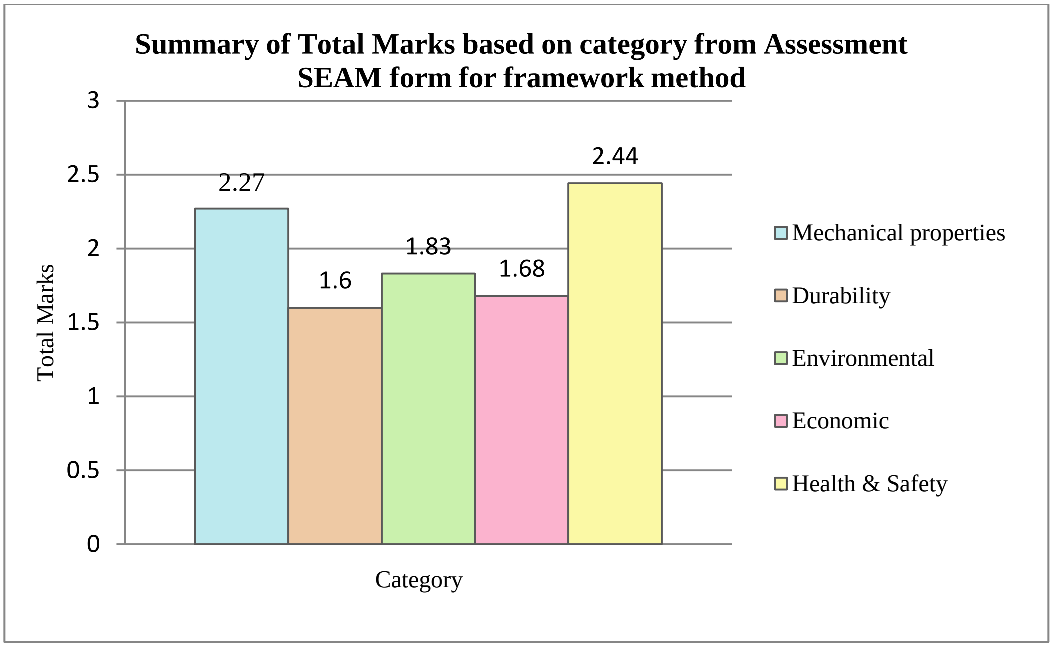


Figure 4.1.1 : Summary of the assessment SEAM form result of the framework method

4.2 Data gathering

All data was gathered from the literature reviews and was evaluate through the assessment form of critical thinking by framework method. Then, all the data are evaluate based on the performance from previous research or field trial test of the utilization of sulfur in asphalt mixture.

The following table showed the findings result together with the justification of marks awarded by the author for every aspects that was studied which in relation to the objectives of studies. Then, the data was analyze through the graph to evaluate the effect of ±5% and ±10% to the weighting factor for every category.

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4.3 Data analysis

4.3.1 Mechanical Properties

The utilization of sulfur in asphalt mixtures have proven increase the performance of mechanical properties based on the previous research. The rut depth result of pavement containing sulfur shows less than the normal asphalt mixtures in mostly field trial test. The stiffness of pavement also increase with the addition rate of sulfur more than 30% in the asphalt mixtures. Then, the moisture sensitivity of SEAM mixtures found there is no different in binder film detachment after the comparative immersion test with the normal asphalt mixtures based on previous research.

According to the assessment form result of the utilization of sulfur in asphalt mixture which is evaluated by author, the total marks of mechanical properties is 2.27. This make the mechanical properties is the second highest value compared to the others category. Then, the data analysis of this study was conducted through the effect of total marks by the percentage of ±10% and ±5% change in weighting factor. Hence, the following graph shows the result of total marks with percentage change in weighting factor for the evaluation of mechanical properties. From the graph, it can be seen that the total marks still not exceed the control marks value which is the weighting factor value. This shows that the total marks without the percentages changes is reasonable due to the percentage change in weighting factor was not exceed the control value.

