THE EFFECT OF GROUND VULCANIZED TIRE RUBBER USED AS ADMIXTURE IN ASPHALT CONCRETE SURFACES ON THE PERFORMANCE OF PRIMARY JORDANIAN HIGHWAY PAVEMENTS

BY

SALTI SALIM HANNA QAQISH

SUPERVISED BY

Dr. RUHI LUTFI AL SHARIF — SUPERVISOR

PROF. SABIR DAHIR — ASSOCIATE SUPERVISOR

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

FACULTY OF GRADUATE STUDIES
UNIVERSITY OF JORDAN
AMMAN – JORDAN

MAY 6, 1991

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

THESIS DISCUSSED ON MAY 6, 1991

APPROVED BY

DR. RUHI LUTFI AL-SHARIF	CHAIRMAN
PROF. SABIR DAHIR	CO-CHAIRMAN
DR. MOHAMMAD HIYASSAT	COMMITTEE MEMBER
DR. NIDAL KATAMINE	COMMITTEE MEMBER
DR. IZZEDDIN KATKHUDA	COMMITTEE MEMBER

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Dr. Ruhi Lutfi AL-Sharif for his helpful suggestions, wise counseling, guidance and encouragement during the course of this study. I sincerely appreciate the cooperation and advice extended by Prof. Sabir Dahir my associate supervisor.

Special thanks to Dr. Mohammad Hiassat, Dr. Nidal Katamine and Dr. Izz eddin Katkhuda for their cooperation and participation as committee members.

I would like to express my deepest gratitude to the Minister Of Public Works And Housing, Mr. Abdel Ra'oof EL-Rawabdeh and to the Secretary General of the Ministry, engineer Rashadan EL-Rashdan, for their encouragement during the course of this work.

Great appreciation is extended to the directors in the Ministry Of Public Works And Housing, Engineers Abdel Jabbar EL-Khateeb, Mohammad EL-Nsoor and Hitham Mraish.

Great thanks to engineers Samir Qaqish, Prof. Samih Qaqish, Azam Amro and Nuha Jomah for their help.

Great thanks to laboratory analyst Ahmad EL-Dwaileh, draftsman Zuhir Awadat, Sally Center for Computer and Translation and Mukhtar Center for their help, each in his specialty.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE OF CONTENTS

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE OF CONTENTS (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE OF CONTENTS (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE OF CONTENTS (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE OF CONTENTS (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE OF CONTENTS (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF TABLES

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF TABLES (CONT'D)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF TABLES (CONT'D)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF TABLES (CONT'D)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF FIGURES

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF FIGURES (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF FIGURES (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF FIGURES (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF FIGURES (Cont'd)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

LIST OF SYMBOLS AND ABBREVIATIONS

Bitumen	:	Asphalt
Mix	:	Rubber-Asphalt Concrete Mixture.
Binder	:	Percent Rubber-Asphalt Blend By Weight Of Total Mix
Rubber	:	Percent Rubber Content By Weight Of Binder.
A.V	:	Percent Air Voids In Total Mix.
V.M.A.	:	Percent Voids In Mineral Aggregate.
C	:	Centigrade Degree.
F	:	Fahrenheit Degree.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

ABSTRACT

The main objective of this research work is to assess the possibility of improving the performance of bituminous concrete mixes used in wearing courses by adding ground vulcanized rubber to these mixes on pavements that carry heavy traffic, and to give the pavement surface a longer life. Rubber has been used as a substitute for part of the bitumen, thus reducing bitumen cost. Since thousands of scrap tires can be used in preparing the ground rubber, another advantage will be having a positive effect on the environment.

Materials used in this research were: the ground vulcanized rubber passing No. 20 sieve obtained from tires' factory near Amman, asphalt cement of 60/70 degree penetration obtained from Jordan Petroleum Refining Company, and limestone aggregate obtained from quarries in Amman area.

Tests were carried out to determine the physical properties of rubber-asphalt blend as the binder. These tests were; ductility, softening point, flash point, fire point, degree of penetration, specific gravity and stripping.

Tests were also conducted on rubber-asphalt concrete mixtures to investigate their mechanical properties. These tests were: Marshall test, Wheel Tracking Machine test and skid resistance test using the British Pendulum Tester.

Marshall test specimens were divided into three identical groups. The first, second and third groups were soaked in water befor they were tested for 1/2 hour at 60 C,

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

24 hours at 60 C and 1/2 hour at 100 C, respectively. Five percentages of binder content by weight of total mix were used and 5 percentages of rubber content by weight of binder were used. The percentages of binder content were 4.5%, 5%, 5.5%, 6% and 6.5% while the percentages of rubber content were 0.0%, 5%, 10%, 15% and 20% by weight of binder.

With respect to the physical properties of rubber-asphalt blend; ductility, degree of penetration, flash point and fire point decreased with the increase of rubber content while softening point and specific gravity increased, but there was no significant change in aggregate stripping.

With respect to mechanical properties, it is concluded that bituminous concrete mixes containing binder contents ranging from 5.4% to 5.8% by weight of total mix while incorporating rubber contents between 7% and 10% by weight of binder, still satisfy requirements of the Ministry of Public Works And Housing Specifications with regard to percent air voids, percent voids in the mineral aggregate, Marshall stability, Marshall flow, Marshall stiffness, retained stability and retained stiffness. Also, the use of these percentages of binder and rubber contents reduced the water and temperature susceptibility of the mix (water and temperature detrimental effect).

It is recommended to mix and compact the rubber bitumen concrete mixes at the same viscosity for all different percentages of rubber contents. Also it is recommended that more laboratory tests be carried out such as

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

the indirect tensile strength test and Texas freeze-thaw pedestal test on mixes, and chemical tests on rubber. Also, other types of rubber, aggregates, bitumen and mixes should be investigated. Furthermore, it is recommended to place and test some field trial strips and to investigate the possibility of using rubber-bitumen blend in seal coats and surface dressing.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

CHAPTER ONE

ROADS IN JORDAN AND RESEARCH OBJECTIVE

1-1 ROADS IN JORDAN

1.1.1 Historical Background:-

Evidences of advanced road building in Jordan since the Roman rule of the region have been discovered; remains of some of these roads are still in existence. Tracks and dirt roads were dominant later on as trade routes, and it was not until after the second world war that some surfaced roads began to appear.

Telford base (1) was used, and roads were built of such massive construction to endure for long periods of time regardless of drainage conditions.

The first scientific approach to road improvement took place after the middle of this century where asphaltic roads came into prominence (1). Rapid and accelerated economic growth and social development in Jordan has placed extensive demands on road construction to accommodate continuing economic expansion and ensure a high level of transport services (1).

The road network in Jordan provides a distribution base for national and international markets. The desire to transport very heavy loads was a great stimulus and exerted a tremendous influence on the advancement of the road building industry and led to great improvements in the design and construction of highways to provide adequate means of transportation over which to operate.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

1.1.2 Road Network

The total length of paved roads in Jordan at present amounts to about 6000 kilometers of primary, secondary and village roads classified as follows (1).

Primary roads	2716 km
Secondary roads	1652 km
Asphaltic village roads	1632 km

Roads extend through all parts of the country, being less extensive in the very remote and isolated areas such as the desert, east and the south east parts of the country.

1.1.3 Road Construction Costs

Due to limited financial resources, there is a need to develop to the maximum extent possible economical and efficient roads that lend themselves to wide use and specific and unique needs while meeting local requirements and conditions.

Increasing attention is being focused on the use of local materials found in the vicinity of the road to be constructed so as to reduce the cost of road building and to be consistent with the needs and economy.

Current estimated costs of construction for different categories of roads is as follows (1):-

Village roads	20000-30000 J.D/km
Secondary roads and two-lane primary roads	60000-100000 J.D/km
Four-lane primary roads	100000-250000 J.D/km

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

1.1.4 Pavement Construction

Pavements are either flexible or rigid. All roads in Jordan, with the exception of Azraq-Jafer road, are constructed as flexible pavements. Azraq-Jafer road, 180 kms long, is now under construction as a rigid pavement. No experience has yet been gained about the use of this type of pavement in Jordan. (1).

A flexible pavement structure consists of three main layers constructed above the subgrade after the completion of the earthwork of the road. The three layers are designated as subbase course, base course and surface course.

The subbase often consists of aggregates of lower quality than the base course. The subbase course is the portion of the flexible pavement structure between the subgrade and the base course. It usually consists of a compacted layer or layers of aggregates either treated or untreated (2).

The base course is the portion of the flexible pavement structure immediately beneath the surface course. The base course consists of hard and durable crushed stone, usually limestone, crushed wadi gravel or screened wadi gravel to the required sizes and gradings (2).

Technical specifications for the materials and workmanship including placing, watering, compaction and finishing of subbase and base courses comply with the 1974 Standard Specifications for the Construction of Road and Bridges in Jordan (3), together with some additions by

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

special specifications.

In general, aggregates for subbase and base shall have the following requirements (4):-

Property	Subbase Course	Base Course
- Percent wear (Abrasion) of aggregates as determined by Los Angeles Test (ASTM C131)	Not more than 50	Not more than 40
- California Bearing Ratio (CBR) (ASHTO T193-81)	30 To 50	80 To 100
- Plasticity Index (P.I) (ASHTO T89-81) (ASHTO T90-81)	2 To 8	2 To 6
- Percent degree of compaction as determined by Modified Proctor. (AASHTO T180-81) (METHOD D) (METHOD B)	100	100

The surface course of flexible pavement consists of a mixture of mineral aggregates and bituminous materials, placed as the upper course and usually constructed on a base course. In addition to its major function as a structural portion of the pavement, it resists the abrasive force of traffic, reduces the amount of surface water penetrating the pavement, and provides a level and uniform riding surface for traffic (2).

The surface course usually consists of one or more binder courses and one wearing course. The 1974 Jordanian Standard Specifications for the Construction of Roads and Bridges (3) require that the binder course be compacted to not less than 97% of daily lab Marshall bulk dry density (ASTM D2726), and the wearing course to not less than 98% of

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

the same density. Some special specifications require that the binder and wearing courses be compacted to not less than 92% of the Maximum theoretical lab density.

The Jordanian specifications also specify the materials which are used in surface courses as follows (3):- Medium curing cut back asphalt, MC-70, is used for prime coat placed directly on the base course.

Rapid curing cut back asphalt, RC-250, is used for tack coat before placing the binder and wearing courses.

Asphalt cement, 60-70 penetration grade, is used for the surface courses (binder and wearing).

Aggregates used shall be non plastic and shall have a Los Angeles wear of not more than 35% and a minimum sand equivalent of 50% (3).

1.1.5 Bituminous Mixes Used In Surface Courses

Engineers and contractors are becoming increasingly aware of the advantages of using high quality bituminous concrete for road surfacing to meet the demand of modern traffic conditions and to ensure top performance standards for highway pavements.

The use of asphalt in highway construction has been expanding rapidly. Hot mixed and hot laid asphalt paving mixtures have become the most popular paving materials.

The requirements of the Jordanian Ministry of Public Works and Housing (MPWH) for bituminous concrete when tested according to the Marshall Method (ASTM D1559) are as follows (1):-

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

property	Binder	Wearing
Stability. kg	1000 min.	1000 min.
Flow (0.01 inch)	8 to 16	8 to 16
Voids in total mix %	3 to 5	3 to 5
Voids in meniral aggregate V.M.A %	13 min.	14 min.
Loss of stability %	25% max	25% max
Stiffness kg/0.01 inch	125 min.	125 min.
Asphalt content %	4-7	4-7

Asphalt mixing plants used in Jordan are of the batch mixing or continuous mixing type but the batch mixing type is more dominant and preferred.

There are about 25 asphalt mixing plants in Jordan of varying capacities ranging from 60 to 200 tons per hour (1). Asphalt mixing plants are mainly of the following brands:- Wabau, Barber-Green, Marini, Sim and Parker.

Annual production of bituminous concrete for the last seven years amounts to about 1.5 million tons per year (1). About 400 four-lane km of bituminous concrete overlays are completed every year with compacted thickness ranging between 50 and 80 mm. (1).

Asphalt production of the Jordanian refinery is around 130000 tons of all grades of asphalt per year (5).

1.1.6 Pavement Performance

It is particularly important that all pavement layers in general and surface courses in particular be properly

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

compacted during construction. Improper compaction of courses and excessive heavy axle loads acting on road surface are more likely to exhibit a variety of types of distress that tend to reduce the life and overall level of performance of pavements. (2).

Heavy vehicles in Jordan play a significant role in affecting the performance and durability of pavements. Heavy axle loads accelerate deterioration. Different deterioration rates for various categories of roads in Jordan clearly show a strong correlation between pavement performance and axle loads. There are several types of pavement failure seen in Jordan. Some of these are: structural failure, fatigue cracking, bleeding, rutting, raveling and potholes (2,6).

Traffic on Jordan roads is controlled through traffic management rules and regulations and policy measures. Traffic laws and regulations are enforced by the Ministry of Public Works and Housing, Public Security Department, and Municipalities' Councils.

The maximum legal limit on a single axle in Jordan is 13 tons. Legal axle load limit in many countries ranges between 8 and 13 tons (1).

A survey of axle loads on Amman-Maan Desert road revealed that a great number of single axle loads exceeded the legal limit of 13 tons and many exceeded 18 tons (1). It should be emphasized that limiting axle loads to the legal limit is of the utmost importance so that damage to roads can be minimized.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

The seriousness of the overloading problem was not fully recognized until the opening of the first section of the completed dual carriage way of Amman-Maan Desert Road in early 1983. The daily vehicle traffic counts on this road were 1400 heavy vehicles (over 20 tons) in each direction in the year 1982. Between 1986 and 1988 this number had risen to around 2000 heavy vehicles in each direction. Clearly, mixes having very high Marshall stability are required to resist these high repeated stresses. (1).

Improvements in the design and production of asphalt concrete is very essential. Emphasis on high quality, well compacted unbound lower pavement layers and very strict quality control can provide a factor of safety to offset the observed overloading. (2). The use of high quality materials constructed properly in adequate thicknesses for the unbound layers of base and subbase have significantly reduced road damage and pavement deterioration. (2). Local practice in asphalt concrete production has involved the use of screened or crushed wadi gravel aggregates and crushed limestone or granite aggregates. It had become clear that wadi gravel aggregates were unsuitable for use in highly stressed asphalt concrete mixes. This means that all asphalt concrete layers should be constructed of fully crushed hard stone which minimizes stripping. (2). The use of hard crushed limestone aggregates is considered essential in achieving asphalt mixtures of high stabilities. Under no circumstances should mixing of poor quality aggregates with good quality

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

aggregates be permitted. (1).

Observations of completed asphalt pavements in Jordan indicated that the denser was the asphalt mix the less was the likelihood of early cracking (1). Therefore it was emphasized at the requirements of M.P.W.H (3) for compaction to be not less than 98% of daily Marshall bulk dry density for the wearing course and 97% for the binder course. It was also vital to achieve satisfactory voids in the mineral aggregate (V.M.A) (13% minimum for binder course and 14% for wearing course), and voids in the mix (V.I.M) (3%-5% for both binder and wearing courses).

There are other possibilities to be explored, such as the use of lower penetration grade bitumen, additives, different design methods for mixes and use of tougher aggregates such as crushed basalt and granites. (1).

The use of the utmost care with every aspect of the pavement construction is very essential and can not be over emphasized. Importation of special equipment would be required, but strict quality control of asphalt manufacture and paving construction is equally important. (2)

The argument of switching to the portland cement concrete pavement construction to carry heavy loadings is strong. Trials using fiber reinforced concrete pavement is presently at early stages of construction.

399019

Therefore this research is considered as an attempt to improve the performance of asphalt mixtures used in primary road surfaces in Jordan.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

1.2 RESEARCH OBJECTIVE

The main objective of this research work is to assess the possibility of improving the performance of bituminous concrete mixes used in wearing courses by adding ground vulcanized rubber to these mixes to carry heavy traffic and to last for a longer life.

Using rubber in these mixes is expected to improve properties of bituminous mixes and, consequently, improve the performance of these mixes under varying environmental conditions and heavy axle loads.

Rubber will be used as a substitute for a part of the bitumen, thus reducing expenses, especially that thousands of scrap tires can be used in preparing the ground rubber.

In addition, using these scrap tires will clean the roads and parks from them, and this will have a positive effect on the environment.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL

Asphaltic paving mixtures are designed primarily for stability and durability (7). Stability criterion requires paving mixtures to have sufficient initial stability to withstand the applied traffic loads. The durability criterion, however, is concerned with the continued satisfactory performance of paving mixtures under the traffic and environmental factors such as sun, rain, frost and soil moisture to which pavement are exposed during their service lives. The most common and costly problem of pavement distress is fatigue cracking of asphalt pavements which is due to the loss of stability as a pavement becomes old, thus less durable.

Asphalt surface treatments and overlays are widely used to maintain and rehabilitate cracked pavements (7). However, use of conventional surfacings of 100 mm or less in thickness has generally resulted in a new problem, namely, reflection cracking (surface replication of the cracks and joints which are in the underlying layers of the pavement). This in turn severely affects the pavement performance and requires additional and costly maintenance. This problem is due to the lack of flexibility in the asphalt pavement (7) required to respond to loading without undergoing cracking.

In recent years, researchers have explored various means of improving the quality of paving mixtures and asphalt

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

materials. Among the methods used is the use of rubber additives in the asphaltic systems. Historically, many rubber asphalt pavements have been constructed throughout the world.

The addition of rubber has a long history (7). Latex, which is the liquid form of rubber, was used in small scale tests more than 50 years ago, and has recently become more widely used. Although the cost of asphalt concrete is increased when latex is used, the extra expense is small and has become less significant with the recent increase in the cost of bitumen. In most previous applications, typically 1.5 to 5 percent of rubber by weight of asphalt has been used. The resulting material has been described as "RUBBERISED ASPHALT" (8).

More recently, however, larger amounts of vulcanized granulated reclaimed tire rubber have been added to asphalt. Rubberized asphalt materials developed for use for reflection crack control membranes, sealants for cracks or joints or bridge decks and the reduction of potential vertical rise of expansive clay. (8).

Rubber tires present a serious disposal problem (9). Millions of tires are discarded every year. They produce serious smoke pollution when burnt, and tend to rise to the surface when burried.

Reclaimed rubber from scrap tires has been used to modify characteristics of the asphalt, or the asphaltic concrete, to reduce the effects of temperature change on the

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

stiffness and elasticity of the pavement structure (7).

Ground vulcanized rubber has been used in asphaltic paving for roads and on airport runways and has shown excellent resistance to cracking (7).

In recent years many highway agencies throughout the U.S.A. and Canada have developed rubber-asphalt using ground vulcanized rubber (7). The ground rubber tires are blended with hot asphalt at temperatures ranging from 175-200 C and reaction is observed between the asphalt and rubber which produces a marked thickening of the mixture and appears to be time/temperature dependent. The potential usefulness of rubber in the different types of surfacings lies chiefly in the prospect of less frequent maintenance needed by a more resilient and tougher material. (7).

2.2 USES OF RUBBER-ASPHALT.

2.2.1 Rubber-Asphalt Stress Absorbing Membranes.

2.2.1.1 Field trials.

In the early 1960's a concept was developed for overcoming the problem of fatigue cracking. Field trials were initiated in the winter of 1964-1965, and results were reported to the Highway Research Board In January, 1966 (10). The concept was based on a composition consisting of 25 percent ground recycled tire rubber reacted with asphalt under a high temperature to form a thick jellied material with good elastometric properties.

The first full-scale field trial of this material took place in January 1967 on the main taxiway on the Phoenix SKY

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Harbor Airport, U.S.A. (11). This pavement had been designed for DC-3 aircraft and had developed severe alligator fatigue cracking under Boing 707 and similar air-craft. This application, though crude, served so well that by the spring of 1968 the equivalent of some 324 lane-km had been placed at the airport and on the streets of Phoenix.

The Arizona Department of Transportation, U.S.A., became interested in this concept for preventing reflection of alligator cracking and in the summer of 1968 constructed a rubber asphalt stress-absorbing membrane (SAM) covering about 4km of severely fatigued cracked pavements on frontage and access roads of the Black Canyon Freeway (10). The general appearance of the application was poor because proper equipment and application techniques for the viscous rubber-asphalt composition had not yet been developed. However, with the passage of time and traffic, the unevenness of the application smoothed out until the appearance became reasonably acceptable. In spite of construction difficulties, it proved the efficiency of the rubber asphalt material in preventing the reflection of alligator cracking. The surface, when examined after 8 years of hard service, was found in excellent condition and showed only minor crack reflection. However, thermal, or shrinkage cracking, reflected through the rubber-asphalt seal coat, but the cracks were narrow and not spalled. Reflection of the extensive alligator cracking had not occurred.

The Arizona Department of Transportation and other

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

public agencies placed several other projects between 1968 and 1971 by using the rubber-asphalt system and had succeeded in controlling the fatigue cracking problem and had achieved variable results in overcoming construction problems, as application techniques were gradually perfected.

One of the most notable projects treated with rubber-asphalt during this period was the main street of Touscon, Arizona, US-80 in the summer of 1969 (10). The street had severely deteriorated with extensive fatigue cracking and innumerable potholes (10). Conventional overlay of sufficient thickness to control the cracking could not be used because of curb height restrictions and drainage conditions. Reconstruction appeared imperative. However, the town authorities decided to try a rubber-asphalt treatment. After six years of service, this project required no maintenance and showed only a few minor reflective cracks and no evidence of spalling.

2.2.1.2 Improvement in the construction process.

A major improvement in the construction process of rubber-asphalt membranes, which improved the reliability of obtaining good workmanship and appearance, was introduced in 1971 (12). This was the solvent dilution process whereby a small quantity of kerosene was introduced into viscous, reacted rubber-asphalt composition. This dilution temporarily reduces the viscosity but after not more than two hours, the viscosity returns to its original condition.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

2.2.1.3 Flagstaff project

The major rubber-asphalt projects that have been discussed were placed in the warmer south in Arizona, although small test sections had been placed in the cold northern area and in other states as early as (1966) (13).

In August 1973, the Arizona Department of Transportation placed its first major rubber-asphalt treatment in the northern part of the state. This 16 km project is located on US-89, approximately 8 km northeast of Flagstaff, and is at an elevation of more than 2200m above sea level. Winters are cold with minimum temperature as low as - 40C and frost depth of 1m in shady areas. The existing surface was severely cracked with fatigue cracking aggravated by frost susceptible base course that caused severe breakup during thawing periods. It was very rough and virtually impassible in the spring of 1973, and it was necessary to place a thin cold-mixed patching course on most of the project to fill the many potholes. In August the rubber-asphalt treatment was placed by using volcanic cinders as cover aggregate. Some pickup was experienced on the project for a short time as the chip size was small and the rubber-asphalt application less than the optimum. Normally, a 10mm nominal size is used, but these chips had a nominal size of approximately 6mm. This project has performed excellently without reflection cracking and with no maintenance.

2.2.1.4 Minnetoka project.

In 1971 Arizona Department of Transportation

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

participated in the National Experiment and Evaluation Program on pavement of Reflective Cracking in Overlays. A 21-km section extending east of Winslow to Minnetoka was chosen for the studies. The project included 26 experimental sections. One of these sections was placed as a Stress Absorbing Membrane (SAM) over the overlay and two of them were placed between the overlay and asphaltic concrete courses as a Stress Absorbing Membrane Interlayer (SAMI). The final inspection of the project was performed in the spring of 1975. Conclusions after this inspection were that SAMI was very effective in preventing reflection of all types of cracks including fatigue, shrinkage and deflection vertical strain, while SAM was effective primarily in controlling fatigue cracking (13).

As a result of this project, in 1975 the Arizona Department of Transportation implemented the use of the SAMI as a standard procedure for all overlays less than 10 mm thick that are placed over pavements where cracking is a problem (13). The cost of this inclusion is absorbed by reducing overlay thickness.

2.2.1.5 The phoenix project

The city of Phoenix, Arizona, U.S.A. began the placement of 91.7 km of rubber-asphalt seals (SAM and SAMI) from 1975 through 1979. The rubber-asphalt seals were applied and observed under the following variety of use and exposure conditions (14):-

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

a- Largest category comprised instances in which rubber-asphalt chip seal was placed directly on existing pavement in poor condition.

b- Rubber-asphalt chip seal was placed directly over primed soil cement.

c- Variation of the preceding soil cement treated base was used which involved using a 102 mm soil cement base which was primed and covered with a 38 mm levelling course of asphalt concrete followed by rubber-asphalt seal coat.

d- Rubber-asphalt treatment was applied directly over a primed clay loam subgrade.

e- A conventional chip seal was placed over an asphalt rubber chip seal particularly where chip loss from rubber-asphalt threatens the integrity of rubber-asphalt layer.

f- Where there was reflection of joint cracks in thin over lays of asphalt concrete over cement concrete pavements, a minimum overlay generally less than 25 mm of open-graded asphalt concrete to achieve levels was placed followed by a rubber-asphalt seal coat.

g- As double seal application on a heavily travelled industrial arterial road in a deplorable condition with cracking and potholes, potholes were filled, primed then a double rubber-asphalt seal coat placed. h- As a rubber-asphalt seal over the existing cracked surface followed by 12 mm open graded finishing course. On very rough

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

streches of original surface, the treatment usually is preceded by a levelling course of asphalt concrete.

i- Rubber-asphalt with 6.3 mm precoated chips was placed on main commercial runway in an airport on both old and new pavements.

The ratio of rubber to asphalt used in these treatments is 25/75 by weight. This rubber-asphalt blend was mixed with 5% kerosene by the weight of rubber-asphalt blend.

In 1976 rubber-asphalt was introduced in which a small amount of extender oil (special oil which causes the rubber to expand and absorb more asphalt) was incorporated into the blend to improve the compatibility of asphalt and reclaimed rubber blend. The ratio of base asphalt to oil extender to rubber blend is approximately 78: 02: 20 by weight (14). The 91.7 km pavements have been evaluated and are still being evaluated. Observations and conclusions reached as a result of the 91.7 km pavements are as follows (14):-

a- The rubber-asphalt is performing well, its principal function of preventing reflection of fatigue-type cracking and shrinkage of soil cement.

b- The most common defect noted during this survey was a loss of cover aggregate generally from non-traffic areas such as center and shoulder portions of the pavement.

c- Bleeding occurred early on a few of the projects and almost invariably was found to be because the chip requirements of the rubber-asphalt had not been satisfied.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

d- There is a need to maintain close liason concerning construction with distributers, chip spreaders and rollers. Chips also must be clean (preferably precoated) and of uniform size to eliminate interference with embedment.

e- The rubber-asphalt has virtually eliminated surface patching maintenance because, even where it has cracked, after many years of service, the cracks do not spall at the edges and do not develop into potholes, as in the case of conventional seal coats.

2.2.2 Rubber-Asphalt Single Surface Treatments With Multilayered Aggregate Structure.

The design of conventional single asphalt surface treatments is based on the premise that the asphalt membrane applied will retain one and only one layer of aggregate chips (7). Therefore, when more than one layer of chips is desired, it is common practice to apply a second asphalt membrane and a second layer of aggregate chips.

