

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



EVALUATION OF SAND-BITUMEN MIX AND RUBBER MEMBRANE
JOINT SEALANTS FOR ONGOING RIGID PAVEMENTS IN ETHIOPIA:
CASE OF DITCHOTO GALAFI CONCRETE ROAD PROJECT

By:
Sara Getachew Worku

A Thesis Submitted to the school of Graduate Studies of Addis Ababa
University in Partial Fulfillment of the Requirement for the
Degree of Master of Science in Road and Transport Engineering

Advisor

Ing. Robeam Solomon (PhD.)

June 2022

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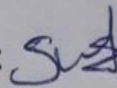
UNDERTAKING

I hereby declare that this thesis entitled "Comparison of Different Sealants (Sand-Bitumen Mix and Rubber Membrane) for Ongoing Rigid Pavements in Ethiopia" was composed by myself, with the guidance of my advisor Dr. Ing. Robeam Solomon, and that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification.

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Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

ABSTRACT

As a part of its Road Sector Development Program (RSDP), the government of Ethiopia has been investing a significant amount of money in constructing different surface type roads. And, due to its higher life span, low maintenance and operation cost, rigid pavements (cement concrete surface types) have been emerging as the preferred pavement type to be constructed in high-temperature areas like the eastern part of Ethiopia, where there are 195.5km long ongoing rigid road projects including the case study project. In rigid pavement construction, space (joint) provided for the concrete pavement slabs was a solution given to the slabs so that they could be able to expand and contract during hot and cold temperatures until incompressible materials intrude between slabs and water infiltrating the subgrade was proved problems. Hence, to mitigate the detrimental effects of such intrusions on the performance and service life of the pavement, sealing the slab joints with sealants has become imperative. In connection with rigid pavement joint sealing practices in Ethiopia, the case study project, unlike the other three similar ongoing road projects in Ethiopia and the trends followed worldwide, has utilized a sand-bitumen mix in place of the renowned silicone joint sealants. Hence, in this research, comparative assessments on different joint sealant types (sand-bitumen mix and rubber) to replace silicone joint sealant were done. Accordingly, starting from the mix design of sand-bitumen mix with varied proportions (20/80, 25/75 and 30/70) and rubber membrane in Horizon Addis Tire laboratory, physical-mechanical properties of both sealants were evaluated in the laboratory as per ASTM standard test method. In addition, field observation was made on the case study project. As the result, unlike the sand-bitumen mix sealant which has failed all the envisaged physical and mechanical tests, the rubber membrane has exhibited incredible resistance to oil, UV, heat and abrasion. Furthermore, the rubber membrane attained an elongation, tensile, adhesion and cohesion strength, 22.2%, 7.4%, 140% and 229.2% higher than the requirement in the respective order whilst the measured hardness and compression sets were within the permissible range. Additionally, during the field observation of the case study project, different types of joint sealant failures at different severity levels (medium =75%) and (low =25%) were detected. Also, initial and maintenance cost comparisons made between the three sealants revealed that application of silicone sealant to seal the joints costs almost 200% and 1572% more than rubber membrane and Sand-Bitumen joint sealant in their respective order. Therefore, this research concluded that, from the alternative sealants, rubber membrane has endowed potential to replace the renowned silicon sealant. In addition, in this research, based on the scope and limitations of this research, recommendations were made.

Key Words: Rigid Pavement, Joint Sealant, Sand-Bitumen Mix, Rubber Membrane and Silicone Sealant

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List of Abbreviations /Glossary

- ERA: Ethiopians Road Administration
- RSDP: Road Sector Development Program
- SMR-20: Standard Malaysian Rubber
- SBR 1500: Styrene Butadiene Rubber
- CIS BR 1220: C is-1,4 Polybutadiene Butadiene Rubber
- HAF-HS: High Abrasion Furnace black High Structure
- DUTREX RA-3: Dutrex play feel lubricant-Red Alert 3
- 6PPD: phenyl-p-phenylene diamine
- DTPD: Ditolyi-P-Phenylendiamine
- DPG: Dipropylene Glycol
- CBS: Cyclohexyibenzothiazol-Sulphenamides
- ASTM: American Society for Testing and Materials
- PHR: Parts per Hundred Rubber
- PCP: Pre-Stressed Concrete Pavement
- JRCP: Jointed Reinforced Concrete Pavements
- CRCP: Continuous Reinforced Concrete Pavement
- JPCP: Jointed Plain Concrete Pavement
- LTR: Low Thermal Resistance

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1. INTRODUCTION

1.1. Background

The construction of the first concrete road dates back to 1908 making its birthplace in Detroit, Michigan, while airfield rigid pavements were introduced nearly two decades later in the 1930s [1]. Since the dawn of concrete road construction, pavement engineers have been working hard to improve the quality of rigid pavements. As parts of such efforts, in rigid pavement construction, space (joint) was provided for the concrete pavement so that they could be able to expand and contract during hot and cold temperatures thereby saved from tensile failure resulted from the innate low tensile strength of concrete slabs. However, just before World War II, incompressible materials intrude between slabs and water infiltrating the subgrade was proved to cause detrimental effects on the performance and service life of the pavement. Hence, to safeguard the open joints from being choked with engulfed incompressible materials and rescue reinforcement bars and dowels from the corrosion application of joint sealant has become crucial. In addition, joint sealants were also necessitated to keep moisture from infiltrating the subgrade [2]. Hence, By mitigating water-related problems such as pumping and softening erosion of subgrade and base layer fines whose infliction on the support of pavement slabs causes higher load stresses in the concrete, pavement settlements, corner cracks and/or faulted transverse or longitudinal joints. Hence, joint sealing or filling enhances the performance of concrete pavements [3]. Since the 1900s, when mankind became aware of the repercussion of leaving the joints open, they introduced deliberate cracks to the rigid pavement and sealed the cracks. Since then, many joint sealant materials have been used with all their controversial features [4], [5].

In Ethiopia, currently, five rigid concrete pavement construction projects covering 226.65 km are underway in the eastern and northern part of the country and the case study project, **Ditchoto Galafi Junction - Elidar - Belho Design and Build Road** is among them.

In the case study project, the contract document subscribes application of silicone sealant to seal transversal and longitudinal joints of the concrete pavement road. However, due to its significant cost implication, hard currency problem, and prolonged time required to import the silicon sealant, the project was obliged to look for other alternative replacement, like the sand-bitumen mix. Hence, to use other alternatives as the silicone sealant (sand-bitumen mix and rubber membrane), both laboratory and

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field performance and cost evaluation of the sand-bitumen mix and rubber membrane was done.

Aiming to understand the true nature of the distinct types of sealants in the field and the laboratory, many researchers and professionals have invested their time and money, and as can be understood from their respective stands reflected in their work, many have agreed to the need to seal joints but the choice on the type of sealants has been controversial [6].

This study, unlike any of the research conducted on the subject, evaluates the field and laboratory performance of sand-bitumen mix and rubber membrane joint sealant to use in place of silicone sealants, fueled by the cost and the time implications of imported joint sealants in addition to the envisaged performances, this research has managed to draw remarkable conclusions regarding joint sealants which are being adopted in rigid pavement joint sealing in Ethiopia.

Whilst no study on the subject area has been conducted in Ethiopia to date, in this study, a pioneering work, at least in Ethiopia, on performance evaluation of sand-bitumen mix and rubber membrane joint sealants to use as the imported silicone sealants was done and based on the finding, a new practice to replace silicon sealants for ongoing rigid pavements in Ethiopia is recommended.

1.2. Statement of the Problem

In the view of growing need for the construction of rigid pavement types and the need safeguard the joints from the detrimental effects of intruding incompressible and infiltrating water, sealing rigid pavement joints with standard sealants like silicone sealant is required. However, due to the hard currency problem, highly inflated cost and time implications of imported sealant types, exploring alternatives sealants than can be prepared locally (with full or partial substitution of components) and to be used in place of the so-called renowned joint sealant types like silicone is required and same was attempted.

However, as the attempt to replace the imported sealants by other alternatives was not supported by researches and empirical outputs, conducting researches on the potential alternatives that can be used as imported sealants (like silicone) is required. Accordingly, this research has focused on comparing the three alternatives, sand-bitumen mix, rubber membrane and silicone sealants, both in their laboratory and field performance and cost wise. Hence, among the three, the case study project has

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utilized sand-bitumen mix as a joint sealant, and this research has an objective of evaluating the sealant (sand-bitumen mix) as applied between the joints of Ditchoto Galafi road project.

In the case study rigid pavement project, even though no technical and engineering justification has been given regarding the qualification of the sealant for the envisaged purpose, sand-bitumen mix joint sealant has been utilized to seal the joints of the road project. Hence, considering the design life of pavement and service life of sealants (durability), construction methodology and maintenance cost requirements of the road, ensuring the appropriateness of this new trend and other potential replacements empirically and present the finding worth research at least, as billions of birr are invested and no room to duplicate the mistake, if any, and/or manage the failure at the early stage.

1.3. Objectives

1.3.1. General Objective: -

The general objective of the research is to study and better understand the endowed comparison of the performance of sand-bitumen mix and rubber membrane, customized in Horizon laboratory, as a joint sealant instead of commonly used silicone sealants for ongoing Rigid Pavements in Ethiopia.

1.3.2. Specific Objectives: -

- To evaluate and verify the potential of sand-bitumen mix to use as silicone sealants.
- To evaluate the potential of rubber membrane to use as silicone sealants.
- To evaluate the field performance of sand-bitumen mix based on field observation of the sealant at Ditchoto Galafi Rigid Pavement Road project.
- To compare the initial and maintenance cost of sand-bitumen mix and rubber membrane joint sealants with the renowned silicone joint sealants.
- To identify the specific features/characteristics, challenges and prospects of utilizing sand-bitumen mix rubber and membrane as a joint sealant.
- To identify comparative pros and cons of using sand-bitumen mix and rubber membrane as a joint sealant (By benchmarking the international practices and lessons learned in using rigid pavement joint sealants).

1.4. Research Questions

- Can sand-bitumen mix fulfill all the desirable properties of formed in place joint sealants?
- Can rubber membrane fulfill all the desirable properties of preformed joint sealants?
- What is the endowed potential of sand-bitumen mix to use as silicone joint sealant?
- What is the endowed potential of rubber membrane to use as silicone joint sealants?
- What is the field performance rating of sand-bitumen mix joint sealant applied at Ditchoto Galafi rigid pavement road project?
- What is the comparative life cycle cost of silicone, sand-bitumen mix and rubber membrane joint sealants if applied to seal the joints of the Ditchoto Galafi rigid pavement road project?
- What are specific features/characteristics, challenges and prospects of utilizing sand-bitumen mix and rubber membrane as a joint sealant?

1.5. Significance of the Research

- The study will introduce alternative sealant materials to the road construction industry as well as to local manufacturers.
- The study will give better engineering judgment to the potential alternatives to replace silicone sealant.
- This study will provide cost comparisons and laboratory and field performance evaluations of alternative sealants.
- The results of the research can influence the existing practice of applying silicone sealants on joints for ongoing rigid pavement construction works and between Deck and Bridge Approach Slab of flexible pavements on Federal roads in Ethiopia by unfolding any inherent potential of sand-bitumen mix and rubber membrane to replace the putative silicone joint sealant.
- The study can be used to fill in the gaps and add to the existing knowledge on the possibility of

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replacing the imported, costly silicone and polysulfide joint sealants with sand-bitumen mix and rubber membranes based on laboratory and field performance evaluation

- The findings of this research may trigger more advanced multidisciplinary research (on an institutional level), as the research is limited to simple laboratory confirmatory tests and short duration field performance evaluation of sand-bitumen mix and rubber membrane joint sealant.

1.6. Scope of the Research

This thesis work evaluates any potential of sand-bitumen mix and rubber membrane joint sealants to use as silicone sealants for ongoing rigid pavements in Ethiopia through;

- Laboratory tests based on the envisaged standards and specifications and field performance of sealant
- Exhaustive literature review and studying the experience of other countries regarding joint sealant applications in their rigid pavements.
- Collecting and analyzing data based on mix design prepared for sand-bitumen mix and material production specification of rubber membrane, and laboratory confirmatory tests and field installation and short lived performance evaluation of the same will be done in a case of Ditchoto-Galafi concrete road project.
- Identify improved, economical methods for sealing joints in concrete pavements.

1.7. Limitations of the Research

This thesis work has limitations on the following points:

- In this study, with the help of the mix design prepared using sand-bitumen mixes and rubber membrane and laboratory confirmatory tests, the effects of vehicular and environmental loading on the joint sealant performance on the field are evaluated. However, field performance evaluation of sand-bitumen mix is done for a short duration which may negatively affect the interpretation and quantification of vehicular movement impacts on joint sealing capabilities of the presumed sand-bitumen mix rigid pavement joint sealants.
- This research is a case study of the Ditchoto-Galafi road project. And research has indicated that the performance of the joint sealant is inextricably associated with the installation method

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and weather condition of the project area. Hence, only one project cannot be a representative model for other projects.

- This research relies merely on literature reviews to assume the performance of silicon as rigid pavement joint sealants. Hence, their comparison with the presumed replacement (sand-bitumen mix and rubber membrane) will be performed based on the findings of others, which may have been affected by the research's context.
- Research has indicated that a multi-disciplined set of rules and a field-tested methodology and sciences are necessary to successfully understand the nature of the technologies related to adhesives and sealants. However, this research is limited to confirmatory laboratory tests and short-lived field performance evaluation of sand-bitumen mix as a joint sealant.

2. LITERATURE REVIEW

2.1 Introduction

The construction of the first concrete road dates back to 1908 making its birthplace in Detroit, Michigan, while airfield rigid pavements were introduced nearly two decades later in the 1930s. Since the dawn of concrete road construction, pavement engineers have been working hard to improve the quality of rigid pavements. However, it was not until the advent of World War II in 1941 that rigid pavements were utilized extensively. During these years, as rigid pavement joints were constructed very wide and with noticeable edge imperfection, the riding quality they provided had been rated as poor. With no further attention given to the preparation of joint surfaces, tar and asphalt were primarily used to seal the rigid pavement joints. Attributed to inattention given to the surface preparation before sealing the joints of rigid pavement and resealing without removing the old sealant has undermined the intended purpose the joint sealants serve and left the resealing technique very ineffective [3].

It was necessary to wait until the end of World War II to resize the long slabs to short slabs as the result of which wider pavement joints were proportionally resized to smaller joints and witnessed significant improvement to the quality of concrete pavements. In addition, significant improvements were brought to sealant adhesion to the pavement by replacing previously adopted techniques, forming the joint in the plastic concrete by Sawing joints. Even though unwanted consequences of increased sealant strains were entertained due to the narrowed and deepened joints during the introduction of this sawing technique, increasing the depth of the joints by nearly $\frac{1}{4}$ of the pavement slab depth was made possible [3]. As problems had always given human beings the audacity to look for solutions, the engineers had used the incident as a stimulus to search for better materials that would withstand these strains. Besides, for jet fuel spills dissolved them, traditional tar and asphalt sealants used to seal slabs at the airport had to be replaced. Research into the use of elastomers as sealants and improving joint surface preparation was undertaken. The importance of the shape factor (sealant depth to width ratio) in field-molded sealants was also affirmed during this time [13].

Even though great advancements made in the World War II-era to date has increased the average life of joint sealants within concrete pavements to five years, sealant life needs to be much greater.

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Regarding the best sealant to assure a long-lasting concrete pavement, agencies still have not reached harmony. The use of continuous reinforced concrete pavements (CRCP) and pre-stressed concrete pavements (PCP) have not always been a suitable replacement for jointed concrete pavement. Even with jointed concrete pavements, both the best sealant to be used to seal the joints and the need to use a sealant at all is currently debatable [6].

2.2 Joint Design and Construction

Concerning the specific types of rigid pavements, four types are identified: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavements (JRCP), pre-stressed concrete pavement (PCP), and continuous reinforced concrete pavement (CRCP)., no steel reinforcement is used and joint spacing is usually between 4.6 and 9.1 meters (for JPCP), but still, the aggregate type and climate are the influencing parameters. In jointed reinforced concrete pavements, the provision of wire mesh steel reinforcement allows the use of larger joint spacing (9.1 to 30 meters), likewise, the pre-stressed steel reinforcement in JPCP allows the use of much larger joint spacing (91 to 232 meters), whereas, continuous reinforced concrete pavements eliminate the need for joints as steel reinforcement is uninterrupted throughout the pavement slab [3]. However, transverse (perpendicular to the flow of traffic) expansion joints which are used to relieve compressive stresses, are rarely used today because they are difficult to maintain and are susceptible to pumping. Designed to relieve curling and warping stresses resulting from temperature or moisture gradients that occur in the slab, longitudinal joints (parallel to the flow of traffic) are provided to concrete pavements. Tensile stresses in concrete that arise from thermal volumetric changes are handled by transverse joints which are also known as contraction joints. To adequately relieve thermal stresses from a concrete slab, the contraction joint need to have certain characteristics. Four elements that should be considered for a good joint system design are joint width, joint depth, backer rod selection, and sealant selection and placement [14]. In addition to allowing easy installation of sealant, the width of a joint has to accommodate the adjacent slabs for expansion during warm climates.

The equation used to calculate the thermal expansion of a concrete slab is as follows:

$$\Delta L = C * L * (\alpha_{concrete} * \Delta T + \epsilon)$$

Where,

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ΔL = change in length of the concrete slab;

C = Sub base/slab frictional factor (0.65 for stabilized material, 0.80 for granular material);

L = original length of the concrete slab;

α_{concrete} = coefficient of thermal expansion for concrete ($\approx 6 \times 10^{-6} 1/^\circ\text{F}$);

ΔT = maximum temperature range; and

ε = shrinkage coefficient of concrete.

When the above equation is used for concrete pavements that are at least 20 years old, simplification to $\Delta L = L * \alpha_{\text{concrete}} * \Delta T$ may be required [15]. According to McGhee, it is not only concrete slab length that greatly affects the thermal coefficient of expansion of the concrete but also the type of aggregate used in the concrete [16]. Even though there was a track record of good quality concrete has performed adequately when the joint spacing (in feet) does not exceed four times the slab thickness (in inches), contraction joint spacing of 4.6 to 6.1 meters (15 to 20 feet) is usually used for plain rigid pavements and as recommendations regarding the joint reservoir depth was concerned, usually, one-fourth to one-fifth of the slab thickness and a minimum of 25 millimeters were dictated. However, in some states, just to avoid the potential resonance of high speeds in automobile suspension systems; joint spacing has been randomized [17].

In the contraction of joints, variable methods may also be adapted. Manually, they may be constructed with a jointer and an edger, placement of plastic strips, sawing after sufficient hardening, or mechanically inserting a steel T-bar to form a groove. However, while a manual method is used, to acquire the envisaged joint depth, the application of a jointer and an edger must be handled with great attention. To mitigate raveling of the edges by the saw blade, sawing the contraction joint should be done as soon as the concrete is hard enough, but still without undermining the potential random cracking [17]. After the sawing is finalized and before the sealant is installed, any shavings should be cleaned from the joint. To get this done, most agencies hire sandblasting, water blasting, wire brushing or some combination thereof, followed by air blasting just before sealing [16]. According to ACI, proper cleaning methods supplement the sealant with a better adhesion surface and would help prevent future spalling due to slab thermal expansion. Also, to mitigate the adverse effect of wet joints on adhesion, the joint should be dry. Grease and oil-type contaminants will also interfere with the formation of a sound bond [18].

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Joint sealant can be classified into two types: field-molded or preformed. When field molded joint sealant types are applied, the shape factor of the sealant is a major parameter that must be taken into consideration. Quantification of the shape factor accounts for the minimization of cohesive strains by enhancing a sufficient bond area to accommodate adhesive stresses at the sealant-joint interface. Typical values for the shape factor range from 0.5 to 1.0 [16].

To select specific type of rigid pavement joint sealant materials for application, some guidelines that should be used include [19]:

- Sealant ductility at cold temperatures,
- Sealant rigidity at high temperatures,
- Sealant compatibility with the aggregate within the concrete slabs, and
- Sealant durability to weather, traffic, and chemical attack.
- Life cycle cost
- Ease of installation
- Ease of replacement

Field moulded sealants may be either hot-poured or cold-poured however, to avoid overheating that in turn causes the sealant to lose some of its elasticity, slow heating of hot-poured sealants is necessary. On the other hand, under heating negatively affects the workability of the sealant by making it hard to place in the joint. Cold-poured sealants, on the other hand, are fabricated by mixing two or more components on the job site just before sealing. It is necessary that the correct material proportions are used and that the components are thoroughly mixed. This will ensure the proper curing of the seal material [19].

As their name indicates, preformed joint seals are formed (molded) before installation in the field and do not require the use of backer material during installation. According to McGhee, the desired properties of materials used for performed seals include [16]:

- Durability (hardness),
- Resiliency, and Compressibility,
- The ability of the material to sustain a long-term compressible state without developing “compression set,” a condition permitting the seal to either drop into the joint or come out

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under traffic.

One characteristic of most preformed seals that allows them to stay compressed during their entire service life is the webbed cross-section. The selected seal should have an uncompressed width of twice the minimum expected width of the joint [16].

2.3 The Need for Joints and Sealants

The detrimental power of both water and incompressible that leads to serviceability failure of the pavement system has necessitated sealing the joints in Portland cement concrete pavements.

Provision of joints for the contraction of concrete structures is necessitated due to the low tensile strength of concrete. Continuously reinforced concrete pavements and long-jointed concrete pavement slabs are expected to crack. These cracks, if left unattended, will lead to the same types of failure as inadequately sealed joints. Jointed concrete pavements with short (10 to 20-ft.) slab lengths are intended to keep the slabs from cracking [1].

The United States was the first place where jointed concrete was first used as a paving system in 1903, since then, wood, tar, asphalt, rubber, inorganic elastomers, and many other materials have been used to seal the joints. At present, in addition to the availability of hundreds of sealants for the pavement designer to choose from, the subject of joint sealing in concrete pavements with an extensive background of research has been published in many papers, articles, and books. Yet, even with all this experience and research, the acceptable sealing of joints continues to be one of the most difficult problems in concrete pavement design and maintenance [1].

Emanating from the fact that the current practice of sealing joints does not truly “seal” the joint throughout the performance or design period of concrete pavement, which is 30 years in Texas, with all the well-known benefits of joint sealing, there has been a controversy over whether these benefits are materialized in actual pavements. Based on field observations and opinions of engineers involved in PCC pavement design, construction and maintenance at several states' Department of Transports (DOTs), the average effective life of joint sealing, varies from seven to ten years, which would require re-sealing joints three to four times during the performance period of PCC pavement in Texas [20].

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However, re-sealing joints are rarely done, even some northern states, such as Wisconsin and Minnesota, do not seal joints where the design speed is more than 45 miles per hour because of the field evidence made in Wisconsin that no difference in PCC pavement performance was observed in PCC pavement sections with joints sealed and not sealed [20]. According to Shober, the very worst performance resulted from partially sealed or filled joints. Based on the extensive field evidence in Wisconsin, Wisconsin DOT passed a policy in 1990 to eliminate all PCC joint sealing in new construction and maintenance. Since then, the necessity to seal joints becomes a national issue. Concrete pavements, as do all concrete structures, tend to move with time. Drying shrinkage and carbonation produce permanent contractions of pavement slabs. At the same time, cyclical expansions and contractions are caused by climatic changes. Vertical movements of pavement slabs are caused by traffic loading and climatic variations [14].

Although some unsealed pavements have provided adequate service in Europe, studies in the United States have proven that sealed joints significantly extend the lives of pavement systems by preventing the intrusion of incompressible water into the pavement and the subsequent serviceability failure of the system [1] citing [13].

Adhesives and sealants surround us in nature and in our daily lives. This could be seen in the fact that many products that we take for granted could never exist if it were not for adhesive bonding or sealing [12].

The most common requirement for joint sealants is that they be able to achieve “weathertightness.” In some applications, they may also be required to reduce sound transmission or prevent passage of air, hot gases, or flames. Other requirements that may influence sealant selection for exterior applications are resistance to ultraviolet (UV) light and air pollution, or acceptable performance in extreme temperatures. Sealant for interior applications may be required to resist mildew, cleaning agents or exposure to aggressive chemicals. Sealants exposed to foot and vehicular traffic must be able to resist abrasion, tearing, puncturing, and other forms of damage caused by sharp objects such as spiked heels, pebbles, and debris. Hard (rigid) sealants have good resistance to this type of damage but their limited elasticity and movement capability restricts their usefulness in “moving joints” such as expansion joints [21].

2.4 General Properties of Sealant Materials

2.4.1 Viscoelastic Property

An elastic material is one in which all strain induced during loading is recoverable once the load is removed. A viscous material, in contrast, will not recover from any strain even after the loading is removed. A material that exhibits both viscous and elastic behavior at a specific temperature and under a certain loading rate is termed viscoelastic [22].

2.4.2 Polymer Property

Three of the main polymer properties that decide whether a sealant is applicable under certain field conditions are the glass transition temperature (T_g), the melt transition temperature (T_m), and the modulus (E) [23]. The melt transition temperature is also very important for determining applicability of a sealant in the field [24], whereas, the modulus of elasticity may be defined as “the ratio of force needed to elongate a sealant by a given amount” [19].