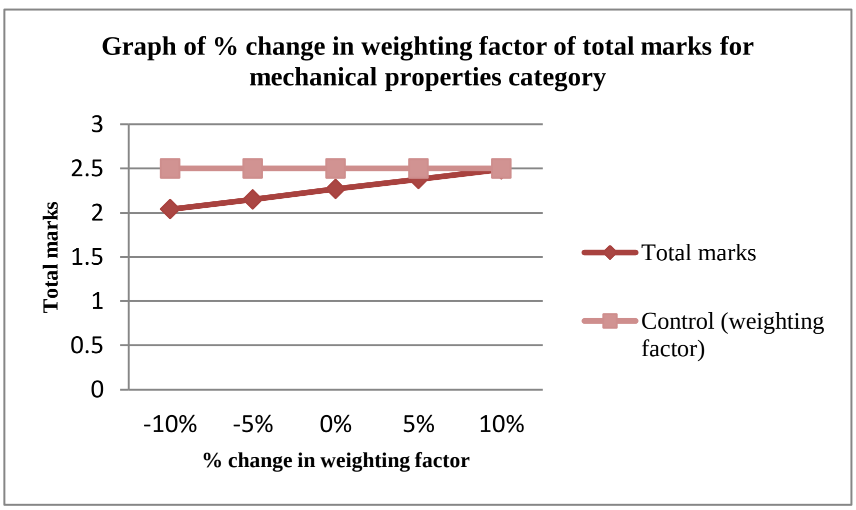

Figure 4.3.1 :Graph of total marks changes in weighting factor for mechanical properties

4.3.2 Durability

For the durability effect in the utilization of sulfur in asphalt mixtures, it was evaluate based on fatigue cracking, water sensitivity and temperature effect. According to previous research, it shows that there is less cycles to failure for the fatigue curve of SEAM mixtures but the problem is the level of strain tends to be lower due to the higher modulus of SEAM mixtures. Hence, the SEAM mixtures should be improved especially for the better binder mixtures and grade. Then, the temperature effect of SEAM mixtures indicate there is no effect on temperature susceptibility by incorporation of 40% sulfur pellet. This proves that the SEAM mixtures able to stand even in a lower temperature and higher stress. However, the fracture temperature becomes reduces when the bitumen becomes softer.

Based on the assessment form result of the utilization of sulfur in asphalt mixture, the total marks of the durability effect in SEAM mixtures indicate the lowest ranking which is 1.60. However this does not mean SEAM mixtures has failed because it can be seen from the mechanical properties aspect the mixtures shows better performance than normal asphalt mixtures. Therefore, the effect of durability of pavement can be improved in SEAM mixtures by emphasized the durability effect. The following graph shows the results of total marks with percentage change in weighting factor for the durability effect of SEAM mixtures. From the graph, the total marks still not exceed the control value marks.

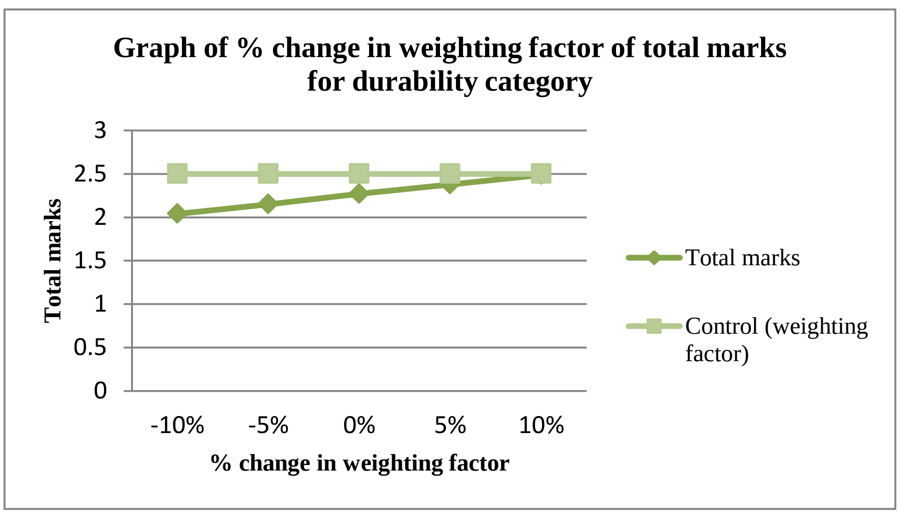

Figure 4.3.2 : Graph of total marks changes in weighting factor for durability

4.3.3 Environmental

An environmental aspect especially during the production process of the sulfur asphalt mixtures is very important due to any change to the environment may produce a significant bad environmental impact. Therefore, effect of the environmental to the sulfur asphalt mixtures in this study was evaluate in two aspect which is air quality and changes in soil. For the air quality effect, there is less data available regarding with the emission of particulate from sulfur. However, based on previous research there is certain amount of un-dissolved elemental of sulfur detected during the operation process but crystallizes similar to dust and fine sands. Hence, the precautions need to be carried out due to it can irritating eyes.