Rubber-asphalt material with unique adhesive and rheological properties has made it possible to form highly elastic single surface treatments with a multilayered aggregate structure where rubber binder is used to retain more than one layer of aggregate chips. The ratio of asphalt to extender oil to rubber blend in this system is approximately 78: 02: 20 by weight. The application rate for the rubber asphalt binder varied from 1.86 to 8.87

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

litres/sq.m. with cover aggregates placed at 13 to 37 kg/sq.m. (14).

2.2.3 Membrane Construction

The early membrane experiments utilized either a slurry spreading, or application of rubber-asphalt material by conventional distributor trucks. Construction problems, encountered with these spreading procedures, created a final product which left much to be desired and it soon became very apparent that new or modified equipment and product-handling methods were needed (7).

With time, a special distributer truck was designed for the mixing, reacting, and spreading of rubber-asphalt (7). This trailer-mounted self-powered unit is equipped with an asphalt heating system even up to 218 C and temperature control devices, an on-board weighing device to help in proportioning materials, a mixing unit capable of producing a reacted homogenous mixture, two asphalt pumps and a full-circulating spray bar with large special nozzles. A recent innovation has been the development of a large mixing tank, for asphalt and rubber blending and reaction, with the distributer trucks thus serving only for spreading.

2.2.4 Improved Hot Mix Asphaltic Concrete Containing Reclaimed Rubber.

Laboratory research as well as test strips laid on a heavily trafficked road in Canada using hot mix asphaltic concrete containing reclaimed rubber have been reported in

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

the proceedings of the Association of Asphalt Paving Technologists, 1977 (15). The main streets in Toronto, Canada are heavily used, and the high winter snow falls and numerous freeze-thaw-cycles cause rapid deterioration of the street surfaces. Metro Toronto Roads and Traffic Department policy has been to provide a load bearing base of portland cement concrete 200 mm thick and to overlay this with 40 mm of hot mix asphalt concrete. The work described in this study was directed towards improving the hot mix asphalt overlay by the use of reclaimed rubber.

A number of test strips, each about 10 m long and 25 mm thick, were laid on a heavily used plant road in Toronto, Canada. This road had a base of 150 mm of crushed limestone, then 75 mm of asphalt base and at the top 150 mm of asphalt concrete (15). The mixing and road laying were carried out at high temperature (150-200) C and it was found that it was necessary to wait 10 minutes before allowing the rolling on the surface. As long as care was taken, there was little pick-up on the roller; however, raking was little more difficult with the rubber mixtures. Some hair cracks was observed, but the final appearance of surface was good in all cases. No problems were encountered in preparing the mixes. A special tank was used for rubber-asphalt mixtures and a recirculating pump kept the materials well mixed at all times. After four months of heavy use, mainly using heavily loaded trucks, there was no sign of wear and tear on any of the experimental strips. On the basis of these promising

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

results, Metro Toronto Roads and Traffic Department laid longer test strips on one of the major streets in Toronto.

Results for voids content, voids in the mineral aggregates, Marshall flow and Marshall stability were obtained for 45 percent coarse aggregate with sand to fines ratios of 3:1, 2:1 and 1:1 with and without vulcanized rubber. It was noted that the voids content and voids in the mineral aggregates greatly increased by adding rubber. When the rubber is preheated with the bitumen for 30 minutes at the same temperature, the void content is even higher. The Marshall stability and Marshall flow were adversely affected by the rubber (15).

2.3 LITERATURE RIVIEW CONCLUSIONS

1- A high percentage of rubber-containing (as granulated tire) asphalt rubber material has been developed all over the world through extensive laboratory and field testing which has many applications for road maintenance and rehabilitation.
2- When placed as a seal (SAM-Stress Absorption Membrane) the system controls reflection of fatigue cracks and is an effective alternate to a major overlay or reconstruction.
3- When placed as interlayer (SAMI - Stress Absorption Membrane Interlayer) the system effectively controls reflection of all cracks.
4- Rubber asphalt system used as membranes over expansive clays helped to reduce swelling.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

5- The performance of the Rubber asphalt system as a water infiltration barrier has been demonstrated in bridge decks.

6- Rubber asphalt systems have been successfully used for the sealing of cracks and joints.

7- The Stress Absorption Membrane (SAM) has potential for use as an overlay for rehabilitating (without crack reflection and with high skid resistance) portland cement concrete pavement and as an effective crack sealer for maintenance.

8- Rubber-asphalt can be used as binder for asphalt concrete mixtures because of possible improved performance due to increased binder film thickness, durability and flexibility despite their low Marshall stabilities.

9- A recent study (9) indicates that of all the alternatives for disposal of rubber tires, the net benefits of use of reclaimed rubber tire for road repair were by far the largest.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

CHAPTER THREE

EXPERIMENTAL WORK AND RESULTS

3.1 TEST METHODS AND SPECIFICATIONS:

The test methods and specifications of this research work comply with one of the following specifications: a- American Association of State Highway and Transportation Officials (AASHTO) (16,17). b- American Society for Testing and Materials (ASTM) (18, 20). c- British Standard (B.S) (19). d- Ministry of Public Works and Housing in Jordan (M.P.W.H) (1,3).

3.2 MATERIALS USED AND TESTS CONDUCTED

3.2.1 Asphalt Cement.

In this research work one type of Asphalt cement was used. It was 60-70 penetration grade obtained from the Jordanian Petroleum Refinery. This grade is commonly used for heavy traffic and hot weather conditions. The bulk specific gravity of this asphalt cement was 1.016.

3.2.2 Rubber.

Ground vulcanized rubber obtained from a tires' factory in the Amman area was ground by a miller and sieved on No. 20 sieve. The bulk specific gravity of this rubber was 1.07.

3.2.3 Rubber Asphalt Cement Blend

The Rubber passing the No. 20 sieve was blended with asphalt cement in different ratios of rubber to asphalt by weight, namely 0.0/100, 5/95, 10/90, 15/85, and 20/80. The

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

rubber and asphalt cement were blended by a stirring rod at a temperature of 160C for one hour (this temperature is usually used in mixing bituminous concrete mixtures containing 60-70 penetration gtade as it meets the viscosity of 170 ± 20 CST. Since the viscosity measurement equipment is inavailable in the laboratory, we used this temperature in mixing all different percentages of rubber-bitumen blend).

Table 3.1 shows tests carried out on asphalt cement, rubber and rubber asphalt cement blend. Average results of these tests are shown in table 3.5 while individual test results are shown in table D.1.

TABLE 3.1 TESTS CARRIED OUT ON ASPHALT CEMENT, RUBBER AND RUBBER ASPHALT CEMENT BLEND

No.	TYPE OF TEST	SPECIFICATION	MATERIAL TESTED	No. of SPECIMENS
1-	Ductility (cm) 77F 5cm/min	ASTM D113	Asphalt cement	2
		ASTM D113	Rubber Asphalt cement blend.	8*
2-	Softening (C), Ring and Ball	ASTM D36	Asphalt cement	2
		ASTM D36	Rubber Asphalt cement blend.	8*
3-	Penetration (0.1mm) 100gm, 5 sec.	ASTM D5	Asphalt cement	2
		ASTM D5	Rubber Asphalt cement blend.	8*
4-	Flashpoint and Firepoint (C). (C.O.C).**	ASTM D92	Asphalt cement	2
		ASTM D92	Rubber Asphalt cement blend.	8*
5-	Specific gravity, 77F	ASTM D70	Asphalt cement	2
		ASTM D70	Rubber	2
		ASTM D70	Rubber Asphalt cement blend.	8*

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

* Two specimens at each blend ratio.

** Cleveland Open Cup.

3.2.4 Aggregates

One type of aggregate was used for both coarse and fine portions. It was crushed limestone aggregate obtained from a quarry in the Amman area. This type is commonly used in hot asphalt mixes in Jordan.

Table 3.2 Shows the tests conducted on crushed limestone aggregates. Average results of these tests are shown in tables 3.6 and 3.7 while individual test results are shown in table D.2.

Table 3.2 THE TESTS CONDUCTED ON CRUSHED LIME STONE AGGREGATE

No.	TYPE OF TEST	SPECIFICATION	No. OF SPECIMENS
1-	Aggregate Abrasion	ASTM C131	2
2-	Plasticity index for materials passing No. 40 sieve	ASHTO T89-81 T90-81	2
3-	Sand equivalent	ASTM D2419	2
4-	Static stripping		
	(of Asphalt cement)	ASTM D1664	1
	(of Rubber Asphalt cement blend)	ASTM D1664	4*
5-	Dynamic immersion test. (of Asphalt cement)	Swedish method (1)	1
	(of Rubber asphalt cement blend)	Swedish method (1)	4*
6-	Texas Boiling test		
	(of Asphalt cement)	Texas method (1)	1
	(of Rubber asphalt cement blend)	Texas method (1)	4*

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Continue

No.	TYPE OF TEST	SPECIFICATION	No. OF SPECIMENS
7-	Aggregate Soundness (Magnesium Sulfate)	ASTM C88	2
8-	Percentages of clay lumps and friable particles	ASTM C142	2
9-	Flakiness index and elongated index	B.S 812	2
10-	Percentage of flint content	M.P.W.H	2
11-	Specific gravity of coarse aggregate (Passing 3/4" sieve and retained on 3/8" sieve)	ASTM C127	2
12-	Specific gravity of coarse aggregate (Passing 3/8" sieve and retained on No.4# seive	ASTM C127	2
13-	Specific gravity of fine aggregate Passing No. 4# sieve)	ASTM C128	2
14-	Aggregate gradation	ASTM C117 C136	1

* One specimen at each ratio

Table 3.3 Shows the upper and lower limits of wearing course gradation according to the specifications employed by the Ministry of Public Works and Housing M.P.W.H. Also it shows the gradation used in this research which is within these limits. These gradations are drawn in Fig 3.1.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

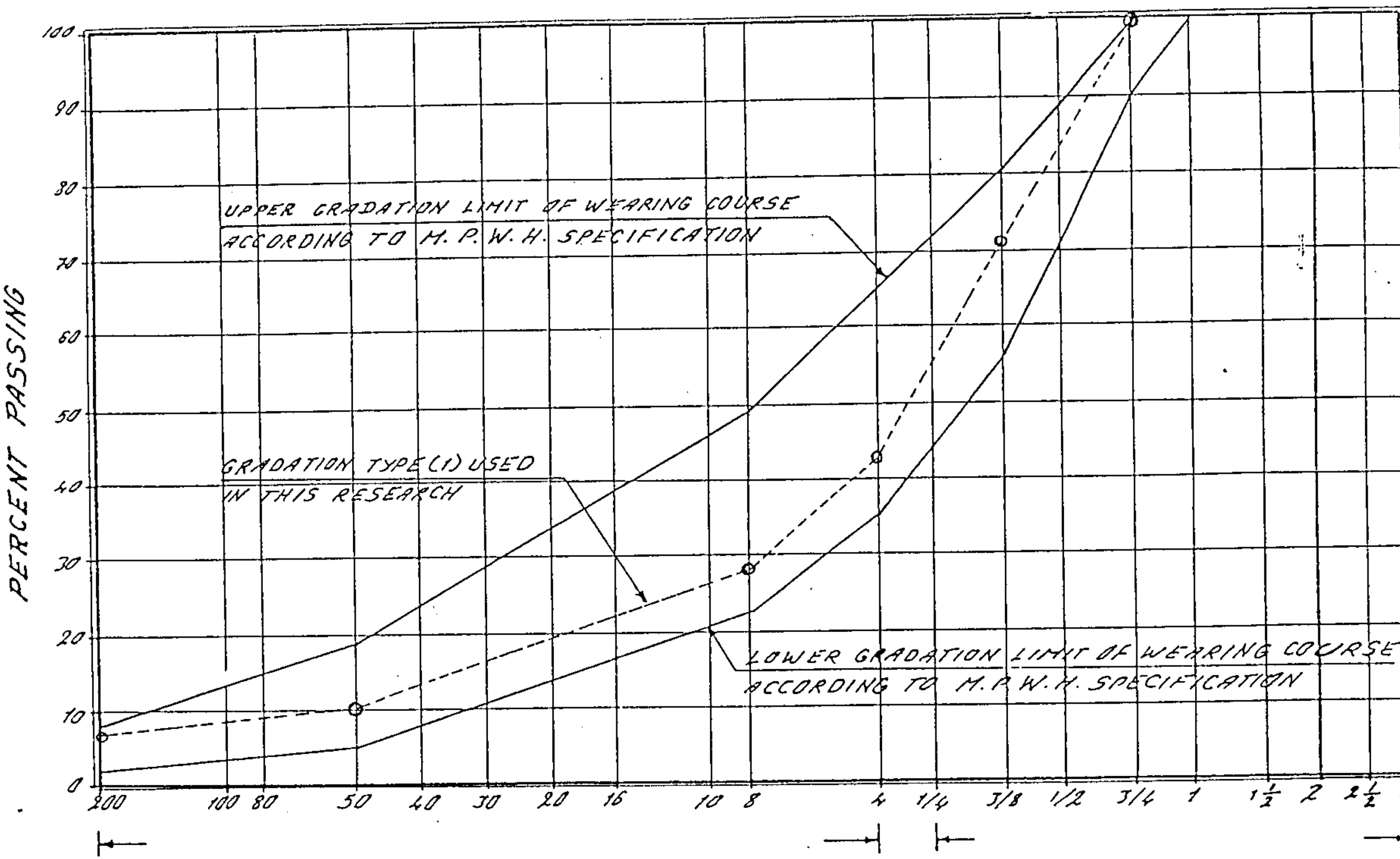


FIG. 3.1 GRADATION LIMITS OF WEARING COURSE ACCORDING TO M.P.W.H SPECIFICATION AND GRADATION TYPE 1 USED IN THIS RESEARCH.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.3 WEARING COURSE GRADATION
SPECIFICATIONS EMPLOYED BY M.P.W.H AND THE ACTUAL
GRADATION USED IN THIS RESEARCH

SIEVE SIZE OR SIEVE NO.	1"	3/4"	3/8"	4#	8#	50#	200#
GRADATION USED IN THIS RESEARCH PASSING %	100	100	71.45	42.62	27.91	10.32	6.7
GRADATION SPECIFICATION EMPLOYED BY M.P.W.H. PASSING%	100	100-90	80-56	65-35	49-23	19-5	8-2

3.3 TEST SPECIMENS:

Marshall specimens of 4 inch. diameter and 2.5 inch. depth were prepared according to Marshall method of mix design ASTM D1559.

Specimens were prepared at different binder contents (Rubber Asphalt cement blend) namely 4.5%, 5%, 5.5%, 6%, and 6.5% by weight of total mix. Each percentage is composed of five different rubber/asphalt cement ratios by weight, namely 0/100, 5/95, 10/90, 15/85, and 20/80. Nine specimens were prepared at each variable, thus bringing the total number of Marshall specimens prepared to 225 specimens.

In preparing each specimen, graded crushed limestone aggregates were heated to 156-160 C (the auther believes that the viscosity of rubber-bitumen blend is of extreme importance for the determination of the mixing and compacting temperatures of rubber-bitumen concrete mixes. However the determination of the viscosity of the rubber-bitumen blend could not have been obtained due to the inavailability of

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

equipment in the laboratory. Therefore the mixing and compacting temperatures for the rubber-bitumen concrete mixes was the same as for the normal bitumen concrete mixes containing bitumen 60-70 penetration grade which meet the vescosity of 170 ± 20 CST for mixing and 280 ± 30 for compancting). The rubber and asphalt cement blend were heated separately to the same temperature and then added to the heated aggregates in the assigned percentages to bring the weight of total mix to 1200 g.

The aggregates, rubber and Asphalt cement were mixed together using a blender and then compacted in the Marshall mould at a temperature of 145-151 C employing 75 blows on each side. Specimens were left to cool at room temperature for one day, and then they were weighted in air and in water to determine the bulk specific gravity according to ASTM D2726.

The specimens were divided into three identical groups and tested for Marshall stability and flow after being soaked in hot water for 1/2 hour at 60 C, 24 hours at 60 C and 1/2 hour at 100 C for the first, second and third groups, respectively.

Average results of tests are given in tables 3.8, 3.9 and 3.10, respetively, while individual test results are shown in table D.3, D.4, D.5, respetively.

The Maximum theoretical specific gravity test was conducted according to ASTM D2041 on specimens incorporating 6.5% binder content (rubber asphalt cement blend) by weight

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

of total mix, and having rubber/Asphalt cement ratios by weight, namely 0/100, 5/95, 10/90, 15/85, and 20/80.

Two specimens were tested at each variable and average results are given in table 3.11 while individual test results are shown in table D.6.

3.4 WHEEL TRACKING MACHINE TEST:

Rectangular specimens were prepared and tested by the Wheel Tracking Machine test (appendix B). Two types of gradations were used, type one was similar to that used in preparing Marshall specimens which is shown in Table 3.3 and drawn in Fig. 3.1, and type two was conforming to the British Road Research and Transport Laboratory Recommended gradation which is shown in table 3.4 and drawn in Fig. 3.2.

Six percent and 4.5% Binder contents by weight of total mix were used for type one and type two gradations, respectively. Rubber/Asphalt cement ratios by weight were 0/100, 5/95, 10/90, 15/85 and 20/80. Three specimens were prepared at each variable, thus bringing the total to 30 specimens. Average results are shown in tables 3.12 and 3.13 while individual test results are shown in table D.7, D.8.

TABLE 3.4 GRADATION RECOMMENDED BY THE BRITISH ROAD RESEARCH LABORATORY

SIEVE SIZE OR SIEVE NO.	3/8"	1/4"	1/8"	14#	52#	200#
PASSING %	100	45	15	10	7.5	4.00

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

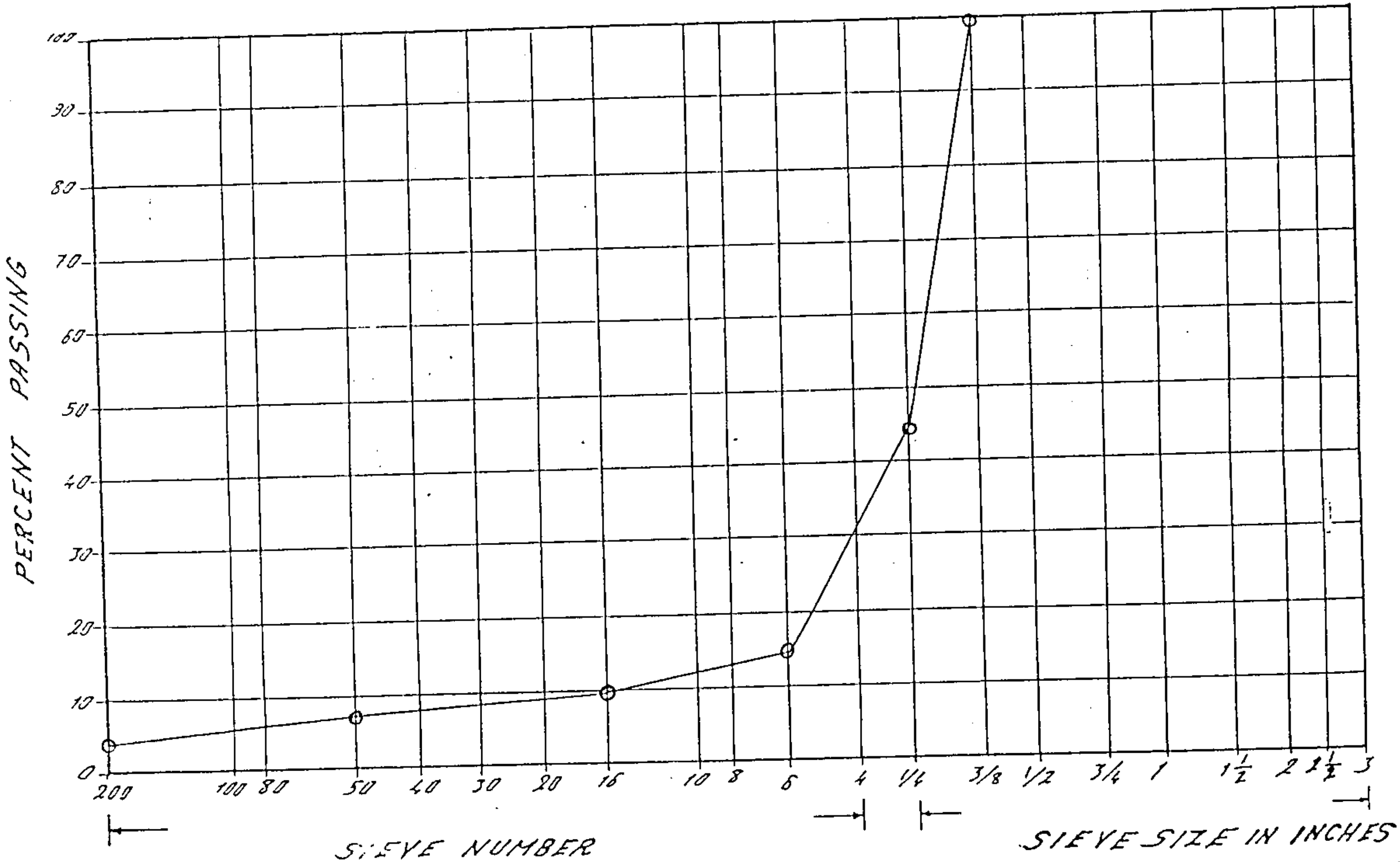


FIG. 3.2 GRADATION TYPE 2 USED IN WHEEL TRACKING MACHINE TEST SPECIMENS

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

3.5 SKID RESISTANCE TEST

The same specimens of type one gradation that were prepared for Wheel Tracking Machine test at 6% binder content were tested for skid resistance as determined by the British pendulum (ASTM E303 and BS 812) (Appendix C).

The specimens were tested for skid resistance before and after being tested by the Wheel Tracking Machine. Average results are shown in table 3.14 while individual test results are shown in table D.9.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE (3.5) EFFECT OF RUBBER ON PHYSICAL

PROPERTIES OF RUBBER-BITUMEN BLEND

Percent Rubber to Percent Bitumen by Weight of Rubber-Bitumen Blend %/%		0.0/100	5/95	10/90	15/85	20/80
Physical Properties	Ductility* (cm)	109	10	9	8.5	8
	Softening Point* (c)	53	55	57	61	63
	Penetration* (0.1 mm)	65	51	48	37	28
	Flash Point* (c)	336	320	318	317	290
	Fire Point* (c)	363	358	338	336	315
	Specific Gravity*	1.016	1.025	1.030	1.035	1.039

Note *: Average of 2 Specimens

TABLE (3.6) EFFECT OF RUBBER ON PERCENT

AGGREGATE STRIPPING

Percent Rubber to Percent Bitumen by Weight of Rubber-Bitumen Blend %/%		0.0/100	5/95	10/90	15/85	20/80	
Type of Test	Dynamic Immersion Test* (Swedish Method) (1)	65	61	63	61	60	Percent
	Texas Stripping Test* (Boiling Test) (1)	99	98	99	98	99	Coated
	Static Stripping Test* (ASTM D664).	99	98	99	98	99	Aggreg--ate

Note *: Average of 10 Opinions.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.7 AVERAGE TEST RESULTS OF PROPERTIES OF CRUSHED LIMESTONE AGGREGATES USED IN THIS RESEARCH.