I. Parameters Affecting Polymer Properties

Polymer chemical parameters include chemical composition, molecular weight, stereochemistry, morphology, and topology. These parameters define the behavior of polymer sealants. By understanding these parameters, better sealants may be synthesized to suit the needs of the engineer. Silicone and neoprene are rubber-like elastomers, meaning that they retract to their original shape once an applied load is removed and have limited extensibility [25].

2.5 Joint Movement

Joint movement may normally be classified as either horizontal or vertical. Horizontal movements are caused by shrinkage and climatic variations. Vertical movements are normally caused by vehicle loads and the warping of the slabs.

2.6 Required Joint Sealant Properties

The desirable properties of joint sealants (field-molded) are listed and explained below [1]:

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- I. Impermeability to water - The sealant should not allow water to enter the joint.
- II. Toughness - The sealant should be able to resist incompressible that are forced into the joint.
- III. Adhesive strength (bond strength) - The sealant must have enough bond strength to resist tensile forces when the joint is open.
- IV. Cohesive strength - Tears should not form in the body of the sealant.
- V. Weatherability - The sealant should be able to withstand many years of extreme climatic conditions.
- VI. Resilience - The sealant must be able to regain its original shape after repeated, long term extensions and contractions.
- VII. Temperature stability - The sealant's modulus of elasticity and performance should not vary as the temperature ranges from its yearly low to about 40° above its yearly high.

Some common characteristics that are shared by adhesives and sealants are listed below [12].

- They must behave as a liquid, at some time in the course of bond formation, in order to flow over and wet (make intimate contact with) the adherends.
- They form surface attachment through adhesion (the development of intermolecular forces).
- They must harden to carry sometimes continuous, sometimes variable load throughout their lives.
- They transfer and distribute load among the components in an assembly.
- They must fill gaps, cavities, and spaces.
- They must work with other components of the assembly to provide a durable product.

2.7 Joint Sealant Failure

When conditions like an adhesive failure, cohesive failure, intrusion failure, extrusion failure, and impregnation of the sealant with incompressible exist, a joint sealant system is considered to have failed [9].

The joint sealant failure can be attributed to several causes. The sealant could fail if the geometrics of the joint are incompatible with the sealant material selected. The incompatibilities might result from the joint being too narrow for the expected movement, the shape factor being incorrect, or the material not having the proper extensibility to accommodate the movement [16].

2.7.1 Adhesive Failure

Adhesive failure occurs when the sealant detaches from the joint wall due to tensile forces in the pavement joint. This type of failure tends to occur intermittently along the length of the joint when the pavement's joint preparation is not correct, although most sealants develop adequate bond strength when joined with clean, dry concrete [9].

2.7.2 Cohesive Failure

Cohesive failure, as it is a tear in the body of the sealant which is also due to tensile stresses in the joint sealant, cohesive failure, unlike adhesive failure, will not occur because of inadequate joint preparation, rather, it occurs when the material is stressed beyond its tensile limit. Like adhesive failure, cohesive failure will allow water to enter the joint [9].

Joint cleaning, shape factor and good sealant installation practice are decisive in the service life of sealants [26]. Kinchen suggested that the service life of sealants varied from zero to six years with most observed failures being adhesive [27] whereas, Oehler and Bashore reported sealant failure between 10 and 15 years of service, with spalling and blowups as the result of failed joint sealants [28].

2.7.3 Intrusion Failure

When a sealant extends, intrusion failure starts as the result, a sealant tends to neck down in the center and then dirt and debris then collect on top of the sealant. Finally, as the slabs expand and the joint contract, the sealant traps the dirt. The sealant may then fail during the following extension. Intrusion failure is most common when a sealant has relaxed during extension, which is when the sealant does not possess adequate resilience to regain its original shape after long term extension or compression [29].

Incompressible intrusion failure occurs when extremely high compressive stress develops in the concrete pavement due to the presence of incompressible materials collected in the joints preventing the joint from closing. System failure will then occur when either compressive or buckling strength is exceeded. At high temperatures, the slabs expand whilst the joints contract. Therefore, the sealant may trap dirt. The sealant then may fail during the following slab extension [29].

2.7.4 Extrusion Failure

Extrusion failure is most common when a joint has been resealed for maintenance reasons when the joint is open. As the joint closes at high temperatures, the material is placed in compression and the sealant either bulges or flows out of the joint. Once the sealant is higher than the pavement surface, it will be either flattened out onto the pavement or pulled out of the joint by passing vehicles. Then, when the joint again expands, there is not enough sealant left to seal it properly. The sealant may then fail as incompressible puncture it or in either adhesion or cohesion [29].

2.7.5 Impregnation with Incompressible

High compressive stresses will develop in concrete pavements if the joints are prevented from closing because incompressible have collected in the joints. Failure of the system will then occur as either the compressive strength or buckling strength of the pavement is surpassed. The sealant must have the ability to reject stones as they are pressed into the joint. This mode of failure is most common in sealants whose modulus of elasticity and resilience are significantly reduced at high temperatures [29].

2.8 Joint Sealant Materials

There are two joint sealant material categories, 1) formed-in-place sealants, and 2) preformed compression seals. For these categories there are excellent choices available from today's manufacturers.

Formed-in-place sealants are in a liquid state for installation. They are either hot- or cold-applied materials that are pumped into place and depend on adhesion to the joint face for successful performance. Preformed compression seals are manufactured, brought to the site on rolls and then inserted into the joint. Compression seals depend on lateral pressure against the joint's sidewalls for long-term success [1].

Usage of the first compression seals is confirmed on I- 94 near Sweet Briar Dam in 1964. There has been an increase in the usage of silicone sealants in concrete joints in the past few years. Preformed neoprene compression joint sealers have been effective at keeping out incompressible but tend to leak water. Preformed neoprene also is known to take a compression set, which is when the neoprene no

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longer presses tightly against the joint wall. Preformed sealers can often pop out of the joints at many locations and cause an open joint and are unsightly [30].

2.8.1 Polysulfide Sealants

I. History

As an elastomeric sealant type used in highway work, polysulfide sealants were the first type of cold poured. After their first introduction to the construction industry in 1952, it took polysulfide sealants no time to be adopted by many states. However, the failure of many of the early installations was witnessed within a few years. Long live the progressive and continued research and developments, today there are polysulfide which work well in pavement applications and, the polysulfide's properties and their prices are rated from the good to intermediate-range [7].

II. Formulation

Sharing as a common denominator with most joint sealants, the constituent composers of polysulfide sealants are the base polymer, the curing agent, some fillers, and in some cases, a plasticizing agent. And reinforcing fillers are added to strengthen the mixture. Among many others, commonly used fillers include carbon black, titanium dioxide, calcium carbonate, ground silica, and hydrated alumina. As clay fillers are usually acidic and acids tend to retard the cure of polysulfide sealants, using clay fillers with polysulfide sealants is not recommendable and also, for its mere benefit to lower the cost of the sealant, Coal tar is used as filler for highway sealants [1].

III. Curing

There are two types of polysulfide sealants based on the component system, namely, one-component and two-component systems, and manufacturers can provide both. The component of the two-component system consists of the polymer, filler, and most of the plasticizer and a component which contains lead dioxide paste, which acts as the curing agent and the remainder of the plasticizer. The two components are mixed immediately before the application of the sealant. Though the general pot life is three hours, it can be shortened to ten minutes. As polysulfide sealants do not cure well at low temperatures, their application on the field should not be allowed at temperatures below 40°F.

Compared to the two-component system, in addition to being more expensive, one component

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polysulfide system is more difficult to manufacture. The one-component system is cured by the absorption of water from the atmosphere [1].

IV. Properties

a) Odor

Even though polysulfide sealants emit a very unpleasant odor when they are not in the cured state, they become odor-free when they are cured. Hence, while working with this material, adequate ventilation is recommendable.

b) Solvent Resistant

Solvent resistance is one of the recognized qualities of polysulfide sealants. In addition to them being waterproof, polysulfide sealants are also very resistant to several organic solvents, oils, and a wide range of chemicals.

c) Toxicity

Tests conducted on polysulfide sealants regarding toxicity and allergic behaviors have assured that polysulfide are both non-toxic and non-allergenic [1].

2.8.2 Silicone Sealants

Silicones are considered high-quality sealants and can be higher in price than other sealants commonly used in the construction industry. They are noted for their ability to withstand many years of exposure to a constantly changing environment and maintain their initial physical properties. Silicone sealants are available in several options of hardness. Low modulus silicones, with Shore A hardness of about 15, have had success in several states.

Silicone sealants were first introduced to the construction industry in 1960. The first silicone sealants evolved acetic acid during their cure. This acid reacted with the calcium of the concrete and led to uncertain adhesion between the sealant and the substrate. However, since the early days of development, several silicone sealants have been developed to evolve neutral by-products, such as alcohol, amides, or amines, which do not react with the concrete [1].

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A. Formulation

In the uncured state the silicone sealant material has three basic ingredients:

1. Long chain silicon polymer
2. Curing agents, and
3. Fillers

Fillers commonly used include calcium carbonate, clay, and ground silica. The sealant in the uncured state is quite workable and soft. Solvents are therefore not necessary, and the result is an almost 100 percent solid sealant. Consequently, shrinkage of the sealant after its placement is almost negligible and its shelf life is somewhat better than that of other one-component materials.

In the cured state, the polymer structure consists of alternating silicon and oxygen atoms. This polymer linkage is similar to that of glass and quartz. Silicone sealants are therefore transparent to ultraviolet radiation.

B. Curing

Silicone sealants are usually supplied as one-part packages containing the liquid silicone sealant material which cures to an elastomeric rubber. The curing process, often referred to as room temperature vulcanization, takes place upon the exposure of the sealant to atmospheric moisture.

C. Properties

The by-products released during the cure of silicone sealants may be either acidic or neutral. The acidic by-product, acetic acid, gives off a strong vinegar odor, while the neutral by-products, such as alcohol, amides, and amines, emit a musty odor.

Regarding hardness, the cured state silicone sealants exhibit exceptionally stable hardness over a large range of temperatures. They will maintain their rubbery property with less stiffening in the cold and less deterioration in the heat than the organic sealants. A typical Shore A hardness for a high modulus silicone sealant material is 35. A low modulus silicone will have a Shore hardness of about 15.

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Concerning abrasion and tear resistance, emanating from partly to its high recovery, the high modulus silicone sealant is characterized by low tear resistance and low abrasion resistance. However, low modulus silicones have tear resistances that are the same or higher than polysulfide and polyurethanes.

Furthermore, as per some research, the silicone sealants exhibit excellent weathering resistance. They can withstand many times the minimum one thousand hours in a weatherometer without any significant change in their physical properties. Also, the property that stands the silicone sealants out from other sealants is their high recovery. Silicones will generally exhibit recovery values of between 90 and 100 percent after compression.

2.8.3 Polyurethane Sealants

The polyurethanes are considered high quality and competitively priced sealants with the characteristics of high recovery, good workability, and good adhesion. The properties of the polyurethanes are, in general, between those of the polysulfide and the silicones. However, one major difference between the silicones and the polyurethanes is that the silicones do not exhibit as great stress relaxation and are, therefore, less resistant to puncture and tear propagation.

One of the problems experienced with the early polyurethanes was water sensitivity. When the urethane sealant was exposed to moisture before complete cure, bubbles would form in the sealant, thereby causing irregularities or large voids in its cross section. Newer polyurethanes avoid this type of distress. However, this problem is recent enough to still adversely affect the image of the sealant [1].

2.8.4 Rubberized Asphalt Sealants

Hot poured materials have been used more often to seal joints and cracks than any other substance. The materials have been used since the early part of the century and have evolved into better quality, cheap sealants. Like others sealant types, though, there are also better and poor rubberized asphalts available.

Initially, straight asphalt was used as a joint sealer, but it was not found to be durable. Recycled rubber from devulcanized tires was added and rubberized asphalts were developed. Today, the medium and

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lower quality rubberized asphalts are still made from used rubber, asphalt, plasticizers, and fillers. However, higher-quality rubberized asphalts are made using virgin synthetic rubbers, such as neoprene.

Rubberized asphalts are hot-poured sealants and require strictly controlled heating practices. For example, if rubberized asphalt should be heated to 400°F, then it should be kept at that temperature during installation. A temperature of 450°F will render the sealant useless. Also, rubberized asphalts may not be cooled after use and then reheated at a later time [1].

2.8.5 Preformed Compression Seals

Neoprene rubber preformed compression seals are the type of preformed seal most used in highway joint sealing. They gained popularity in the 1960s after the first unsuccessful polysulfide and polyurethanes were introduced and failed. Other preformed sealants have been made using EPDM, silicone, and butyl rubbers, but these have not enjoyed the popularity of the neoprene seals. Preformed compression seals are the most expensive type of seal, but a properly installed neoprene seal may perform well for 20 years or more. The most commonly used shape for preform seals for highway joints is the chevroned later.

Preformed sealants arrive ready to install. Typically, manufacturers require that they be supplied with the expected low and high temperatures at the site to select the correct size seal. The seal must have a recovery pressure of 3 pounds per square inch at the maximum joint width. A lubricant adhesive is used to ease installation and assure adequate bond. However, tile lubricant- adhesive has no true load carrying capacity by itself. Power-operated machines capable of placing about 20 feet of seal per minute are currently available. These machines pre compress the seal, coat the joint wall with lubricant-adhesive, and insert the seal into the joint. It is necessary that the seal not be stretched during placement otherwise; it will not perform correctly [7].

As a type of butyl sealant, Neoprene sealants take different forms such as polyisobutylene, isobutylene, and isoprene and according to Kumar; they usually have good oil, chemical, ozone, oxidation, and heat resistance. Both single and double bonds are contained in the hydrocarbon backbone of neoprene. In addition to van der Waals' bonds between molecules, Hydrocarbons have strong covalent bonds, resulting in relatively low glass and melt transition temperatures. It is common

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knowledge that the melt transition temperature increases as the molecular weight increases and neoprene usually consists of a long chain with a high molecular weight [33].

Attributed to the natural crystallization occurring, when strain is applied and thus acting as reinforcement, to achieve high mechanical strengths, butyl rubbers usually do not need any reinforcing filler [25]. However, the double bonds in neoprene cause kinks and bends, preventing a tight crystalline structure from forming [32]. Neoprene, however, is very rigid due to its normally high crosslink density.

2.9 Field and Laboratory Evaluation of Joint Sealants

2.9.1 Field Evaluation of Joint Sealants

In an attempt to better evaluate joint sealants under harsh conditions; many field studies have been conducted. Thanks to Steffes, who has designed and developed an innovative, non-destructive, broad coverage joint seal tester that yields quick results. This test method, which was developed by the Iowa Department of Transportation, uses a foaming shampoo-water solution and a vacuum. The foaming solution is poured into the sealant area, and then the vacuum is applied. The presence of bubbles becomes evident for any leak in the seal quickly. As might not be noticeable by the usual inspection method, we could say that this method allowed the identification of cracks within the joint sealant [33].

Among essential practices in the service life of sealants are joint cleaning, shape factor and sealant installation method [26]. Being most observed failures adhesive, Kinchen suggested that the service life of sealants varied from zero to six years [27], whereas the other report by Oehler and Bashore confirmed sealant failure between 10 and 15 years of service, with spalling and blowups as the result of failed joint sealants [28].

For two decades, the 1960s and 1970s, the New Jersey Department of Transportation concentrated on testing and improving the suggested methods of design and construction of joint systems [8]. The study conducted on two simple-span, composite design bridges for nine years starting from 1965 concluded that the combined use of a preformed, elastomeric joint sealant and an armored joint design would adequately prevent the intrusion of moisture and debris into the bridge deck. In addition, unattainable workmanship needed from the contractor to exercise formed and sawing methods of joint

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construction has failed the practices to adopt such methods.

Using the pavement test section in Chillicothe, Ohio, the effects of base material, joint spacing, and dowel type on the horizontal movements of concrete pavement joints were examined [15]. The pavement sections were prepared using a 6.4 or 12.2-meter joint spacing, a stabilized or granular base, and a standard or a plastic-coated dowel and to be compared with the theoretical slab expansion, horizontal expansion measurements were taken continuously. A study conducted for 20 years starting from 1972 revealed the type of base material, type of base stabilization, joint spacing, and type of dowel bars have no such significant effect on the horizontal joint movements after their construction.

On the objective of rating the effectiveness of seals based on visual inspection, in categories such as general appearance, condition of anchorage, debris accumulation, water tightness, surface damage, a noise under traffic, ease of cleaning and replacement, and age; other field study was performed on about 360 joint seals in Ohio [33]. In the study, twenty-four sealant types were evaluated with ages ranging from one month to 15 years. For all the cases considered in the study, poor sealant performance was overwhelmingly attributed to poor workmanship during seal installation. Another investigation that assured compartmented and closed cellular preformed neoprene sealants performs better than two-component cold-mixed polysulfide sealants was carried out on three joint sealants in Charlottesville, Virginia by Noble. In the study, due to the compression set, the polysulfide sealants failed prematurely and any incompressible material that infiltrated the joints caused damage to the load transfer devices but did not cause considerable spalling [35].

Another field study conducted by Collins was on twelve joints sealed with silicone which he has monitored for eight years after sealing. Although the minor failure was observed, a total of nine per cent in the first nine months, results indicated excellent bonding. Some sealants, like rubberized asphalt, experienced failure within two years and their performance was rated as poor [9].

In another evaluation made on liquid and preformed sealants used in transverse joints by Wolters, Periodic observations were made through the service life of each sealant, as the result, liquid sealants performed sufficiently in the first three years, while preformed sealants showed failure up to 56 per cent of the joint [10]. In another study, sealants failed within two years in sawed joints and performed satisfactorily when used as a rehabilitation technique to repair joints [36].

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Unlike the others above one field study has questioned the need to seal joints at all. The said study was done in the 1950s and 1960s where the contraction joints in portions of several Wisconsin roadways were purposely left unsealed to determine the effect on the surrounding pavement performance [11]. And after subsequent observations, it seemed that the joint and pavement performance was enhanced by the absence of joint seals. However, to verify those findings, a controlled experiment was designed by the Wisconsin Department of Transportation in 1974. In the study, the effects of various joint spacing (6.1, 12.2, 18.3, and 24.4 meters) and sealant types (rubberized asphalt, coal tar-based PVC, two-component cold-poured polysulfide, preformed neoprene, and standard sealant), as well as the effect of leaving contraction joints unsealed in certain pavement sections were investigated and during 10 years of monitoring the pavement sections, no faulting or blowups were observed in the sections with unsealed joints though joint spalling was observed quite frequently. However, as the Wisconsin Department of Transportation concluded, regarding a cost-effectiveness analysis of joint sealant maintenance, that joint sealing might not be justified in some situations.

2.9.2 Laboratory Evaluation of Joint Sealants

Many attempts have been made to accurately simulate field loading and/or environmental conditions in the laboratory. Among them, a series of tests conducted on five types of sealants, those are, two-part polysulfide, silicone, hot-poured rubberized asphalt, polyurethane, and preformed sealant is one [9]. On the said test, the effect of load on elongation was evaluated and silicone performed the best at -7°C with an elongation of 760 per cent at approximately 220N tensions, while rubberized asphalt performed the worst with only 12.8 per cent elongation. One typical observation made on the elongation test of silicon sealant was that loads were almost constant throughout the elongation and bond tests on the five tested materials showed that no bonding was evident for any of them after five extensions (6.5mm) of the cold- applied sealant or three extensions of the hot-poured sealant after being maintained for four hours at -10°C . Other tests such as flow, stress relaxation, shear fatigue, penetration, and ageing were conducted. However, even this "almost" comprehensive investigation failed to assess the simultaneous effect of dynamic shear and horizontal deflections, while concentrating on material property-related tests.

Many calculations of shear movement with a known tension modulus adopt the Pythagorean Theorem, but Shisler and Klosowski studied modulus characteristics of several sealants in tension,

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longitudinal shear, and transverse shear in they have assesses the validity of the theorem alongside. Unlike polyurethane seals where the Pythagorean Theorem may be used to calculate horizontal movement without an inherent safety factor, the silicone sealants that were evaluated showed a greater elongation in shear than in tension and the use of the Pythagorean Theorem to calculate shear movement in silicone sealants incorporates an inherent safety factor because of the silicones' superior performance in shear. The polyurethane seals, however, exhibited approximately the same elongation when loaded in shear and tension [37].

A study performed at Virginia Tech has evaluated the performance of sealant by simultaneous tensile and shear loading. According to Abo-Qudais, in a fixture developed at Virginia Tech, sealant sandwiched between two concrete cubes was tested. The two-sealant types sandwiched for evaluation were silicone and polyurethane, and the two aggregate types were concrete cubes of limestone and granite. Various joint widths and horizontal deflections were also considered. Cyclic shear deflections simulate the heavy overpassing traffic, while static tensile deflections simulate slab contraction at cold temperatures. Besides, some sealant specimens were exposed to freeze/thaw cycles before mechanical loading. It was concluded that silicone is very reactive with the limestone in the concrete, thus causing poor adhesion to the substrate and premature failure at large horizontal deflections and joint widths. The best sealant/aggregate combination proved to be silicone/granite. Polyurethane, on the other hand, performed moderately with either aggregate. It was also found that exposure to freeze/thaw cycles had an insignificant effect on sealant performance [38].

The correlation between heat ageing and strength reduction in joint sealants was studied and reported by Jones [36]. Sealant specimens' strengths were evaluated before and after exposure to thermal cycles and low temperature, and ageing were investigated by the Portland Cement Association [38]. To evaluate the effect of weathering and the bond of sealants when debris was incorporated into incurred material, Thornton used a weather-ometer and no visible deterioration was noticeable in the silicone sealants [40]. However, specimens usually failed cohesively in bond testing due to insufficiency of curing, while cured specimens failed adhesively. Gurjar conducted similar research, performing tensile relaxation tests on weathered and unweathered silicone sealant specimens. One-part, self-levelling silicone specimens were aged for 0, 500, 1000, 1500, and 2000 hours in a Ci65A Weather-ometer. A master curve for the sealant relaxation modulus was produced using the data [41].

In an attempt to investigate the effects of moisture and temperature on silicone sealant performance,
Sara Getachew, AAiT

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Tock loaded sealant specimens in tension at a temperature range of 0°C to 30°C after they have been submerged in water. The pH of the water ranged from 5 to 12. The study found that exposure to moisture had little effect on the measured tensile properties and also, for a temperature range of 0°C to 30°C, the tensile properties were unaffected. However, strong acid solutions (pH < 2.0) seriously affected the performance of the sealant [42].

Poor workmanship during installation and inadequate surface preparation of the concrete substrate can also be the source of problems with joint sealant performance. Evans attributes the harshness of concrete as a substrate for adhesives to its extreme alkalinity, the weak, powdery surface layer, and its tendency to crack soon after it is formed. His testing revealed that the nature of concrete substrate must be studied further to improve seal adhesion [43].

Numerous literatures have addressed different sealant types with their unique properties and level of performance. However, the conclusions of many of the studies conducted over the past thirty years contradict each other regarding the need and performance of sealants. Thus, to better understand the property, type, function, and performance of the sealant in Ethiopia's socio-economic context (sand-bitumen mix and rubber membrane in situation), more problem-oriented researches need to be conducted as the conflicts and debates over the subject area are not resolved yet. Hence, this subject is researchable.

3. MATERIALS AND METHODS

In this research, the two potential alternatives (Rubber membrane and Sand Bitumen mix) that can give the function as silicone sealant were evaluated. Accordingly, the mix design of the two potential alternatives were done based on the mix adopted by the case study project for sand-bitumen and resemblance with renowned elastomers in the concrete pavement joint sealing for rubber membrane. The Sections below have discussed the materials used, the mix design preparation and testing fixtures of Rubber Membrane and Sand-Bitumen mix.

3.1 Sample Mix Design

3.1.1 Rubber membrane

In an attempt to lower production and unit cost of the new joint sealant (rubber membrane joint sealant material formulated in Horizon Addis Tire Laboratory), the mix design aimed to make resemblance with famous, imported and very expensive neoprene (whose excellent performance as performed joint sealant is witnessed by research) was done (based on the company specification) with the under listed constituents.

1. Natural Rubber (SMR-20) and Synthetic Rubbers(SBR 1500 and HIGH CIS BR 1220)
2. Filler (N-339/HAF-HS)
3. Processing Aid (DUTREX RA-3 OIL)
4. Activators (ZINK OXIDE 98% and RUBBER GRADE STERGIC ACID)
5. Antioxidant (6PPD)
6. OZONE PROTECT.WAX PE/OSW
7. Accelerators (DTPD,DPG and CBS)
8. Volcanizing Agent (NORMAL SULPHUR)

Among the above-listed components of the formulated rubber membrane, the natural rubber (SMR-20) (with technical and financial support from Horizon Tire manufacturing, is cultivated by local farmers at Bebek, and synthetic rubbers (SBR 1500 and HIGH CIS BR 1220) are made the components of the formulation to replace the neoprene. The exact percentage combination of the above-listed constituents of the formulated rubber and their contribution in Parts per Hundred Rubber (PHR) with respective weight is tabulated in table 3.1 below, which are based on the specification of the company, Horizon tire factory.