Then, there is no changes in soil or run-off water quality that may affected the environmental aspect of sulfur asphalt mixtures. However, the environmental aspects may arise if the maintenance of the pavement was not conducted with efficient whereas the leaching problem can occur when the drainage around the road is clogged.From the assessment form result of the utilization of sulfur in asphalt mixture, the total marks of the environmental effect in SEAM mixtures is relatively good which is 1.83. Then, the following graph shows the environmental effect result of total marks by the percentage change in weighting factor was still not exceed the control value marks.

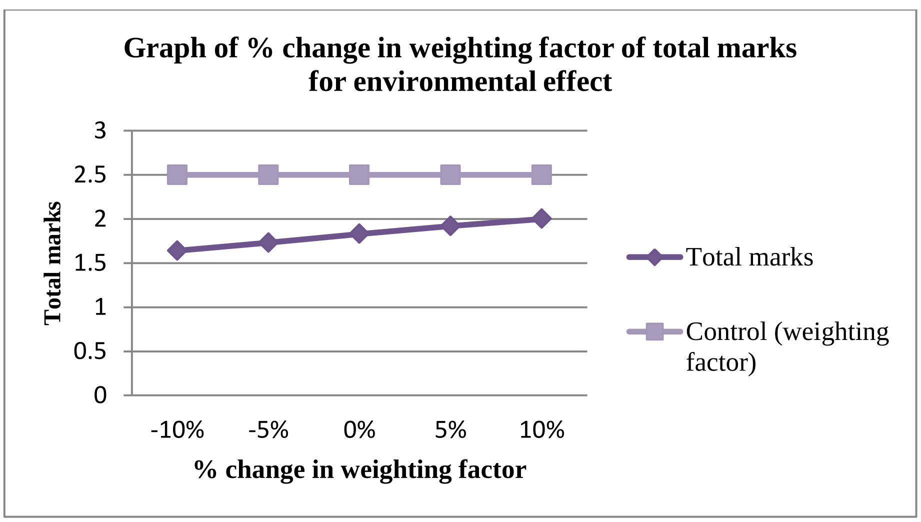

Figure 4.3.3 : Graph of total marks changes in weighting factor for environmental

4.3.4 Economic

Economic impact from the utilization of sulfur in asphalt mixtures was evaluate based on two aspect in this studies which is life cycle cost and socio economic factor. The life cycle cost of SEAM mixtures is important to keep the supply of sulfur is available and affordable so that it is effective to conducted. Based on the literature reviews, there is no problem with the availability of sulfur now due to the increase number in oil and gas industries that prevents of sulfur present in fossil fuels which causing the price of sulfur drop. Then, the sulfur asphalt mixtures able to reduce paving material costs as much as 21 percent based on previous research.

For the socio economic factor, the utilization of SEAM mixtures able to reduces the oncoming sulfur surplus for a market about nearly one million tons of sulfur annually. According to the assessment form result of the utilization of sulfur in asphalt mixtures, the total marks of economic effect is 1.68 which still in the good ranking. The following graph shows the result of total marks with percentage change in weighting factor of the economic aspects. From the graph, it can be seen that the total marks still not exceed the control value marks.

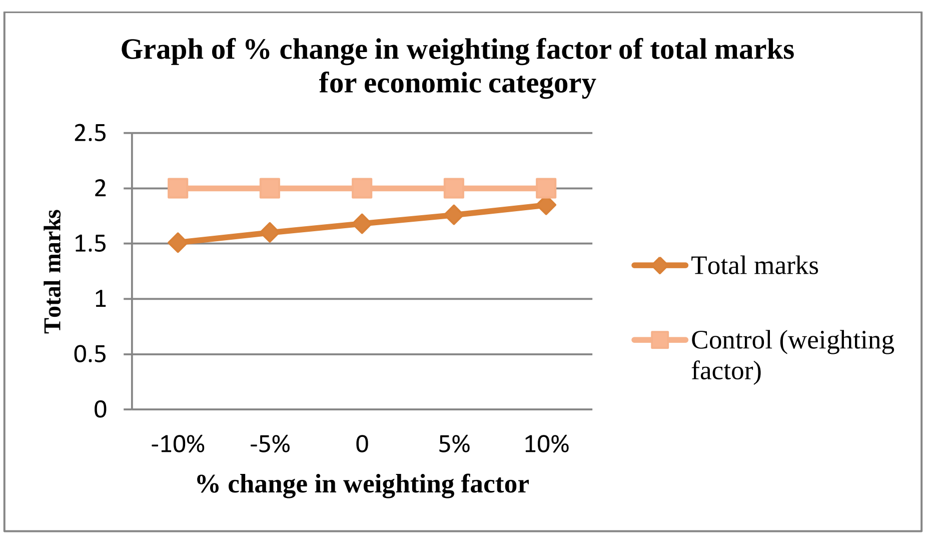

Figure 4.3.4 : Graph of total marks changes in weighting factor for economic

4.3.5 Health & Safety

Health and safety issues are related with the measures taken to produce the safe environment for employees and workplace during working time. Hence, risk of any potential hazard that may arise need to be consider even in the small percentage. In this studies, the health and safety is evaluate based on three aspects which is transportation, impact to human and recycled material or waste. For the transportation impact, the problem is related with the storage of liquid asphalt at high temperature and following the vacuum distillation. However, this issues was overcome by using the sulfur pellets.