TYPE OF TEST	AVERAGE RESULTS	REQUIREMENTS OF M.P.W.H.
- Aggregate Abrasion %	26.3	35 max.
- Plasticity Index For Materials Passing No. 40# Sieve. %	Non Plastic	Non Plastic
- Sand Equivalent. %	61	50 min.
- Aggregate Soundness % (Magnesium Sulfate)	12 (3"/4-3"/8), 9.73 (3"/8-4#)	12 max.
- Percentages of Clay Lumps And Friable Particles. %	0.05(3"/4-3"/8) 0.2 (3"/8-4#)	0.25 max.
- Flakiness Index %	18 (3"/4-3"/8) 20 (3"/8-4#)	25 max.
- Elongation Index %	6 (3"/4-3"/8, 16 (3"/8-4#)	25 max.
- Percentages of Flint Content %	Nil	5 max.
- Specific Gravity of Coarse Aggregate (Most Aggregate Passing 3"/4 Sieve And Retained on 3"/8 Sieve).	2.509 oven dry	---
- Specific Gravity of Coarse Aggregate (Most Aggregate Passing 3"/8 Sieve And Retained on No. 4# Sieve).	2.473 oven dry	---
- Specific Gravity of Fine Aggregate (Most Aggregate Passing No. 4# Sieve)	2.383 oven dry	---

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.8 AVERAGE TEST RESULTS OF MECHANICAL PROPERTIES OF RUBBER ASPHALT CONCRETE MIXTURES. MARSHALL SPECIMENS WERE TESTED AFTER HAVING BEEN SOAKED IN WATER FOR 1/2 HOUR AT 60 C

Percent Binder Content By Weight Of Total Mix. %	Percent Rubber To Percent Asphalt By Weight Of Abinder Content %/%	Bulk Unit Weight g/cc	Percent Air Voids In Total Mix % A.V	Percent Voids In Mineral Aggregate % V.M.A	Marshall Stability Pounds	Marshall Flow 0.01 inch	Stiffness = Stability / Flow = Pound / 0.01 inch
4.5 %	0/100	2.215	8.45	13.54	3022	9	336
	5/95	2.232	7.84	12.88	3901	8.7	448
	10/90	2.215	8.59	13.54	3503	8.5	412
	15/85	2.190	9.66	14.52	3402	8	425
	20/80	2.166	10.69	15.45	3351	7.5	447
5 %	0/100	2.240	6.75	13.02	3803	9.6	396
	5/95	2.256	6.18	12.40	4002	9.4	426
	10/90	2.220	7.73	13.80	3551	8.7	408
	15/85	2.212	8.12	14.11	3422	8.2	417
	20/80	2.209	8.28	14.23	3401	7.6	447
5.5 %	0/100	2.261	5.20	12.67	3450	10.6	325
	5/95	2.276	4.68	12.09	4052	10.2	397
	10/90	2.230	6.66	13.87	3551	9.2	386
	15/85	2.217	7.27	14.37	3453	8.5	406
	20/80	2.214	7.44	14.48	3352	7.7	435
6 %	0/100	2.280	3.72	12.40	3452	11.4	303
	5/95	2.289	3.46	12.06	3851	10.7	360
	10/90	2.235	5.8	14.13	3353	9.5	353
	15/85	2.222	6.41	14.63	3250	8.6	378
	20/80	2.220	6.55	14.71	3202	7.8	410
6.5 %	0/100	2.261	3.89	13.59	2951	13	227
	5/95	2.278	3.25	12.94	3353	12	279
	10/90	2.233	5.2	14.66	2552	10.5	243
	15/85	2.220	5.85	15.16	2401	9.5	253
	20/80	2.215	6.12	15.35	2362	8.3	284

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.9 AVERAGE TEST RESULTS OF MECHANICAL PROPERTIES OF RUBBER ASPHALT CONCRETE MIXTURES. MARSHALL SPECIMENS WERE TESTED AFTER HAVING BEEN SOAKED IN WATER FOR 24 HOUR AT 60

Percent Binder Content By Weight Of Total Mix. %	Percent Rubber To Percent Asphalt By Weight Of Binder %/%	Bulk Unit Weight g/cc	Marshall Stability Pounds	Marshall Flow 0.01 inch	Stiffness = Stability / Flow = Pound / 0.01 inch	Percent Retained Stability = Stability 24 Hour At 60 C / Stability 1/2 Hour At 60 C %	Percent Retanied Stiffnes = Stiffnes 24 Hour At 60 C / Stiffnes 1/2 Hour At 60 C %
4.5 %	0/100	2.212	2537	11.9	297	84	88
	5/95	2.230	3315	8.0	414	85	92
	10/90	2.216	2695	8.2	329	77	80
	15/85	2.192	2380	8.4	283	70	66
	20/80	2.163	2077	7.8	266	62	60
5 %	0/100	2.242	2964	8.7	341	78	86
	5/95	2.253	3280	8.6	381	82	90
	10/90	2.221	2734	8.2	333	77	82
	15/85	2.211	2497	8.3	301	73	72
	20/80	2.210	2312	7.9	292	68	65
5.5 %	0/100	2.261	2588	9.5	272	75	84
	5/95	2.274	3159	9.3	340	78	86
	10/90	2.231	2734	8.5	322	77	83
	15/85	2.216	2553	8.4	304	74	75
	20/80	2.214	2412	7.7	313	72	72
6 %	0/100	2.282	2484	10.3	241	72	80
	5/95	2.287	2888	9.8	295	75	82
	10/90	2.236	2613	8.7	300	78	85
	15/85	2.223	2665	8.2	325	82	86
	20/80	2.221	2720	7.5	363	85	88
6.5 %	0/100	2.260	2006	12.0	167	68	74
	5/95	2.277	2479	11.1	223	74	80
	10/90	2.234	2015	9.7	208	79	85
	15/85	2.220	2016	8.8	229	84	91
	20/80	2.214	2077	7.6	273	88	97

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.10 AVERAGE TEST RESULTS OF MECHANICAL PROPERTIES OF RUBBER ASPHALT CONCRETE MIXTURES. MARSHALL SPECIMENS WERE TESTED AFTER HAVING BEEN SOAKED IN WATER FOR 1/2 HOUR AT 100 C

Percent Binder Content By Weight Of Total Mix. %	Percent Rubber To Percent Asphalt By Weight Of Binder %/%	Bulk Unit Weight g/cc	Marshall Stability Pounds	Marshall Flow 0.01 inch	Stiffness = Stability / Flow = Pound / 0.01 inch	Percent Retained Stability = Stability 1/2 Hour At 100 C / Stability 1/2 Hour At 60 C %	Percent Retanied Stiffnes = Stiffnes 1/2 Hour At 100 C / Stiffnes 1/2 Hour At 60 C %
4.5 %	0/100	2.213	2114	9.8	216	70	64
	5/95	2.230	2925	9.5	308	75	69
	10/90	2.212	2310	9.9	233	66	57
	15/85	2.191	1938	9.1	213	57	50
	20/80	2.167	1742	8.1	215	52	48
5 %	0/100	2.241	2584	10.5	246	68	62
	5/95	2.257	2880	10.1	285	72	67
	10/90	2.221	2379	10.0	238	67	58
	15/85	2.213	2052	9.0	228	60	55
	20/80	2.210	1870	7.8	240	55	54
5.5 %	0/100	2.263	2277	11.7	195	66	60
	5/95	2.278	2876	11.1	259	71	65
	10/90	2.233	2414	10.6	228	68	59
	15/85	2.218	2139	9.3	230	62	57
	20/80	2.213	1977	8.1	244	59	56
6 %	0/100	2.281	2243	12.7	177	65	58
	5/95	2.287	2580	12.0	215	67	60
	10/90	2.234	2278	10.4	219	68	62
	15/85	2.221	2210	9.1	243	68	64
	20/80	2.222	2208	8.3	266	69	65
6.5 %	0/100	2.260	1770	14.4	123	60	54
	5/95	2.276	2178	13.4	163	65	58
	10/90	2.235	1760	11.5	153	69	63
	15/85	2.221	1728	10.5	165	72	65
	20/80	2.214	1770	8.9	199	75	70

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.11 MAXIMUM THEORETICAL SPECIFIC GRAVITY OF RUBBER-ASPHALT CONCRETE MIXTURES CONTAINING 6.5% BINDER CONTENT (RUBBER-BITUMEN BLEND) BY WEIGHT OF TOTAL MIX

Percent Rubber To Percent Bitumen By Weight Of Binder Content %/%	0.0/100	5/95	10/90	15/85	20/80
Maximum Theoretical Specific Gravity*	3.352	2.354	2.356	2.358	2.360

Note*: Average Of Two Specimens.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.12 EFFECT OF RUBBER ON RUBBER-BITUMEN

MIXTURES HAVING TYPE 1 GRADATION SHOWN IN FIGURE 3.1

AND 6% BINDER CONTENT. THESE MIXTURES WERE TESTED BY THE

WHEEL TRACKING MACHINE

Percent Rubber to Percent Bitumen by Weight of Rubber-Bitumen Blend (Binder) %/% --->	0.0/100	5/95	10/90	15/85	20/80
TIME (HOURS)	PENETRATION* (MM)				
0.5	2	1	0.75	1	1.2
1	2.5	1.25	1	1.25	1.5
1.5	2.75	1.35	1.15	1.25	1.5
2	2.9	1.5	1.25	1.25	1.5
2.5	3	1.65	1.35	1.35	1.5
3	3	1.75	1.5	1.5	1.5
4	3	2	1.5	1.5	1.5
5	3	2.25	1.5	1.75	1.5
6	3	2.25	1.5	1.75	1.75
7	3	2.25	1.75	1.75	1.75
8	3	2.25	1.75	2	1.75
9	3	2.25	2	2	2
10	3	2.25	2	2.25	2
11	3	2.25	2.25	2.25	2.25
12	3	2.25	2.5	2.25	2.25
13	3	2.25	2.5	2.5	2.5
14	3	2.25	2.5	2.5	2.5
15	3	2.25	2.5	2.5	2.75
16	3	2.25	2.5	2.5	3
17	3	2.25	2.5	2.5	3.25
18	3	2.25	2.5	2.5	3.25
19	3	2.25	2.5	2.5	3.5
72	3	2.25	2.5	2.5	3.5

Note*: Average of 3 Specimens.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE 3.13 EFFECT OF RUBBER ON RUBBER-BITUMEN MIXTURES HAVING TYPE 2 GRADATION SHOWN IN FIGURE 3.2 AND 4.5% BINDER CONTENT. THESE MIXTURES WERE TESTED BY THE WHEEL TRACKING MACHINE

Percent Rubber to Percent Bitumen by Weight of Rubber-Bitumen Blend (Binder) %/% --->	0.0/100	5/95	10/90	15/85	20/80
TIME (HOURS)	PENETRATION* (MM)				
1	1	0.3	2.5	1.5	1
2	1	0.6	3	2.2	1.5
3	1	1	3.5	3	2
4	1.5	1	3.8	3.2	2.3
5	2	1	4	3.3	2.6
6	2	1	4.1	3.4	2.8
7	2	1	4.2	3.5	3.1
8	2.2	1	4.3	3.7	3.4
9	2.6	1	4.4	3.8	3.6
10	3	1	4.5	4	4
11	3.3	1	4.5	4.1	4.1
12	3.3	1	4.7	4.2	5
13	3.3	1	4.8	4.3	6.5
14	3.3	1	4.9	4.4	8
15	3.3	1	5	4.6	28**
16	3.3	1	5.2	4.6	
17	3.3	1	5.3	4.8	
18	3.3	1	5.4	4.9	
19	3.3	1.1	5.5	5	
20	3.3	1.1	5.5	5	
21	3.3	1.1	5.5	5	
22	3.3	1.1	5.5	5	
23	3.3	1.1	5.5	5.1	
24	3.3	1.1	5.5	5.1	
25	3.3	1.1	5.5	5.1	
26	3.3	1.1	5.5	5.1	
27	3.3	1.2	5.5	5.2	
28	3.3	1.2	5.5	5.3	
29	3.5	1.2	5.5	5.4	
30	3.7	1.2	5.5	5.5	
31	3.8	1.2	5.5	5.8	
32	4	1.2	5.5	6.5	
33	4	1.2	5.5	7	
34	4	1.2	5.5	8.4	
35	4.2	1.2	5.5	12	
36	4.3	1.2	5.5	28***	
37	4.4	1.2	5.5		

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Continue

38	4.5	1.2	5.5			
39	4.5	1.205	5.5			
40	4.5	1.205	5.5			
41	4.5	1.3	5.5			
42	4.5	1.3	5.5			
43	4.5	1.3	5.5			
44	4.5	1.3	5.5			
45	4.5	1.305	5.5			
46	4.5	1.305	5.5			
47	4.5	1.4	5.5			
48	4.5	1.4	5.5			
49	4.5	1.4	5.5			
50	4.5	1.4	5.5			
72	5	1.5	6			

Note* : Average of Three Specimens.

Note** : Failure Occurred After Average Time of 14.5 Hours.

Note***: Failure Occurred After Average Time of 36 Hours.

TABLE 3.14 EFFECT OF RUBBER ON THE SKID RESISTANCE OF RUBBER-BITUMEN MIXTURES HAVING TYPE 1 GRADATION SHOWN IN FIGURE 3.1 AND 6% BINDER CONTENT. THE SPECIMENS WERE TESTED BEFORE AND AFTER THE WHEEL TRACKING TEST.

Percent Rubber to Percent Bitumen by Weight of Rubber-Bitumen Blend (Binder) %/%	0.0/100	5/95	10/90	15/85	20/80
Skid Resistance Number (BPN) Before The Wheel Tracking Test*	91	87	81	84	91
Skid Resistance Number (BPN) After The Wheel Tracking Test*	64	61	58	59	62

Note*: Average of 3 Specimens.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

CHAPTER FOUR

ANALYSIS AND DISCUSSION

4.1 EFFECT OF RUBBER CONTENT ON PHYSICAL PROPERTIES OF BITUMEN.

4.1.1 Effect Of Rubber Content On Ductility.

Figure 4.1 shows that ductility decreases rapidly by adding to asphalt cement 5% rubber by weight of rubber-bitumen blend then it decreases very slowly with further increase in rubber. The decrease in ductility is due to the increase in viscosity caused by adding rubber to the rubber bitumen blend.

4.1.2 Effect Of Rubber Content On Softening Point.

Figure 4.2 shows that the softening point increases as the rubber content increases from zero percent to 20 percent by weight of blend. This is caused by the increase in viscosity of blend with the increase in rubber.

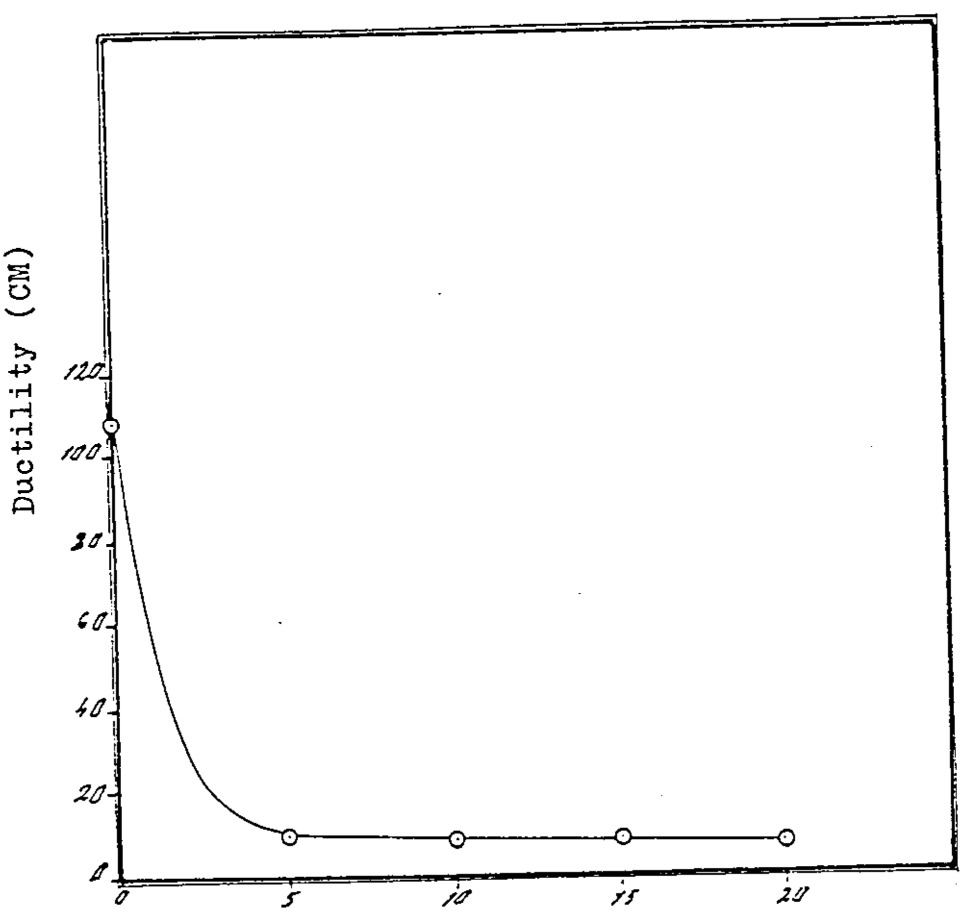
4.1.3 Effect Of Rubber Content On Penetration.

Figure 4.3 shows that penetration decreases with the increase in rubber. The decrease in penetration is due to the increase in viscosity of blend caused by adding rubber. It is noticed that 5-10% rubber will reduce penetration from 57 to 48 below which the binder will become difficult to work with.

4.1.4 Effect Of Rubber Content On Flash Point And Fire Point.

Figure 4.4 shows that flash point and fire point

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Rubber Content By Weight Of Binder %

Fig.4.1 Relationship Between Percent Rubber And Ductility Of Rubber-Bitumen Blend.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

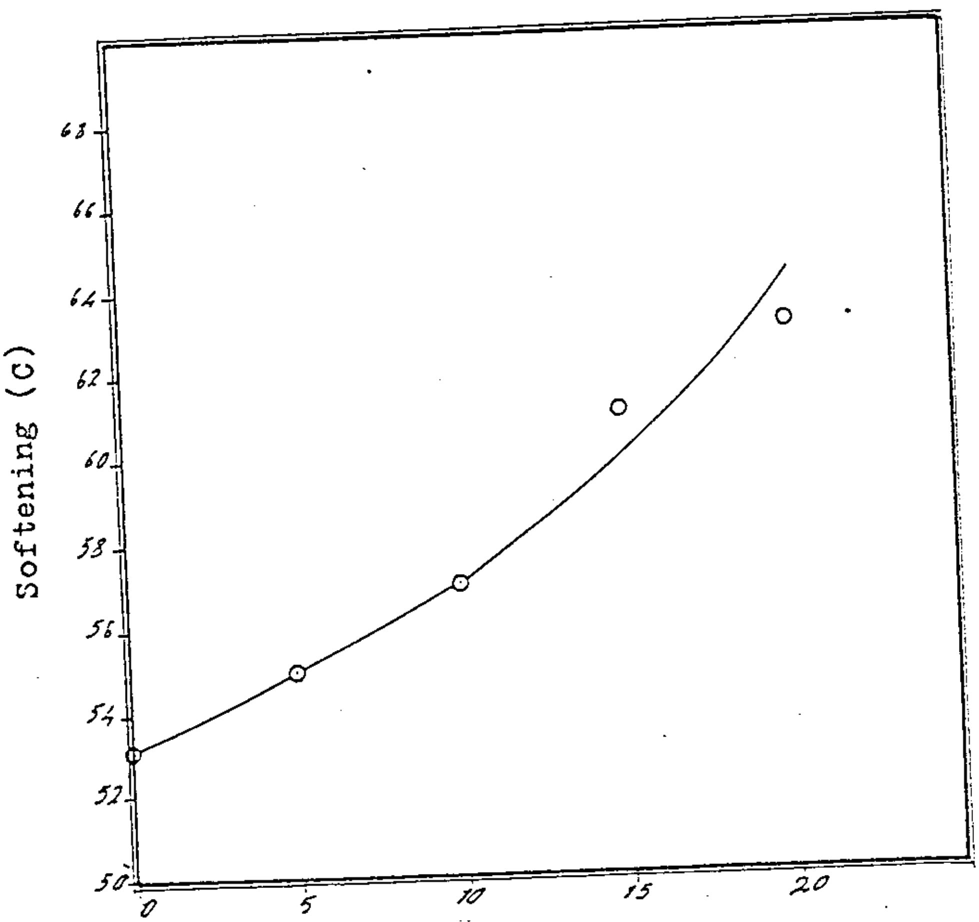
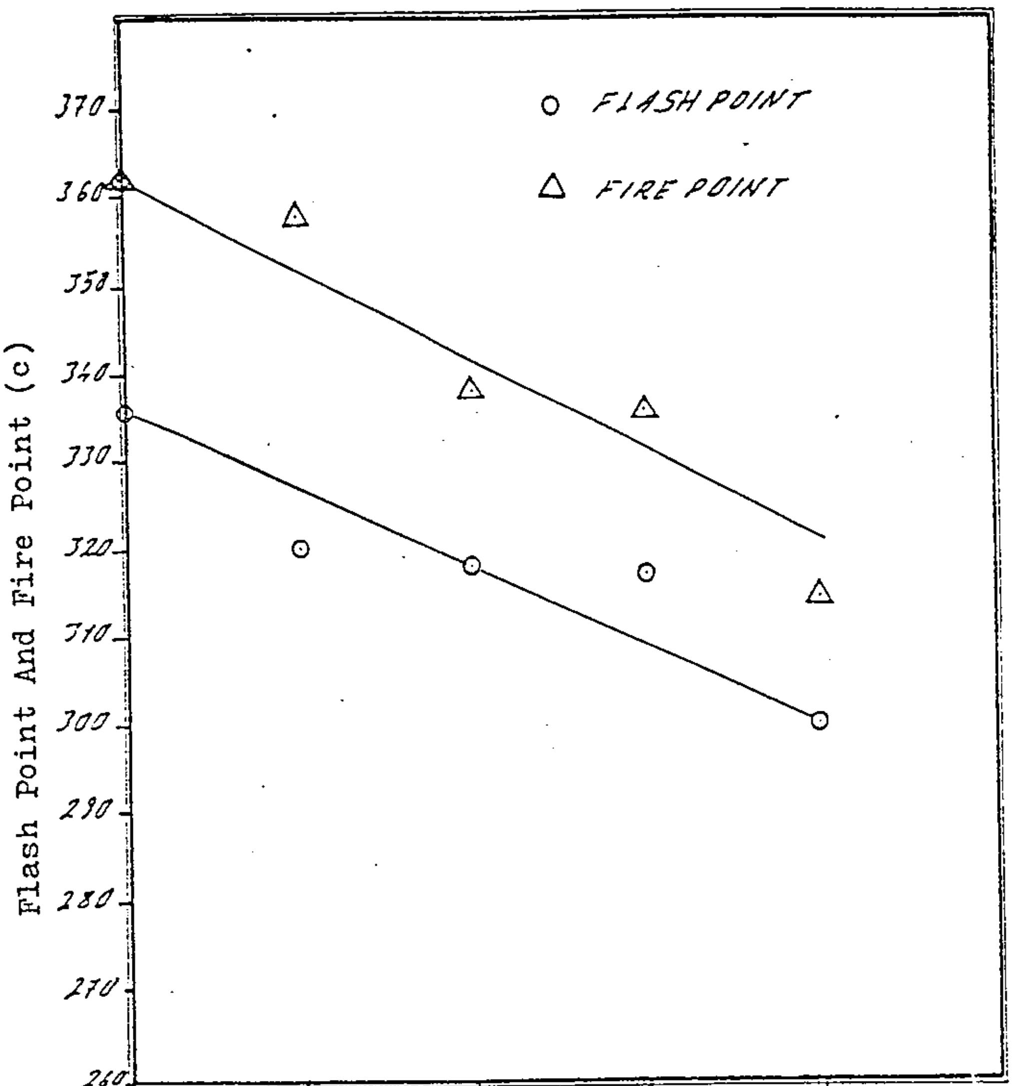


Fig.4.2 Relationship Between Percent Rubber And Softening Of Rubber-Bitumen Blend.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Rubber Content By Weight Of Binder %

Fig 4.4 Relationship Between Percent Rubber And Flash Point And Firepoint Of Rubber-Bitumen Blend.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

decrease with the increase in rubber content. It is suggested that the decrease in flash point and fire point is due to a gas produced by heating of rubber bitumen blend. The amount of this gas is quite high as the rubber content increases, thus, there is more decrease in flash point and fire point as the rubber content increases.

4.1.5 Effect Of Rubber Content On Specific Gravity.

Figure 4.5 shows an increase in specific gravity of the blend with the increase in rubber content. This is expected, since the specific gravity of rubber is slightly higher than the specific gravity of bitumen.

4.2 EFFECT OF RUBBER CONTENT ON AGGREGATE STRIPPING.

Figure 4.6 shows that the percentage coating of aggregates decreases very slowly with the increase in rubber content as determined by the Dynamic Immersion Test (the swedish method) (1). On the other hand, it is noticed that there is no significant change in percentage coating with the increase in rubber content when the aggregates were tested according to Texas State Test (boiling test) (1) and Static Stripping Test ASTM D1664.

4.3. EFFECT OF RUBBER CONTENT ON MECHANICAL PROPERTIES OF ASPHALT CONCRETE MIXTURES.

4.3.1. Effect Of Rubber Content On Unit Weight Of Asphalt Concrete Mixtures.

Figure 4.7 shows the relationship between rubber content and unit weight of the mix. It is noticed that the

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

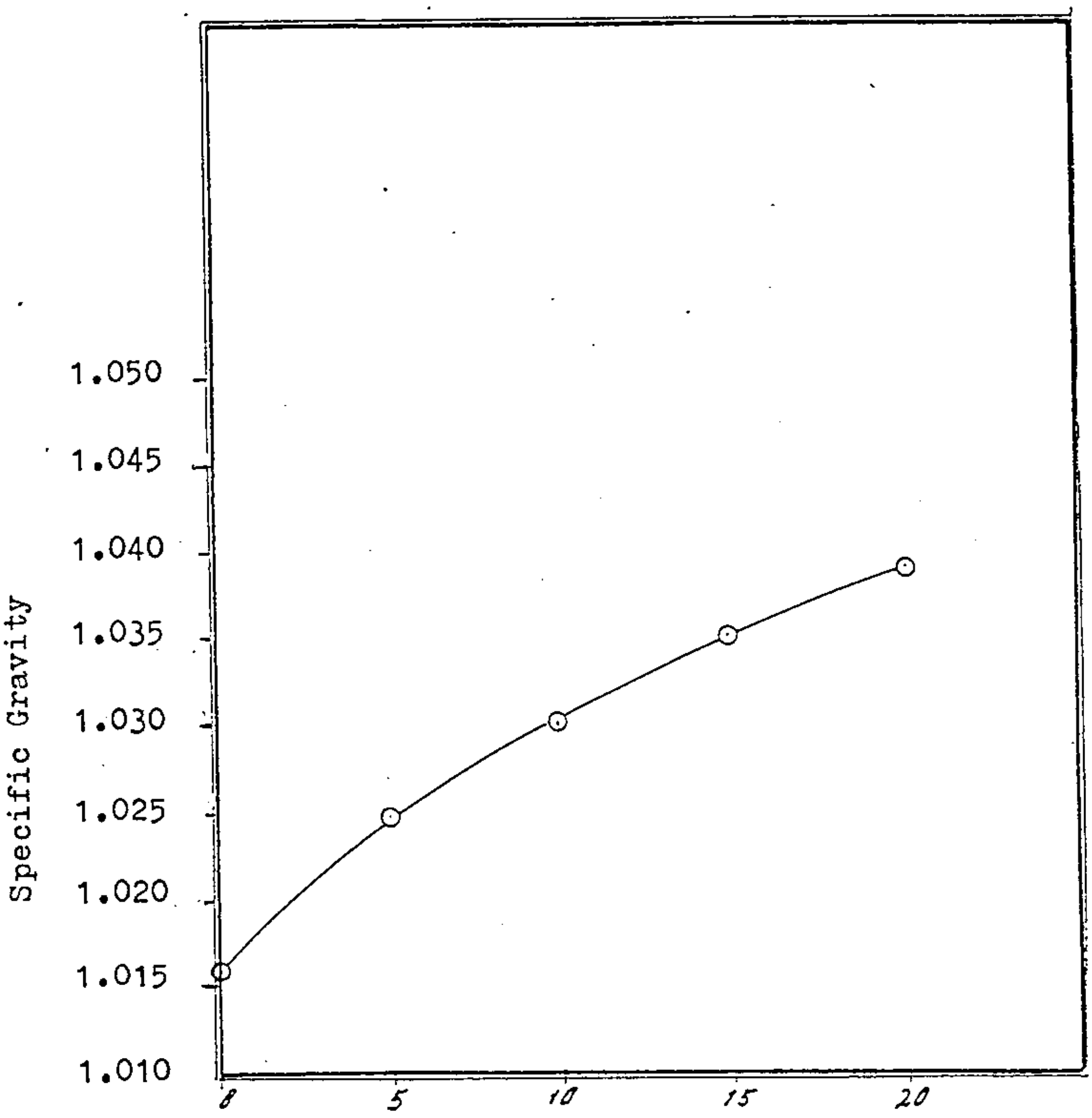


Fig 4.5 Relationship Between Percent Rubber And Specific Gravity Of Rubber-Bitumen Blend.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