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Table 3.1 Mix design of Rubber Membrane

Material Type	Percentage	PHR	Weight (g)
SMR-20	2.40	5.00	48.05
SBR 1500	38.42	80.00	768.48
HIGH CIS BR 1220	7.20	15.00	144.1
N-339/HAF-HS	35.06	73.00	701.25
DUTREX RA-3 OIL	11.52	24.00	230.55
ZINK OXIDE 98%	0.96	2.00	19.21
RUBBER GRADE STERGIC ACID	0.48	1.00	9.6
6PPD	0.96	2.00	19.21
OZONE PROTECT.WAX PE/OSW	0.96	2.00	19.21
DTPD	0.48	1.00	9.6
DPG	0.14	0.30	2.88
CBS	0.53	1.10	10.57
NORMAL SULPHUR	0.86	1.80	17.29
Total	100	208.2	2000

Source: - Standard Specification of Horizon tire factory.

3.1.2 Sand-Bitumen Mix

Adapting the sand-bitumen mix design used by the case study project, the sand-bitumen mix design was prepared by using different mix proportions fetching the sand from Bure River and 40/50 and 60/70 penetration grade Bitumen. The exact percentage proportion of sand and bitumen used in the mix design of sand-bitumen mix joint sealant with the respective weight of each option is tabulated in table 3.2 below.

Table 3.2 Formulation of Sand-Bitumen Mix

Description	Item	Proportion (%)	Weight (g)
Option-1	Bitumen	80	1,392
	Sand	20	348
Option-2	Bitumen	75	1,305
	Sand	25	435
Option-3	Bitumen	70	1,218
	Sand	30	522

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In adapting the depicted proportions of sand-bitumen (high bitumen and low sand content by weight), the considerations made and principles followed have aimed to keep the elastic property of the famous elastomers which are known for their elastic property. Hence, as sand is non-elastic, and bitumen is, the weighted proportion in the mix has considered the contribution of sand to high temperature resistance, hardness, oil and abrasion resistances required by the elastomers, whereas, the bitumen contribution in the mix was to enhance the tensile and compression set (ability to rebound) ability of the mix, which is supplemented by the plastic property of the bitumen.

3.2 Testing Fixtures

Joint Sealants in rigid pavement roads are required to seal the joints thereby mitigate the intruding of incompressible material and infiltration of water between rigid concrete slabs. Since, the performance of the joint sealants is affected by mechanical loading and environmental condition which may impose different type of sealant failures. Therefore, to assure and validate the capacity and performance of the alternative sealants, performance evaluation of the sealants both in the field and laboratory is necessary.

All testing fixtures used in the experiments to assess the desired joint sealant properties were conducted based on ASTM D2000 Standard Test Methods. Fortunately, the Quality Assurance Unit in Horizon Addis Tire Manufacturing PLC has adopted the same standard (ASTM D2000 Standard Test Methods) in their routine of quality assurance of their tire products. Therefore, the required tests for sealants, rubber membrane and sand-bitumen mix have been conducted as per ASTM D2000 Standard Test Methods on Horizon Addis Tire Manufacturing plc [44].

3.2.1 Durometer Hardness

Durometer Hardness Testing measures the hardness of rubber elastomers and plastic materials. The most widely used hardness measuring instrument is called the Durometer. It measures hardness values in the points ranging from zero to 100 points. Accordingly, zero represents a very soft material, while 100 points represent hard material. The photos of the said Durometer as specified in the ASTM D2240 Standard Test Methods and Horizon Quality Assurance Laboratory are depicted in figure 3.2.1 below.

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Figure 3.2.1 Hardness testing equipment (ASTM) and Horizon Addis Tire Lab respectively

3.2.2 Compression Set

Compression Set testing determines the ability of an elastomeric material to maintain its elastic properties after exposure to prolonged compressive stress. ASTM D395 describes two types of compression set tests:

- Method A, compression set under constant load; and
- Method B, compression set at constant deflection of 25%.

The photos of the said compression set testing equipment as specified in the ASTM D395 Standard Test Methods and Horizon Quality Assurance Laboratory are depicted in figure 3.2.2 below.



Figure 3.2.2 Compression Set Test machine

3.2.3 Tension/Elongation

This test method evaluates the tensile properties of vulcanized thermoset rubbers and thermoplastic elastomers and describes two types of Tension tests:

- Method A, using dumbbells and straight section specimens; and
- Method B, using cut ring specimens.

The photos of elongation testing equipment, as specified in the ASTM D412 Standard Test Methods and Horizon Quality Assurance Laboratory, are depicted in figure 3.2.3 below respectively.

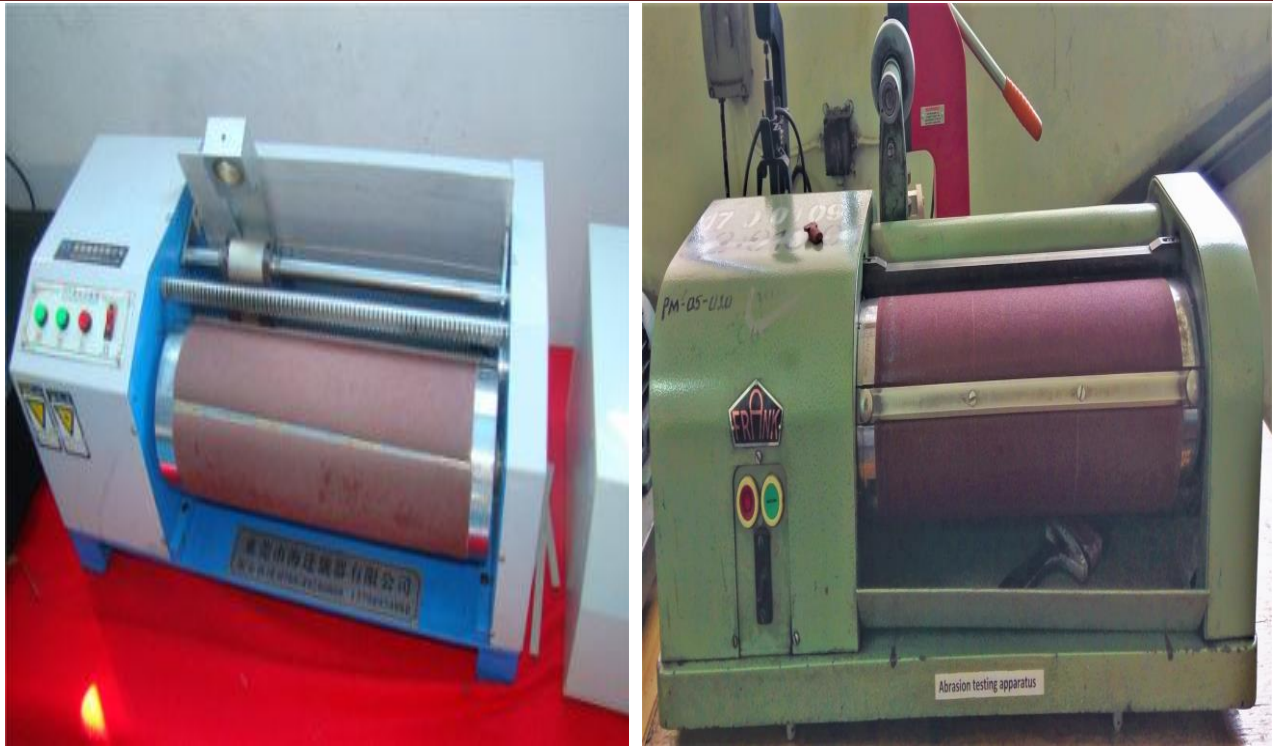


Figure 3.2.3 Elongation Testing Equipment

3.2.4 Abrasion Resistance

Abrasion resistance is the ability of elastomers and rubber material to withstand repeated abrasion by rubbing, scratching or scraping motion. In this laboratory set up to measure the abrasion resistance of the rubber membrane and sand-bitumen mix under the experiment, the rubbing, scratching, and scraping simulate the moving vehicles and lateral pressure exerted from the walls of rigid pavement at sealant and concrete interface. The photo of the said abrasion resistance testing equipment as specified in the ASTM D5963 Standard Test Methods and Horizon Quality Assurance Laboratory are depicted in figures 3.2.4 below in the respective order.

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Figures 3.2.4 abrasion resistance testing equipment

3.2.5 Heat Resistance

Heat resistance is the ability of elastomers to withstand the influence of elevated temperature (heating). Accordingly, as per the heat resistance test requirement, the rubber membrane and sand-bitumen mix specimen were exposed to the deteriorating ageing (heat) by exposing them to elevated temperatures for specified periods. Then, their physical properties, hardness, tensile strength and ultimate elongation were determined. The results were compared with the properties determined on both original specimens, and the changes were noted. The determination of the physical properties was carried out according to ASTM test methods D412. The photo of the said Oven (used to heat the specimen) as specified in the ASTM D573 Standard Test Methods and Horizon Quality Assurance Laboratory are depicted in figures 3.2.5 below in the respective order.

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Figure 3.2.5 Oven Machine

3.2.6 Oil Resistance

Oil resistance is the ability of elastomers to withstand the effect of liquid (oil). In this test method, the specimen (the rubber membrane and sand-bitumen mix) were exposed to oil for specified durations and temperature ranges. The resulting deterioration of the two sealants was determined by measuring the changes in physical properties, such as hardness, stress/strain properties (ASTM test methods D412), and changes in mass and volume before and after immersion in the test liquid (oil). Concerning tension and elongation tests, the said oil resistance test also uses the testing equipment in the Horizon quality assurance laboratory.

3.2.7 Adhesion Test

The adhesion test measures the ability of elastomers and rubber material resistance to the adhesion failure, the failure of the bonds due to tensile force between the joint material, for instance, elastomers and substrate surface. In this laboratory set up to measure adhesion strength of the rubber membrane and sand-bitumen mix under the experiment by adhesion T peel tests, the bonding is simulated to result from exerted force to separating the joint sealant from the walls of rigid pavement concrete interface. The photo of the said adhesion strength testing equipment as specified in the ASTM D1876 Standard Test Methods and Horizon Quality Assurance Laboratory are depicted in figure 3.2.7 below in the respective order.

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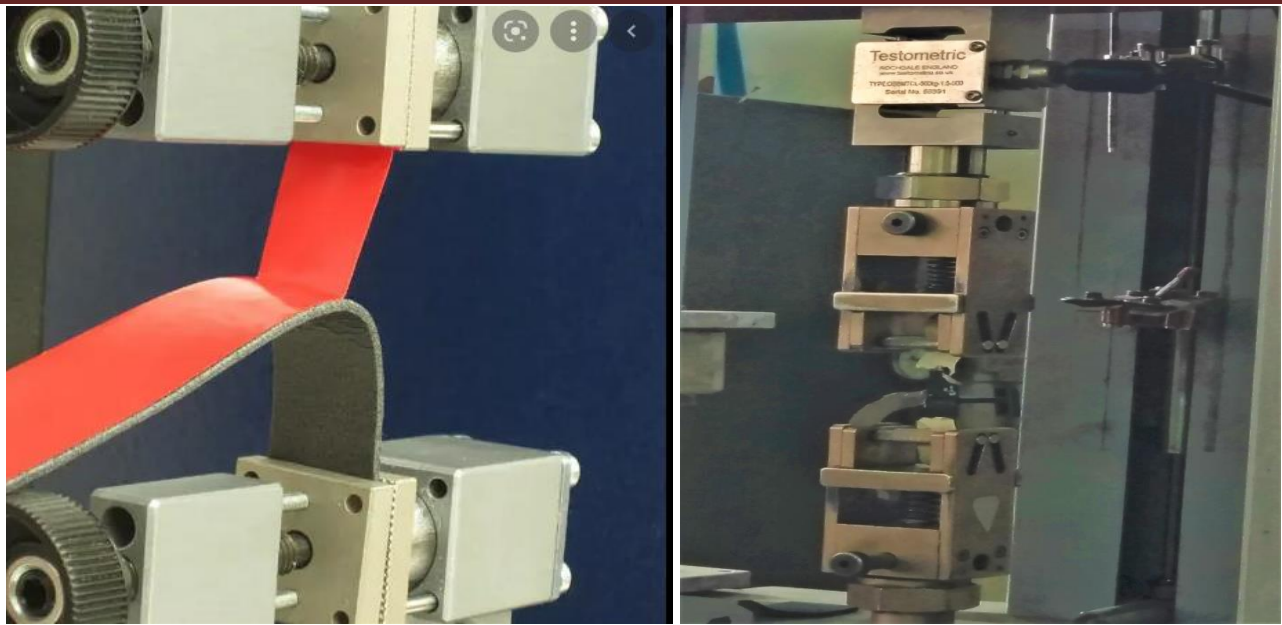


Figure 3.2.7 adhesion strength testing equipment

3.2.8 Cohesion (Tear) Test

The Cohesion or tear test measures the ability of elastomers to withstand the cohesion failure, failure of the bond due to tensile stresses in the body of the sealant, or it is a tear in the body of the sealants. In this laboratory set up to measure cohesion or tear strength of the rubber membrane and sand-bitumen mix under the experiment by tear test, the tear test simulated the applied force separating the joint sealant inside particles each other. The photo of the said cohesion or tear strength testing equipment as specified in the ASTM D624 Standard Test Methods and Horizon Quality Assurance Laboratory are depicted in figures 3.2.8 below in the respective order.



Figures 3.2.8 cohesion or tear strength testing equipment

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Table 3.2.9 Summary of test method

S.N	Test Method	Standard	Unit	Measuring Equipment	Determine Property
1.	Hardness	ASTM-D2240	Shore-A	Durometer	The hardness of rubber, elastomers and plastic materials.
2.	Compression Set	ASTM-D395	%	Compression Device	The ability of elastomeric material to maintain elastic properties after exposure to prolonged compressive stress.
3.	Tensile/ Elongation	ASTM-D412	MPa	Testometric	The tensile properties of vulcanized thermoset rubbers and thermoplastic elastomers
4.	Abrasion Resistance	ASTM-D5963	Mg	Abrader Rotary Machine	The ability of elastomeric material to resist repeated abrasive/frictional actions for instance rubbing, scratching or scraping motions.
5.	Heat Resistance	ASTM-D573	Shore-A and %	Oven, Durometer and Testometric	The ability of elastomers to withstand the deterioration of physical properties, hardness, tensile strength and ultimate elongation with time caused by elevated temperature (heating).
6.	Oil Resistance	ASTM-D471	Shore-A and %	Glass test tube, Oven, Durometer and Testometric	The ability of elastomers to withstand the influence of liquid (oil) on the deterioration of physical properties, hardness, tensile strength, ultimate elongation and change in mass and volumetric increasing.
7.	Adhesion (T-Peel) Strength	ASTM-D1876	MPa	Testometric	The ability of elastomers and rubber material resistance to the adhesion failure, the failure of the bonds due to tensile force between the joint material and substrate surface
8.	Cohesion or Tear Strength	ASTM-D624	KN/m	Testometric	The ability of elastomers and rubber material resistance to the cohesion failure, the failure of the bonds due to tensile force in the body of the sealant, or it is a tear in the body of the sealants

3.3 Specimen Preparation

The procedures followed in the specimen preparation of rubber membrane and sand-bitumen were as per ASTM D2000. In the next sections, sample preparation of rubber membrane and sand-bitumen mix is presented.

After the formulation of the rubber membrane (as per Horizon Addis Tire Manufacturing PLC quality assurance guideline), Optimal Physical-Mechanical Properties of LTR Compounds were done. Then the synthesized gum of rubber was taken to the furnace at 150 °c to cure and bake the rubber into sheet form for 30 minutes.

After 30 minutes in the furnace, with the help of gloved hands, the cured rubber was pulled out of the oven and then was left for 30 minutes to cool off before it was taken to a cutting/molding machine where the cured rubber was molded to the desired shape based on ASTM D2000.

Regarding sand and bitumen mix, the bitumen (40/50 and 60/70 Penetration Grade) was heated to 150 °c temperature for a longer duration to enhance mixing with the sand at the proportion of 80/20, 75/25, and 70/30. However, in molding the specimen into the required shape, similar procedures were being followed with the exception that the sand-bitumen mix was placed in the oven at 150 °c only for a couple of seconds.

3.3.1 Sample Preparation and Test Procedure for Ultimate Elongation Test

Using a standard dumbbell specimen cutting dies, two sets of five specimens of length 20mm and width of 5.6mm were cut from a vulcanized sheet of rubber and sand-bitumen mix prepared as per ASTM D3182 and ASTM D3183 procedures. Then dumbbells were conditioned for at least 30 minutes before beginning the test. The thickness of the reduced (gauge length) section of the dumbbells was measured and recorded and the specimen was carefully placed between the grips of the testing machine to provide uniform alignment. Finally, an extensometer was made to grip the specimen at the reduced section of the dumbbell and the testing machine is activated and the grips begin to separate at the rate of 500 mm/minute. The photos of the said prepared sample for elongation test as specified in the ASTM D412 Standard Test Methods, as were prepared in Horizon quality assurance laboratory for rubber membrane and sand-bitumen are depicted in figure 3.3.1 below respectively.

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Figure 3.3.1 Dumbbell specimens of rubber membrane and sand-bitumen mix

The only variable requiring manual measurement was the thickness of the sample, other parameters like length and width of the dumbbell specimens were determined from the mold sizes as it was perceived to be precise. Besides, the elongation testing machine was so sophisticated that, no interval reading of any parameters of the experiment's interest was required, that is, while and after the conclusion of the test, the computer connected to the elongation testing equipment summarizes the data and result.

3.3.2 Sample Preparation and Test Procedure for Compression Set

After two sets of two specimens of cylindrical disk shape were prepared using a standard cylindrical disk shape molding machine, their thickness was measured and recorded. The specimen was then placed between the plates of the compression set assembly and the specimen was compressed to 75% of its original height, and spacers were used to ensure that the compression force is accurately maintained.

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Finally, the loaded compression set assembly was placed in an oven at a 150 °c temperature for the period of 22 hours as suggested by ASTM D395 Standard Test Methods. After the specified 22 hours were over, the specimen was removed from the oven and the final thickness of the specimen was then measured after it was conditioned for 30 minutes. The photos of the said sample as specified in the ASTM D395 Standard Test Methods and as were prepared in Horizon quality assurance laboratory are depicted in figure 3.3.2 in the respective order.



Figure 3.3.2 Sample preparation for Compression Set as per ASTM and Horizon Lab

According to ASTM D395 Standard Test Methods, compression set of elastomeric materials, rubber membrane in this experiment was calculated by the formula given below.

$$CB, \% = \left[\frac{(t_o) - (t_i)}{(t_o) - (t_n)} \right] * 100$$

Where,

C_B = Compression Set,

t_o = Original thickness of the specimen,

t_i = Final thickness of the specimen,

t_n = Thickness of the space bars

3.3.3 Sample Preparation and Test Procedure for Hardness

Similar to the samples prepared for the tension/elongation test, a dumbbell specimen of the rubber membrane and sand-bitumen mix was prepared for this test and they were placed on a hard flat surface

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after which the indenter of the durometer gauge was pressed into the specimen making sure that it was parallel to the specimen surface. The hardness value was then read within one second of firm contact with the specimen. To keep specimens flat and parallel and prevent variance in measurement values, the gauge was installed on a 12.5N constant-load operating stand. The photos of the samples as specified in the ASTM D2240 Standard Test Methods and as were prepared in Horizon quality assurance laboratory for rubber membrane and sand-bitumen are depicted in figure 3.3.3 below in the respective order.



Figure 3.3.3 Dumbbell Samples for hardness test ASTM standard and Horizon

3.3.4 Sample Preparation and Test Procedure for Abrasion

To evaluate the abrasion resistance of the rubber membrane under investigation, as per ASTM D5963 the same sample preparation method for the compression set test was utilized. After the initial mass of the cylindrical shaped specimen was measured and recorded, the samples were plunged into the opening (handler) of the same size as the sample so that the sample could rub the rough surface of the rotating abrasion machine for 5 minutes. Finally, after the specified 5 minutes were over, the specimen was removed from the handler and the final mass of the specimen was then measured then abrasion test was also expressed in terms of the Abrasion (volume) loss of the test specimen. The photo of the said sample as was prepared in Horizon quality assurance laboratory is depicted in figure 3.3.4 below. This test could not be conducted for sand-bitumen specimens as the sample melted when exposed to 150 °c of the molding machine. In addition, an attempt to mold the specimen into the required shape by heating it at a lower temperature and conducting the abrasion test failed due to the extremely low abrasion resistance of

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the sand-bitumen mix.



Figure 3.3.4 Sample and test equipment set up for Abrasion

According to ASTM D 5963 Standard Test Methods, abrasion resistance of elastomeric materials, rubber membrane in this experiment the mass loss of each test pieces is calculated by the formula given below.

$$\Delta m_t = [m_o - m_i]$$

Where,

Δm_t = Mass loss of the test piece in mg,

m_o = Original Mass of test pieces before Abrasion in mg,

m_i = Final Mass of test pieces After Abrasion in mg,

In order to determine the abrasion loss (AA) of rubber membrane, as clearly stated on ASTM D5963, the loss in mass (mean value of ten single test pieces) shall be converted in to volume loss using the density (volume loss equal mass loss divided by density) of the test rubber. The volume loss is then corrected by using the ratio of the abrasiveness of the abrasive sheet (S) and nominal abrasiveness (S_o). In accordance with ASTM D5963, the values of S and S_o are specified as 200 mg and within a specified range of 180 to 220mg respectively. Accordingly, Horizon tire factory, adapted 200mg for both abrasiveness of the abrasive sheet and nominal abrasiveness of abrasive sheet, therefore the ratio of $\frac{S_o}{S}$, $\frac{200 \text{ mg}}{200 \text{ mg}}$ become one.

According to ASTM D 5963 Standard Test Methods, Abrasion resistance of elastomeric materials, rubber membrane expressed as abrasion (volume) loss of each test pieces was calculated by the formula given below.

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$$A_A, mm^3 = \left[\frac{(\Delta m_t * S_o)}{(d_t * S)} \right]$$

Where,

A_A = Abrasion loss in mm^3 ,

Δm_t = Mass loss of the test piece in mg,

d_t = Density of the test rubber in mg/mm^3 ,

S_o = Nominal Abrasiveness in mg, 200mg and

S = Abrasiveness in mg.

3.3.5 Sample Preparation and Test Procedure for Heat Resistance Test

Like the samples prepared for the tension/elongation test, two sets of five dumbbell specimens of the rubber membrane of length 20mm and width of 5.6 mm was cut from a vulcanized sheet prepared for ASTM D3182 and ASTM D3183 procedures and the dumbbells were conditioned for at least 30 minutes before beginning the test. Then as per ASTM D573, the physical changes, maximum change in hardness, tensile strength and ultimate elongation were measured after the specific samples prepared for the respective tests mentioned above were heated at $200^{\circ}C$ for 70 hours. The photo of the said sample as was prepared in Horizon quality assurance laboratory is depicted in figure 3.3.5 below. For the same reason given for the abrasion resistance test, we could not perform a heat resistance test as the sand-bitumen mix melts when exposed to the oven temperature of $200^{\circ}C$.



Figure 3.3.4 Sample Set up inside and outside oven for heat resistance

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I. The Effect of Heat on Hardness

As specified ASTM D 573, the five dumbbell test specimen whose hardness were measured before were heated at 200 °c for 70 hours and then their hardness was re- measured.

The maximum change in hardness is calculated by using the formula below.

$$\Delta H, \% = \left[\frac{(H_f) - (H_o)}{(H_o)} \right] * 100$$

Where,

H_o = Hardness value before heating,

H_f = Hardness value after heating,

ΔH = Change in hardness, %.

II. The Effect of Heat on Elongation

As specified ASTM D 573, the five dumbbell specimen whose elongation were measured before were heated at 200 °c for 70 hours and then their elongation was re-measured.

The maximum change in ultimate elongation is calculated by using the formula below.

$$\Delta E = \left[\frac{(E_f) - (E_o)}{(E_o)} \right] * 100$$

Where,

E_o = Ultimate elongation value before heating,

E_f = Ultimate elongation value after heating,

ΔE = Change in ultimate elongation, %.

III. The Effect of Heat on Tensile Strength

As specified ASTM D 573, the five dumbbell specimen whose ultimate stress (tension at break point) were measured before were heated at 200 0c for 70 hours and then their tension resistance limit was re-measured.

The maximum change in tensile strength is calculated by the formula presented below.

$$\Delta T = \left[\frac{(T_f) - (T_o)}{(T_o)} \right] * 100$$

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Where,

T_o = Tensile strength value before heating,

T_f = Tensile strength value after heating,

ΔT = Change in tensile strength, %.

3.3.6 Sample Preparation and Test Procedure for Oil Deterioration Test

Like the samples prepared for tension/elongation test, for sealant, rubber membrane. Using a standard dumbbell specimen cutting dies, two sets of five specimens of length 20mm and width of 5.6 mm were cut from a vulcanized sheet prepared as per ASTM D3182 and ASTM D3183 procedures and the dumbbells were conditioned for at least 30 minutes before beginning the test. Then in line with ASTM D471, the physical changes, maximum change in hardness, tensile strength and ultimate elongation and change in mass and volumetric increase of the same were measured after the specific samples were prepared for the respective tests mentioned above were the test specimens immersed in diesel fuel at 150 °C for 70 hours. The photo of the said sample as was prepared in Horizon quality assurance laboratory is depicted in figure 3.3.6 below.