Then, impact to human for this studies is related with the emission of toxic gas which is hydrogen dioxide (H_2S) and sulfur dioxide (SO_2). Based on literature reviews, the toxic gas and pollutants including H_2S and SO_2 are within the safe limits when the temperature is to be less than 145ºC. Hence, the temperature limit need to be control to avoid the emission on toxic gas that effect to human. However, an alternative of safety precautions can be implement such as wearing the respiratory, skin and eye protection. Regarding with the recycle material of sulfur asphalt mixtures, SEAM paving mixtures have been successfully recycled in double-drum continuous pants and in batch plants based on previous research.

According to the assessment form result of the utilization of sulfur in asphalt mixtures, the total marks of health and safety is 2.44 which is the higher marks compared to the others category. This is due the author believe that the safety and health aspect is important element especially to protect the employees at work. It does not effective if other factors show better performance but the health and safety issues was not emphasized. Then, the following graph shows the result of total marks with percentage change in weighting factor for the evaluation of health and safety. From the graph, it shows the total marks still not exceed the control value marks.

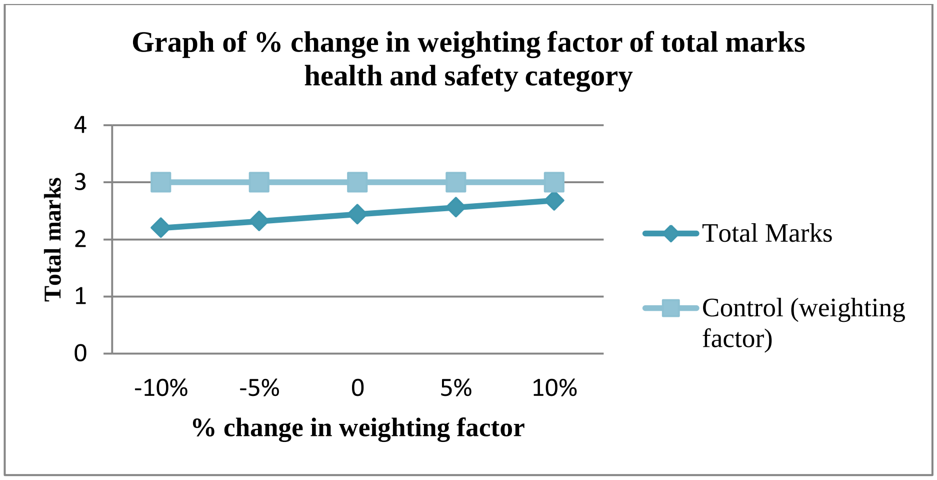

Figure 4.3.5 : Graph of total marks changes in weighting factor for health and safety

The below graph indicated the summary of total marks of percentage change in weighting factor for all category. From the graph, it can be seen that all the graph is in linear line which represent the total marks was change with regular and within the weighting factor value. However, the total marks of initial value awarded by author and ±10% in weighting factor was change after the addition of all categories. The addition value of all categories for 10% in weighting factor is 10.78 and the initial value of marks awarded by author is 9.82. This indicated that the addition of 10% in weighting factor value of all categories is the highest value compared the initial value marks awarded by author and the others percentage.