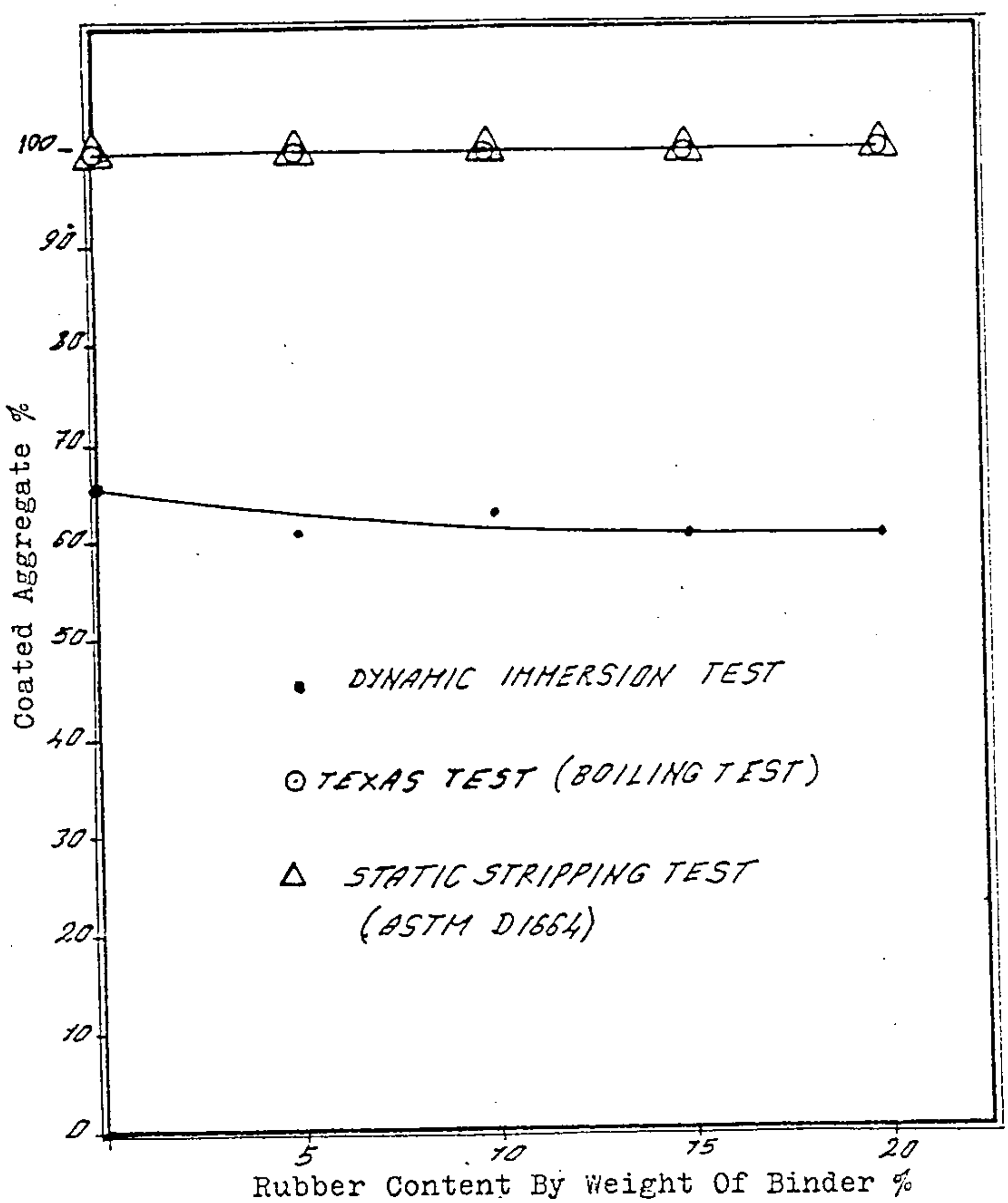
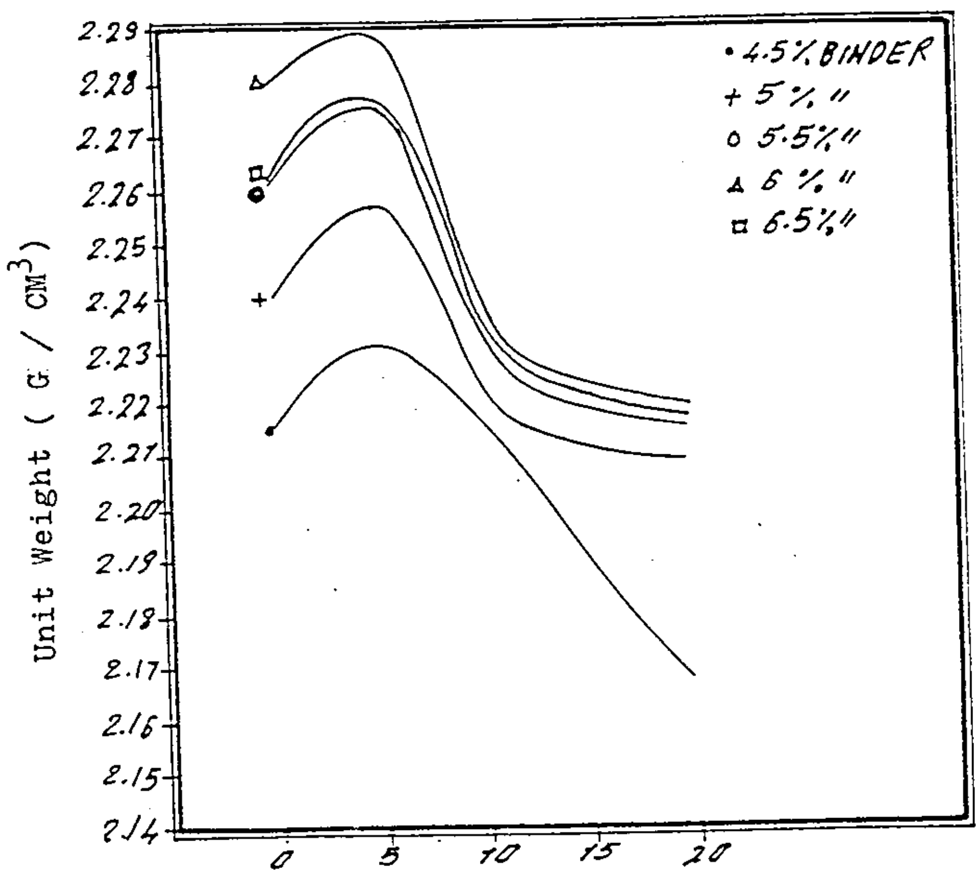


Fig.4.6 Relationship Between Percent Rubber And The Percent Coated Aggregate Of Rubber Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Bubber Content By Weight of Binder %

Fig.4.7 Relationship Between Percent Rubber And Unit Weight Of Rubber Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

unit weight increases with the addition of rubber until the rubber reaches the value of 5% then the unit weight decreases with further increase in rubber. This is true for all mixtures containing different percentages of rubber-bitumen blend (binder) contents. The initial increase in unit weight is partly due to the higher specific gravity of rubber and partly because rubber has some lubricating effect which helps in facilitating compaction. At this rubber content, the viscosity of binder (which increases with the addition of rubber) is suitable for good compaction. The decrease in unit weight, with further increase in rubber content, is due to the difficulty in compaction caused by further increase in the viscosity of the binder. This means that there is an optimum rubber content of 5% for producing maximum unit weight. It is noticed that this maximum value in unit weight, at 5% rubber content varies with the variation in binder content.

When these maximum unit weights (at fixed rubber content of 5%) are plotted against binder content in Fig 4.8, it is observed that the maximum unit weight increases with the increase in binder content until the binder content reaches the value of 6%, then the maximum unit weight decreases with an increase in binder content. The initial increase in maximum unit weight is due to the increase in compaction caused by the increase in binder content which lubricates the particles and makes the mix more workable. The decrease in maximum unit weight with further increase in

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

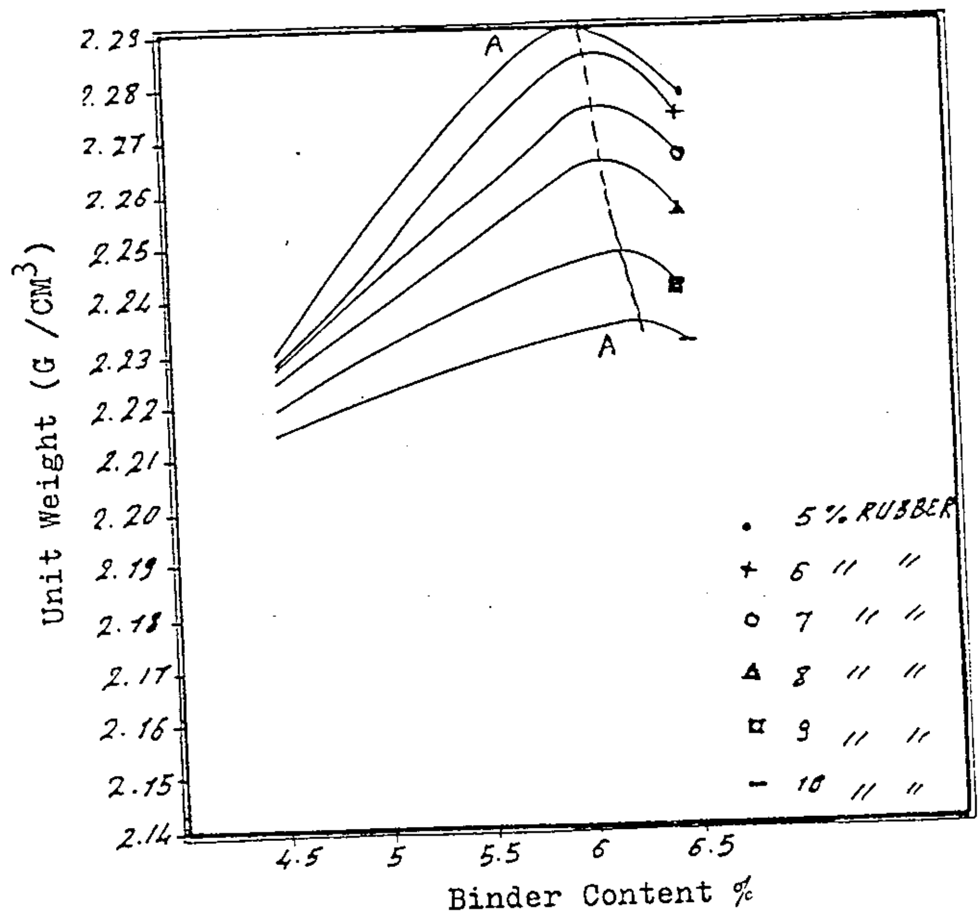


Fig 4.8 Relationship Between Percent Binder Content And Unit Weight of Rubber Asphalt Concrete Mixtures. This Figure Is Derived From Figure 4.7.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

binder content is due to the separation of aggregates by binder which consequently decrease unit weight. It has been concluded that the maximum mix density is obtaind at an optimum binder content of 6% containing 5% rubber.

When on Fig 4.8 we develop similar curves at 6, 7, 8, 9 and 10% rubber content we notice that the optimum binder content for the maximum unit weight, at these different percentages of rubber content, increases as the percentage of rubber increases, because with increase in rubber content the mixture needs more lubricating material (binder) so that workability and good compaction can be fulfilled. The line A-A which passes through the maximum unit weights at different percentages of rubber clarifies this point.

4.3.2 Effect Of Rubber Content On Percent Air Voids In Asphalt Concrete Mixtures.

Figure 4.9 shows the relationship between rubber content and percent air voids. It is noticed that the percent air voids decreases with the increase in rubber content until the rubber reaches the value of 5% after which the percent air voids increases as the rubber increases. This is true for all mixes containing different percentages of binder contents. The decrease in percent air voids with the addition of rubber is due to the lubricating effect of rubber while keeping viscosity of the binder suitable for compaction. The increase in percent air voids with more addition of rubber is due to the difficulty in compaction caused by further increase in viscosity. This means that

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

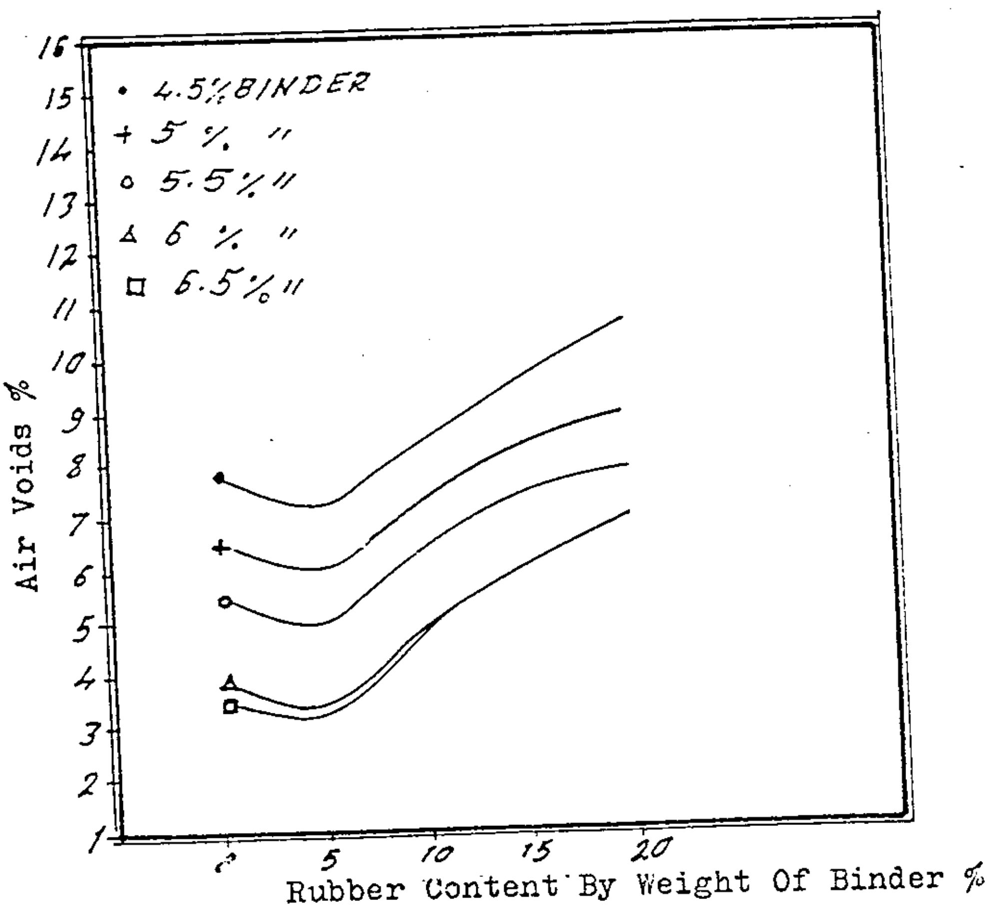


Fig 4.9 Relationship Between Percent Rubber And Percent Air Voids In Rubber Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

there is an optimum rubber content of 5% for the minimum percent air voids for all mixes containing different binder. It is noticed that these minimum values, at 5% rubber, vary with the variation in binder content.

When these minimum percent air voids (at fixed rubber content of 5%) are plotted against binder content in Fig 4.10. From this figure, it may be seen that the minimum value of percent air voids decreases with the increase in binder content. This is partly because more binder makes the mix more workable and this improves the compaction, and partly because the binder fills some voids. Consequently percent air voids decreases with an increase in binder content. It is noticed also that at 6 percent binder content, percent air voids become 3.3% which is a reasonable value for mixes.

When on the same Fig 4.10 we develop similar curves at 6, 7, 8, 9 and 10% rubber content, we notice that the box ABCD shows the ranges of binder contents and rubber contents that fulfill the range of 3 to 5 percent air voids which is required by M.P.W.H. The range of binder content which fulfill this range of percent air voids is between 5.4% and 6.5% which is incorporating rubber content between 5% and 10%.

4.3.3 Effect Of Rubber Content On Percent Voids In The Mineral Aggregates (% V.M.A).

Figure 4.11 shows the relationship between rubber content and percent V.M.A. It is noticed that the percent

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

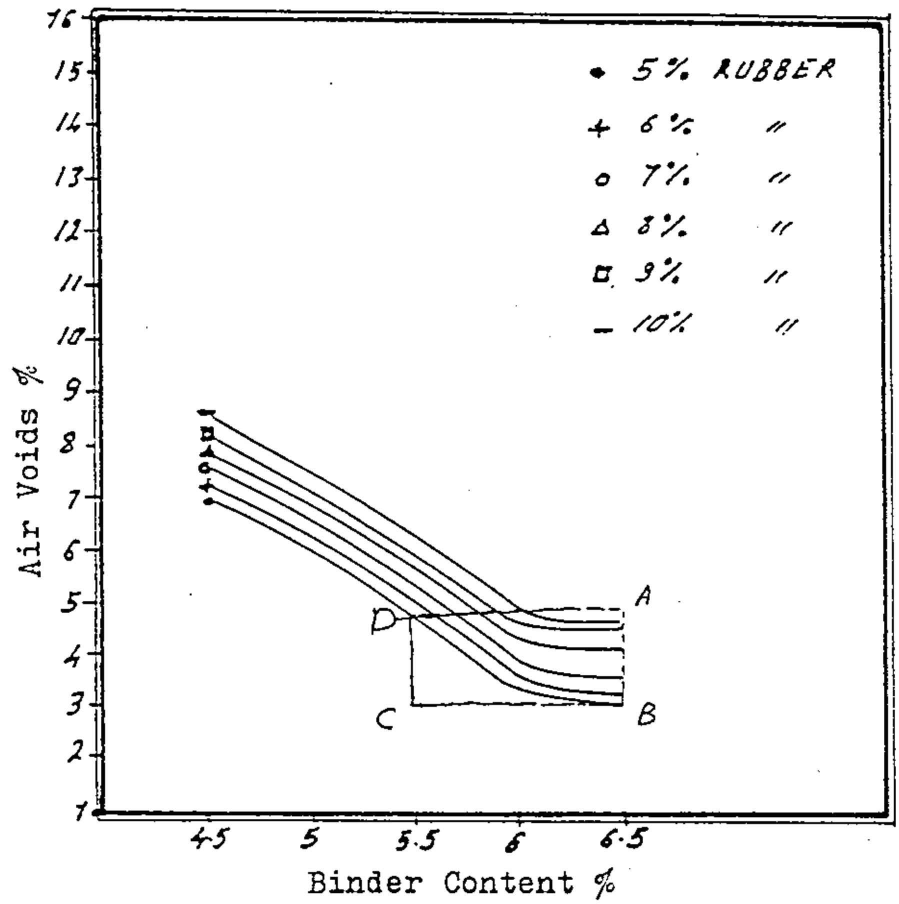
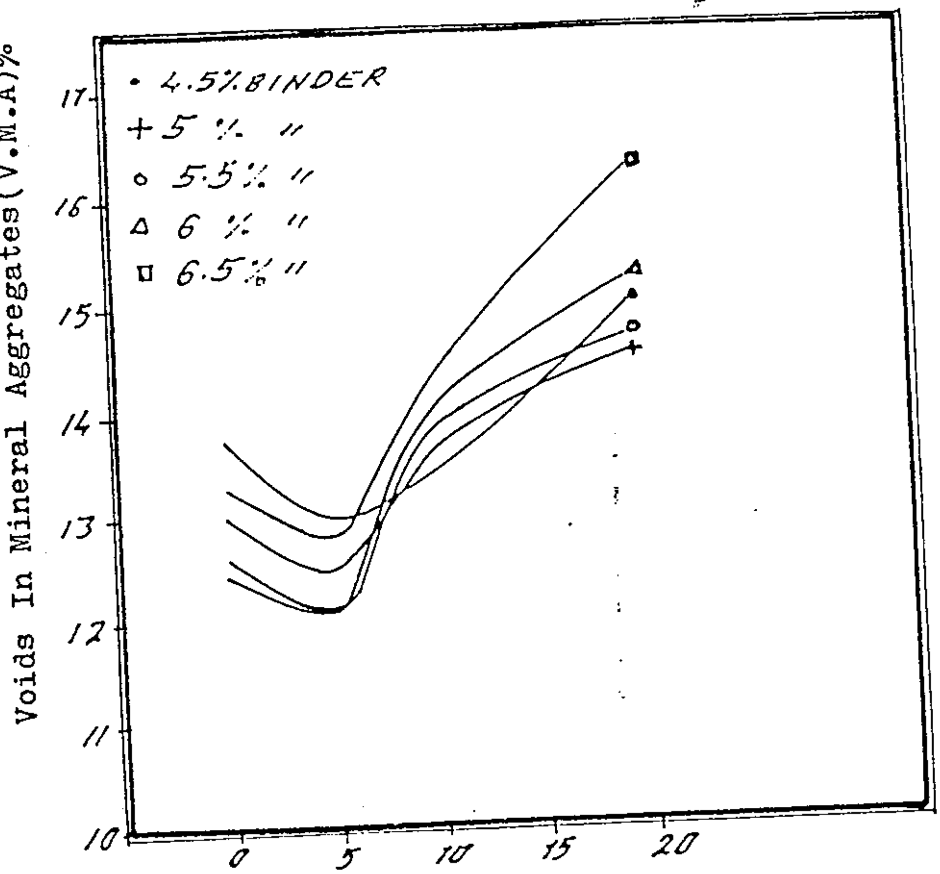


Fig 4.10 Relationship Between Percent Binder Content And Percent Air Voids Of Rubber Asphalt Concrete Mixtures. This Figure Is Derived From Figure 4.9.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Rubber Content By Weight Of Binder %

Fig.4.11 Relationship Between Percent Rubber And Percent Voids In Mineral Aggregates(V.M.A) Of Rubber-Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

V.M.A decreases with the addition of rubber until the rubber content reaches the value of 5%, then percent V.M.A increases with an increase in rubber content. This is true for all mixes containing different percentages of binder contents. The decrease in percent V.M.A, with the addition of rubber is due to the high compaction caused by the lubricating effect of rubber and the suitable viscosity of the binder. The increase in percent V.M.A, with addition of more rubber content, is due to the difficulty in compaction caused by further increase in viscosity. It is noticed that there is an optimum rubber content (5%) for the minimum values of percent V.M.A for all mixes at all binder contents. It is noticed also that these minimum values vary with the variation in binder content.

When minimum values of percent V.M.A (at fixed rubber content of 5%) are plotted against binder content in Fig 4.12 we find that the minimum value of percent V.M.A decreases with the increase in binder content until the binder content reaches the value of 5.75%, then the minimum value of percent V.M.A increases as the binder increases. The initial decrease of minimum value of % V.M.A with the increase in binder content is due to the lubricating effect of binder which increase workability of mix which improves the compaction and consequently decreases the percent air voids and percent V.M.A. The increase in minimum value of percent V.M.A, with more increase in binder content, is due to the particles separation caused by the binder.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

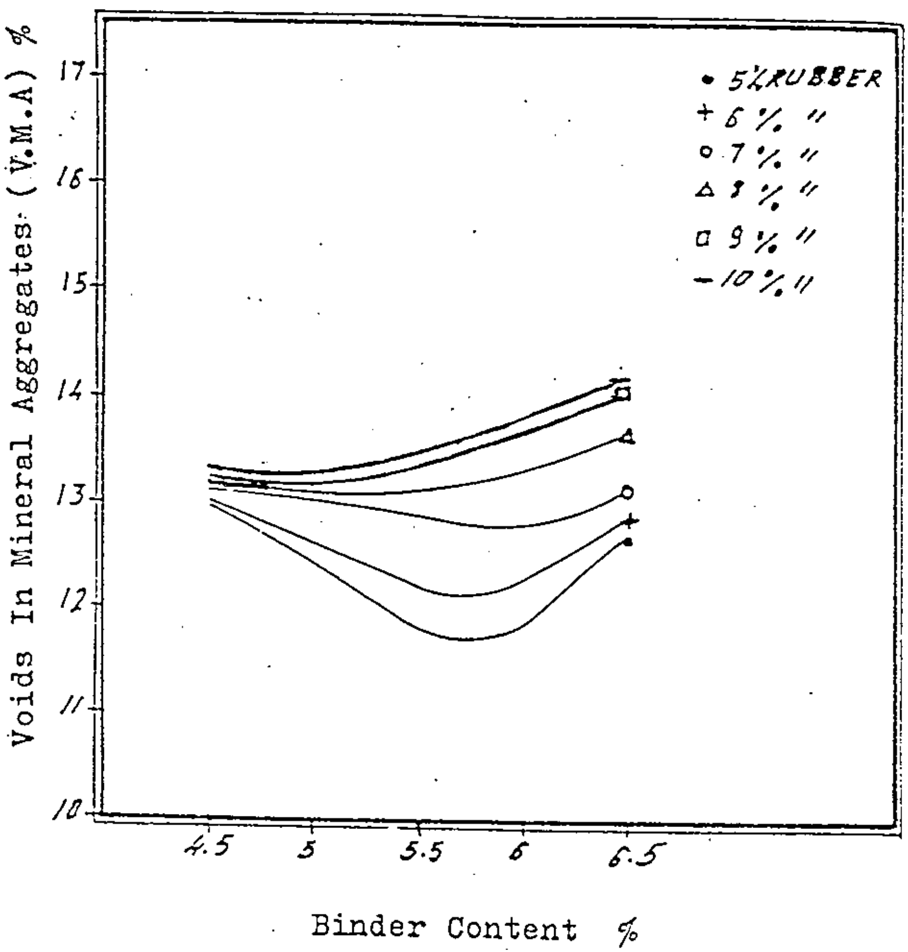


Fig. 4.12 Relationship Between Percent Binder Content And Percent Voids In Minerat Aggregates (V.M.A) Of Rubber Asphalt Concrete Mixtures. This Figure Is Derived From Figure 4.11 .

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

When on the same Fig 4.12 we develop similar curves at 6, 7, 8, 9 and 10% rubber, we notice that the range of binder content between 4.5 and 6.5% which is incorporating rubber content between 7% and 10% fulfill the value of 13 percent V.M.A which satisfies the % V.M.A required by M.P.W.H.

4.3.4 Effect Of Rubber Content On Marshall Stability.

Figure 4.13 shows the relationship between rubber content and Marshall stability. It is noticed that Marshall stability increases with the increase in rubber content until the rubber content reaches the value of 5%, then the stability decreases as the rubber content increases. This is true for all mixes containing different percentages of binder contents. The initial increase in Marshall stability with the addition of rubber is due to the more adhesive forces caused by the increase in the viscosity of the binder. The decrease in Marshall stability with more addition of rubber, however, is due to the difficulty in compaction caused by further increase in viscosity. It is noticed that there is an optimum rubber content which gives maximum Marshall stability for all mixes containing different binder content. It is noticed also that these maximum values vary with the variation in binder content.