Figure 3.3.6 Sample Set up inside and outside diesel fuel for Oil resistance

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A. The Effect of Oil on Mass

As specified ASTM D 471, the five dumbbell specimen whose mass were measured before were immersed in ASTM Reference Fuel (F), Diesel fuel at 150 °c for 70 hours and then their mass was re-measured.

The maximum change in mass is calculated by the formula presented below.

$$\Delta M, \% = \left[\frac{(M_2 - M_1)}{(M_1)} \right] * 100$$

Where,

M1= Initial mass of Specimen before immersion, g,

M2= Mass of Specimen after immersion in oil, g,

ΔM= Change in mass, %.

B. The Effect of Oil on Volume

As specified ASTM D 471, by implemented the Water Displacement Method for Water-Insoluble Liquids and Mixed Liquids, the five dumbbell specimen whose mass were measured in air and water respectively before immersed in ASTM Reference Fuel (F), Diesel fuel at 150 °c for 70 hours and then their mass was re-measured in air and water respectively. Then determination of change volume was conducted.

The maximum change in volume is calculated by using the formula below.

$$\Delta V, \% = \left[\frac{(M_3 - M_4) - (M_2 - M_1)}{(M_2 - M_1)} \right] * 100$$

Where,

M1= Initial mass of Specimen in air, g,

M2= Initial mass of Specimen in water, g,

M3= Mass of Specimen in air after immersion in oil, g,

M4= Mass of Specimen in water after immersion in oil, g,

C. The Effect of Oil on Hardness

As specified ASTM D 471, the five dumbbell specimen was immersed in ASTM Reference Fuel (F), Diesel fuel at 150 °c for 70 hours and then their hardness was measured.

The maximum change in hardness is calculated by using the formula below

$$\Delta H = (H_i - H_o)$$

Where,

H_o= Original hardness before immersion, unit

H_i= Hardness after immersion in oil, unit

ΔH= hardness change after immersion in oil, units,

D. The Effect of Oil on Ultimate Elongation

As specified by ASTM D 471, the five dumbbell specimens whose elongation was measured before being immersed in ASTM Reference Fuel (F), Diesel fuel at 150 °c for 70 hours and then their elongation was re-measured.

The maximum change in ultimate elongation is calculated by using the formula below.

$$\Delta E, \% = \left[\frac{(E_i) - (E_o)}{(E_o)} \right] * 100$$

Where,

E_o= Original Ultimate Elongation before immersion

E_i= Ultimate Elongation after immersion in oil

ΔE= Change in Ultimate Elongation after immersion in oil ,%

E. The Effect of Oil on Tensile Strength

As specified by ASTM D 471, the five dumbbell specimen whose ultimate stress (tension at a breakpoint) was measured before being immersed in ASTM Reference Fuel (F), Diesel fuel at 150 °C for 70 hours and then their tension resistance limit was re-measured.

The maximum change in tensile strength is calculated by the formula presented below.

$$\Delta T, \% = \left[\frac{(T_i) - (T_o)}{(T_o)} \right] * 100$$

Where,

T_o = Original Tensile Strength before immersion

T_i = Tensile Strength after immersion in oil

ΔT = Change in Tensile Strength after immersion in oil ,%,

3.3.7 Sample Preparation and Test Procedure for Adhesion Test

To evaluate the adhesion strength (T-peel) of the rubber membrane under investigation, as per ASTM D1876 the sample, test panel properly prepared and bonded the rubber membrane together with the separated material, paper the test panel have 152mm and 305 mm width and length respectively but bonded only over approximately 241 mm of their length. Cut the bonded panels into 25mm wide test specimens by a means that is not deleterious to the bond. The 76mm (3in.) long not bonded ends were bent apart, perpendicular to the glue line, for clamping in the grips of the testing machine. After peeling the test specimen through a T-shape by exerting the constant load on each test specimen then measure the adhesion strength of the sample test specimen. The photo of the said sample as was prepared in Horizon quality assurance laboratory is depicted in figure 3.3.4 below.

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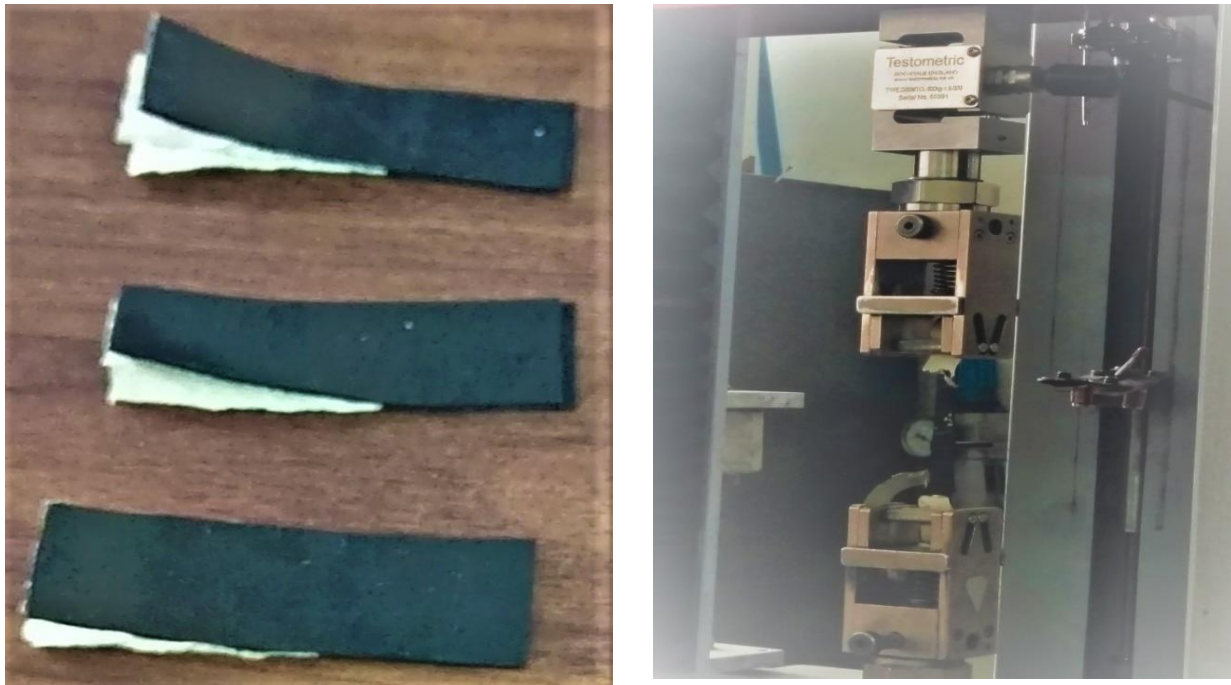


Figure 3.3.7 Sample and Test Equipment Set up for Adhesion (T-peel)

Besides, the tension testing machine was so sophisticated that, no interval reading of any parameters of the experiment's interest was required, that is, while and after the conclusion of the test, the computer connected to the tension testing equipment summarizes the data in tabular and graphical form.

On the recorded parameters, there is conducted a change of unit such that, the forces at break from kilogram-force (kgf) to Newton (N) by multiple 9.81 with of result and take the length of the bonded specimen equally one millimeter, unit per liner millimeter.

According to ASTM D1876 the adhesion bond strength is calculated by the formula presented below.

$$A_s = \left[\frac{F}{A (W * L)} \right] * 100$$

Where,

F = The break force, in N,

W = Width of bonded Specimen, in mm,

L = Length of bonded Specimen, in mm, take unit per liner millimeter,

A = Area of bonded Specimen, in mm²,

A_s = the adhesion bond strength, in Newton per millimeter square or Mega Pascale, N/mm² or MPa

3.3.8 Sample Preparation and Test Procedure for Cohesion (Tear) Test

Using a standard right angle (90°) or Type-C specimen cutting die-C, five specimens were cut through a die-C cutting machine from a vulcanized sheet prepared as per ASTM D3182 and ASTM D3183 procedures and the samples were conditioned for at least 30 minutes before beginning the test. Then the Type-C test specimen was carefully placed between the grips of the testing machine and load was applied to pull the test specimen, finally determining the tear or cohesion strength of the sample test specimen. The photos of the said sample as specified in the ASTM D624 Standard test Methods and as were prepared in Horizon quality assurance laboratory for rubber membrane and sand-bitumen are depicted in figure 3.3.8 a , 3.3.8 b and 3.3.8 c below in the respective order.



Figure 3.3.8 a. Sample of Rubber membrane for Tear or Cohesion Test (ASTM D624)

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Figure 3.3.8 b. Sample Rubber membrane for Tear or Cohesion Test at Horizon Laboratory



Figure 3.3.8 c. Sample bitumen-san mix for Tear or Cohesion Test at Horizon Laboratory

The only variable requiring manual measurement was the thickness of the sample, other parameters like length and width of the test specimens were determined from the mold sizes as it was perceived to be precise. Besides, the tension testing machine was so sophisticated that, no interval reading of any parameters of the experiment's interest was required, that is, while and after the conclusion of the test,

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the computer connected to the tension testing equipment summarizes the data in tabular and graphical form.

According to ASTM D624, to determine the tear strength of Type-C, the maximum force at break and the median thickness of each test specimen were taken (change of unit of force at break and thickness of test specimen was also done). Therefore, the tear strength is calculated by the formula presented below.

$$Ts = \left[\frac{F}{d} \right] * 100$$

Where,

F = The maximum force, in KN, for Types A, B or C,

D = The median thickness of each test piece, in m,

T_S = The tear strength, in Kilo Newton per meter of thickness, KN/M.

4 RESULTS AND DISCUSSIONS

4.1 Observation

The field observation on the case study project was done. Accordingly, visual inspection on the status of the sand-bitumen mix joint sealant with respect to sealant failure type was made. Hence, from the field observation, inspection of the sample before and after environmental conditioning, qualitative and quantitative data were collected. Also, notes taken during specimen preparation were used as qualitative data to supplement the measurements obtained during laboratory experiments focusing on any application problems with preformed sealants, rubber membrane and sand-bitumen mix.

4.1.1 Environmental Conditioning

The rubber membrane dumbbell samples immersed in distilled water (to simulate the effect of moisture at the field) and jet diesel fuel (to simulate vehicle and jet fuel spills at highways and airfields) for 70 hours were observed to neither swell nor got stiffer, whereas, the sample of the sand-bitumen mix which was made to pass through similar conditions was observed to exhibit no change when immersed in distilled water but the bitumen in sand-bitumen mix dissolved in fuel. However, the effect of environmental conditioning on silicon sealant appearance was significant. That is, the environmental conditioning, except for moisture, appeared to have an adverse effect on the silicone sealant appearance. Jet fuel exposure resulted in severe swelling. The silicone would swell approximately 100% and become very soft when in contact with the jet fuel and though did not get swell, the silicon exposed to 1000 hours of UV became stiffer [6]. Unlike the silicon which the synergistic effect of the jet fuel, UV, and moisture on the sealant was quite profound, the rubber membrane specimens under investigation were first exposed to 1000 hours of UV, followed by 48 hours of jet fuel exposure and 120 hours of moisture exposure just like the silicone mentioned above, and slight fading of the rubber membrane was witnessed. Also, the sand-bitumen mix undergone on similar conditioning was observed to withstand all the adverse effects except fuel impact where the bitumen got dissolved.

4.2 Experimental Test Results

As per the laboratory tests conducted on rubber membrane and sand-bitumen mix, the results and analysis in connection are presented in the sections below.

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4.2.1 Rubber Membrane

4.2.1.1 Laboratory test Results for Tension/Elongation Test

Five standard dumbbell specimens were conducted test. Accordingly, for each sample, the stress at 100%, 200%, 300% and ultimate elongation (break) was recorded. Table 4.2.1.1 has summarized the said test results as herein below.

Table 4.2.1.1 Laboratory Test Results for Tension/Elongation Test

Test No	Force @ Break (Kgf)	Stress @ Break (MPa)	Stress @ 100% (MPa)	Stress @ 200% (MPa)	Stress @ 300% (MPa)	Strain @ Break (%)	Thickness (mm)
1	21.921	18.280	2.890	7.296	12.267	437.575	2.10
2	19.331	16.120	2.703	7.110	12.142	393.275	2.10
3	19.967	17.483	2.529	6.184	10.727	461.550	2.00
4	20.448	16.276	2.475	6.417	11.298	412.975	2.20
5	19.833	17.811	2.760	7.069	12.039	432.300	1.95
Mean	20.300	17.194	2.671	6.815	11.695	427.535	2.07

As depicted in the table 4.2.1.1 above, the rubber membrane under investigation was proved to exhibit the under listed characteristics regarding the elongation test.

- ✓ As per ASTM-D412, elastomers are required to attain ultimate elongation of 350% but on average, the rubber membrane was able to elongate more than 425% of its original size before it reached its ultimate and break. Such property of the rubber membrane will enable it to elongate as large as required when it is pressed inward (squeezed) out by the lateral pressure from the wall of the rigid pavement joints during contraction(cold temperature). Also, it also tell the ability of the rubber membrane to adjust it length and width in the confined volume of the joints so that any change in width of the rubber membrane by the pressing pressure from the joints is compensated by the elongation of the rubber membrane longitudinally.

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- ✓ On average, the rubber membrane was proved to withstand 17MPa tension before it went too excess and torn apart.
- ✓ The research conducted by Alexander M and his team has indicated that silicon sealant was able to elongate by 410% and withstand 150 psi (1.03MPa). Also, in his thesis work, Ramzi has showed that the silicone can elongate 510% under 4MPa tension while rubberized asphalt performed worst with 12.8% elongation. Hence, when the results found for the rubber membrane is compared with this result; we could see that the rubber membrane has resisted 16.5% more tension than the silicon sealant and elongated 1.03% more than silicone sealant. So, this result indicates that rubber membrane is performing even better.

To depict the stress-strain relationship until the attainment of ultimate elongation of the rubber membrane; the same data was analyzed graphically as presented in figure 4.2.1.1 a. below.

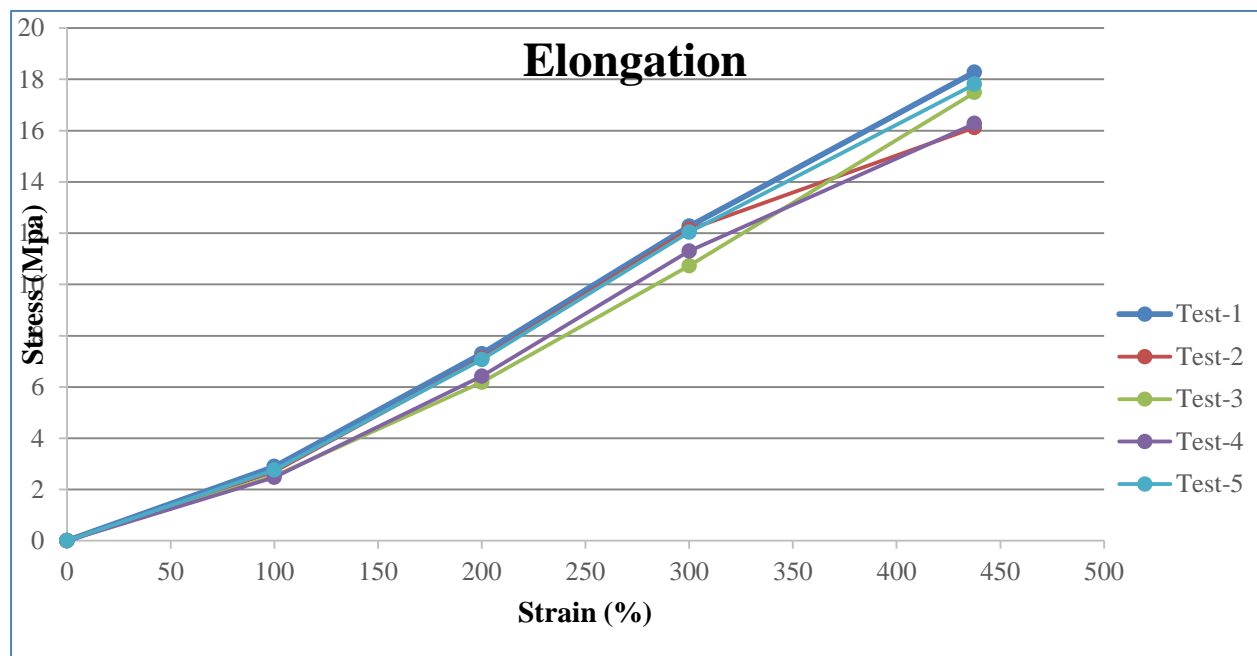


Figure 4.2.1.1.a. Ultimate Elongation Graph

The average stress and strain relationship for the five rubber specimen is presented in figure 4.2.1.1 b. below

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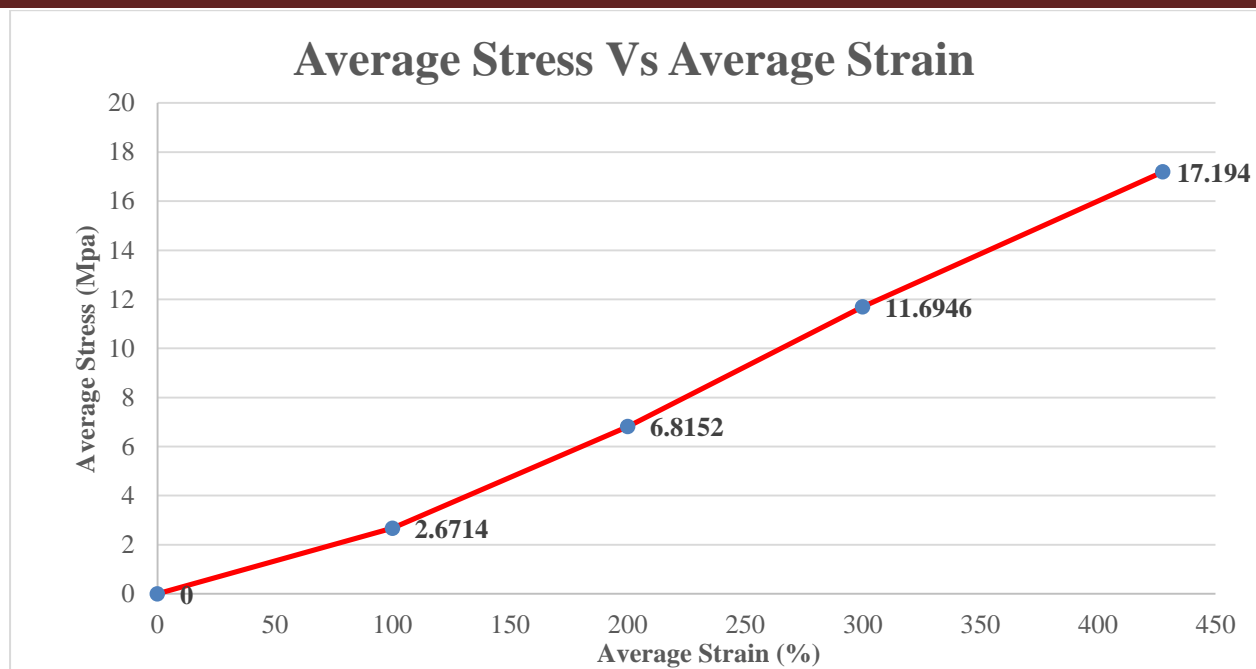


Figure 4.2.1.1 b. Average Stress VS Average Strain Relationship

As depicted in the figure 4.2.1.1.b above, both the stress and elongation (strain) increases linearly and on average, the first, second and third 100% elongations (100%, 200% and 300% elongations) are induced by 2.671MPa, 6.815MPa and 11.695MPa stresses, that is, the stress required to cause the first 100% strain (elongation) is lesser by a factor of 1.5 than the second 100% elongation and 1.8 than the third 100% elongation. This means, the stress required to set the rubber membrane in to elongation is smaller than the stress required to maintain the elongation or the strain resistance of the rubber membrane increases when approaching the break point (ultimate elongation), or much smaller stress can cause the rubber membrane to elongate by the same percent at the beginning of the elongation process than at the middle and end. The stress that caused the rubber membrane to break at 427% elongation is the tensile strength of the rubber membrane, which is, 17.19MPa. The computer connected with the elongation testing equipment (testometric) has analyzed the compression ability of the rubber membrane to be nearly 46%, this means, the rubber membrane can be compressed to 46% of its volume so that it can fill the rigid pavement joints of smaller gap and continue to exert lateral pressure on the walls of the joints, which is required for its installation and lasting performance.

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4.2.1.2 Laboratory Test Results for Compression Set Test

Two specimen of cylindrical disk shape were conducted test and the desired parameters for the specified test were collected during the process and the said data are summarized in the table 4.2.1.2 below.

Table 4.2.1.2 Laboratory Test Results for Compression Set Test

Test No.	Original Thickness of Specimen (t_o) (mm)	Final Thickness of Specimen (t_i) (mm)	Thickness of Spacer Bar (t_n) (mm)	Compression Set (C_B) (%)
Test-1	12.63	11.2	4.5	17.59
Test-2	12.34	10.74	4.5	20.41
Mean	12.485	10.97	4.5	19.00

Compression Set Testing determines the ability of an elastomeric material to maintain its elastic properties after exposure to prolonged compressive stress and compression seals depend on lateral pressure against the joint sidewalls for long-term success. As the compression set calculation on the rubber specimen revealed, on average, only 19% of the original thickness is set due to exposure to prolonged compressive stress. Stating this the other way, the rubber membrane has proved its ability to maintain 81% of its elastic properties after exposure to prolonged compressive stress while ASTM D2000 sufficed the lower limit to 60%. That is, maximum permissible change in thickness of the rubber membrane due to prolonged compressive stress as envisaged by ASTM D2000 standard specification is 40%, any value beyond this makes the rubber membrane to no longer presses tightly against the joint walls of the rigid pavement, rather pop out of the joints. And, in this test, due to prolonged stress on the rubber membrane, only 19% change in the original thickness is detected (81% recovery) while silicone sealant was able to recover 83% of its volume after prolonged compressive stress [1]. This property of the rubber membrane is highly essential because the very operational principle of preformed sealant is based on the ability of elastomers (sealants) to press tightly against the joint wall by counterbalancing the lateral pressure from the walls during expansion when the compressed joint sealants are relieved from the compressive stress. Graphical interpretation of the compression set test result is depicted in figure 4.2.1.2 below.

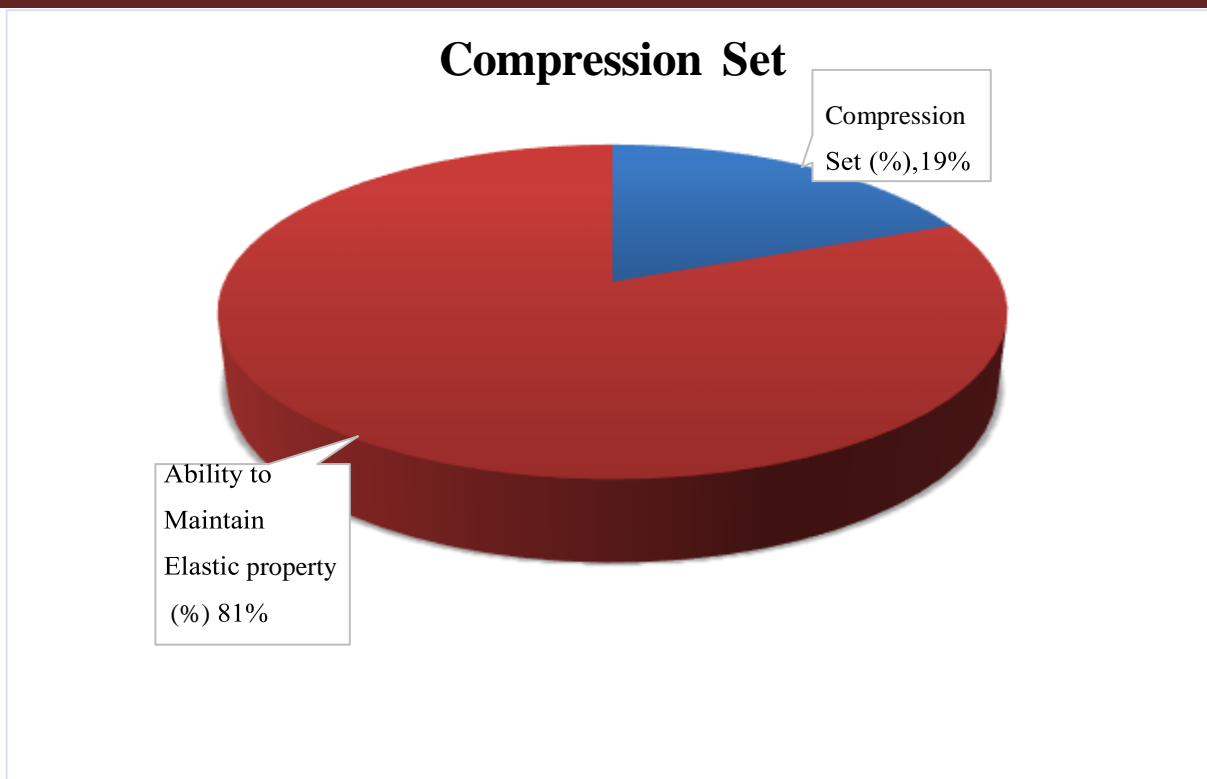


Figure 4.2.1.2 Compression Set Graph

4.2.1.3 Laboratory Test Results for Hardness Test

Similar to the samples prepared for the tension/elongation test, five dumbbell specimen were conducted test. The measured hardness values for each specimen are tabulated in table 4.2.1.3 below.