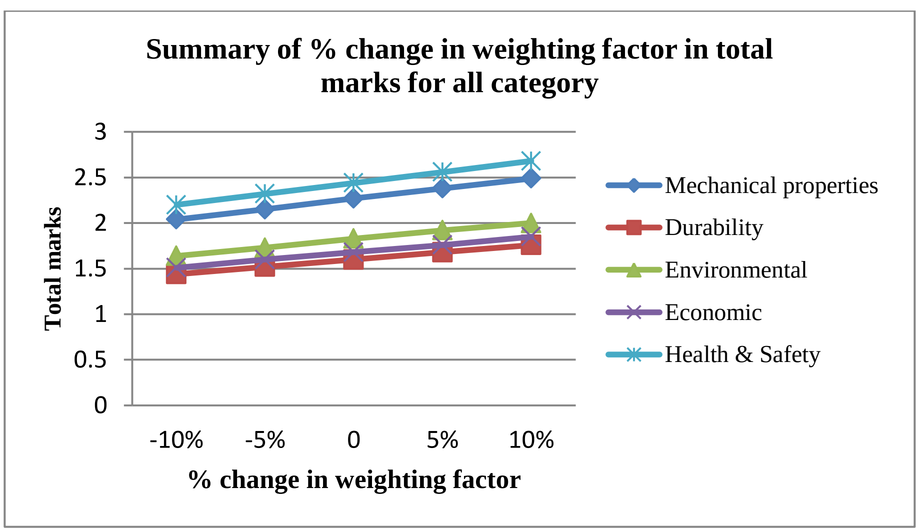

Figure 4.3.6 : Graph summary of total marks changes in weighting factor for all category

CHAPTER 5
CONCLUSION & RECOMMENDATION

Sulfur extended asphalt modifier (SEAM) has improved the performance of the pavement and making it more stronger than any other additive in use now. According to the literature reviews, mechanical properties effect of sulfur on road construction has increased stiffness and reduced permanent deformation. This can be seen from the rutting test result where the ratio of 40/60 sulfur asphalt concrete mix gave the less rutting problem. Then, health & safety effect of the utilization of sulfur in asphalt mixtures was still within safe limit condition during production process as long as workers follow the safe operating procedures in order to avoid the health hazards especially of the emissions gaseous of sulfur dioxide (SO_2) and hydrogen sulfide (H_2S).

However, the durability effect of modified sulfur is still not achieving the standards life years of road which is 20 years. The most previous test has been conducted during 10 until 5 years period test. Hence, the durability effect of sulfur on road construction still need to be studied to achieved the minimum standard life years of road.

For the improvement of this research, a few matters are recommended for the future effort enhancement of this research. The recommendations are as follow:

- Safety practices for the handling of sulfur modified asphalt mixtures need to be implement and emphasized.
- The durability of utilization sulfur on road construction needs to investigate more.
- Using the pellets shape of sulfur elemental in the sulfur extended asphalt mixtures rather than using the liquid sulfur due to it more easily to produce the harmful effect.

- Always to ensure the temperature during the operational process is below the maximum temperature limit.

5.1 Relevancy to the objectives

The purpose of having this project completed is to determine and analyze the use of sulfur as a constituent in asphalt wearing and base course in relation with some aspect which is mechanical properties, durability, environmental, economic and health and safety. So far, the project completion is still serving the purposes and hopefully, can meet the requirement set early.

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APPENDICES

Appendix A : Example Calculation of Sulfur Asphalt Ratio Mixture

The following is the example calculation to convert a conventional mix design to an equivalent volume of total binder (sulfur and asphalt) based on Bureau Mixes work.

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

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

This total binder content is then divided accordingly :

20 x 5.8 % = 1.16 % sulfur

80 x 5.8 % = 4.64 % asphalt

Reference :

FHWA-HIF-12-037 *Tech Brief, An Alternative Asphalt Binder, Sulfur-Extended Asphalt (SEA)*, (2012)

Appendix B: Problem in Road Construction

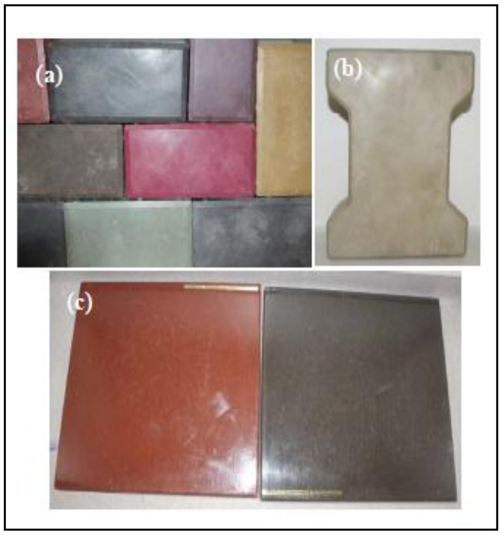
Permanent deformation in a road in Qatar

Portland concrete degradation from seawater in Qatar

Reference :

Innovative Solutions for Sulfur in Qatar, Al-Ansary, M. (2010)

Appendix C : Sulfur Concrete Product



Paving blocks, I-Blocks and Tiles

Shell sulfur concrete chessboard

Sulfur concrete color

Recycle product from Shell sulfur

Reference :

Innovative Solutions for Sulfur in Qatar, Al-Ansary, M. (2010)