When we draw maximum stability values (at fixed rubber content of 5%) against binder content in Fig 4.14 we see that the maximum Marshall stability increases with the increase in binder content until the binder content reaches the value of

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

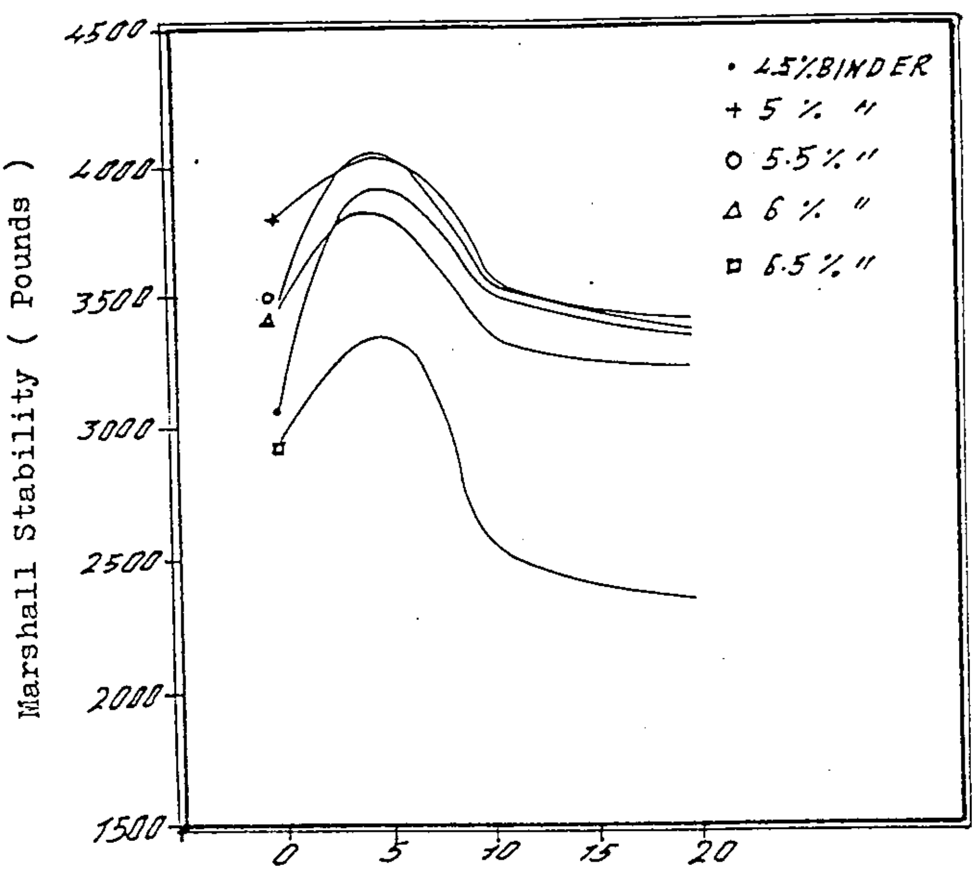


Fig.4.13 Relationship Between Percent Rubber And Marshall Stability Of Rubber Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

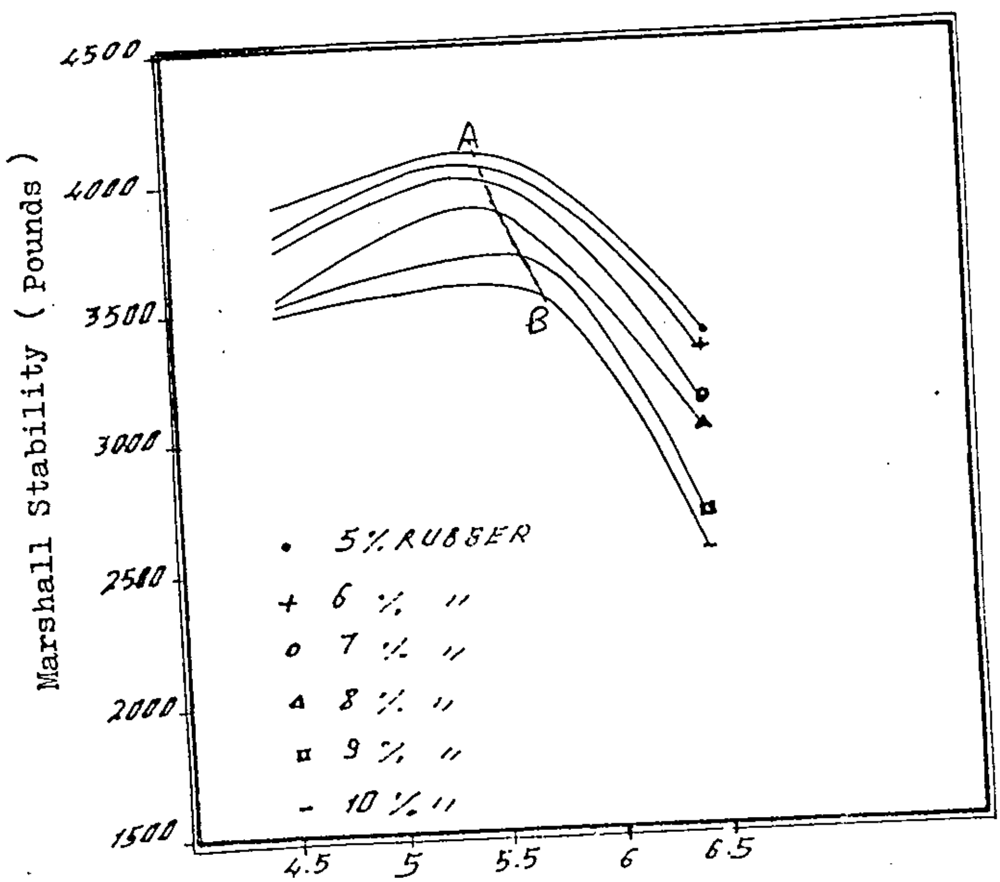


Fig. 4.14 Relationship Between Percent Binder Content And Marshall Stability Of Rubber-Asphalt Concrete Mixtures.

This Figure Is Derived From Figure 4.13.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

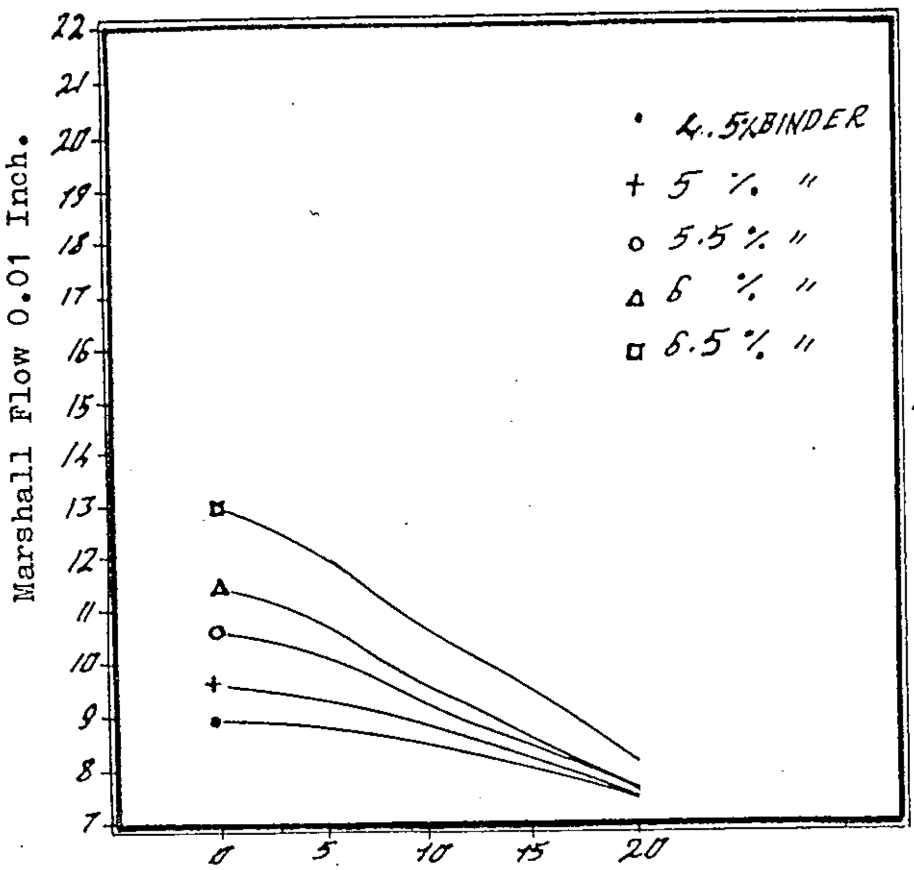
5.5% then the Marshall stability decreases as the binder content increases. The initial increase in maximum Marshall stability with the increase in binder content is due to the lubricating effect of binder which cause a good compaction. The decrease in maximum Marshall stability with the more increase in binder content is due to the separation of aggregates by binder which decreases the friction between particles and consequently decreases the stability.

When on the same Fig 4.14 we develop similar curves at 6, 7, 8, 9 and 10% rubber, we notice that the optimum binder content for the maximum stability increases as the rubber content increases. This increase in percent binder content, with the increase in rubber content, may be caused by the need of the mixture for more lubricating material (binder) to reach the good workable and compaction condition. Line A-B shows how the optimum binder content behaves. It is noticed that the maximum values of stability at binder content ranging from 5.2% to 5.8% and incorporating rubber content between 5% and 10% are higher than the value of 2200 lb which is the minimum value required by M.P.W.H.

4.3.5 Effect Of Rubber Content On Marshall Flow.

Figure 4.15 shows the relationship between rubber content and Marshall flow. It is noticed that Marshall flow decreases with the addition of rubber at constant binder content. This is true for all mixes containing different percentages of binder contents. The decrease in Marshall flow with the addition of rubber content may be due to the

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Rubber Content By Weight Of Binder

Fig.4.15 Relationship Between Percent Rubber And Marshall Flow Of Rubber-Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

more resistance to flow caused by the increase in viscosity of the binder.

When we draw flow (at fixed rubber content of 5%) for all mixes against binder content in Fig 4.16 we notice that Marshall flow increases with the increase in binder content at constant rubber content of 5% because more binder content causes less resistance to flow.

When on the same Fig 4.16 we develop similar curves at 6, 7, 8, 9 and 10% rubber content we notice that the increase in flow with the increase in binder content is true at all rubber contents but the increase in flow with increase in binder content is more clear at low rubber content. At high percentages of rubber content, the effect of binder decreases and all mixes have almost similar flow (which is slow) which mean that at high rubber content the rubber is a controlling factor. We notice also that at binder content ranging from 4.5% to 6.5% and incorporating rubber content between 5% and 10% result in a range of flow between 8/100 and 16/100 inch which is the range of flow required by the M.P.W.H.

4.3.6 Effect Of Rubber Content On Stiffness

Figure 4.17 shows the relationship between rubber and stiffness. Stiffness is defined as the ratio of Marshall stability to Marshall flow. It is noticed that the stiffness increases with the addition of rubber to the binder. This is true for all mixes containing different percentages of binder contents. The increase in stiffness with the addition of rubber is mainly due to the increase in viscosity of the

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

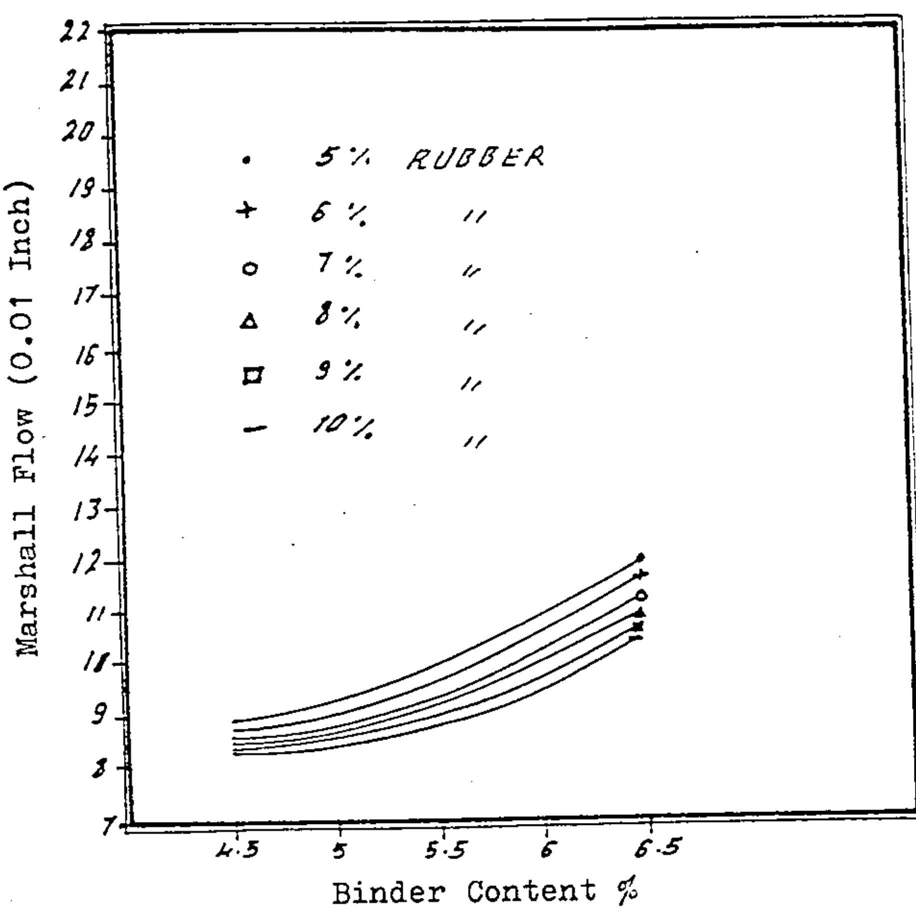


Fig 4.16 Relationship Between Percent Binder Content And Marshall Flow Of Rubber Asphalt Concrete Mixtures. This Figure Is Derived From Figure 4.15

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

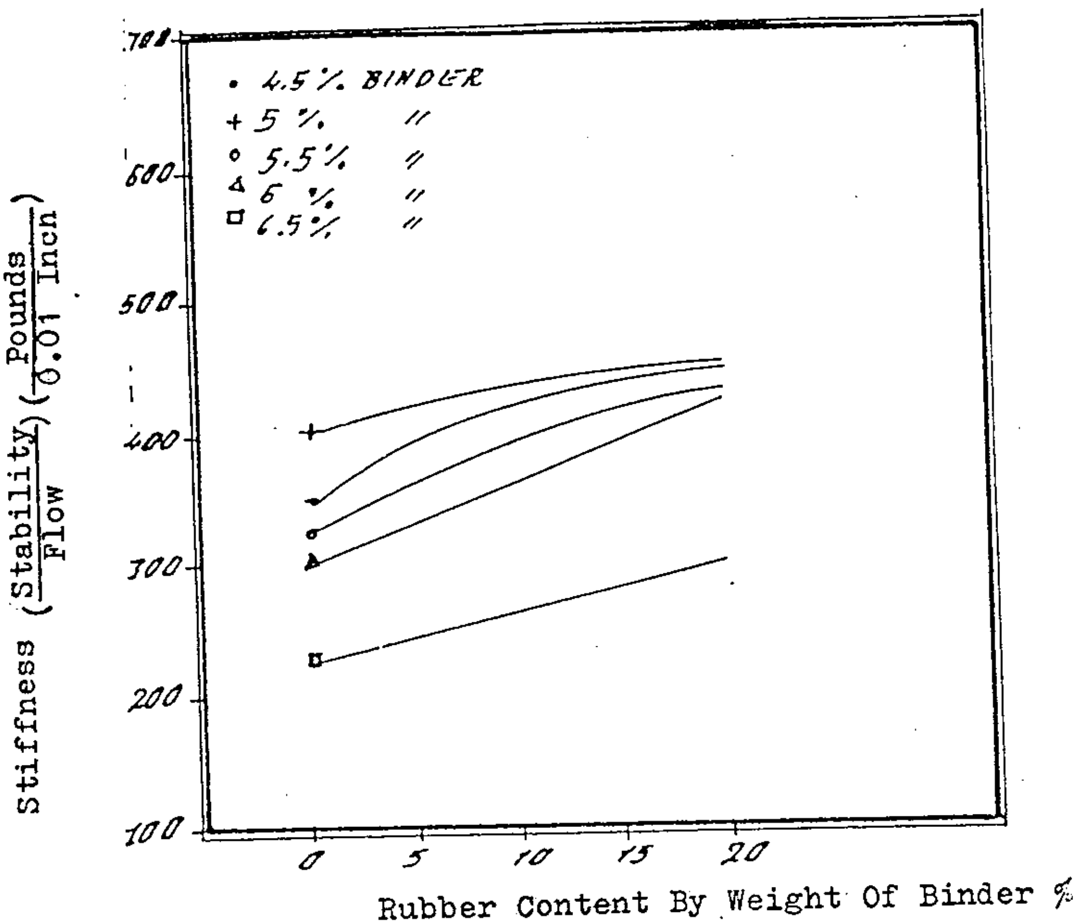


Fig.4.17 Relationship Between Percent Rubber And Stiffness Of Rubber-Asphalt Concrete Mixtures.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

binder which lead to decrease in flow and consequently increase in stiffness.

When stiffness (at fixed rubber content of 5%) is drawn against binder content in Fig 4.18 it may be noticed that the stiffness increases with the increase in binder content until the binder reaches the value 5%. Then the stiffness decreases as the binder content increases. The initial increase in stiffness is due to the lubricating effect of the binder which lead to good compaction and consequently to an increase in stability and an increase in stiffness. The decrease in stiffness with more increase in binder content is due to the increase in flow and decrease in friction between particles which consequently lead to decrease in stiffness.

When on the same Fig 4.18 we develop similar curves at 6, 7, 8, 9 and 10% rubber content, we notice that the values of stiffness at binder content ranging from 4.5% to 6.2% and incorporating rubber content between 5% and 10% are higher than the minimum value required by the M.P.W.H. which is 280 lb/0.01 inch.

4.3.7 Effect Of Rubber Content On Retained Stability Of Asphalt Concrete Mixture After Having Been Soaked In Water For 24 At 60 C.

Figure 4.19 shows the relationship between rubber content and retained stability after the specimens having been soaked in water for 24 hours at 60 C. It is noticed that the retained stability increases with the increase in

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

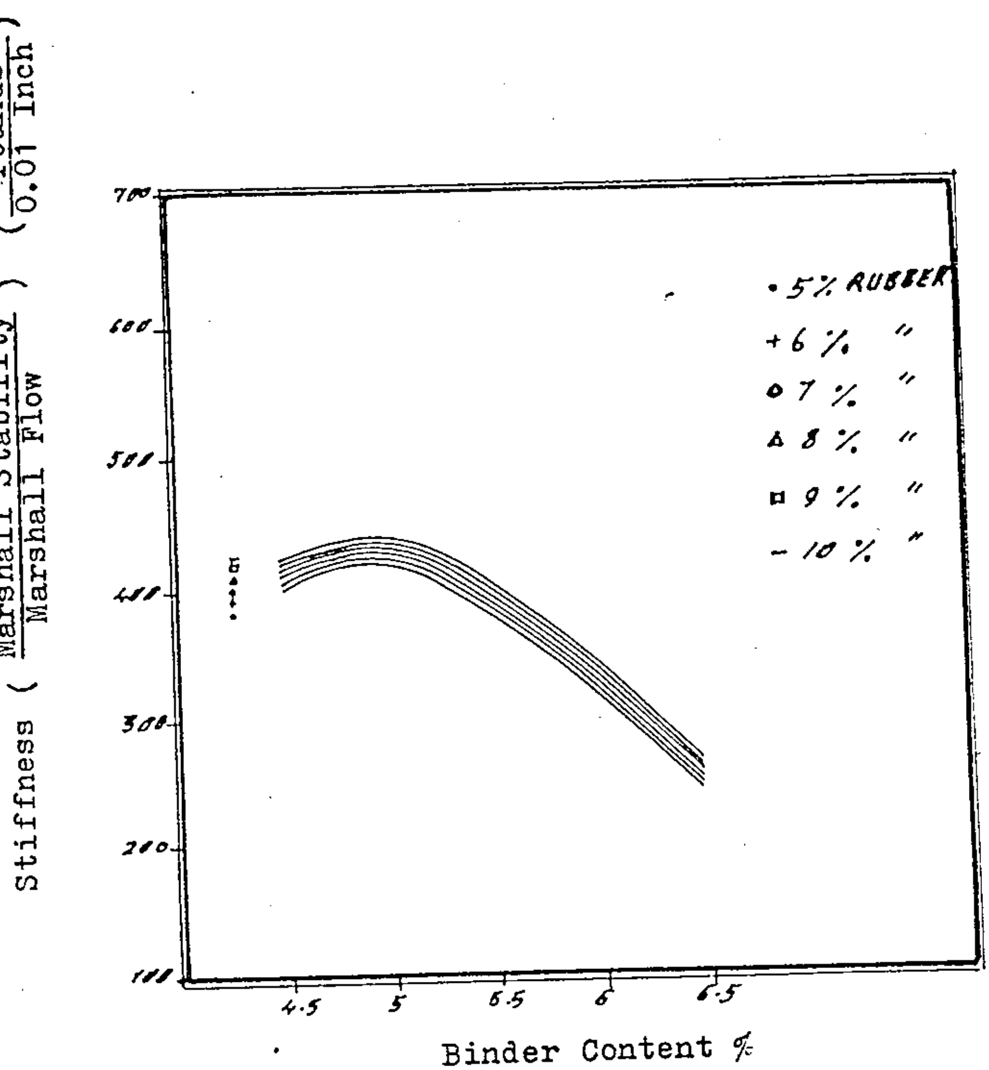


Fig. 4.18 Relationship Between Percent Binder Content And Stiffness $\left(\frac{\text{Marshall Stability}}{\text{Marshall Flow}}\right)$ Of Rubber-Asphalt Concrete Mixtures.

This Figure Is Derived From Figure 4.17.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

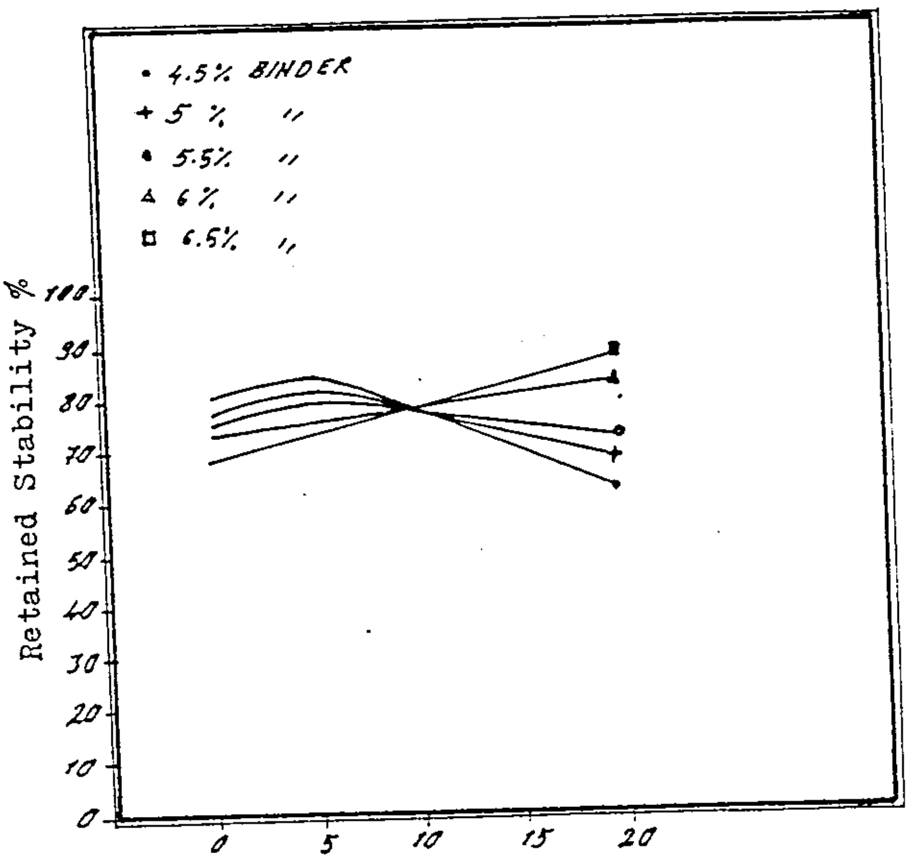


Fig 4.19 Relationship Between Percent Rubber And Percent Retained Stability Of Rubber Asphalt Concrete Mixtures Being Soaked In Water For 24 Hours At 60 C.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

rubber content until the rubber reaches the value of 5% then the retained stability decreases as the rubber content increases. This is true for all mixes containing percentages of binder contents up to 5.5% while the retained stability of mixes containing 6% and 6.5% binder content increases progressively with the increase in rubber content. The initial increase in retained stability, at binder contents up to 5.5%, with the increase of rubber content is thought to be due to the increase in viscosity of binder (while retaining good compaction at low rubber content) while the decrease in retained stability is due to the detrimental effect of water on the mix, since high percentage of rubber increases viscosity of binder and consequently makes compaction difficult, increases voids and allows hot water come in contact with aggregate particles, thus decreasing the friction between these particles which in effect reduce stability. The continuous increase in retained stability with the addition of rubber at 6% and 6.5% binder contents is caused by suitable viscosity of binder content and good compaction which do not permit more hot water to come in contact with the particles.

When we draw the retained stability at rubber to binder content ranging from 5% to 10% against binder content ranging from 4.5% to 6.5% in Fig 4.20 we see that the retained stability decreases with the increase in binder content at all percentages of rubber content. The decreace in retained stability with the increase in binder content

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

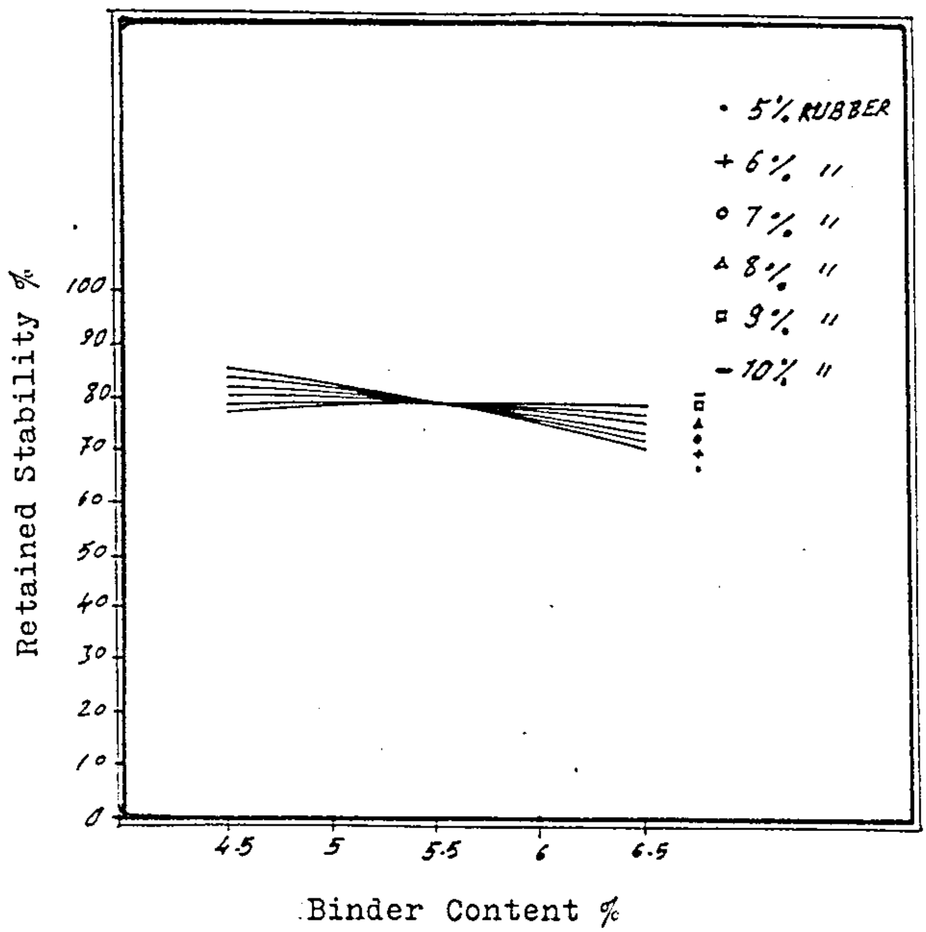


Fig. 4.20 Relationship Between Percent Binder Content And Percent Retaind Stability Of Rubber Asphalt Concrete Mixtures Being Soaked In Water for 24 Hours At 60 C.
This Figure Is Derived From Figure 4.19 .