Table 4.2.1.3 Test Results for Hardness Test

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Hardness Value	65	64	65	65	64	64.6

- ✓ According to ASTM-D2240, the hardness of elastomers need to fall in ranges 55 to 65 (Shore-A). As depicted in the table 4.2.1.3, the hardness of the rubber membrane is 64.6. Hence, as it is within the permissible range, the ability of the rubber membrane to resist (withstand) any piercing (puncture) from incompressible when applied between the joints is guaranteed. The hardness of silicone, polysulfide and hot poured rubberized asphalt sealants were indicated to be in the range of 40-60, 35-50 and 15-20 (shore-A) [1]. Hence, obviously, the rubber membrane hard material than the other.

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4.2.1.4 Laboratory Test Results for Abrasion Resistance Test

Ten specimen of cylindrical disk shape were conducted test and the mass loss of each test pieces of the specimen are summarized in the table 4.2.1.4.a below.

Table 4.2.1.4.a Laboratory Test Results for Abrasion Resistance Test

Test No	Original Mass of test pieces before Abrasion (mg) (m_o)	Final Mass of test pieces After Abrasion (mg) (m_i)	Mass loss of the test pieces (mg) (Δm_t)
Sample-1	3290	3210	80.00
Sample-2	3340	3250	90.00
Sample-3	3390	3310	80.00
Sample-4	3270	3180	90.00
Sample-5	3270	3190	80.00
Sample-6	3320	3230	90.00
Sample-7	3390	3290	100.00
Sample-8	3330	3240	90.00
Sample-9	3410	3320	90.00
Sample-10	3330	3250	80.00
Average	3334	3247	87

According to ASTM D5963 abrasion loss (AA) of rubber membrane, abrasion loss in volume is summarized in the table 4.2.1.4.b below.

Table 4.2.1.4.b Volume change due to abrasion

Test No	Mass loss of the test pieces (mg) (Δm_t)	Density of the test pieces (mg/mm^3) (d_t)	Nominal abrasiveness / Abrasiveness of the abrasive sheet (S_o/S) (mg)	Abrasion (Volume) loss in (mm^3)
Sample-1	80.00	1.22	1.0	65.57
Sample-2	90.00			73.77
Sample-3	80.00			65.57
Sample-4	90.00			73.77
Sample-5	80.00			65.57
Sample-6	90.00			73.77
Sample-7	100.00			81.97
Sample-8	90.00			73.77
Sample-9	90.00			73.77
Sample-10	80.00			65.57
Average	87			71.31

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In addition, to express abrasion loss in percentage, assumption was made that all test pieces loss their mass totally. As a result, the mass loss (Δm_t) and original mass (m_o) of each test pieces became the same. Then the average total abrasion loss becomes 2732.79 mm^3 . However, as indicated in the above table, the actual average abrasion loss of test pieces is 71.31 mm^3 . When we compare the average actual abrasion loss of test pieces is 2.61 % from 100% of total average actual abrasion loss of test pieces.

Abrasion Resistance Testing determines the ability of an elastomeric material, rubber to resist abrasive (frictional wear) after exposed to mechanical actions. As could be drawn from the abrasion resistance calculation on the rubber test specimen, only nearly 2.61% of abrasion (volume) loss was recorded due to the abrasive actions. Stating this the other way, the rubber membrane has proved its ability to retain 97.39 % of its volume after exposed to prolonged abrasive (frictional wear) action. According to ASTM D5963, the abrasion (volume) loss expressed as volume loss in cubic millimeters, a smaller number (less than 6%) indicates better abrasion resistance. Hence, 2.6% average volume loss value of the rubber membrane indicates the fact that rubber membrane has good abrasive (wear) resistance. Graphical interpretation of the abrasion resistance test result is depicted in figure 4.2.1.4 below.

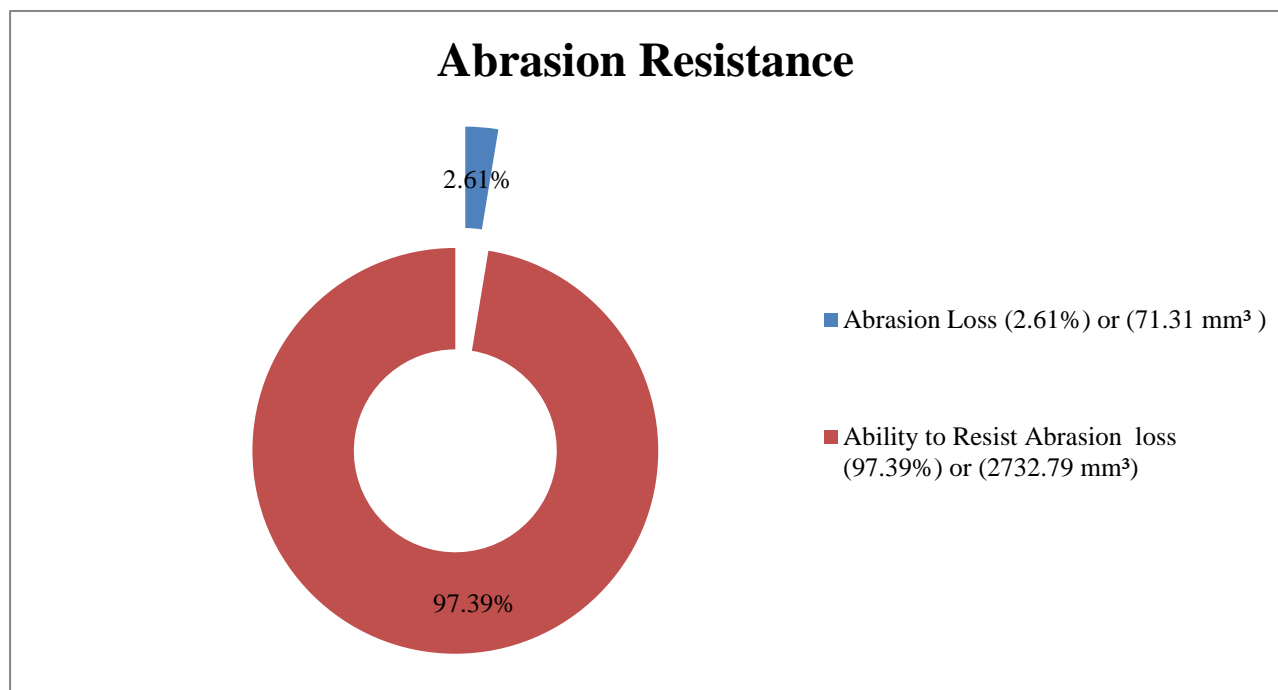


Figure 4.2.1.4 Abrasion Resistance Graph

- ✓ In the view of the test results, we can conclude that the rubber membrane has the required resistance to the rubbing, scratching or scraping motion from the heavy vehicle tires and

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other hard materials. Also, silicon sealant was proved to have a good abrasion resistance in addition to cure rate and temperature resilience [19]. However, in contrast to this finding, Alexander M, has indicated that silicone sealants has low abrasion resistance [1].

4.2.1.5 Laboratory Test Results for Heat Resistance Test

I. The Effect of Heat on Hardness

The five dumbbell test specimens were conducted test and the hardness values of the specimen before and after environmental conditioning (heating) are summarized in table 4.2.1.5.1 below.

Table 4.2.1.5.1 the Effect of Heating on Hardness

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Hardness Value Before Heating (H ₀)	65	64	65	65	64	64.6
Hardness Value After Heating (H _f)	74	73	74	74	73	73.6
Max Change in Hardness (ΔH) (%)	13.85	14.06	13.85	13.85	14.06	13.93

If the change in hardness was expressed in shore A, instead of converting the changes in to percentage (%), simply the average of change in hardness was taken and the result could become nine (9). The result, change in hardness indicated that, the rubber membrane get stiffer when exposed to aging. As depicted in figure 4.2.1.5.1 below, the hardness value of the rubber membrane increased when heated.

As per ASTM-D573 requirement, the change in hardness value of the elastomers ± 15 (Shore-A) is tolerable. Hence, as depicted in table 4.2.1.5.1 above, the maximum change in the hardness of rubber membrane after being heated for the specified duration is 13.93 (Shore-A). This property of the rubber membrane designates its ability to maintain the original physical properties even after environmentally conditioned.

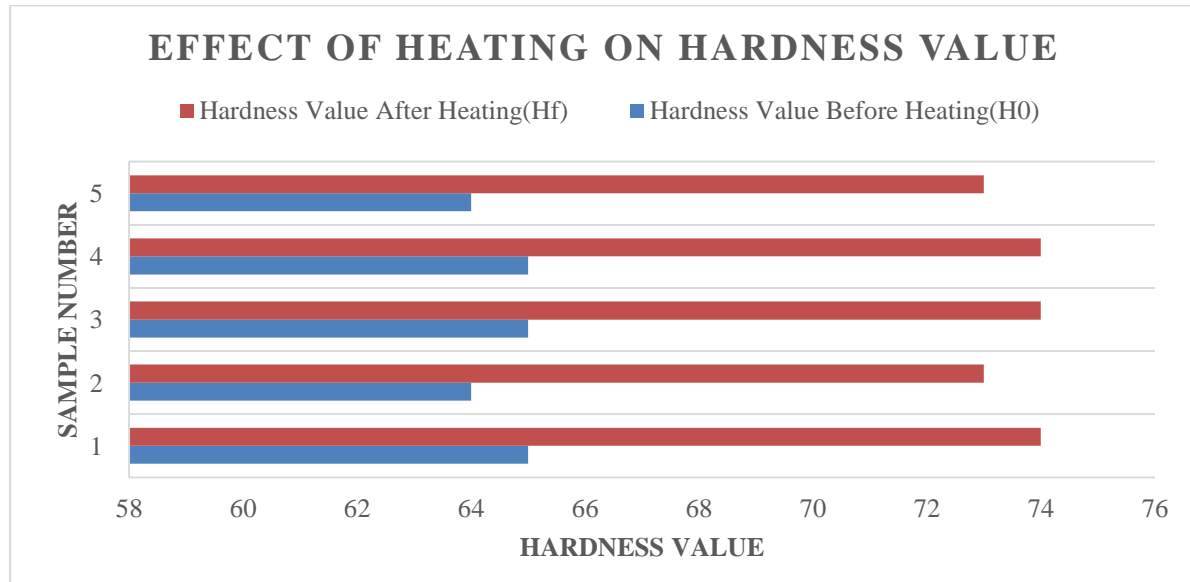


Figure 4.2.1.5.1 Effect of heating on hardness value

Like silicon sealant which gets stiffer when exposed specified range of temperature, when rubber membrane is heated to specific range of temperature, it became harder and becomes dense, consequently, the hardness increases.

II. The Effect of Heat on Elongation

The five dumbbell specimens were conducted test and the elongation values before and after heating are summarized in table 4.2.1.5.2 below.

Table 4.2.1.5.2 the Effect of Heating on Ultimate Elongation

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Ultimate Elongation Value before Heating (E0) (%)	437.575	393.275	461.55	412.975	432.3	427.535
Ultimate Elongation Value After Heating (Ef) (%)	413.962	360.495	426.632	375.242	379.164	391.099

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Max Change in Ultimate Elongation (ΔE) (%)	-5.396	-8.335	-7.565	-9.137	-12.291	-8.545
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As depicted in figure 4.2.1.5.2 below, the specimen not heated has elongated more than the one which was exposed to temperature.

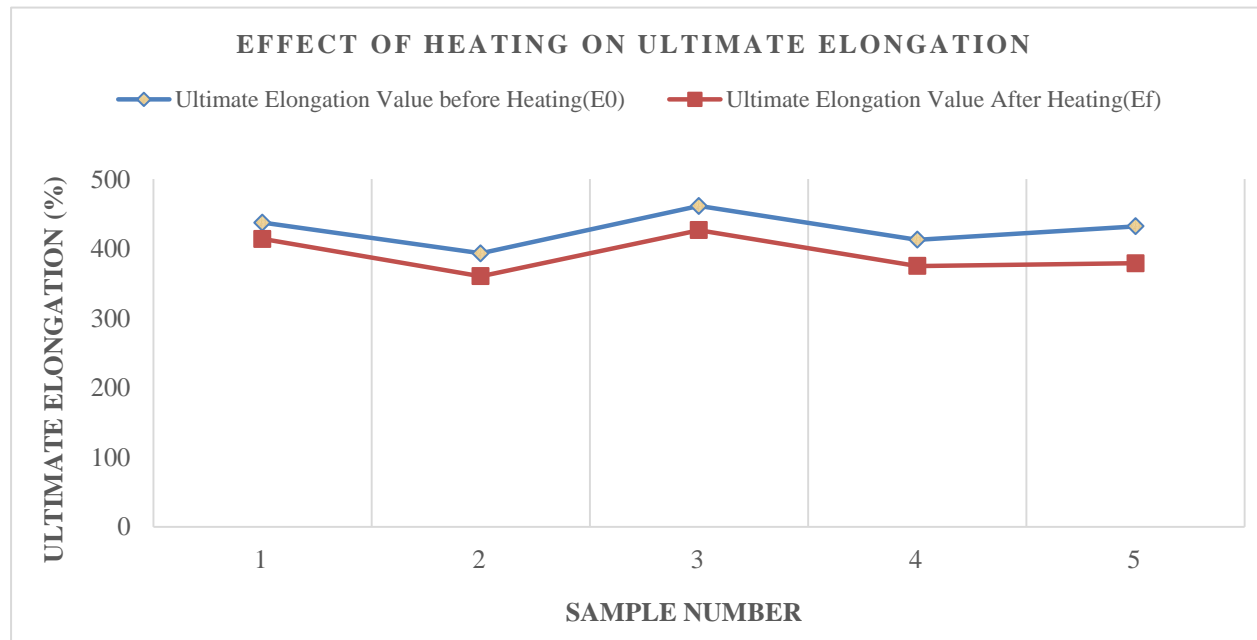


Figure 4.2.1.5.2 Effect of Heating on Ultimate Elongation

As depicted in the figure 4.2.1.5.2, when elastomers are heated to specific range of temperature for some duration, they get harder, in turn, decrease their elastic behavior and elastic limit, which limits them to elongate more.

As per ASTM-D573 requirement, the change in elongation value of the elastomers -50% is tolerable. Hence, as depicted in table 4.2.1.5.2 above, the maximum change in the elongation of rubber membrane after being heated for the specified duration is -8.5%. This property of the rubber membrane designates its ability to maintain the original physical properties even after environmentally conditioned (exposure to the field hot temperatures).

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III. The Effect of Heat on Tensile Strength

The five dumbbell specimens were conducted test and the tension strength values before and after heating are summarized in table 4.2.1.5.3 below.

Table 4.2.1.5.3 Effect of Heat on Tensile Strength

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Tensile Strength Value before Heating(MPa) (T ₀)	18.28	16.12	17.483	16.276	17.811	17.194
Tensile Strength Value After Heating(MPa) (T _f)	17.144	15.124	16.572	15.287	16.852	16.1958
Max Change in Tensile Strength (ΔT) (%)	-6.214	-6.179	-5.211	-6.076	-5.384	-5.813

As depicted in figure 4.2.1.5.3 below, heating the rubber membrane in the specified range of temperature and duration has decreased its tensile strength.

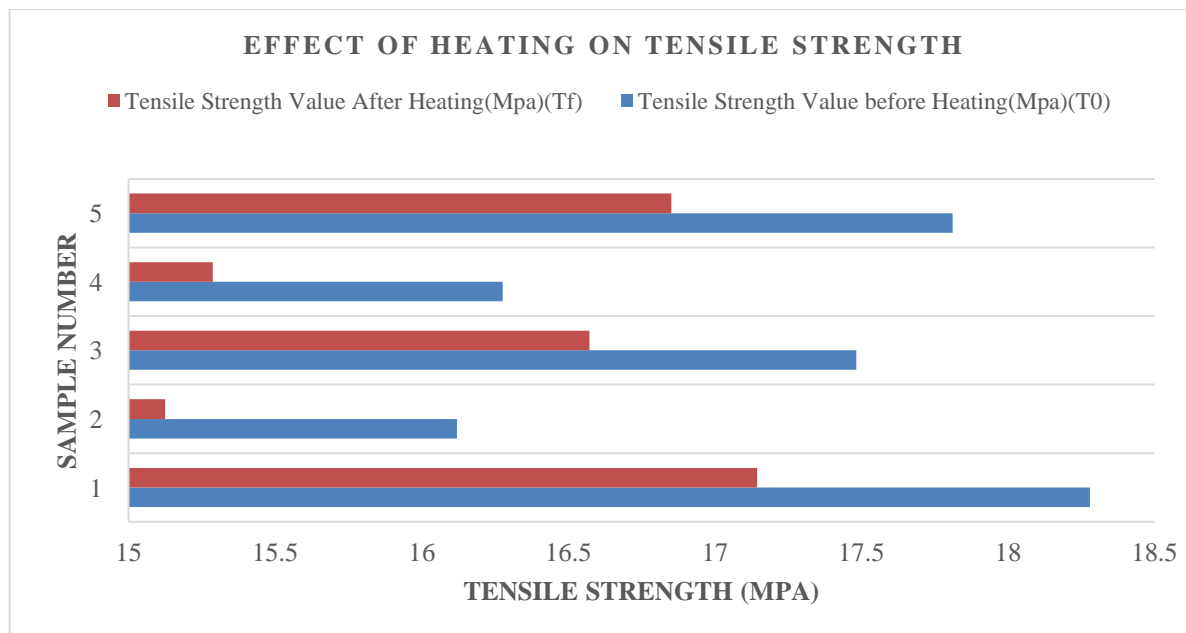


Figure 4.2.1.5.3 Effect of heating on tensile strength of the rubber membrane

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When the rubber membrane is heated, it becomes harder and less elastic, that is, its elastic limit decreased (its ability to elongate before reaching the break point). As depicted in Figure 4.2.1.1.b stress-strain graph above, stress is directly proportional with strain. Hence, the smaller the elongation, the smaller the stress (tensile strength) will be.

4.2.1.6 Laboratory Test Results for Oil Resistance Test

A. The Effect of Oil on Mass

The five dumbbell specimens were conducted test and mass values of the specimen before and after immersing in ASTM Reference Fuel (F), diesel fuel are summarized in table 4.2.1.6.1 below.

Table 4.2.1.6.1 the Effect of Oil on Mass

Test No.	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Initial mass of specimen (g) (M_1)	4.94	4.83	4.88	4.85	4.69	4.84
Mass of specimen after immersion in oil (g) (M_2)	4.96	4.84	4.9	4.86	4.71	4.85
Change in mass (%) (ΔM)	0.405	0.207	0.410	0.206	0.426	0.33

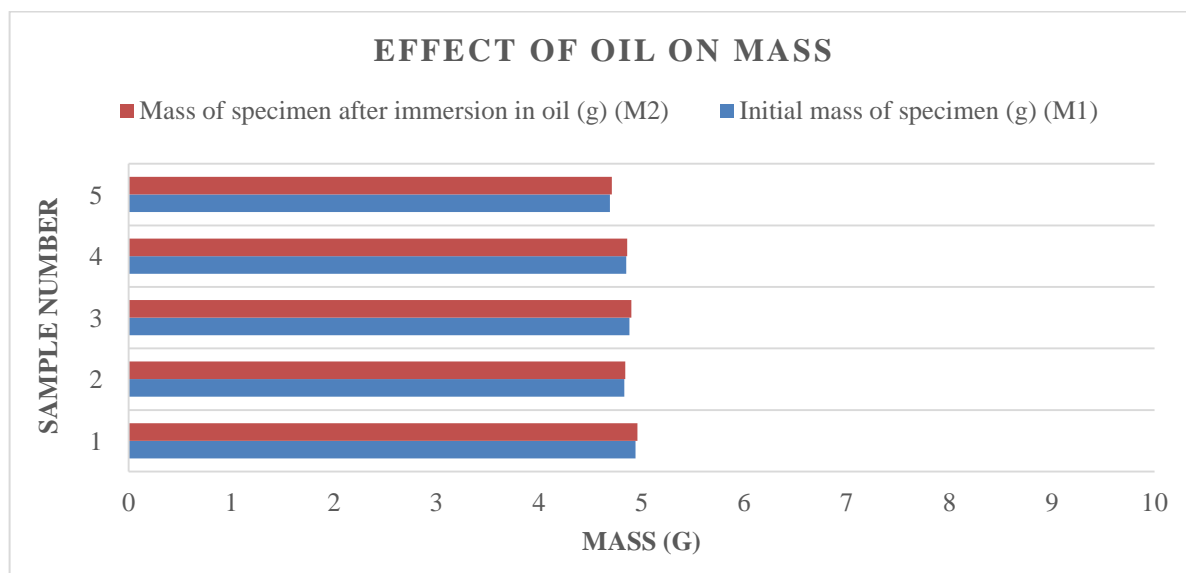


Figure 4.2.1.6.1 Effect of Oil on Mass

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As depicted on the figure 4.2.1.6.1, rubber specimen immersed in oil show insignificant change in mass implying that they are not susceptible to oil absorption and the ensuing detrimental effect.

B. The Effect of Oil on Volume

The five dumbbell specimens were conducted test and the mass values of the specimen in air and water before and after immersing in ASTM Reference Fuel (F), diesel fuel and change in volume are summarized in table 4.2.1.6.2 below.

Table 4.2.1.6.2 the Effect of Oil on Volume

Test No.	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Initial mass of specimen in air (g) (M1)	4.94	4.83	4.88	4.85	4.69	4.84
Initial mass of specimen in water (g) (M2)	4.35	4.25	4.29	4.32	4.08	4.26
Mass of specimen in air after immersion in oil (g) (M3)	4.96	4.84	4.90	4.86	4.71	4.85
Mass of specimen in water after immersion in oil(g) (M4)	4.310	4.205	4.258	4.277	4.045	4.22
Change in volume (%) (ΔV)	9.61	9.56	9.61	9.32	9.09	9.44

As depicted in table 4.2.1.6.2, the effect of oil on the volume change of the rubber membrane is insignificant, implying that the rubber membrane has a good oil resistance which makes it suitable and preferable for highways and airfields where the odds to be exposed to the spills of vehicle and jet fuels is not null.

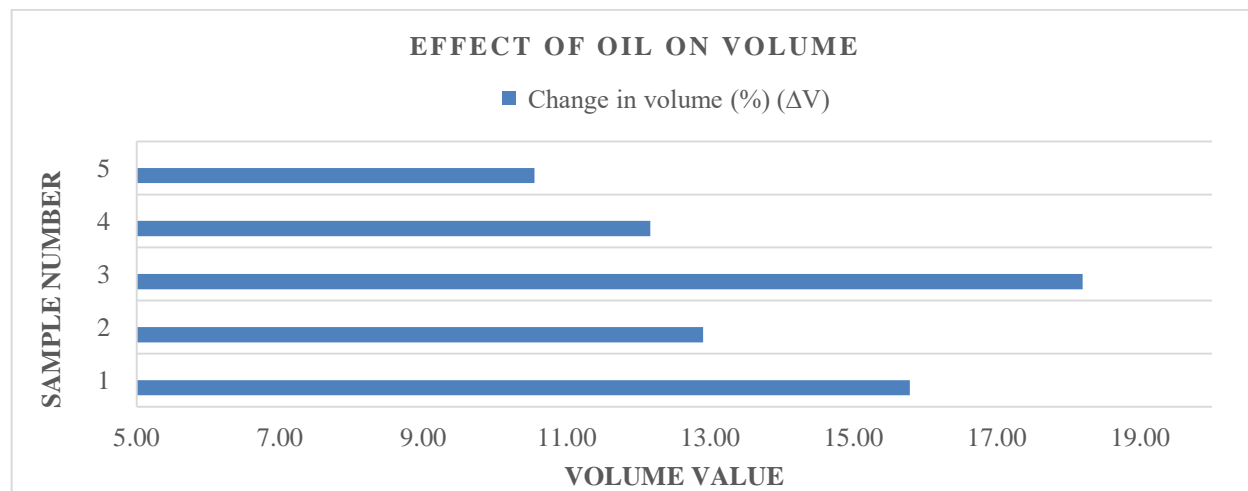


Figure 4.2.1.6.2 Effect of Oil on Volume

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C. The Effect of Oil on Hardness

The five dumbbell test specimens were conducted test and the hardness values of the specimen before and after immersing in ASTM Reference Fuel (F), Diesel fuel are summarized in table 4.2.6.3 below.

Table 4.2.1.6.3 the Effect of Oil on Hardness

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Original Hardness Value Before Immersion (Ho)	65	64	65	64	65	64.6
Hardness Value After Immersion (Hi)	54	55	55	55	55	54.8
Max Change in Hardness (ΔH) (unit)	-11.0	-9.0	-10.0	-9.0	-10.0	-9.8

If the change in hardness was expressed in shore A, the average of change in hardness was taken and the result could become near to ten (10). The result, change in hardness indicated that, the rubber membrane get softer when exposed to oil (diesel fuel) immersion.

As per ASTM-D471 requirement, the change in harness value of the elastomers ± 15 (Shore-A) is tolerable. Hence, as depicted in table 4.2.1.6.3 above, the maximum change in the elongation of rubber membrane after being heated for the specified duration is -9.8 (Shore-A). This property of the rubber membrane designates its ability to maintain the original physical properties even after environmentally conditioned (exposure to the fuel spills).

As depicted in figure 4.2.1.6.3 below, the hardness value of the rubber membrane decreased when immersed in diesel fuel.

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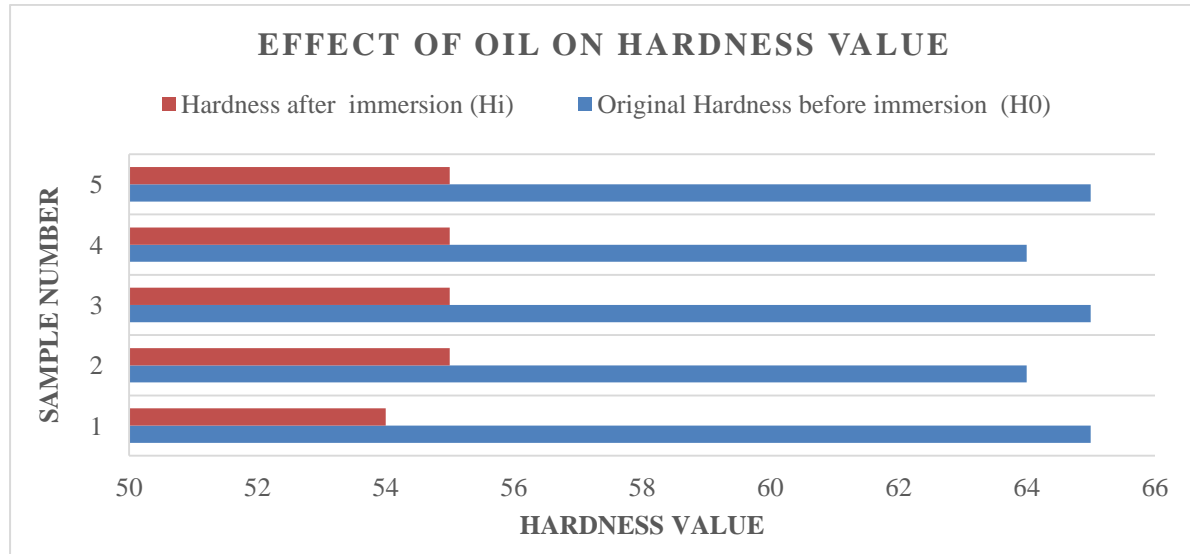


Figure 4.2.1.6.3 Effect of Oil on Hardness

D. The Effect of Oil on Ultimate Elongation

The five dumbbell specimens were conducted test and the elongation values before and after immersing in ASTM Reference Fuel (F), Diesel fuel are summarized in table 4.2.1.6.4 below.

Table 4.2.1.6.4 the Effect of Oil on Ultimate Elongation

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Ultimate Elongation Value before Immersion (E ₀)	437.575	393.275	461.55	412.975	432.3	427.535
Ultimate Elongation Value After Immersion (E _i)	345.108	308.488	371.722	332.000	352.806	342.024

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Max Change in Ultimate Elongation (ΔE) (%)	-21.132	-21.559	-19.462	-19.608	-18.389	-20.001
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As depicted in figure 4.2.6.4 below, the specimen immersed in diesel fuel has not elongated more than the one which was not exposed to the influence of liquid (oil).

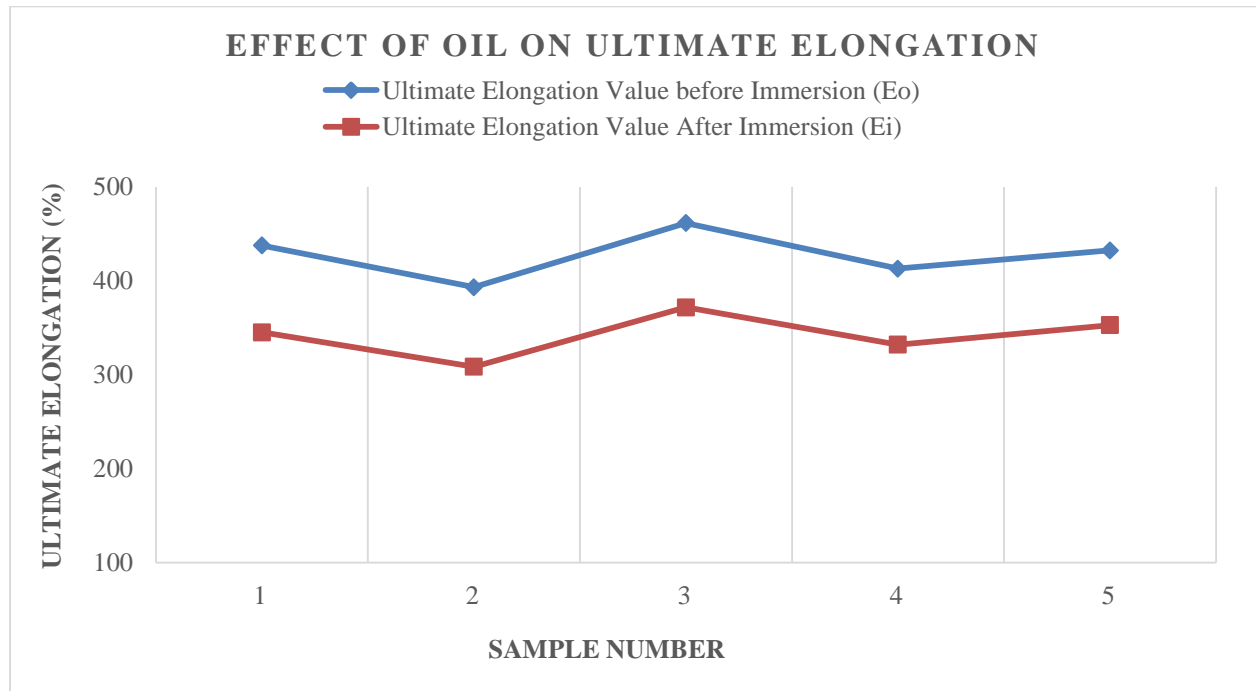


Figure 4.2.1.6.4 Effect of Oil on Ultimate Elongation

E. The Effect of Oil on Tensile Strength

The five dumbbell specimens were conducted test and the tension strength values before and after immersing ASTM Reference Fuel (F), Diesel fuel are summarized in table 4.2.1.6.5 below.

Table 4.2.1.6.5. Effect of Oil on Tensile Strength

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Original Tensile Strength Value before Immersion (T_o) (MPa)	18.28	16.12	17.483	16.276	17.811	17.194

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Tensile Strength Value After Immersion (Ti) (MPa)	14.417	12.645	14.080	13.085	14.036	13.653
Max Change in Tensile Strength after Immersion (ΔT) (%)	-21.132	-21.559	-19.462	-19.608	-21.196	-20.591

As depicted in figure 4.2.1.6.5 below, the rubber membrane immersed in fuel at room temperature for specified durations was found to exhibit reduction in its tensile strength.

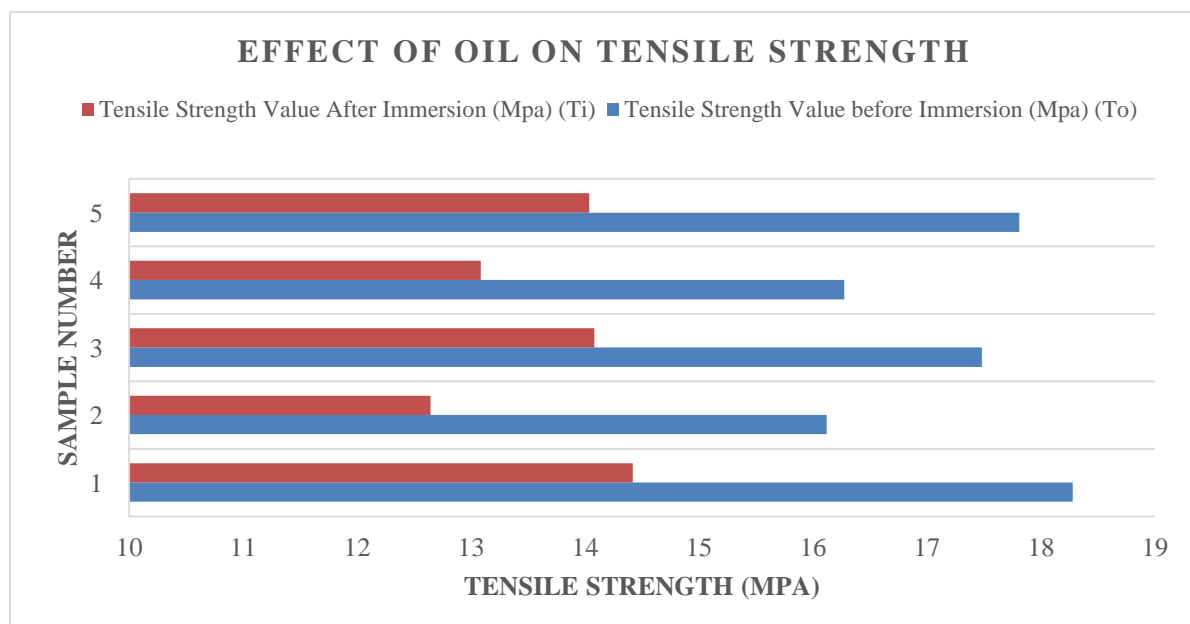


Figure 4.2.1.6.5 Effect of Oil on Tensile Strength

As per ASTM-D471 requirement, the change in tensile strength of the elastomers -50% is tolerable. Hence, as depicted in table 4.2.1.6.5 above, the maximum change in tensile strength of rubber membrane after exposed to oil for the specified duration is -20.59%. This property of the rubber membrane designates its ability to maintain the original physical properties even after environmentally conditioned (exposure to the fuel spills).

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Generally, according to many research conducted in this regard silicone sealant has excellent solvent resistance and aging properties [1]. However, Ramzi E has indicated the fact that they get stiffer, swell and become very soft when in contact with the diesel fuel.

4.2.1.7 Laboratory Test Results for Adhesion Test

The three test specimens were conducted test and the adhesion strength test results are summarized in the table 4.2.1.7 below.

Table 4.2.1.7 Laboratory Test Results for Adhesion Strength

Test No	Sample-1	Sample-2	Sample-3	Average
Force @ Peak (KN)	0.096	0.090	0.102	0.096
Force @ Break (Kgf)	8.997	8.061	8.618	8.559
Force @ Break (N)	88.261	79.078	84.543	83.961
Width of bonded Specimen (mm)	25.0	25.0	25.0	25.0
Length of bonded Specimen (mm)	1.0	1.0	1.0	1.0
Area of bonded Specimen (Width * Length) (mm ²)	25.0	25.0	25.0	25.0
Adhesion Bond strength (N/mm ² or MPa)	3.53	3.16	3.38	3.36

As per ASTM-D1876, minimum adhesion resistance of elastomers is required to be 1.4MPa. Hence, as depicted in table 4.2.1.7 above, the rubber membrane was able to resist 3.36 MPa peel force. This property of the rubber membrane designates its ability to resist adhesion failure, the failure of the bonds between the wall of the joint and rubber membrane due to tensile force between the joint materials. According to research, even though no numerical data were found, silicon sealants also are proved to have good adhesion resistance [1, 6]. Hence, comparison of such findings with results of this research for rubber membrane, we could conclude that rubber membrane had performed as good as silicon sealant.

4.2.1.8 Laboratory Test Results for Tear Resistance or Cohesion Test

The five Type-C specimens were conducted test. Accordingly, test results of each sample and cohesion or tear strength are summarized in the tables 4.2.1.8.a and b below.

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Table 4.2.1.8.a Laboratory Test Results for Tear Strength for all test Specimens

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Force @ Peak (Kgf)	16.899	17.678	16.874	17.132	17.104	17.137
Force @ Break (Kgf)	16.899	17.678	16.652	16.781	17.057	17.013
Force @ Break (N)	165.779	173.421	163.356	164.622	167.329	166.901
Force @ Break (KN)	0.166	0.173	0.163	0.165	0.167	0.167
Thickness (mm)	2.2	2.1	2.1	2.05	2.2	2.130
Thickness (m)	0.0022	0.0021	0.0021	0.00205	0.0022	0.002
Tear Strength (N/mm)	75.354	82.582	77.789	80.303	76.059	78.417
Tear Strength (KN/m)	75.354	82.582	77.789	80.303	76.059	78.417

From five Type-C specimens take the maximum force at break and median thickness the determine tear strength. Tables 4.2.1.8.b has summarized the recorded parameter from the above table 4.2.1.8.a.

Table 4.2.1.8.b Laboratory Test Results for Tear Strength

Test No	Value
Median Thickness (mm)	2.1
Median Thickness (m)	0.0021
Maximum Force @ Break (kgf)	17.678
Maximum Force @ Break (N)	173.421
Maximum Force @ Break (KN)	0.173
Tear Strength (N/mm)	82.582
Tear Strength (KN/m)	82.582

As per ASTM-D624, minimum cohesion strength (Tear Resistance) of elastomers is required to be 26KN/m. Hence, as depicted in table 4.2.1.8.b above, the rubber membrane was able to resist 85.58 KN/m tear force. This property of the rubber membrane designates its ability to withstand cohesion failure, failure of the bond due to tensile stresses in the body of the sealant, or a tear in the body of the sealants due to tear force from the joints during expansion phase.

One of the disadvantages of silicone sealants were their tendency to become impregnated with debris easily and tear apart from within [6]. Also, according to Alexander M., the tear resistance of silicone was 4.52 N/m (0.0045KN/m) [1]. Hence, when compared to the tear resistance of rubber membrane (85.58KN/m), there is a significant difference in strength of the two sealants with the rubber membrane performing far better than the silicone sealants.

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4.2.1.9 Comparison of Laboratory Test Results with ASTM Specification and International Researches

For ease of referencing, the laboratory test results of the rubber membrane is compared with ASTM specification basic requirements for silicone sealant, FC Material preformed sealants (Elastomers) as tabulated in table 4.2.1.9 below.

Table 4.2.1.9.a. Laboratory Test Result vs. ASTM Specification

S.N	Material Property	Test Requirement	Standard	Unit	Specification	Test Result
1	Physical Property	Hardness	ASTM-D2240	Shore-A	60±5	64.6
		Min. Tensile Strength	ASTM-D412	MPa	16	17.19
		Min. Ultimate Elongation		%	350	427.53
2	Compression Set (22 hours @ 175 °c)	Maximum Permissible Change	ASTM-D 395	%	40	19
3	Heat Resistance (70 hours @ 200 °c)	Max. Change in Hardness	ASTM-D573	Shore-A	±15	9
		Max. Change in Tensile Strength		%	±30	-5.81
		Max. Change in Ultimate Elongation		%	-50	-8.55
4	Oil Resistance (70 hours @ 150 °c)	Max. Change in Hardness	ASTM-D471	Shore-A	±15	-9.8
		Max. Change in Tensile Strength		%	-50	-20.59
		Max. Change in Ultimate Elongation		%	-30	-20.0
		Max. Change in Volume		%	120	9.44
5	Abrasion Resistance	Max. Abrasion loss in Mass	ASTM-D5963	mg	200	87
6	Adhesion (T-Peel) Strength	Min. Adhesion Resistance	ASTM-D1876	Mpa	1.4	3.36
7	Tear or Cohesion Strength	Min. Tear Resistance	ASTM-D624	KN/m	26	85.58

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

Table 4.2.1.9.b. Laboratory Test Result vs. International Researches

S.N	Material Property	Test Requirement	Unit	Specification	Test Result of Rubber Membrane	Test Result of Silicone	Name of Authors
1	Physical Property	Hardness	Shore-A	60±5	64.6	40-60	Alexander M
		Min. Tensile Strength	MPa	16	17.19	1.03	Alexander M
						4	Ramzi E
		Min. Ultimate Elongation	%	350	427.53	410	Alexander M
510	Ramzi E						
2	Compression Set (22 hours @ 175 °C)	Maximum Permissible Change	%	40	19	17	Alexander M
3	Oil Resistance (70 hours @ 150 °C)	Max. Change in Hardness	Shore-A	±15	-9.8	Excellent solvent resistance	Alexander M
		Max. Change in Tensile Strength	%	-50	-20.59		
		Max. Change in Ultimate Elongation	%	-30	-20.0	Swell and become very soft	Ramzi E
		Max. Change in Volume	%	120	9.44		
4	Abrasion Resistance	Max. Abrasion loss in Mass	mg	200	87	Good abrasion resistance	Klosowski J.M
						Low abrasion resistance	Alexander M
5	Adhesion (T-Peel) Strength	Min. Adhesion Resistance	Mpa	1.4	3.36	Good adhesion resistance	Alexander M and Ramzi E
6	Tear or Cohesion Strength	Min. Tear Resistance	KN/m	26	85.58	0.0045	Alexander M
						Tear apart from within	Ramzi E

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

4.2.2 Sand – Bitumen Mix

4.2.2.1 Laboratory test Results for Tension/Elongation Test

Five standard dumbbell specimens were conducted test. Accordingly, for each sample, the stress at break and ultimate elongation (break) are summarized in table 4.2.2.1 a and b below.

For 60/70 PG

Table 4.2.2.1.a Laboratory Test Results for Tension/Elongation Test

Test No	Force @ Break (Kgf)	Stress @ Break (MPa)	Stress @ 100% (MPa)	Stress @ 200% (MPa)	Stress @ 300% (MPa)	Strain @ Break (%)	Thickness (mm)
1	0.390	0.065	-	-	-	20.430	6.2
2	0.301	0.049	-	-	-	22.000	6.2
3	0.141	0.019	-	-	-	18.350	6.1
4	0.284	0.031	-	-	-	28.700	6.1
5	0.260	0.023	-	-	-	12.320	6.2
Mean	0.275	0.037				20.360	6.160

For 40/50 PG

Table 4.2.2.1.b Laboratory Test Results for Tension/Elongation Test

Test No	Force @ Break (Kgf)	Stress @ Break (MPa)	Stress @ 100% (MPa)	Stress @ 200% (MPa)	Stress @ 300% (MPa)	Strain @ Break (%)	Thickness (mm)
1	1.950	1.560	-	-	-	48.011	10.85
2	1.716	1.372	-	-	-	55.000	10.675
3	1.058	0.760	-	-	-	43.123	10.675

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4	1.562	1.240	-	-	-	60.270	10.85
5	1.508	1.196	-	-	-	40.656	10.85
Mean	1.559	1.226				49.412	10.780

As depicted in the table 4.2.2.1 above, the ability of sand-bitumen mix under investigation to elongate was proved to be very minimal; it was exhibiting almost non-elastic behavior like brittle materials. From the conducted elongation test the following conclusion can be drawn.

- ✓ On average, the sand-bitumen mix was able to elongate only 20% and 49% for 60/70 and 40/50 penetration grade respectively of its original size before it reached its ultimate and break.
- ✓ On average, the sand-bitumen mix was proved to withstand no tension force for both grade of bitumen penetration.

4.2.2.2 Laboratory Test Results for Hardness Test

Similar to the samples prepared for the tension/elongation test, five dumbbell specimen were conducted test. The measured hardness values for each specimen are tabulated in table 4.2.2.2 a and b below.

For 60/70 PG

Table 4.2.2.2.a Test Results for Hardness Test

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Hardness Value	9	9	7	7	9	8.2

For 40/50 PG

Table 4.2.2.2.b Test Results for Hardness Test

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Hardness Value	21	21	20	21	20	20.6

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4.2.2.3 Laboratory Test Results for Oil Resistance Test

A. The Effect of Oil on Mass

The five dumbbell specimens were conducted test and mass values of the specimen before and after immersing in ASTM Reference Fuel (F), diesel fuel are summarized in table 4.2.2.3.1 a and b below.

For 60/70 PG

Table 4.2.2.3.1.a the Effect of Oil on Mass

Test No.	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Initial mass of specimen (g) (M_1)	12.47	14.96	11.43	10.69	13.87	12.68
Mass of specimen after immersion (g) (M_2)	-	-	-	-	-	-
Change in mass (%) (ΔM)	-	-	-	-	-	-

For 40/50 PG

Table 4.2.2.3.1.b the Effect of Oil on Mass

Test No.	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Initial mass of specimen (g) (M_1)	21.82	23.19	20.23	19.99	22.89	21.62
Mass of specimen after immersion (g) (M_2)	-	-	-	-	-	-
Change in mass (%) (ΔM)	-	-	-	-	-	-

To calculate the maximum change in mass of the test specimen, mass of the test specimen after immersion is mandatory. However; when sand-bitumen specimen was immersed in diesel fuel, it dissolved totally that it was impossible to find sand-bitumen mix as a unit sealant. Thus, from the test results, it could be concluded that bitumen in sand-bitumen mix has zero resistance to fuel, that is, bitumen was dissolved in oil.

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Likewise, due to the said zero resistance of bitumen in sand-bitumen mix to fuel, changes of the physical properties such that; the hardness, elongation and tensile strength of the test specimen of the sand-bitumen mix after being immersed in fuel could not be measured quantitatively. But it could be drawn from the measured test results that sand-bitumen mix exposed to fuel spills losses all the envisaged physical properties mentioned above as its existence as a unit mix ceased immediately after being exposed to the fuel for a certain durations.

4.2.2.4 Laboratory Test Results for Tear Resistance or Cohesion Test

For 60/70 PG

The five Type-C specimens were conducted test. Accordingly, test results of each sample and cohesion or tear strength are summarized in the tables 4.2.2.4.1.a and b below.

Table 4.2.2.4.1.a Laboratory test results for tear strength

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Force @ Peak (Kgf)	0.970	1.140	1.670	1.070	0.870	1.144
Force @ Break (Kgf)	0.307	0.461	0.895	0.342	0.210	0.443
Force @ Break (N)	3.012	4.522	8.780	3.355	2.060	4.346
Force @ Break (KN)	0.0030	0.0045	0.0088	0.0034	0.0021	0.004
Thickness (mm)	6.2	6.1	6.1	6.2	6.2	6.16
Thickness (m)	0.0062	0.0061	0.0061	0.0062	0.0062	0.00616
Tear Strength (N/mm)	0.486	0.741	1.439	0.541	0.332	0.707975
Tear Strength (KN/m)	0.486	0.741	1.439	0.541	0.332	0.705

From five Type-C specimens take the maximum force at break and median thickness the determine tear strength. Tables 4.2.2.4.b has summarized the recorded parameter from the above table 4.2.2.4.a

Table 4.2.2.4.1.b Laboratory Test Results for Tear Strength

Test No	Value
Median Thickness (mm)	6.2
Median Thickness (m)	0.0062
Maximum Force@ Break (kgf)	0.895
Maximum Force @ Break (N)	8.780
Maximum Force @ Break (KN)	0.0088
Tear Strength (N/mm)	1.416
Tear Strength (KN/m)	1.416

As depicted in table 4.2.2.4.1.b above, the sand-bitumen mix has only 1.416 KN/m tear resistance.

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For 40/50 PG

The five Type-C specimens were conducted test. Accordingly, test results of each sample and cohesion or tear strength are summarized in the tables 4.2.2.4.2.a and b below.

Table 4.2.2.4.2.a Laboratory test results for tear strength

Test No	Sample-1	Sample-2	Sample-3	Sample-4	Sample-5	Average
Force @ Peak (Kgf)	4.074	5.016	6.4128	4.494	3.654	4.730
Force @ Break (Kgf)	3.408	4.333	5.728	3.796	3.192	4.091
Force @ Break (N)	33.430	42.511	56.192	37.241	31.314	40.137
Force @ Break (KN)	0.0334	0.0425	0.0562	0.0372	0.0313	0.040
Thickness (mm)	10.85	10.675	10.675	10.85	10.85	10.780
Thickness (m)	0.01085	0.010675	0.010675	0.01085	0.01085	0.0108
Tear Strength (N/mm)	3.081	3.982	5.264	3.432	2.886	3.7291
Tear Strength (KN/m)	3.081	3.982	5.264	3.432	2.886	3.7291

From five Type-C specimens take the maximum force at break and median thickness the determine tear strength. Tables 4.2.2.4.b has summarized the recorded parameter from the above table 4.2.2.4.a

Table 4.2.2.4.2.b Laboratory Test Results for Tear Strength

Test No	Value
Median Thickness (mm)	10.850
Median Thickness (m)	0.01085
Maximum Force @ Break (kgf)	5.728
Maximum Force @ Break (N)	56.192
Maximum Force @ Break (KN)	0.0562
Tear Strength (N/mm)	5.179
Tear Strength (KN/m)	5.179

As depicted in table 4.2.2.4.2.b above, the sand-bitumen mix has only 5.179 KN/m tear resistance

4.2.2.5 Laboratory Test Results for other Required Tests

- Compression Set Test
- Abrasion Resistance Test
- Heat Resistance Test
- Adhesion Test

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As per the test requirements of the ASTM D2000, attempts to conduct the aforementioned tests were made. However, emanating from the requirements of the tests, the test specimen of the sand-bitumen was needed to pass through the process of heating (ageing) at a minimum of 100 °c before specimens are molded to the required shape. Unfortunately, when the test specimen was heated, the bitumen from the sand-bitumen mixture melt and made the mix very soft, in which case it was not possible to mold the mixture to the required shape and conduct the required test.