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

incorporating 5% to 10% of rubber content is due to the fact that more binder decreases the friction forces between the particles, therfore, decreases the stability. It is noticed also that the values of retained stability fulfill the requirement of M.P.W.H, which is 75%, are at binder content of 4.5% up to 6.5% incorporating rubber content from 5% to 10%.

4.3.8. Effect Of Rubber Content On Retained Stability Of Asphalt Concrete Mixtures After Having Been Soaked In Water For 1/2 Hour At 100 C.

Figure 4.21 shows the relationship between rubber and retained stability after the specimens were soaked in water for 1/2 hour at 100 C. It is noticed that the retained stability increases with the increase in rubber content until the rubber reaches the value of 5% then the retained stability decreases as the rubber content increases.

This is true for all mixes containing percentages of binder contents up to 5.5% while the retained stability of mixes containing 6% and 6.5% binder contents increases continuously with the increase in rubber content. The initial increase in retained stability at binder content up to 5.5%, with the increase of rubber is assumed to be due to the increase in viscosity of binder (while retaining good compaction at low rubber content) while the decrease in retained stability is thought to be due to detrimental effect of water on the mix, since high percentage of rubber increases viscosity of binder and consequently makes

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

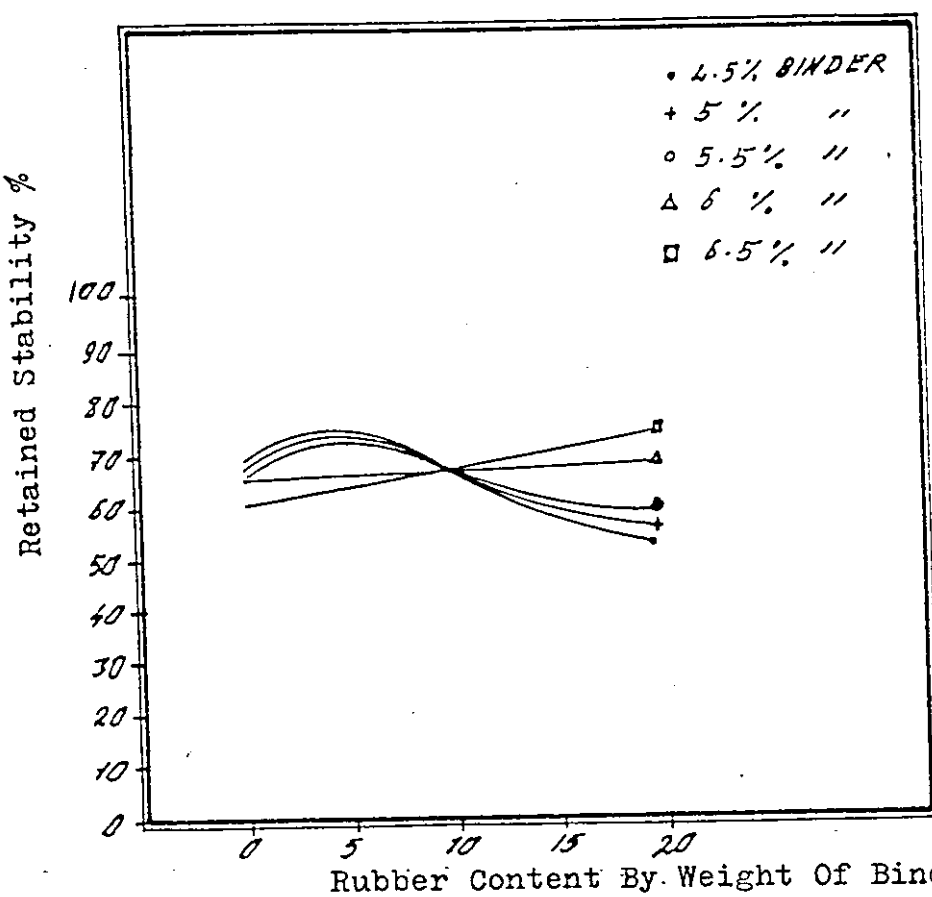


Fig 4.21 Relationship Between Percent Rubber And Percent Retained Stability Of Rubber Asphalt Concrete Mixtures Being Soaked In Water For ½ Hour At 100 C.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

compaction difficult, increases voids and allows hot water come in contact with aggregate particles, thus decreasing the friction between these paticles which in effect reduce stability and retained stability of the mix. The increase in retained stability with the addition of rubber at 6 and 6.5% binder contents is thought to be due to suitable viscosity of binder content and good compaction which do not permit more boiling water to come in contact with the particles.

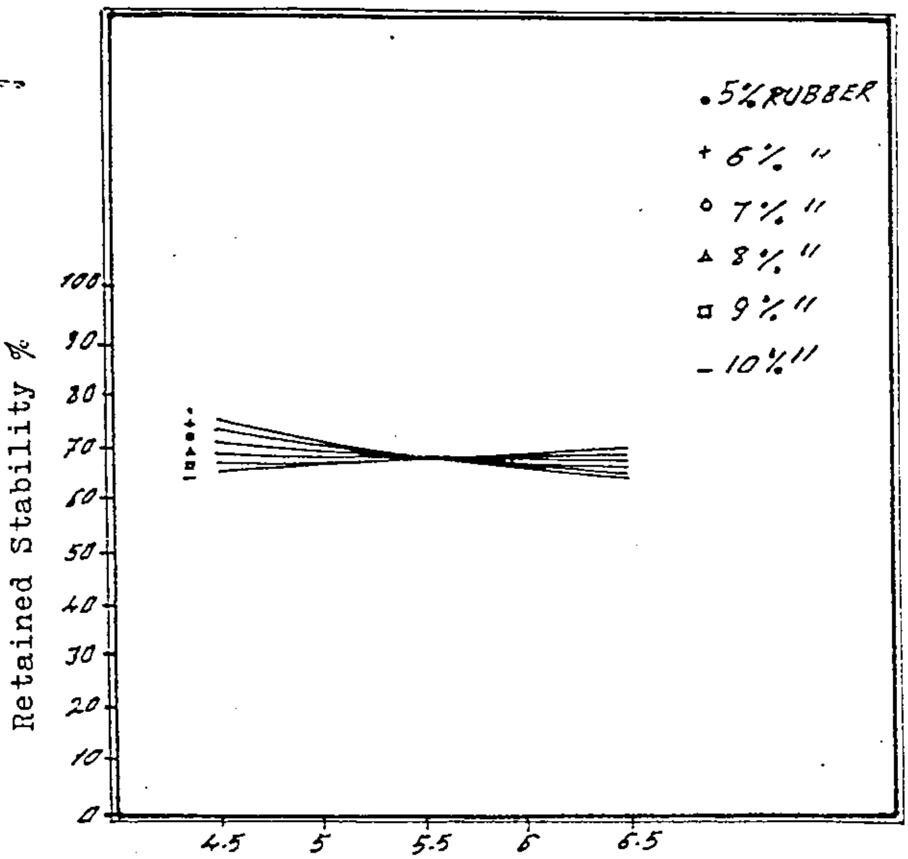
When we draw the retained stability at 5% up to 10% rubber content against binder content in Fig 4.22, we see that the retained stability decreases with the increase in binder content at percentages of rubber content. The decrease in retained stability with the increase in binder content incorporating 5%-10% of rubber content is due to the fact that more binder content decreases the friction forces between the aggregate particles and consequently decreases the retained stability.

It is noticed that the values of retained stability are below the requirement of M.P.W.H, which is 75%, but they are concentrated between the values of 65% and 75% at the binder content of 4.5% to 6.5% incorporating rubber content between 5% and 10%.

4.3.9. Effect Of Rubber Content On Retained Stiffness Of Asphalt Concrete Mixtures After Having Been Soaked In Water For 24 Hours At 60 C.

Figure 4.23 shows the relationship between rubber content and retained stiffness after the specimens were

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Binder Content %

Fig. 4.22 Relationship Between Percent Binder Content And Percent Retained Stability Of Rubber Asphalt Concrete Mixtures Being Soaked In Water For ½ Hour At 100 C.
This Figur Is Derived From Figure 4.21

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

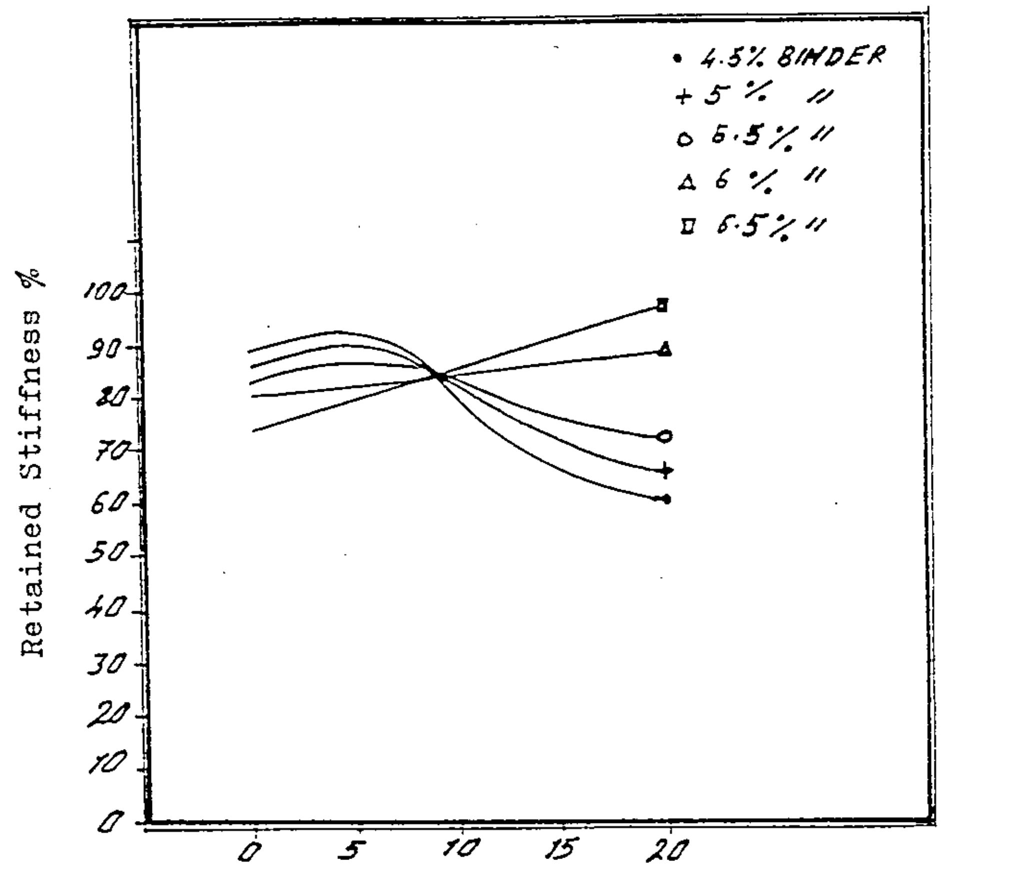


Fig 4.23 Relationship Between Percent Rubber And Percent Retained Stiffness Of Rubber Asphalt Concrete Mixtures Being Soaked In Water For 24 Hours At 60 C.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

soaked in water for 24 hours at 60 C. It is noticed that the retained stiffness increases with the increase in rubber content until the rubber reaches the value of 5% then the retained stiffness decreases as the rubber content increases. This is true for all mixes containing percentages of binder contents up to 5.5% while the retained stiffness of mixes containing 6% and 6.5% binder content increases continuously with the increase in rubber content. The initial increase in retained stiffness, at binder content up to 5.5%, with the increase in rubber is thought to be due to the increase in viscosity of binder (while retaining good compaction at low rubber content) which consequently increases the stability and decreases the flow. The decrease in retained stiffness is thought to be due to the detrimental effect of water on the mix, since high percentage of rubber increases viscosity of binder and consequently makes compaction difficult, increases voids and allows hot water come in contact with aggregate particles thus decreasing the friction between these particles which in effect reduce stability and stiffness of the mix.

The continuous increase in retained stiffness with the addition of rubber at 6% and 6.5% binder content is assumed to be caused by suitable viscosity of binder content and good compaction which do not permit more water to come in contact with the particles which consequently reduce the flow and increase the stiffness.

When we draw the retained stiffness at 5% up to 10%

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

rubber content against binder content in Fig 4.24 we see that the retained stiffness decreases with the increase in binder content at all percentages of rubber content. The decrease in retained stiffness with the increase in binder content containing 5%-10% of rubber content is due to the fact that more binder increases flow and decreses friction forces between aggregate particles and consequently decreases stiffness.

It is noticed that the values of retained stiffness are higher than 75%, which is the minimum value required by M.P.W.H, at binder content ranging between 4.5% and 6.5% and containing rubber content from 5% to 10%.

4.3.10. Effect Of Rubber Content On Retained Stiffness Of Asphalt Concrete Mixtures After Having Been Soaked In Water For 1/2 Hour At 100 C.

Figure 4.25 shows the relationship between rubber content and retained stiffness after the specimens having been soaked in water for 1/2 hour at 100 C. It is noticed that the retained stiffness increases with the increase in rubber content until the rubber reaches the value of 5% then the retained stiffness decreases as the rubber content increases. This is true for all mixes containing percentages of binder contents up to 5.5% while the retained stiffness of mixes containing 6% and 6.5% binder content increases progressively with the increase in rubber content.

The initial increase in retained stiffness, at binder contents up to 5.5%, with the increase in rubber is thought

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

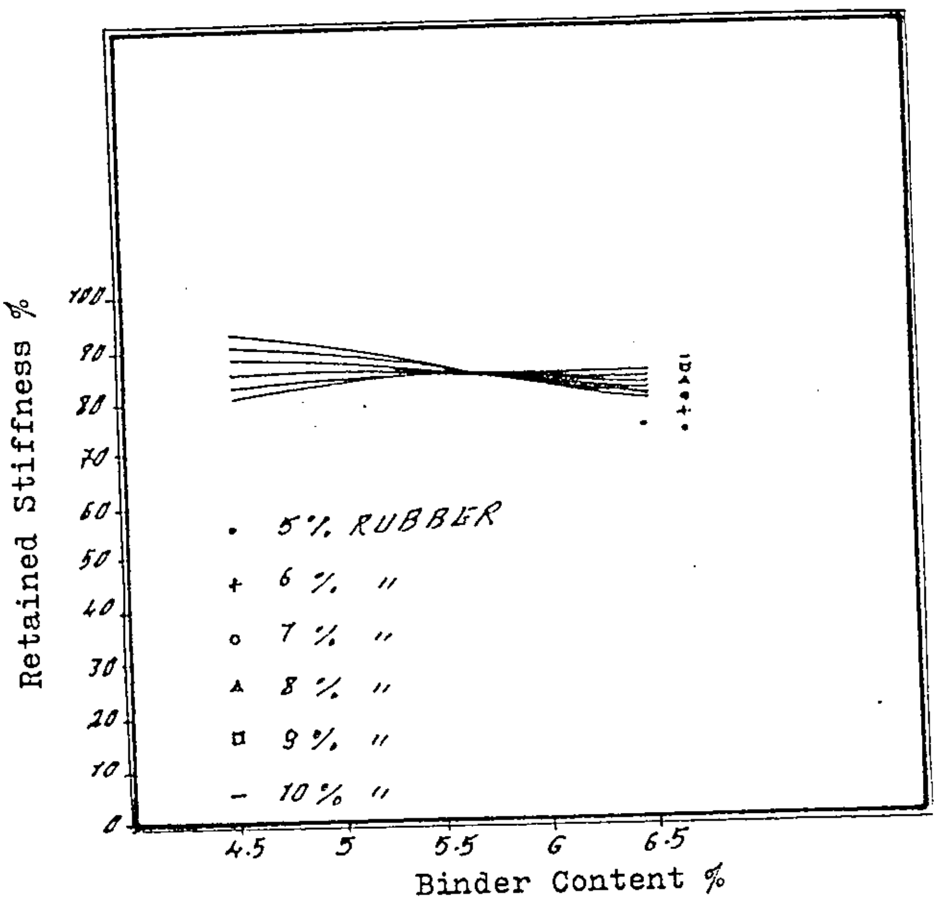


Fig.4.24 Relationship Between Percent Binder Content And Percent Retained Stiffness Of Rubber-Asphalt Concrete Mixtures Being Soaked In Water For 24 Hours At 60 C.This Figure Is Derived From Figure 4.23

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

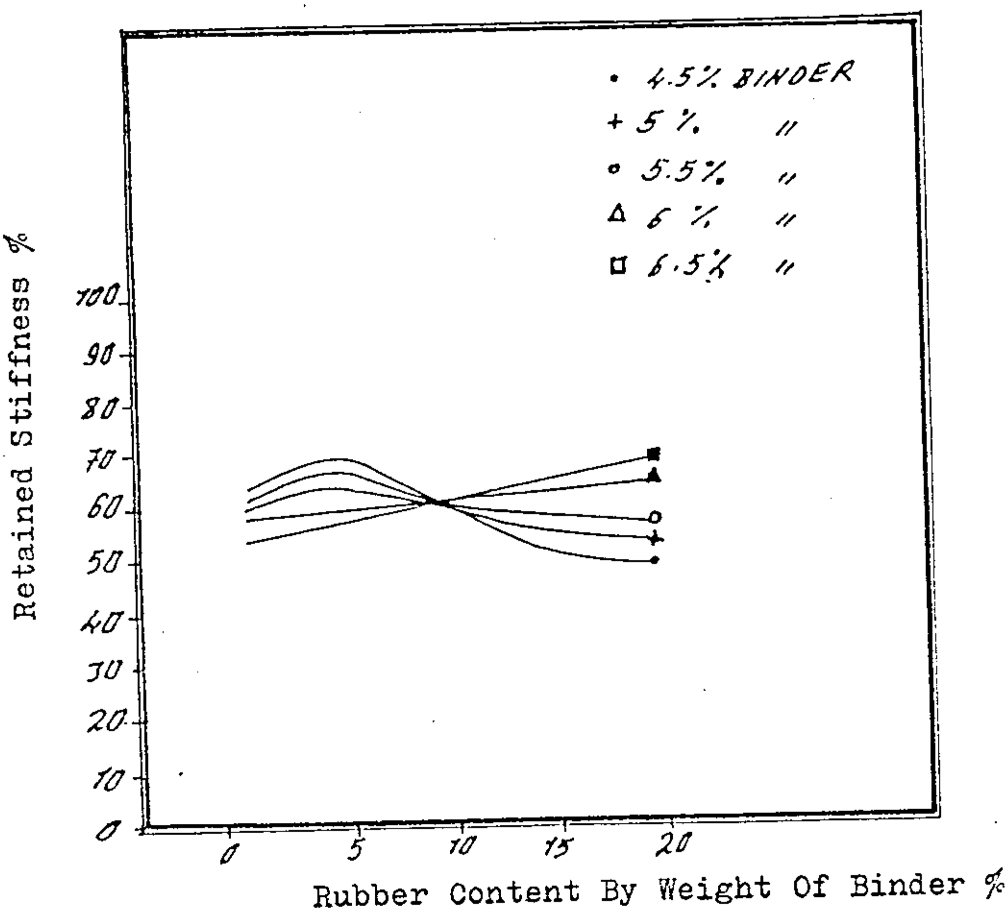


Fig.4.25 Relationship Between Percent Rubber And Percent Retained Stiffness Of Rubber-Asphalt Concrete Mixtures Being Soaked In Water For ½ Hour At 100C.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

to be due to the increase in viscosity of binder which consequently increases the stability and decreases the flow. The decrease in retained stiffness is assumed to be due to detrimental effect of water on the mix, since high percentage of rubber content increases viscosity of binder and consequently makes compaction difficult, increases voids and allows hot water come in contact with aggregate particles thus decreasing the friction between these particles which in effect reduce stability and stiffness of the mix.

On the other hand the increase in retained stiffness with the addition of rubber while employing 6% and 6.5% binder content is assumed to be caused by suitable viscosity of binder content and good compaction which do not permit more boiling water to come in contact with the particles. Consequently this action reduces the flow and increases the stiffness of the mix.

When we draw the retained stiffness at 5% up to 10% rubber content against binder content in Fig 4.26 we see that the retained stiffness decreases with the increase in binder content at all percentages of rubber content. The decreease in retained stiffness with the increase in binder content containing 5%-10% of rubber is due to the fact that more binder increases flow and decreases friction forces between aggregate particles and consequently decreases stiffness.

It is noticed that the values of retained stiffness are lower than the value of 75% which is required by the M.P.W.H at binder content ranging from 4.5% to 6.5%

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

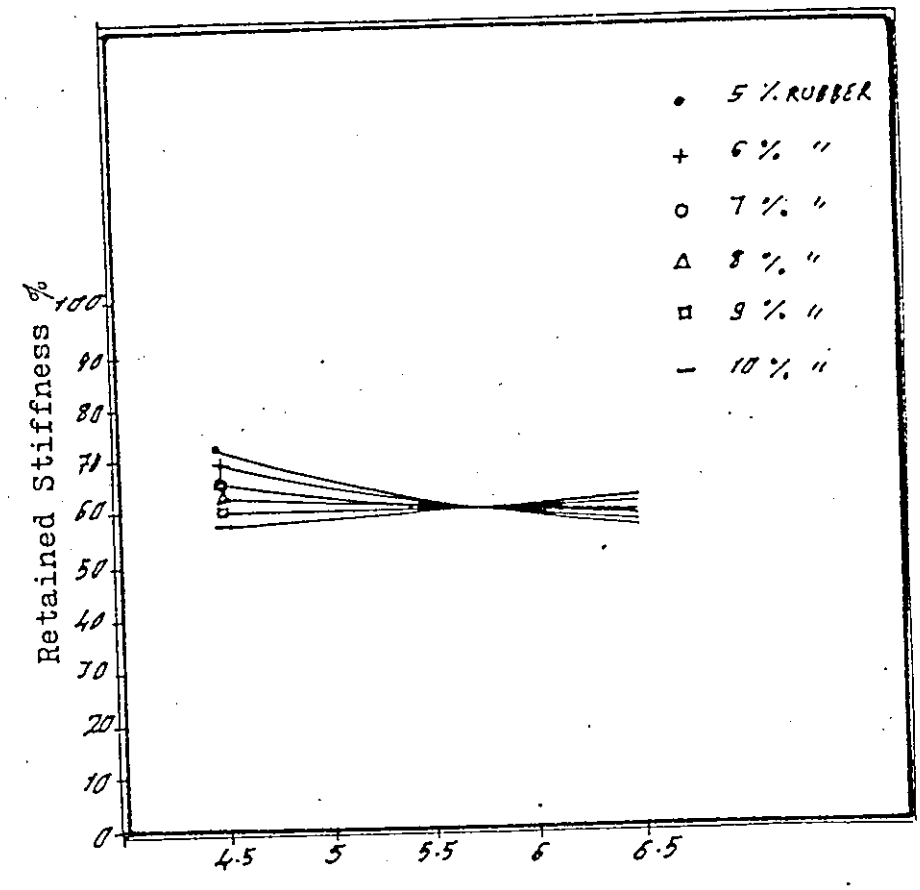


Fig 4.26 Relationship Between Percent Binder Content And Percent Retained Stiffness Of Rubber Asphalt Concrete Mixtures Being Soaked In Water For ½ Hour At 100 C.
This Figure Is Derived From Figure 4.25.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

containing rubber between 5% and 10% (the test temperature here is 100 C but the test temperature of Marshall test is 60 C).

4.4 EFFECT OF RUBBER CONTENT ON PERFORMANCE OF ASPHALT CONCRETE RECTANGULAR SPECIMENS TESTED BY THE WHEEL TRACKING MACHINE.

This test was carried out to investigate the effect of rubber on aggregate stripping, resistance to penetration and resistence to the bonding failure of asphalt concrete mixtures.

4.4.1 Specimens of Type 1 Gradation Shown In Fig. 3.1 And 6 Percent Binder Content.

Figure 4.27 shows the relationship between time and the penetration (Appendix B) under the wheel load at different percentages of rubber content by weight of binder content. It is noticed that an increase in penetration occured in all specimens at the beginning, then penetration became stable and no bonding failure occured to specimens after 72 hours of testing period. It is shown also that the period of time, before the permanent penetration became stable increases with the increase in rubber content. This increase in period of time is because of the resistance to compaction under the wheel due to the high viscosity of binder caused by the increase in rubber content.