4.2.2.6 Comparison of Sand-Bitumen Mix Laboratory Test Results with ASTM Specification

For ease of referencing, the laboratory test results of the sand-bitumen mix is compared with ASTM specification basic requirements for silicone sealant, FC Material preformed sealants (Elastomers) as tabulated in table 4.2.2.6 a and b below.

Table 4.2.2.6.a Laboratory Test Result vs. ASTM Specification for 60/70 PG

S.N	Material Property	Test Requirement	Standard	Unit	Specification	Test Result
1	Physical Property	Hardness	ASTM-D2240	Shore-A	60±5	8.2
		Min. Tensile Strength	ASTM-D412	MPa	16	0.037
		Min. Ultimate Elongation		%	350	20.36
2	Tear or Cohesion Strength	Min. Tear Resistance	ASTM-D624	KN/m	26	1.416
3	Oil Resistance (70 hours @ 150 °c)	Max. Change in Hardness	ASTM-D471	Shore-A	±15	Bitumen in sand-bitumen mix totally dissolved in the oil (No oil resistance)
		Max. Change in Tensile Strength		%	-50	
		Max. Change in Ultimate Elongation		%	-30	
		Max. Change in Volume		%	120	
4	Compression Set (22 hours @ 175 °c)	Max Permissible Change	ASTM-D 395	%	40	Duo to low heat resistance of the sand-bitumen mix, these tests could not pass from specimen preparation stage when the mix flows as bitumen melts
5	Heat Resistance (70 hours @ 200 °c)	Max. Change in Hardness	ASTM-D573	Shore-A	±15	
		Max. Change in Tensile Strength		%	±30	
		Max. Change in Ultimate Elongation		%	-50	

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

6	Abrasion Resistance	Max. Abrasion loss in Mass	ASTM-D5963	%	6	
7	Adhesion (T-Peel) Strength	Min. Adhesion Resistance	ASTM-D1876	MPa	1.4	

Table 4.2.2.6.b Laboratory Test Result vs. ASTM Specification for 40/50 PG

S.N	Material Property	Test Requirement	Standard	Unit	Specification	Test Result
1	Physical Property	Hardness	ASTM-D2240	Shore-A	60±5	20.6
		Min. Tensile Strength	ASTM-D412	MPa	16	1.226
		Min. Ultimate Elongation		%	350	49.412
2	Tear or Cohesion Strength	Min. Tear Resistance	ASTM-D624	KN/m	26	5.179
3	Oil Resistance (70 hours @ 150 °C)	Max. Change in Hardness	ASTM-D471	Shore-A	±15	Bitumen in sand-bitumen mix totally dissolved in the oil (No oil resistance)
		Max. Change in Tensile Strength		%	-50	
		Max. Change in Ultimate Elongation		%	-30	
		Max. Change in Volume		%	120	
4	Compression Set (22 hours @ 175 °C)	Max. Permissible Change	ASTM-D 395	%	40	Duo to low heat resistance of the sand-bitumen mix, these tests could not pass from specimen preparation stage when the mix flows as bitumen melts
5	Heat Resistance (70 hours @ 200 °C)	Max. Change in Hardness	ASTM-D573	Shore-A	±15	
		Max. Change in Tensile Strength		%	±30	
		Max. Change in Ultimate Elongation		%	-50	
6	Abrasion Resistance	Max. Abrasion loss in Mass	ASTM-D5963	%	6	
7	Adhesion (T-Peel) Strength	Min. Adhesion Resistance	ASTM-D1876	MPa	1.4	

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Note: to evaluate the effect of proportion of sand and bitumen in sand-bitumen mix, in addition to the 20/80 proportion, all the tests were repeated for other mix proportions (25/75 and 30/70 sand-bitumen mix proportions). In addition, to consider the effect of bitumen penetration grade in the mix design, 40/50 grade bitumen was also utilized. However, no significant change in the test result compiled in table 4.2.2.6 a and b above was observed.

4.3 Field Observation

Field observation was conducted on the case study project, Ditchoto Galafi Junction - Elidar - Belho Design and Build Road Project. For this concrete road, transversal and longitudinal joints are provided at 5m and 3.5m spacing (continuous) respectively. Including the depth of backer rod, the joint has a total depth of 31.75mm and width of 10mm, which is to be sealed by the silicone joint sealant. Figure 4.3 below shows joint details [45].

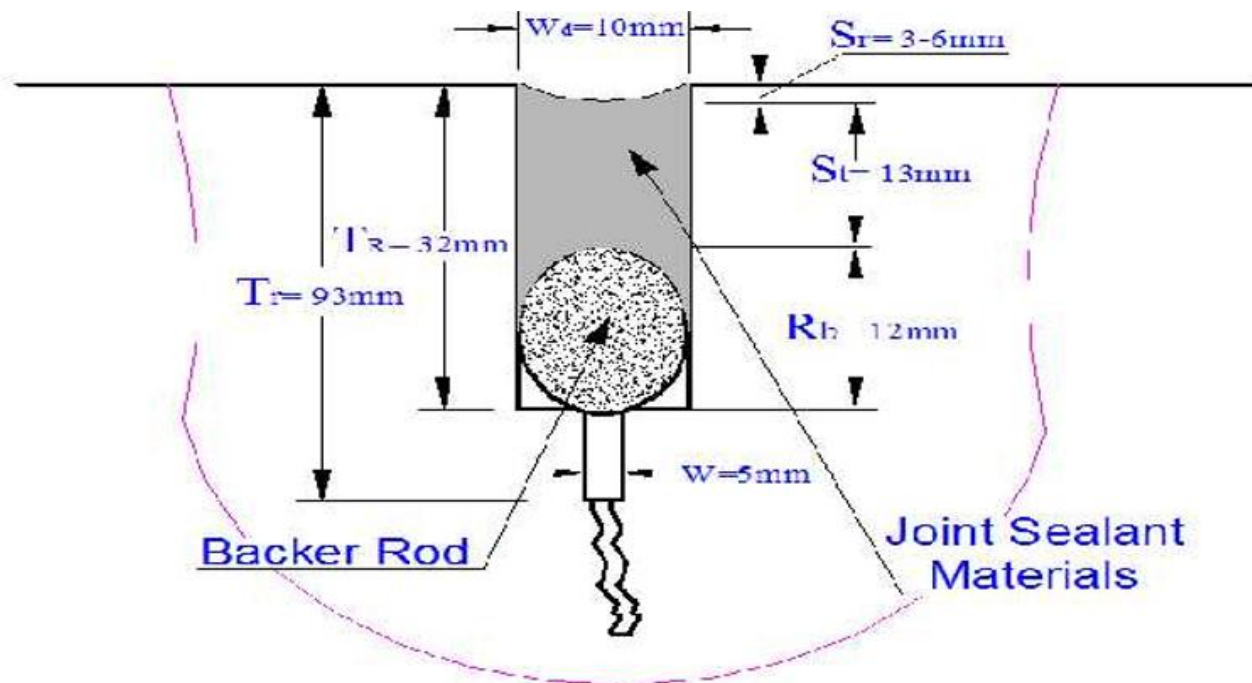


Figure 4.3 Sealant joint details

Table 4.3 a Joint detail dimensions

Sealant Type	Joint Width (inch)	Backer Rod Dia.(inch)	Minimum Joint Depth(inch)	Sealant Bead Thickness(inch)
Silicone	3/8	1/2	1 ¼	1/4

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In the case study project, the contract requires transversal and longitudinal joints of the rigid pavement to be sealed by silicone joint sealant. However, averring to the hard currency problem and costs of the said joint sealant, joints are sealed with sand-bitumen mix joint sealant. Even though the said replacement was done with the consent of the Employer, Ethiopian Road Administration, no standard and specification was adapted in preparation and installation of the envisaged sealant as there was no research witnessed experience in this regard. Hence, except the trial and error method, no scientific procedure was followed in selecting the grades, the mix proportions and other pertinent parameters used to select constituent materials in the mix. Among many others as indicated at the objective of the research section, this research has aimed to give scientific justification for this joint sealant which was totally subjective to the project.

Accordingly, in addition to the tests conducted to evaluate the performance of sand-bitumen mix in the laboratory, visual inspection on the performance of the sand-bitumen mix was done and the under listed checklist was compiled in table 4.3 below.

The identification of the defects conducted along the road corridor for each transversal and longitudinal joint at 5m and 3.5m spacing (continuous) respectively then the determine the failures range by comparing the magnitude of distress on the length segment of the rigid pavement with the total length of the rigid pavement [10, 11, 47, 48, 49, 50, 51].

Table 4.3 b Types of joint sealant failure checklist

Ditchoto – Galafi Juncction-Elidar-Belho Design and Build Road Project Check list				
No	Type of Failure for sealant, sand-bitumen mix	Status		
		Low	Medium	High
1	The magnitude of sealant deterioration		√	
2	Adhesion bond failure		√	
3	Cohesion bond failure		√	
4	Intrusion problem		√	
5	Extrusion problem	√		
6	Proper installation of the joint sealant material		√	
7	Intrusion of incompressible		√	
8	Bleeding and Settlement		√	
9	Cracking of sealant material	√		

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

Legend;

- Low= Defects in less than 5 percent of the joint length.
- Medium= Defects in less than 5 percent, but more than 35 percent of the joint length.
- High= Defects in more than 35 percent of the joint length.

As indicated in the Table 4.3 above, the severity of more than 75% of the joint sealant failures fall under medium category and the rest type of failures are in low status category. Hence, despite the project 10 years warranty period given for the sand-bitumen mix sealant, at the first year of DLP, 75% of the project joint sealant has exhibited different types of failures along between 5% to 35% of the joint length (severity level is medium).

In conclusion, the performance of the sand-bitumen mix joint sealant was evaluated in the laboratory and all the results summarized from the respective tests have indicated that the sand-bitumen joint sealant did not meet the required ASTM specifications. Furthermore, the field observation of the applied sand-bitumen mix joint sealant has asserted that, even at this early stage of implementation (the project was completed in August 2021), most of the sand-bitumen mix joint sealants have suffered from different sealant failures. Hence, the performance of the sand-bitumen mix sealant is below par in both measurements.

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

During field observation, some sample photos portraying sand-bitumen mix and related joint failures were taken. Some of them are presented in figure 4.3 below.



Figure 4.3 Joint sealant failures

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

4.4 Economic Evaluation

The Ditchoto Galafi JPCP type of concrete pavement has 7m width and 80km length. The spacing of transversal and longitudinal joints is at 5m and 3.5m in their respective order. Hence, to seal $10 \times 31.75 \times 3.5 \times 2 \times 1000 \times 14,000$ cubic millimeter (transversal joint) and $10 \times 31.75 \times 1 \times 1000 \times 80,000$ cubic millimeter (longitudinal joint) reservoir, we need to invest nearly ETB 104,714,344.80 to seal the joints with silicone sealant, while only ETB 50,835,763.20 and ETB 6,658,997.30 suffices to seal similar volume joints with rubber membrane and sand-bitumen mix joint sealant types respectively. Conspicuously, Silicon costs almost 200% and 1572% more than rubber membrane and Sand-Bitumen joint sealant in their respective order.

Table 4.4 Economic evolution of joint sealant types

Type of Joint	Joint volume to be filled (m ³)	Silicone price/m ³ (ETB)	Rubber membrane price/m ³ (ETB)	Bitumen price/m ³ (ETB)	Sand Price/m ³ (ETB)	Total Price of Silicon per Joints (ETB)	Total Price of Rubber Membrane per joints (ETB)	0.8*Bitumen price/m ³ (ETB)	0.2*Total Price of Sand /m ³ (ETB)	Total Cost of Sand-Bitumen Mix (ETB)
Transversal	0.0022225	1,717,755.00	833,920.0	136,415.00	517.6	61,083,367.80	29,654,195.20	3,880,733.92	3,681.17	3,884,415.09
Longitudinal	0.0003175	1,717,755.00	833,920.0	136,415.00	517.6	43,630,977.00	21,181,568.00	2,771,952.80	2,629.41	2,774,582.21
Total Cost						104,714,344.80	50,835,763.20	6,652,686.72	6,310.58	6,658,997.30

Note: Prices quoted for imported joint sealants and industry products are average prices from January 2022 to date and exchange rate used for conversion to ETB is 50(\$1=ETB 50). Application utilization rate per gallon of neutral cure silicone as specified by product manufacturers was also considered.

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

Research has shown that the service life of silicone sealants ranges from 3 to 6 years, while the design life of rigid pavements is 40 years. The poor road maintenance culture in Ethiopia, coupled with the short service life of the sealant, worsens the situation and spurs you to look for any other option. However, the presumed replacements of silicone sealant, the rubber membrane, formulated in Horizon laboratory to resemble the Neoprene has witnessed 20 years of service life, and sand-bitumen mix, though its service life is not known to researchers, due to its very minute initial cost, the odds to be preferred to the silicon sealant is very high despite the required frequency of maintenance. Hence, with silicon joint sealant, throughout the service life of the rigid pavement, the pavement needs to be resealed nearly seven times. On the other hand, the joints sealed by using the presumed substitute, the rubber membrane, need to be maintained only twice. Such frequency of maintenance will increase the maintenance cost of the silicon sealant by nearly 85%. In the case of Detcheto Galafi, the initial and maintenance cost of silicon sealant becomes ETB 628,286,068.80 while that of the rubber membrane is ETB 101,671,526.40. Also, considering the replacement of the sand-bitumen mix joint sealant annually, the life cycle cost becomes nearly ETB 266,359,891.97.

A research by Ramzi E had asserted the relative expensiveness of silicon sealants but a lot more research agreed on the expensiveness of preformed sealants [6, 1].

4.5 Advantage and Disadvantage of the Sealants

- The construction of formed in place joint sealants like silicone was unsuccessful because of the unattainable workmanship needed from the contractor, especially the installation of the Backer Rod [6], [9]. Hence, as installation of readymade (preformed) rubber membrane is done by using simple installation equipment, it is less sensitive to the installation methodology than the silicon sealant, as the result of which we will be able to rescue our rigid pavements from premature failure emanated from merely workmanship errors of joint sealing.
- One of the most common premature failure types observed on silicon sealants was adhesive failure due to either when the pavement's joint preparation is not correct or in most cases, inadequate bond strength with the wall [9]. On the other hand, there is no such failure on the rubber membrane due to the very basic operational principle of preformed joint sealant (due to its ability to resist compression set (rebound) and exert lateral pressure on the rigid pavement joints, it will always press tight against the walls).

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As clearly indicated in the research title, this research aimed to evaluate the potential of sand-bitumen mix and rubber membrane to replace the renowned silicone sealant. Accordingly, based on the performance evaluations of the presumed replacements in Horizon Addis Tire Manufacturing laboratory as per the envisaged ASTM standards and the Ditchoto Galafi road project, the following conclusions are drawn.

As test results of the rubber membrane revealed, the rubber membrane has fulfilled the desired physical, mechanical and other properties envisaged by ASTM standard specifications. The laboratory tested parameters for which the rubber membrane has complied are listed below:

- ✓ Hardness: As envisaged by ASTM standard specification (ASTM D 2240), the acceptance criteria for hardness ranges from 55-65 Shore A whereas the test result for the rubber membrane is 64.6 Shore A.
- ✓ Tensile Strength: The tensile strength of the rubber membrane under investigation is found to be 17.19MPa while ASTM standard specification (ASTM D 412) sets the lower bound to 16 MPa.
- ✓ Ultimate Elongation: Minimum ultimate elongation required by ASTM standard specification (ASTM D 412) is 350% but the rubber membrane under this study has elongated by 427.53%.
- ✓ Compression Set: Laboratory test result of the rubber membrane regarding the maximum permissible change due to compression revealed that the change in Thickness(height) observed is 19% while the desired maximum compression set as per ASTM standard specification (ASTM D 395) is 40%.

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

- ✓ Heat Resistance: As a measure of heat resistance of the rubber membrane, Max Change in Hardness, Max Change in Tensile Strength and Max Change in Ultimate Elongation were tested in accordance with ASTM D 573, accordingly, the maximum change in hardness, tensile strength and ultimate elongation are 9, -5.81 and -8.55 respectively while ASTM standard specification sets the upper bound to ± 15 , ± 30 and -50 respectively.
- ✓ Oil Deterioration Test: Only 8.9% volume change is detected on the rubber membrane though ASTM standard specification (ASTM D 471) allows 120% volume change after immersion in the oil (jet fuel) under the specified temperature and condition.
- ✓ UV and moisture Resistance: Any physical changes resulting from the rubber membrane exposure to UV and moisture were observed, as the result, the rubber membrane neither swells nor got stiffer.
- ✓ Abrasion Resistance: As per ASTM-D5963, mass loss up to 200mg is tolerable but the rubber membrane lost on average 87mg only.
- ✓ Adhesion Resistance: as per ASTM-D1876, elastomers are expected to resist up to 1.4MPa but the rubber membrane was proved to have 3.36MPa adhesion strength.
- ✓ Cohesion Strength: preformed joint sealants are required to have minimum tear strength of 26KN/m, while the rubber membrane was proved to have 85.58KN/m.
- ✓ On the other hand, the sand-bitumen mix, which was already in use to seal the joints of the Detcheto Galafi rigid pavement road project, has fulfilled none of the ASTM requirements set for Silicon sealants. In addition, from the field observation conducted on the case study project, even at this early stage, sealant failures were detected.
- ✓ However, emanating from the higher life cycle cost of the silicon sealants, it is beneficiary to seal and reseal joints with sand-bitumen mix every year throughout the service life of the road, thereby addressing the durability issues such joint sealants are flawed.

Evaluation of Sand-Bitumen Mix and Rubber Membrane Joint Sealants for Ongoing Rigid Pavements in Ethiopia

This research concludes that rubber membrane can successfully replace silicone sealant, even with a lesser life cycle cost, better durability and response to environmental conditioning whilst neither the laboratory test results nor field performance evaluations of the sand-bitumen mix sealant favor the existing trends in sealing rigid pavement joints with such sealant.

5.2 Recommendations

To improve the quality of researches conducted on the subject matter and to shed further light on joint sealant performance in concrete pavements, the following recommendations may be considered:

- Though the application of rubbers for joint sealing is not new for the industry, due to their expensiveness and availability problems, they could not be given the same chance as silicone and polysulfide joint sealants to prove their peculiarities in this regard. Hence, this research has made one more extra step to show the potential of customized rubber membranes to replace renowned joint sealants. Therefore, the researcher would like to recommend further investigation on the field performance of the customized rubber membrane and make the presumed substitution practicable.
- As the case study project is in the first year of the defect liability period, it will be too early to visualize all performance-related qualities or flaws. Hence, the researcher recommends further investigation on the field performance of sand-bitumen mix.
- As per the statistics of the Ethiopian Road Administration, there are more than 150 bridges plus 226.65km of ongoing rigid pavement constructions. Sealing the bridge expansion joints with the recommended rubber membrane will make the cost-saving enormous. Also, since the requirements of sealants per expansion joint of the bridge are insignificant, it is recommendable to assess the field performance of the joint sealant by applying them in bridge expansion joints (Pilot test).
- Based on the field and laboratory evaluations of the sand-bitumen mix, this research recommends rubber membrane joint sealant as an alternative option to imported joint sealants (like silicone). Furthermore, not to duplicate mistakes, this research discourages the use of sand-bitumen mix as a joint sealant as both laboratory and field performance of the sand-bitumen mix is below par.

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Appendix



Figure 1. Natural Rubber from Bebek plantation



Figure 2. Crude rubber just after formulation (from Bebek)