When we plot the penetration against rubber content after 24 hours and 72 of testing period in Fig 4.28, we see

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

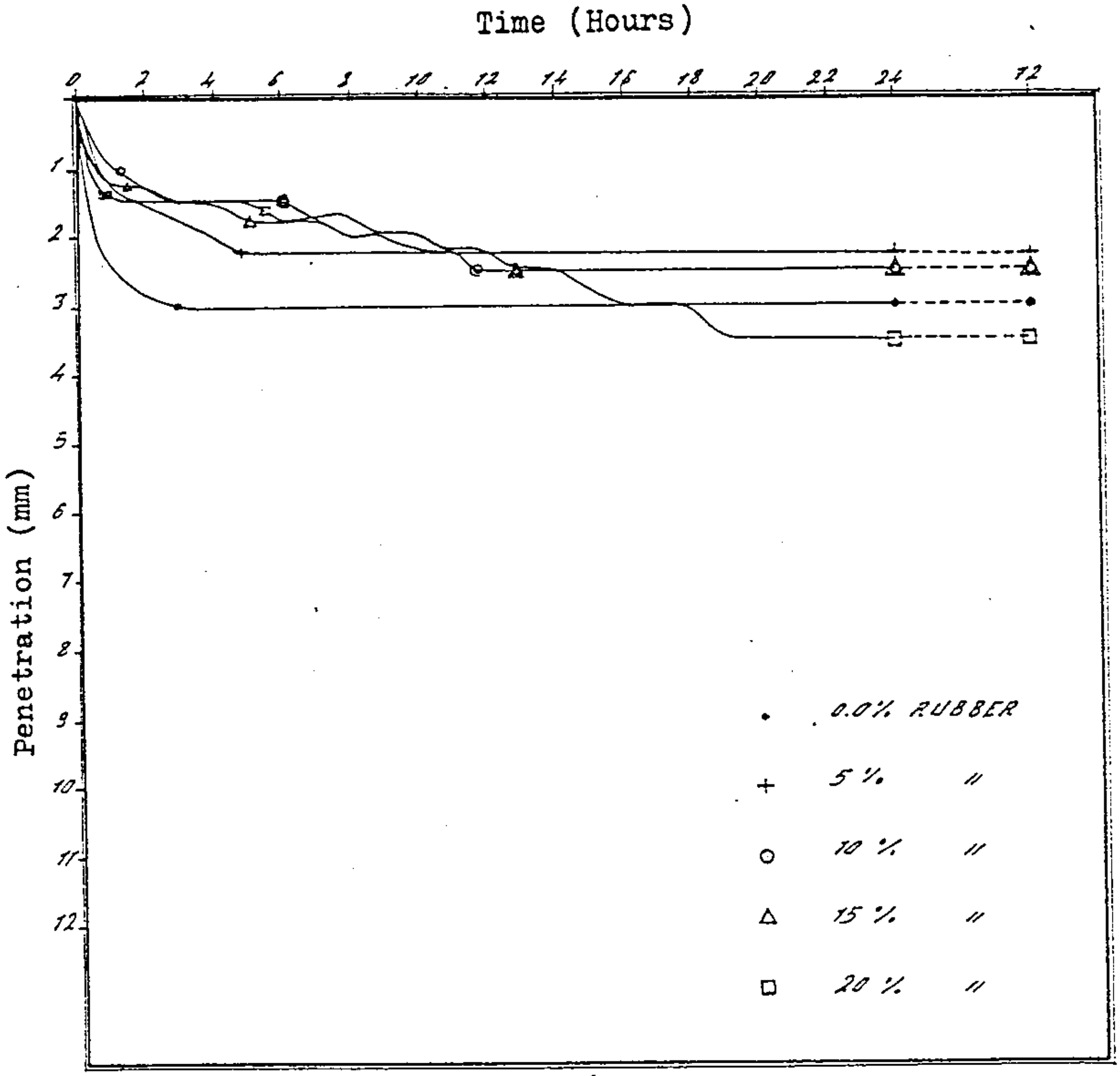


Fig 4.27 Relationship Between Time* And Penetration of Rubber Asphalt Concrete Specimens Having Type 1 Gradation And 6 % Binder Content (Rubber Bitumen Blend). These Specimens Were Tested By The Wheel Tracking Machine.

Note*: Time Of Testing.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

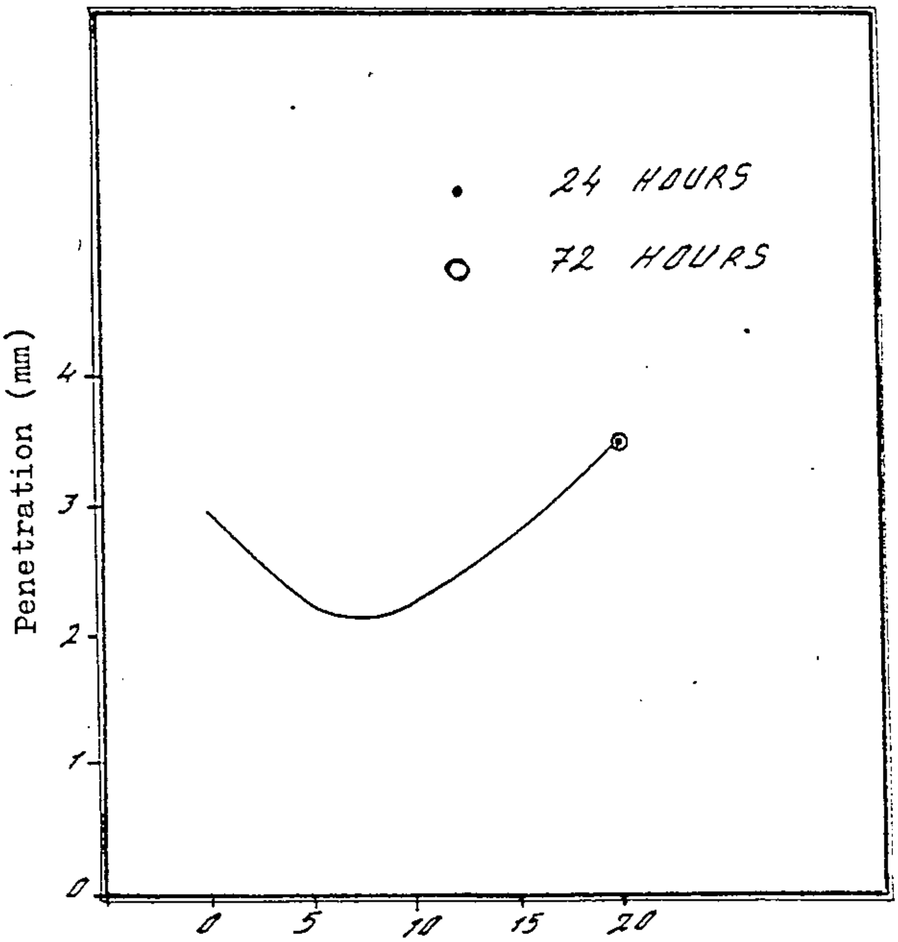


Fig 4.28 Relationship Between Percent Rubber And Penetration Of Rubber Asphalt Concrete Mixtures Having Type 1 Gradation And 6% Binder Content Tested By Wheel Tracking Machine For 2 periods Of Time 24 And 72 Hours.

This Figure Is Derived From Figure 4.27

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

that both curves coincides. It is noticed also that the penetration decreases with the increase in rubber content until the rubber reaches the value of 7.5% by weight of binder then the penetration increases as the rubber content increases. It is thought that the initial decrease in penetration is due to the lubricating effect of rubber with suitable viscosity of binder which lead to good compaction of mix and consequently lead to more resistance to aggregate stripping and deformation. The increase in penetration with the increase in rubber is due to the less resistance to the aggregate stripping and deformation caused by poor compaction of mix due to the high viscosity of the binder.

4.4.2 Specimens Of Type (2) Gradation Shown In Fig. 3.2 And 4.5 Percent Binder Content.

Figure 4.29 shows the relationship between the time of test and penetration (Appendix B) under the wheel load at different percentages of rubber content by weight of binder content. It is noticed that an increase in penetration occured in all specimens at the beginning, then it became stable in specimens having 0.0%, 5%, and 10% rubber but bonding failure occurred in specimens containing high percentages of rubber content, namely 15% and 20% rubber. It is shown also that the bonding failure time of mixtures having 20% rubber, is shorter than those having 15% rubber content because of the poor compaction caused by high viscosity at higher rubber content and also because of the low amount of bitumen in the rubber bitumen blend (binder)

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

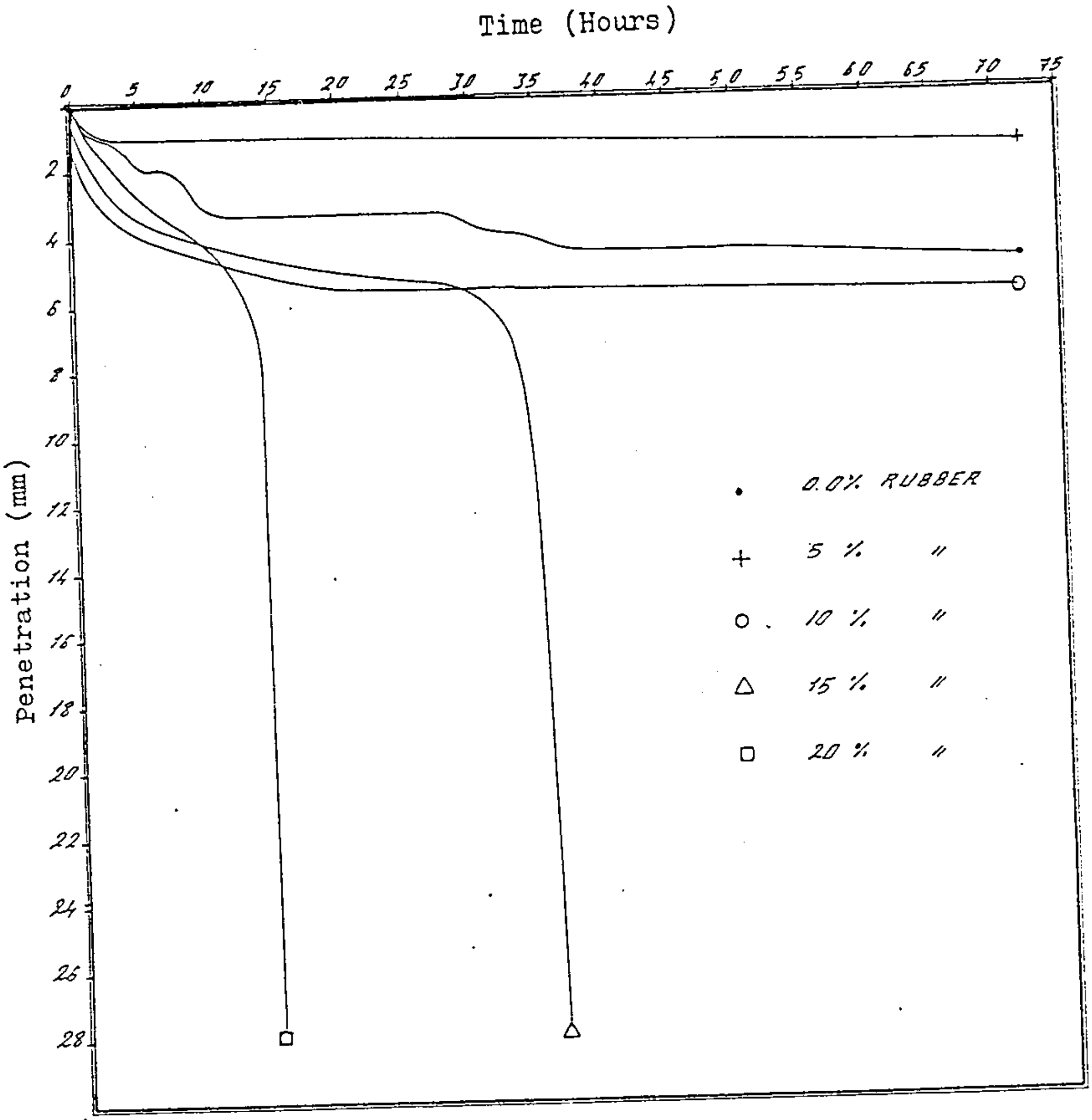


Fig 4.29 Relationship Between Time* And Penetration Of Rubber Asphalt Concrete Specimens Having Type 2 Gradation And 4.5 Percent Binder Content (Rubber Bitumen Blend). These Specimens Were Tested By The Wheel Tracking Machine.

Note *: Time Of Testing.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

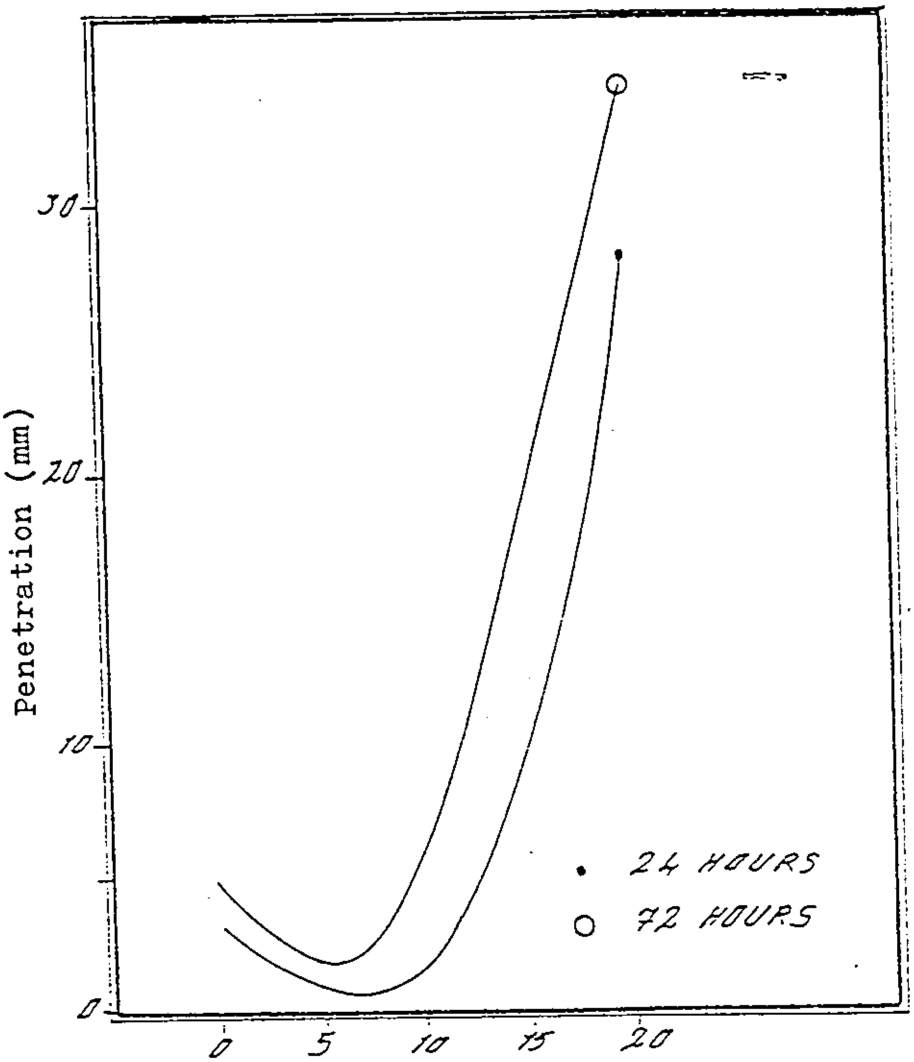
which cause less resistance to aggregate stripping and water effect.

When we draw the penetration against rubber after 24 hours and 72 hours of testing period in Fig 4.30 we see that the penetration decreases with the increase in rubber content until the rubber reaches the values 7.5% and 6% after 24 hours and 72 hours, respectively, then the penetration increases as the rubber content increases. The initial decrease in penetration is due to the lubricating effect of rubber with suitable viscosity of binder which lead to good compaction of mix and consequently lead to more resistance to aggregate stripping and deformation. The increase in penetration with the increase in rubber is due to the less resistance to aggregate stripping and deformation caused by poor compaction of mix due to the high viscosity of binder and low amount of bitumen in the binder.

4.5 EFFECT OF RUBBER CONTENT ON SKID RESISTANCE OF ASPHALT CONCRETE MIXTURS.

Figure 4.31 shows the relationship between rubber content and skid resistance of rubber bitumen mix specimens Type 1 shown in Fig. 3.1 gradation with 6 percent binder content. The specimens were tested for skid resistance by the British pendulum tester (Appendix C) before and after having been tested by the Wheel Tracking Machine (Item 4.4.1). It is noticed that the skid resistance decreases slightly with an increase in rubber content. The progressive decrease in skid resistance with the increase in rubber

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit



Rubber Content By Weight Of Binder %

Fig 4.30 Relationship Between Percent Rubber And Penetration Of Rubber Asphalt Concrete Mixtures Having Type 2 Gradation And 4.5% Binder Content Tested By Wheel Tracking Machine For Two Periods Of Time 24 And 72 Hours. This Figure Is Derived From Figure 4.29

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

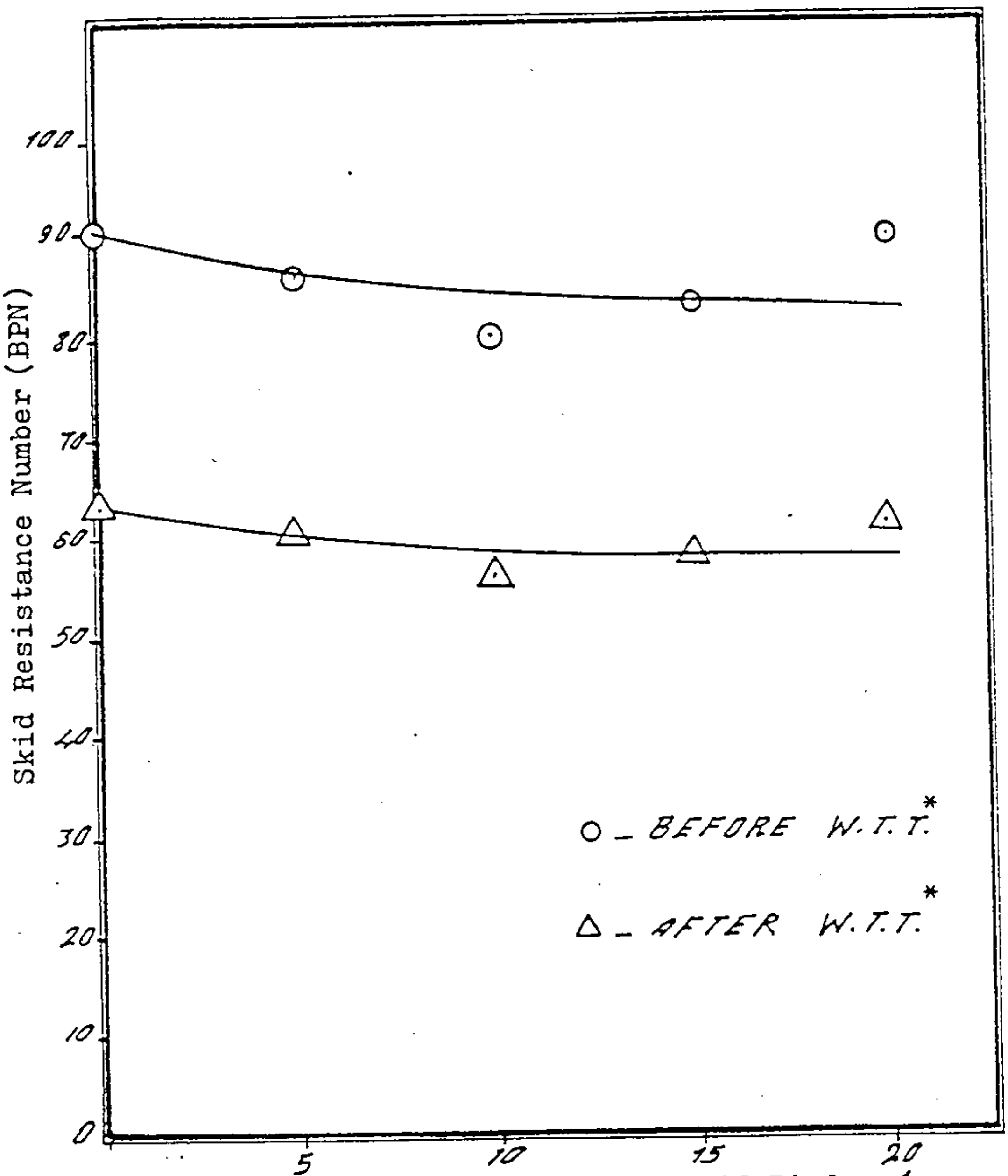


Fig 4.31 Relationship Between Percent Rubber And Skid Resistance (BPN) Of Rubber Asphalt Concrete Mixtures Before And After Being Tested By Wheel Tracking Machine.
Note * Wheel Track Test.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

content is expected, because rubber usually causes decrease in skid resistance whether this rubber is mixed with bitumen or is present as powder on the road abraded from vehicles wheels. It is noticed also from Fig. 4.31 that the values of skid numbers of the specimens before the Wheel Track Test are higher than the values of the same specimens after the same test. This is attributed to the polishing which happened to the specimen surfaces during the Wheel Track Test and to the bleeding caused by the excessive compaction after the same test.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS:

According to the previous discussion, the following conclusions have been obtained.

1. Physical properties of rubber-bitumen blend changed with the addition of rubber content. Softening point and specific gravity increased, whereas ductility, penetration, flash point and fire point decreased.
2. There is no significant effect on aggregate stripping property when the rubber is added to the rubber-asphalt mixtures.
3. The maximum Marshall mix density is obtained at a binder content of 6% by weight of total mix containing 5% rubber by weight of binder.
4. The range of binder content between 5.4% and 6.5% incorporating rubber content between 5% and 10% by weight of binder fulfill the range of 3 to 5 percent air voids which is required by the Ministry of Public Works and Housing (M.P.W.H.).
5. The range of binder content between 4.5% and 6.5% by weight of total mix containing the range of rubber content between 7% and 10% by weight of binder result in 13 percent V.M.A. which is the minimum value required by M.P.W.H.
6. When using rubber in the range of 5% to 10% by weight of binder in the range of rubber-bitumen binder between 5.2%

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

and 5.8% by weight of total mix, mix Marshall stability values are usually higher than the 2200 lb minimum value which is required by the M.P.W.H.

7. When using the percentages of rubber to binder between 5% and 10% in the range of binder between 4.5% and 6.5%, the range of Marshall flow in test specimens remains between 8/100 and 16/100 inch, which is the range of flow required by the M.P.W.H.
8. The values of Marshall specimen stiffness when using rubber between 5% and 10% by weight of binder and mix binder between 4.5% and 6.2%, are higher than the minimun stiffness value of 280 lb/0.01 inch which is required by the M.P.W.H.
9. The values of retained stability at binder contents of 4.5% up to 6.5% by weight of total mix incorporating rubber content of 5% up to 10% by weight of binder, are higher than the value of 75% which is required by the M.P.W.H.
10. The values of retained stiffness at binder contents ranging from 4.5% up to 6.5% by weight of total mix incorporating rubber content of 5% up to 10% by weight of binder are higher than the value of 75% which is required by M.P.W.H.
11. With respect to temperature susceptibility of the mix, the values of retained stability are below the value of 75% which is required by the M.P.W.H. The values of retained stability fall in the range of 65% to 75% when

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

using binder content of 4.5% to 6.5% and incorporating rubber content of 5% to 10%.

12. With respect to temperature susceptibility of the mix, the values of retained stiffness are between 55% and 70% (these values are lower than the value of 75% which is required by the M.P.W.H.) at binder content of 4.5% to 6.5% containing rubber content of 5% to 10%.
13. The range of rubber content between 5% and 10% by weight of binder is suitable when added to the rich and dense graded mixes where it minimize the aggregate stripping and the permanent deformation (rutting) of the mix.
14. The range of rubber content between 4% and 7.5% by weight of binder is suitable when added to the poor and loose graded mixes where it minimizes the aggregate stripping and the permanent deformation (rutting).
15. There is no significant effect of adding rubber on the skid resistance property of the asphalt concrete mixes.

In summary bituminous concrete mixes containing binder content in the range of 5.4% to 5.8% by weight of total mix could incorporate 7%-10% rubber content by weight of binder and still satisfy requirements of the Ministry of Public Works and Housing specifications with regard to air voids, V.M.A., Marshall stability, Marshall flow, stiffness, retained stability and retained stiffness (Fig. 5.1 shows the ranges of binder content that fulfill the requirements of M.P.W.H.), and it reduces water and temperature susceptibility of the mix (water and temperature detrimental

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

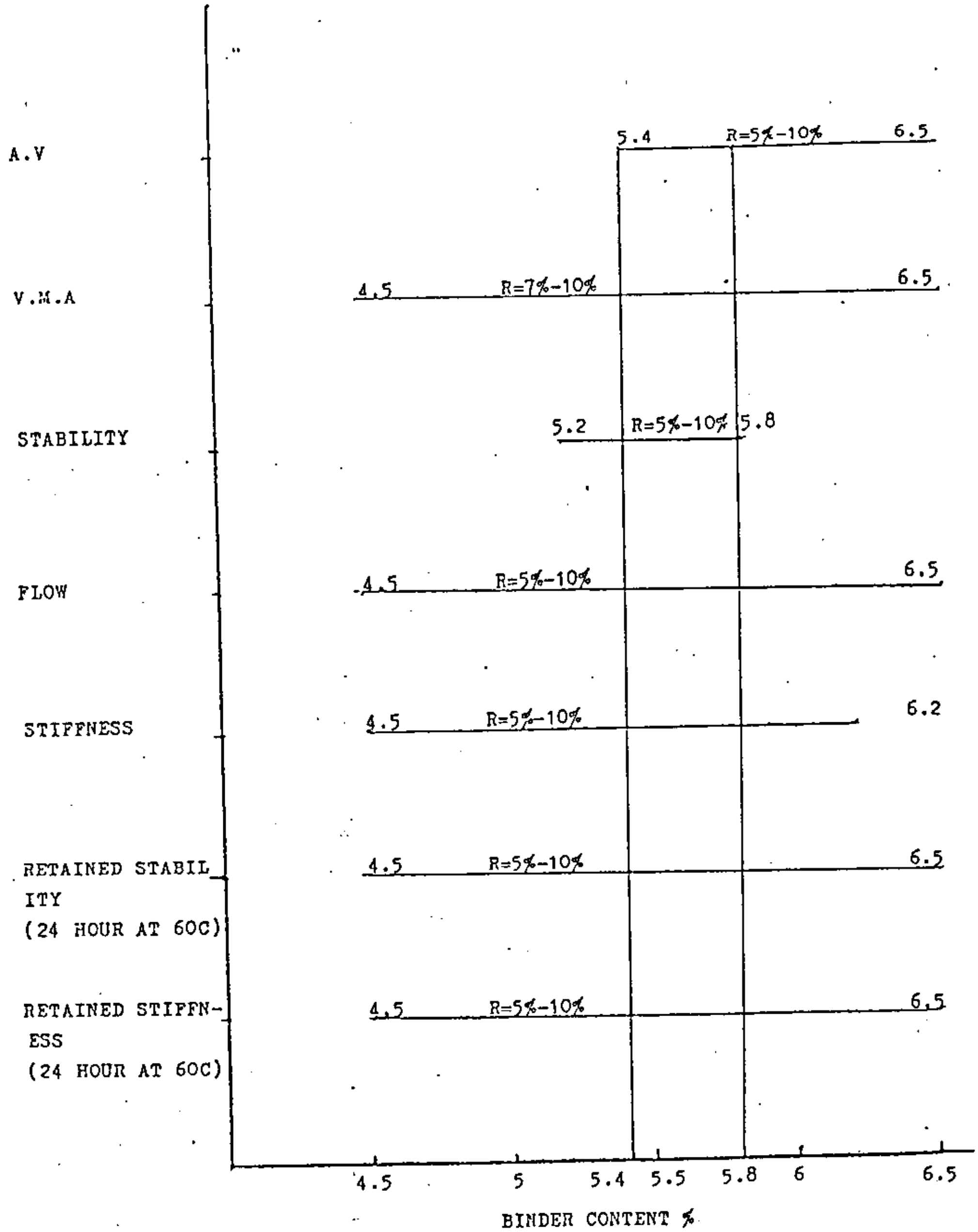


Fig 5.1 The Ranges Of Percent Binder Content By Weight Of Total Mix That Fulfill The Requirements Of M.P.W.H For Marshall Test Specimens Properties.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

effect). The addition of rubber will reduce in the quantity of bitumen needed for any given asphalt concrete mix.