Figure 3. SMR-20 Rubber



Figure 4. SBR-1500 Rubber



Figure 5. CI S BR-1200 Rubber



Figure 6. Components of the formulated rubber membrane



Figure 7. Mixer of Components of the formulated rubber membrane

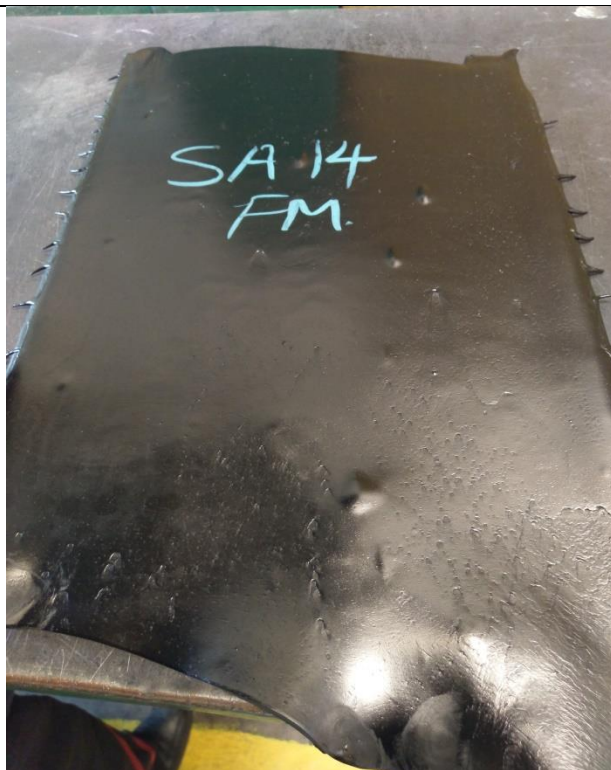


Figure 8. Final Rubber material just after formulation



Figure 9. Rubber Curing Machine

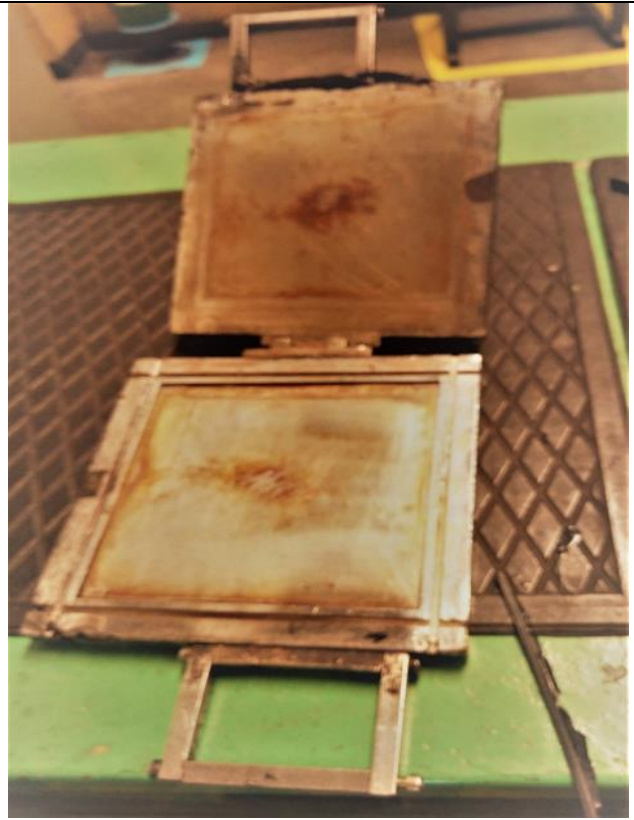


Figure 10. Mold for Curing of Rubber Sample



Figure 11. Compressor

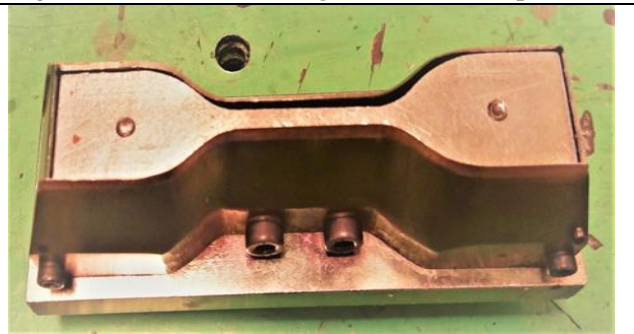


Figure 12. Cutting mold for dumbbell and tear, Type-C specimen respectively



Figure 13. The specimens after curing



Figure 14. Sample Cutting machine for both dumbbell and tear specimens



Figure 15. Type C or Right angle Tear Specimen for rubber membrane

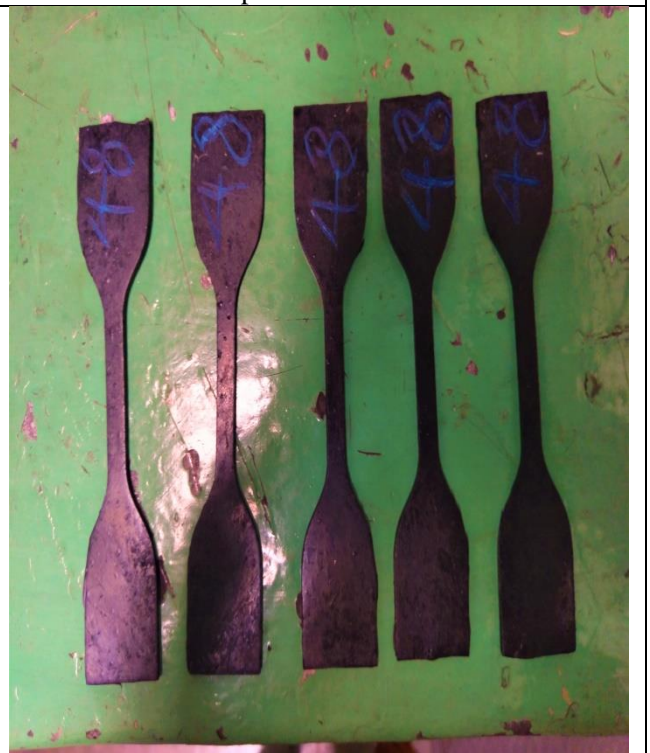


Figure 16. Dumbbell Specimen for rubber membrane



Figure 17. Tension/Elongation Test Machine



Figure 18. Hardness testing equipment

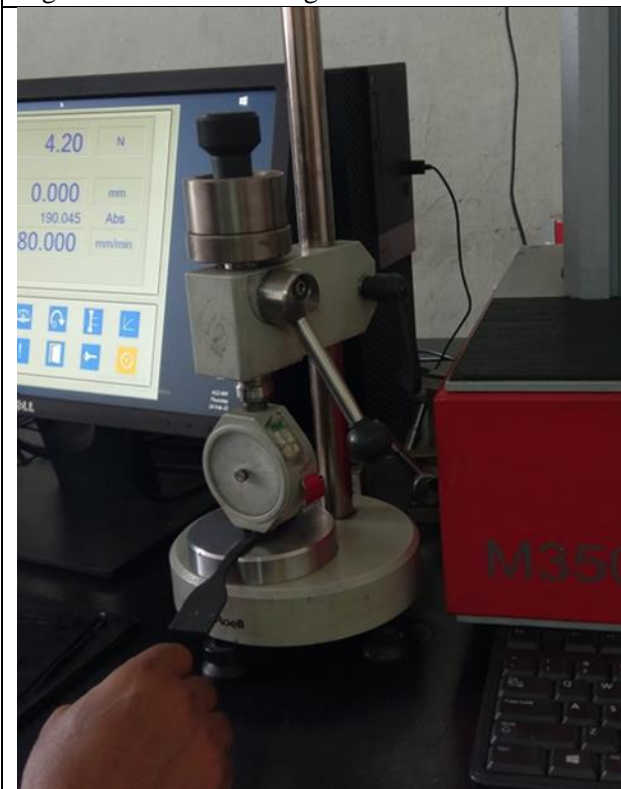


Figure 19. Specimen Hardness measurement for Rubber membrane



Figure 20. Specimen thickness measurement for Rubber membrane



Figure 21. Elongation test on progress



Figure 22. Tear (Cohesion) test on progress

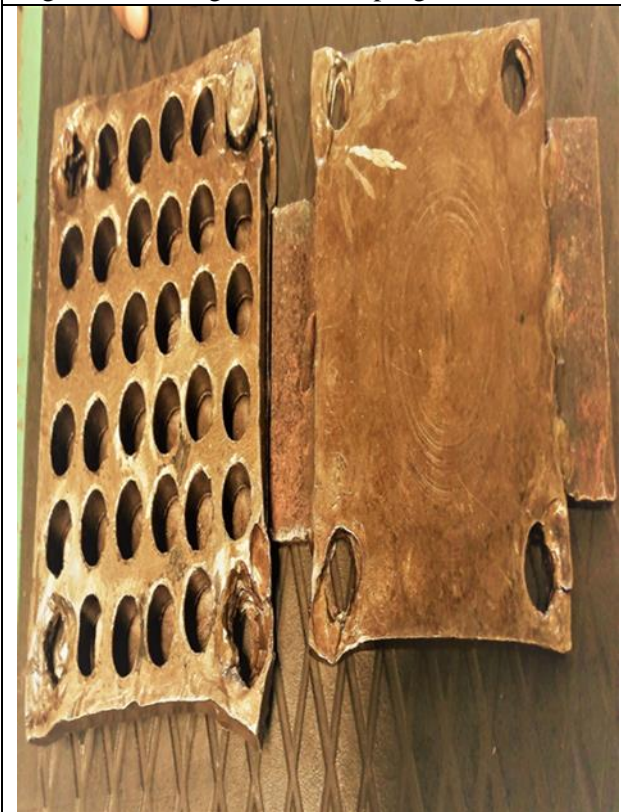


Figure 23. Mold of Specimen for Abrasion Test and Compression Test



Figure 24. Specimen for Abrasion Test



Figure 25. Abrasion Test Machine



Figure 26. Specimen for Compression Test



Figure 27 . Specimen before curing for Adhesion Test



Figure 28. Specimen for Adhesion Test



Figure 29. Adhesion test on progress

HORIZON ADDIS TYRE MANUFACTURING PLC
Optimal Physical-Mechanical Properties of
Vulcanizate Compounds Dumbbells

Identification code: CHCL-06-0111

Compound Number	Shore A (Sk A)	Tensile Strength (Mpa)	Modulus @ 300 (Npa)	Elongation (%)
04 FM	60.00-63.00	Min 14.00	8.20-13.20	350.00-550.00
17 FM	65.50-72.50	Min 16.50	10.00-17.00	360.00-550.00
14 FM	72.00-81.00	Min 16.50	12.00-20.00	370.00-470.00
08 FM	64.00-71.00	Min 14.00	6.50-12.50	420.00-420.00
49 FM	56.00-62.00	Min 7.50	3.50-9.50	455.00-655.00
51 FM	51.00-56.00	Min 14.00	7.50-13.50	310.00-540.00
54 FM	60.00-65.00	Min 9.50	6.55-10.85	300.00-470.00
73 FM	81.00-88.00	Min 15.00	9.00-16.00	320.00-480.00
86 FM	66.00-72.00	Min 18.00	7.50-13.00	390.00-590.00
BC 1243 FM	85.00-61.00	Min 18.50	8.40-14.60	230.00-550.00
CO 1227 FM	58.00-64.00	Min 18.00	10.00-16.00	340.00-540.00
CO 1754 FM	60.00-66.00	Min 13.50	5.85-10.85	420.00-590.00
SO 1401 FM	54.00-60.00	Min 19.00	7.20-12.20	425.00-595.00
TO 1221 FM	60.00-65.00	Min 18.00	8.00-14.00	390.00-570.00
TO 1700 FM	55.00-65.00	Min 18.00	10.00-16.00	360.00-560.00
5061 FM	60.00-65.00	Min 9.50	4.00-8.00	160.00-250.00
5447 FM	72.00-79.00	Min 10.60	4.00-8.00	175.00-190.00
8493 FM	72.00-79.00	Min 18.00	8.90-13.90	412.00-574.00
TT10-FM	60.00-64.00	Min 20.00	9.80-15.80	398.00-598.00
721-FM	61.00-67.00	Min 19.00	8.30-13.30	440.00-660.00
TT08-FM	57.00-63.00	Min 13.00	8.40-14.40	360.00-560.00
ILC-FM	61.50-65.50	Min 18.50	6.50-12.50	400.00-600.00
ELP-FM	54.00-58.00	Min 17.50	8.00-14.00	390.00-590.00
BRCC-FM	57.50-63.50	Min 17.50	7.70-13.60	390.00-560.00
TCC-FM	58.00-65.00	Min 17.00	7.20-13.20	425.00-595.00
BOP-FM	57.00-63.00	Min 16.00	5.80-10.80	480.00-630.00
PSWT-FM	54.00-60.00	Min 17.00	10.00-16.00	390.00-550.00
MT12-FM	61.00-67.00	Min 17.00	10.00-16.00	390.00-550.00

LAST IDENTIFICATION CODE: CHCL-06-0119

Prepared by: Shift Technologist (Conf.) Name: Melaku Mesle Signature:	Checked by: Tyre Technologist Name: Yitayal Workneh Signature:	Rechecked by: RMSC Technology Head Name: Tadesse Mengist Signature:	Approved by: PIQA Dep. Manager Name: Yohannes Melaku Signature:
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Figure 30. Horizon specification guideline

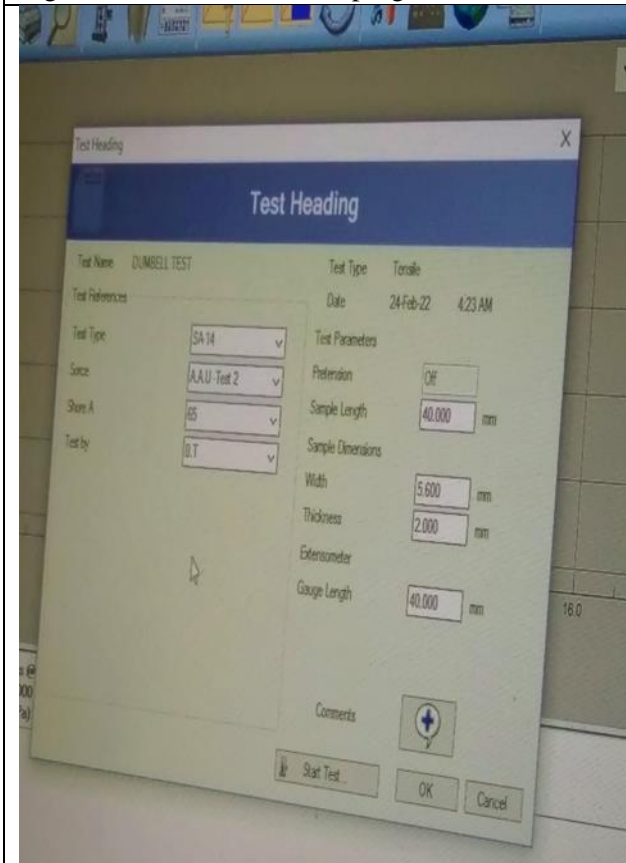


Figure 31. Specimen test data

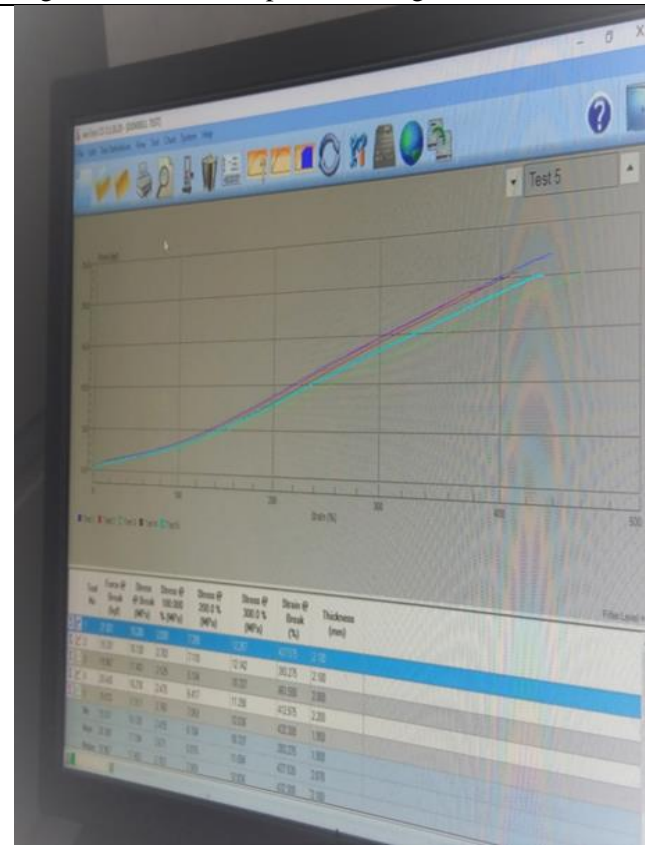


Figure 32. Elongation / Tension Test Result



Figure 33. Heat (aging) Machine, Oven



Figure 34. Specimen in dry oven

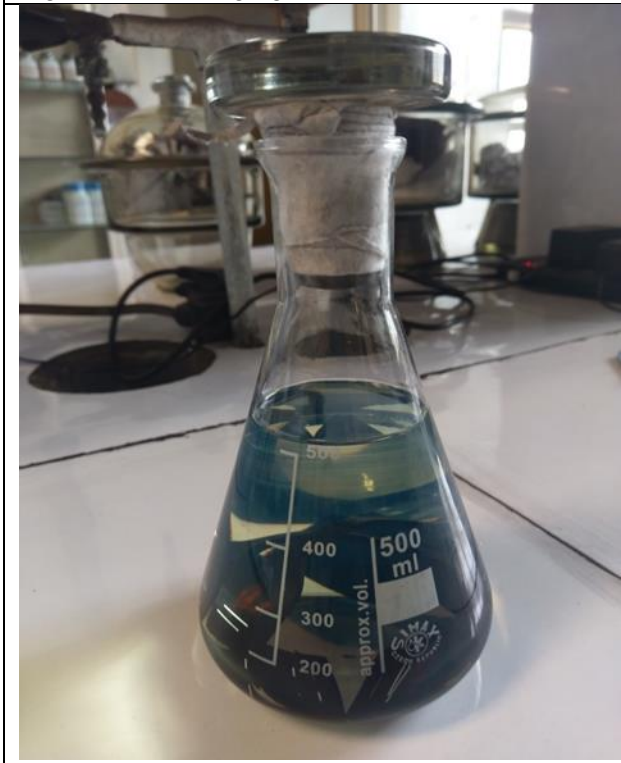


Figure 35. Specimen immersed in ASTM Reference Fuel (F), Diesel fuel



Figure 36. Specimen after oil immersion test

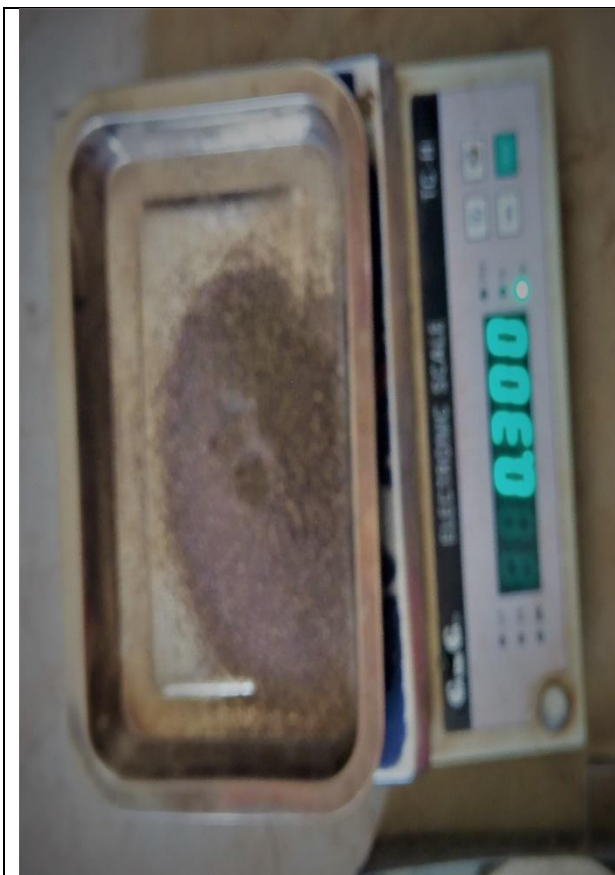


Figure 37. Sand



Figure 38. Bitumen

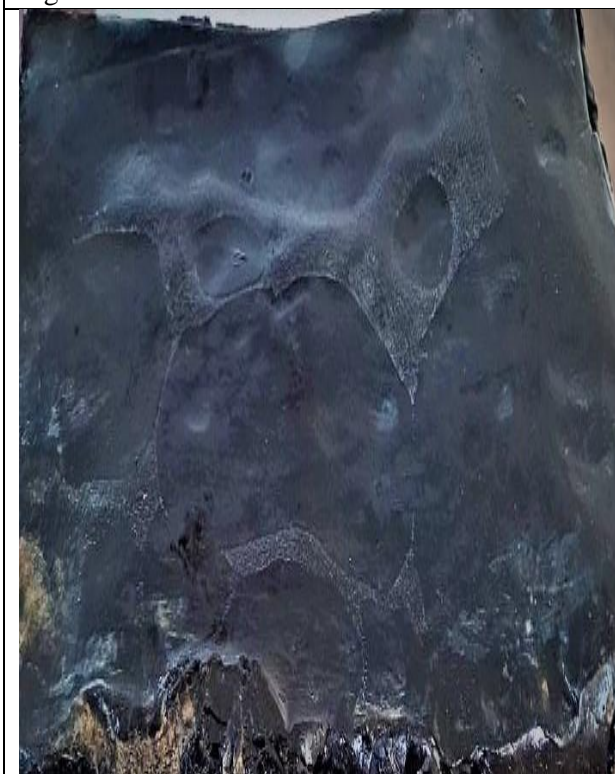


Figure 39. Mixture of Sand and Bitumen after formulation



Figure 40. Specimen of Sand and Bitumen after curing

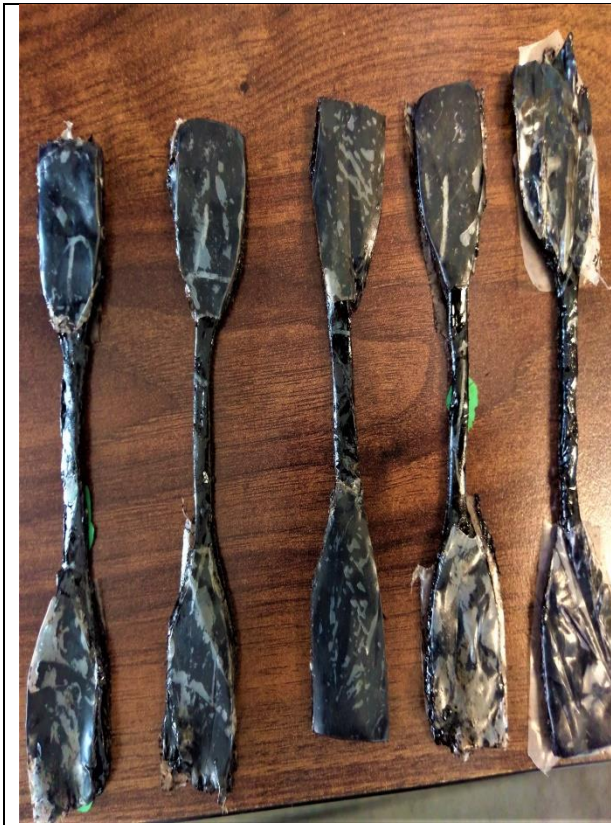


Figure 41. Dumbbell Specimen for Mixture of Sand and Bitumen



Figure 42. Type C or Right angle Tear Specimen for Mixture of Sand and Bitumen



Figure 43. Specimen Hardness Measurement for Mixture of Sand and Bitumen



Figure 44. Specimen thickness measurement

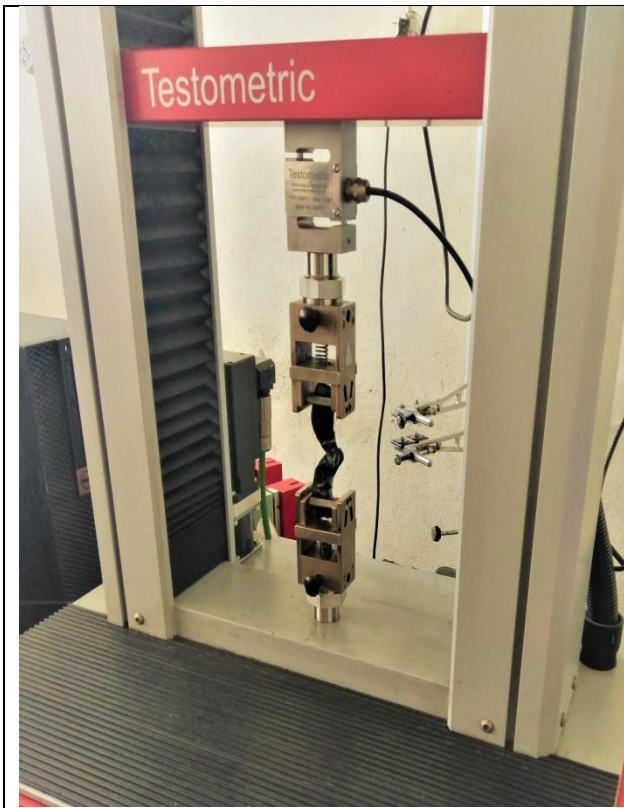


Figure 45. Tear (Cohesion) test on progress for Mixture of Sand and Bitumen

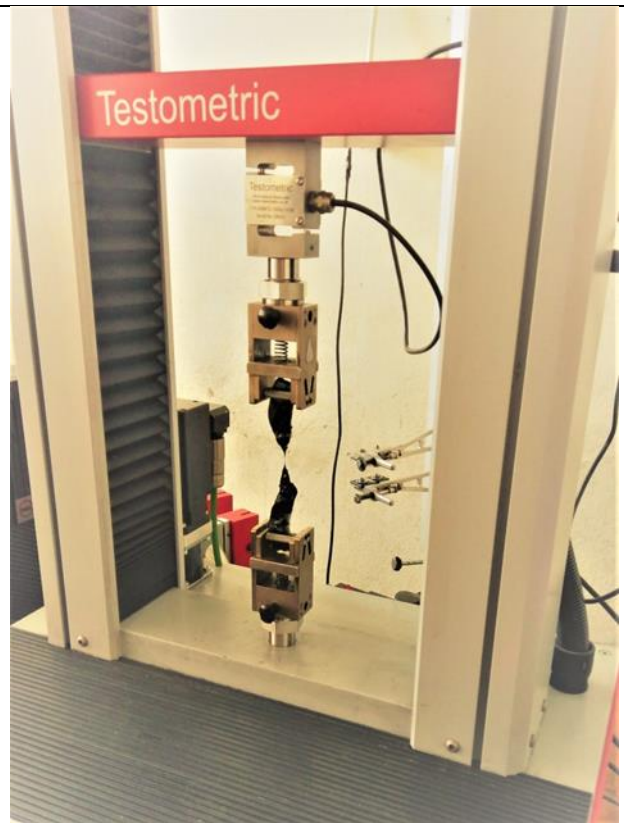


Figure 46. Tear (Cohesion) test sample @ break point



Figure 47. Elongation test on progress for Mixture of Sand and Bitumen



Figure 48. Elongation test sample @ break point



Figure 49. Specimen immersed in ASTM Reference Fuel (F), Diesel fuel



Figure 50. Specimen has been dissolved after oil immersion test

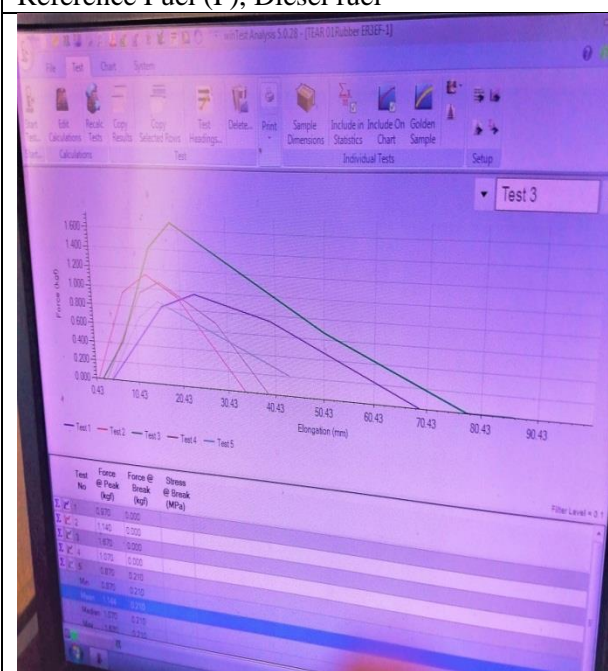


Figure 51. Tear (Cohesion) Test Result

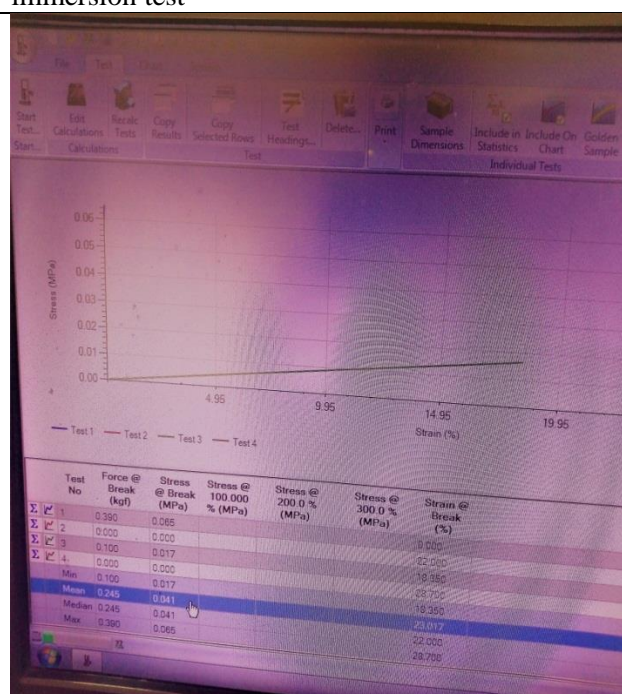


Figure 52. Elongation / Tension Test Result



Figure 53. On Ditchoto –Galafi different failure in sealed mixture of Sand and Bitumen



Figure 54. Some stretches of Ditchoto- Galafi Junction- Elidar-Belho Design and Build Road project