5.2 RECOMMENDATIONS.

According to the previous conclusions, the following recommendations are offered:

1. It is recommended that rubber additives in the range of 7 to 10 percent by weight of binder be used where their addition has shown improvements on mix quality.
2. It is recommended also to mix and compact the rubber bitumen concrete mixes at the same viscosity of that for the normal binder (bitumen 60-70 penetration degree). Therefore it is believed that the mixing and compacting temperature for rubber bitumen concrete mixes should have been higher than that used in this research work.
3. Other laboratory tests such as the indirect tensile strength and Texas freeze- thaw pedestal tests should be conducted on mixes containing rubber-bitumen binder.
4. Field trial strips should be placed and tested to establish a correlation between the laboratory tests and the real field conditions of rubber bitumen mixes.
5. Chemical properties of rubber should be investigated.
6. Other types of rubber, aggregates, bitumen and mixes should be investigated.
7. Possibility of mixing rubber with bitumen used in seal coats and surface dressings, should be investigated.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

REFERENCES

1- Informations about Roads in Jordan. Planing Directorate, Ministry of Public Work and Housing, Amman Jordan, 1990.

2- Al-Sharif, R, L. The simplified procedure for design and construction of roads. Second part. Amman Jordan, 1984.

3- Specifications for construction of roads and briges. Ministry of Public Works and Housing, Amman, Jordan, 1974.

4- Al-Sharif, R, L. Materials properties. Amman Jordan, 1986.

5- Informations about Asphalt in Jordan. Library center, Jordan Petroleum Refining Company, 1990.

6- Al-Sharif, F, L. The simplifide procedure for design and construction of roads. First part. Amman Jordan, 1981.

7- Improved asphalt containing reclaimed rubber for paving purposes. National center for construction labs. Iraq-Bagdad, 1988.

8- Szathowshi, W.S. Resistance to cracking of rubberized asphalt: Full scale experiment of trunk road A6 in Leicestershire Road Research Laboratory Report LR 308, 1970.

9- Westerman, R.R. Tires: Decreasing soil wastes and manufacturing throughput, markets, profits and resource recovery, Report EPA 600/5-78-009, Municipal Environmental Development Research Laboratory, Office of Research and Development, U.S. Environmental Protection

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Agency, Cincinnati, Ohio, July 1978.

10- McDonald, C.H. A new patching material for pavement failures. Paper presented at 45th Annual Meeting, HRB, 1966.

11- McDonald, C.H. Bituminous paving as related to large commericial airports in the urban environment. Paper presented at the 50th Annual Meeting, HRB, 1971.

12- Olsen, R.E. Rubber-asphalt binder for seal coat construction, Federal Highway Administration, Implementation Package 73-1, 1973.

13- McDonald, C.H. Asphalt - rubber compounds and their applications for pavement, 21st California Streets and Highway Conference, 1969.

14- Schnormeier, R.H. Eleven year pavement condition history of asphalt-rubber seals in Phoenix, Arizona, ASTM STP, 724, Dec. 1980.

15- Piggot, M.R. Ng, W. George, J.D. and Woodhams, R.T. Improved Hot mix asphalts containing reclaimed rubber, Proc., AAPT Technical Sessions, Feb. 21-23, 1977.

16- The American Association of State Highway and Transportation Officials AASHTO, Standard speci-fications for Transportation Materials and Methods of Sampling and Testing part 1 specifications, Washington July 1986.

17- The American Association of State Highway and Transportation officials AASHTO, Standard specifications for Transportation Materials and Methods of sampling and Testing. Part 11. Methods of sampling and testing.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Washington. July 1986.

18- Annual Book of ASTM standards. Road and Paving Materials; Travelled surface characteristics. Sec. 4 volume 4.03 April 1984.

19- British standard. B.S 812. London 1985.

20- Annual book of ASTM Standards. Roofing, Waterproofing, and Bituminous Materials Sec. 4 volume 4.04 April 1984.

21- Road Research Laboratory. Bituminous Materials in Road Construction. London, August 1962.

22- Controls Company. Instructions for using the portable skid-resistance tester. Instruction Manual. England 1983.

23- The Asphalt Institute. Asphalt Technology and Construction Practices, Instructor's Guide. Educational Series No. 1 (ES-1). Second Edition January 1983.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

BIBLIOGRAPHY

1- Annual book of ASTM standard. Rubber, Natural and synthetic-general test methods, Carbon black, Sec. 9 volume 9.01 July 1984.

2- Annual book of ASTM standards. Rubber product, Industrial-specifications and related test method; gaskets; tires. Sec. 9 volume 9.02 July 1984. ASTM 1916 Race Street/ Philadelphia, PA 19103 (215) 299-5400.

3- Frobel R.K. Jimenez R.A. and cluff C.B. Laboratory and field development of asphalt-rubber for use as a water proof membrane. Submitted to Arizona Highway Department, phoenix May 1977.

4- Lansdon H.G. The blending of granulated rubber and asphalt for use as a crack sealant. ADOT Research Section. July 1976.

5- Lansdon H.G. Construction Technique of placement of asphalt-rubber membranes. Arizona Department of Transportation Prepared for presentation to the thirteenth paving conference, University of New Mexico, Department of civil Engineering Albuquereque, New Mexico. January 8-9. 1976.

6- Vallerga B.A. G.R. Morris, Huffman J.E. and Huff B.J. Applicability of asphalt-rubber membranes in reducing reflection cracking, presented at the AAPT Symposium on "prevention and Control of Reflection cracking" held in Luisville, kentucky on February 19, 1980.

7- Huffman J.E. The use of ground vulcanized rubber in

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

asphalt, Asphalt pavement construction: New material and Techniques, ASTM STP 724. J.A. Scherocman. Ed., American Society for Testing and materials December 1980.

8- Vallerga, B.A. and Bagley, J.R., "Design of Asphalt-Rubber Single Surface Treatments with Multilayered Aggregate structure". Asphalt Pavement construction: New Materials and Techniques, ASTM STP 724. J.A. Scherocman, Ed., American Society for Testing and Materials. December 1980.

9- McBee, W.C. Sulliran, T.A., and Saylak, D., "An Overview of sulfur Extended Asphalt usage, Asphalt pavement construction: New Materials and Techniques. ASTM STP 724, J.A. Scherocman, Ed. American Society for Testing and Materials, December 1980.

10- Cheethan, A., Haas, R., kenneppohl G., and Bean, D., Improved characterization of sulfur-Asphalt Materials for Structural Analysis, Asphalt Pavement construction: New Materials and Techniques. ASTM STP 724. J.A. Scherocman, Ed. American Society for Testing and Materials, December 1980.

11- Bissada. A.F. and Anani. A.A. Evaluation of Rubberized Limestone filler in Asphalt Paving Mixtures. Reprinted from Rubber chemistry and Technology. vol. 57, No. 1 March - April 1984 printed in U.S.A.

12- National Cooperative Highway Research Program Synthesis of Highway Practice 9. Pavement Rehabilitation Materials and Techniques. Highway Research Board. Washington.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

D.C. 1972.

13- Modern Tire Dealer. Tire tool and equipment merchandising guide; scrap tire solutions. A Bill publication convering tire sales and Automotive service vol. 71 No. 5. U.S.A pittsfield. Mid April 1990.

14- Transportation Research Record 843. National Academy of sciences. Washington D.C. 1982. Shuler. S. Specification Requirements for Asphalt-Rubber.

15- Jimenez. R.A. Laboratory Measurements of Asphalt-Rubber Concrete Mixtures. Transportation Research Record 843. National Academy of Sciences. Washington. D.C. 1982.

16- Stephens. J.E. Field Evaluation of Rubber-Modified Bituminous concrete. Transportation Research Record 843. National Academy of Sciences. Washington. D.C. 1982.

17- Morris. G.R., Chen J.N. and Divito J.A. Application of Asphalt Rubber on New Highway Pavement Construction. Prepared for Presentation at the 61ST Annual Meeting of the Transportation Research Board. U.S.A. Arizona. January 1982.

18- Morris. G.R., Cher N.J., and Divito. J.A. Finite element analysis of Ariqona's three-layer overlay system of rigid pavements to prevent relective cracking prepared for presentation at the 1982 Annual Meeting of Association of Asphalt Paving Technologists. U.S.A, Arizona. February, 1982.

19- Frobel R.K., Jimenez R.A., Cluff C.B. and Morris G.R. Asphalt-Crumb Rubber waterproofing membrane. U.S.A.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Arizona. July 1977.

20- LaCron, Bobby D.,"Rubber Used in Asphalt-Rubber Applications", paper presented at National Seminaron Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

21- McDonald, Charles H., "Recollections of Early Asphalt-Rubber History", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

22- Brown, Douglas J., "Involvement of the FHWA's Demonstration Projects Division in the Development of Asphalt-Rubber Paving Materials", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

23- Schnormerier, Russell H., "Time Proves Asphalt-Rubber Seals Coat Effective", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

24- Weiss, Lawrence L., "Asphalt-Rubber Chip Seals in South Dakota", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

25- Magers, R.H., "Hot Rubber-Asphalt Used as a Stress Absorbing Membrane Interlayer (SAMI)", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

26- Giles, Keith E. and Clark, William H, III, "Asphalt-Rubber Interlayers on Rigid Pavements in New York State, paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

27- Bertelson, T., "Asphalt-Rubber use as a Crack Sealer", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

28- Morris, G.R., "Control of Expansive Highway Subgrades with Asphalt-Rubber Memberanes: Arizona's Experience", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas October 27-29, 1981.

29- Vallerga, B.A., "Design and Specification Changes for Paving Mixes with Asphalt-Rubber Binders", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

30- Huffman, J.E., "Pavement Preparation for Asphalt-Rubber Treatments", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

31- Epps, J.A. and Gallaway, Bob M., "Cost and Energy Associated with Asphalt-Rubber Binders", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

32- Oliver, John W.H., "Reasearch on Asphalt-Rubber at the Australian Road Research Board", paper presented at National Seminar on Asphalt-Rubber, San Antonio, Texas, October 27-29, 1981.

33- Rababah, A.M. Effect of Portland Cement and Rubber Ash on water susceptibility of Bituminous Mixtures and Binder Properties. Thesis Submitted in Partial Fulfillment of Requirement for the Degree of Master of Science in Civil Engineering at Jordan University of Science and

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Technology. November, 1988.

34- Dijk W. Van. Practical fatigue characterization of Bituminous Mixes. Amesterdam 1975.

35- Yoder E.J. and Witczak M.W. principles of pavement design, A wiley - Intersecience Publication John Wiley and Sons, Inc. New York 1975.

36- The Asphalt Institute, Model Construction Specifications For Asphalt Concrete And Other Plant-Mix Types. Specification Series No. 1 (SS-1) November 1984.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

APPENDIX A

EQUATIONS USED IN DETERMINING THE MARSHALL SPECIMEN BULK UNIT WEIGHT, PERCENT AIR VOIDS IN TOTAL MIX AND PERCENT VOIDS IN MINERAL AGGREGATES (23).

$$1-\ Gsb = \frac{100}{\frac{Ps1}{Gs1} + \frac{Ps2}{Gs2} + \frac{Ps3}{Gs3}}$$

$$2-\ Gse = \frac{100 - Pb}{\frac{100}{Gmm} - \frac{Pb}{Gb}}$$

$$3-\ Gmm = \frac{100}{\frac{Ps}{Gse} + \frac{Pb}{Gb}}$$

$$4-\ Gmb = \frac{W1}{W3 - W2}$$

$$5-\ A.V = \left(1 - \frac{Gmb}{Gmm}\right) * 100$$

$$6-\ V.M.A = 100 - \frac{Gmb * Ps}{Gsb}$$

Ps : Percent aggregates by weight of total mix.

Ps1 : Percent coarse aggregates (3"/4 - 3"/8) by weight of mixed aggregates (30 in this study).

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Ps2 : Percent coarse aggregates (3"/8-4#) by weight of mixed aggregates (30 in this study).

Ps3 : Percent fine aggregates (passing No.4# sieve) by weight of mixed aggregates (40 in this study).

Pb : Percent binder content (rubber-bitumen blend) by weight of total mix.

Gb : Specific gravity of binder content (rubber-bitumen blend).

Gs1 : Dry specific gravity of coarse aggregate (3"/4 - 3"/8).

Gs2 : Dry specific gravity of coarse aggregate (3"/8 - 4#).

Gs3 : Dry specific gravity of fine aggregate (passing No. 4# sieve).

Gsb : Dry specific gravity of mixed aggregate (2.4466 in this study).

Gse : Effective specific gravity of mixed aggregate (2.588 in this study).

Gmm : Maximum theoretical specific gravity of total mix.

W1 : Marshall specimen dry weight in air.

W2 : Marshall specimen submerged weight in water.

W3 : Marshall specimen saturated weight (dry surface) in air

Gmb : Marshall specimen bulk unit weight.

A.V : Percent air voids in total mix.

V.M.A: Percent voids in mineral aggregates.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

APPENDIX B

THE ROAD RESEARCH LABORATORY IMMERSION WHEEL TRACKING TEST.

B.1 THE MACHINE.

The machine shall conform to the following requirements (21):-

a- The speed of passage of wheels over the specimen shall correspond to 25 double passes per minute over specimen 12 inch long (small variations from 25 passes per minutes may be allowed but conversion of the failure time should be made by multiplying by X/25 where X is the actual speed of the machine).

b- The temperature of the water bath shall be regulated to 40 ± 1C.

c- The types used shall be composed of hard rubber. The hardenss of rubber shall be 80 3 when tested by Dunlop hardness gauge.

d- The wheel load, determined by direct suspension from spring balance of the wheel- axle in a horizontal position, shall be 40 ± 1/2 lb.

e- The wheels used shall be as specified in British Road Research Laboratory Drawing No. 7468 and the recorder used for determination of the end point shall be as in Road Research Laboratory Drawing No.746 C. The diameter of each wheel is 8 inch. and its width is 2 inch.

B.2 PREPARATION OF TEST SPECIMENS.

The Rubber Asphalt mixtures type 1 and type 2 mentioned in Item 3.4 were prepared as follows (21):- The

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

rubber and asphalt cement were heated and added seperately to the preheated aggregate and then mixed together at the same temperature 156-160. The mixture then filled loosely in preheated special metal mould (30.5 cm long, 9.3 cm wide, and 2.8 cm depth) then compacted at the temperature 145-151 by hand using a steel roller of diameter 4 inch, weighing 34 lb which was preheated to the temperature of compaction.

The rolling was carried out by the following method:- With the longitudinal axis of the roller at right angles to the longitudinal axis of the mould, rolling took place from the middle of the mould outwards in each direction. All materials falling outside the mould shall be replaced. Rolling had been continued over the full length of the mould until the roller rested on the rim of the mould and in that case the densities of mixtures reached the values of 2g/cc and 1.75g/cc for type one and type two respectively. The specimens then were cooled at the room temperature for one day before they tested by the machine.

B.3 TEST PROCEDURE.

The water bath was filled with water and then maintained at 40 C. The specimens were placed in water bath (at 40 C) for one hour before commencing the test.

The loaded wheels were placed on the specimens with stress of 30 lb/sq. inch. on each specimen and rolling started.

The test was continued until failure occured, or for at least 24 hours.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Fig. (B.1) shows the diagram of test machine for immersion wheel-tracking test (21).

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

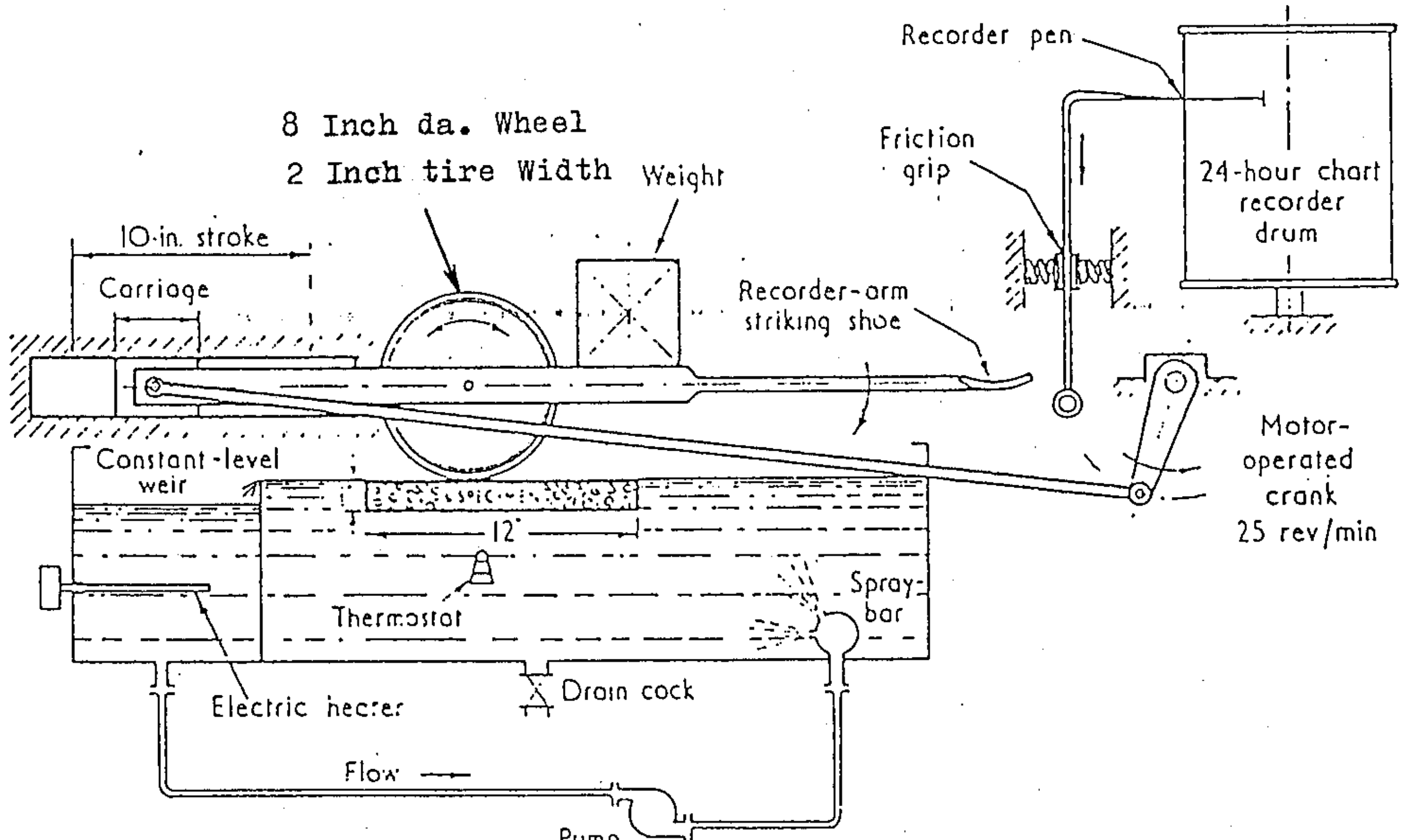


Fig.B.1 Diagram Of The Wheel Tracking Machine

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

APPENDIX C

THE PORTABLE SKID-RESISTANCE TESTER

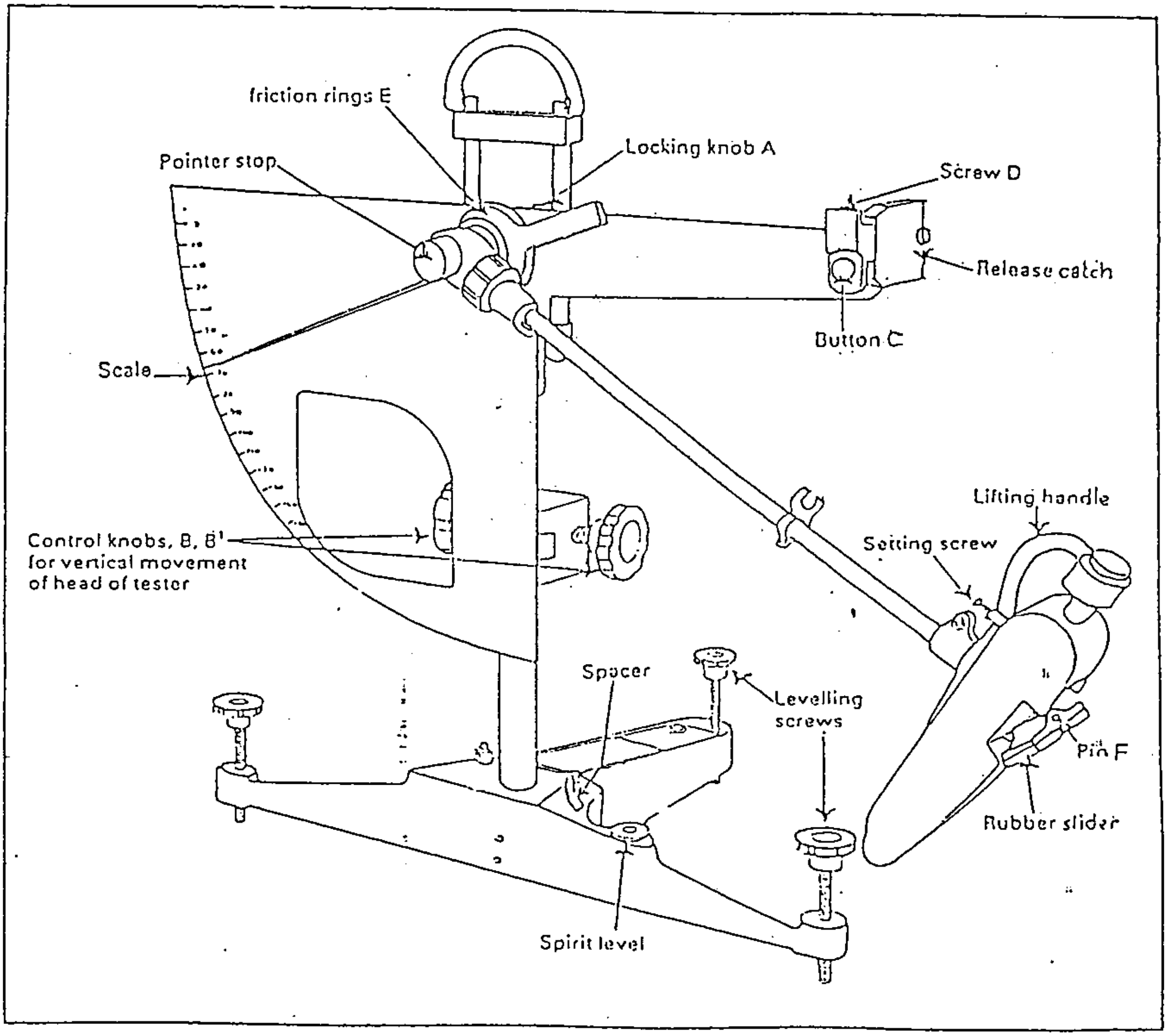
The portable tester shown in fig C.1 (22) was developed at the Road Research Laboratory some years ago to provide highway engineers with a routine method of checking the resistance of wet road surfaces to skidding. The Apparatus measures the frictional resistance between rubber slider (mounted on the end of a pendulum) and the road surface. The characteristics of the apparatus were chosen as far as possible to simulate sliding between vehicle tyre and road at 50 km/h. Table (C.1) shows the suggested minimum values of skid resistance measured with the portable tester.

TABLE (C.1) THE SUGGESTED MINIMUM VALUES OF SKID RESISTANCE MEASURED WITH THE PORTABLE TESTER.

CATEGORY	TYPE OF SITE	MINIMUM SKID RESISTANCE SURFACE WET
A	Difficult sites such as: 1- Round about. 2- Bends with radius less than 150 m on unrestricted roads. 3- Gradients 1 in 20 or steeper of length greater than 100 m. 4- Approaches to traffic lights on unrestricted roads.	65
B	Heavily trafficked roads in urban areas carrying more than 2000 vehicles per day.	55
C	All other sites	45

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Figure (C-1):British Pendulum Tester.



All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

APPENDIX D

INDIVIDUAL TESTS RESULTS

TABLE D.1 INDIVIDUAL TEST RESULTS OF PHYSICAL PROPERTIES OF RUBBER-BITUMEN BLEND

Percent Rubber to Percent Bitumen by Weight of Rubber-Bitumen Blend %/%	Physical Properties											
	Ductility (cm)		Softening Point (c)		Penetration (0.1 mm)		Flash Point (c)		Fire Point (c)		Specific Gravity	
	Spe*1	Spe.2	Spe.1	Spe.2	Spe.1	Spe.2	Spe.1	Spe.2	Spe.1	Spe.2	Spe.1	Spe2
0.0%	112	106	54	52	64.5	65.5	338	334	360	366	1.017	1.015
5/95	10.5	9.5	55.5	54.5	50.5	51.5	323	317	360	356	1.026	1.024
10/90	8.5	9.5	58	56	48.5	47.5	321	315	335	341	1.029	1.031
15/85	9	8	61.5	60.5	37.5	36.5	315	319	339	333	1.036	1.034
20/80	7.5	8.5	64	62	27.5	28.5	287	293	313	317	1.038	1.040

Note*: Specimen

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.2 INDIVIDUAL TEST RESULTS OF PROPERTIES OF CRUSHED LIMESTONE AGGREGATES USED IN THIS RESEARCH

TYPE OF TEST	SPECIMEN 1	SPECIMEN 2
Abrasion %	26.7	25.9
Plasticity Index For Materials Passing No. 40# Sieve. %	Non Plastic	Non plastic
Sand Equivalent %	60	62
Aggregate Soundness (Magnesium Sulfate)%	12 (3"/4 - 3"/8) 9.26 (3"/8-4#)	12 (3"/4 - 3"/8) 10.2 (3"/8-4#)
Percentages Of Clay Lumps And Friable Particless. %	0.06 (3"4-3"/8) 0.21 (3"/8-4#)	0.04 (3"/4-3"/8) 0.19 (3"/8 - 4#)
Flakiness Index %	17 (3"/4 - 3"/8) 19 (3"/8 - 4#)	19 (3"/4 - 3"/8) 21 (3"/8 - 4#)
Elongation Index %	5 (3"/4 - 3"/8) 15 (3"/8 - 4#)	7 (3"/4 - 3"/8) 17 (3"/8 - 4#)
Flint Content %	Nil	Nil
Specific Gravity Of Coarse Aggregate (3"/4-3"/8)	2.505 Oven Dry	2.512 Oven Dry
Specific Gravity Of Coarse Aggregate (3"/8 - 4#)	2.471 Oven Dry	2.474 Oven Dry
Specific Gravint Of Fine Aggregate (Passing No. 4# Sieve)	2.379 Oven Dry	2.386 Oven Dry

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.3 INCIVIDUAL TEST RESULTS OF MECHANICAL PROPERTIES OF RUBBER ASPHALT CONCRETE MIXTURES. MARSHALL SPECIMENS WERE TESTED AFTER HAVING BEEN SOAKED IN WATER FOR 1/2 HOUR AT 60 C

Percent Binder Content By Weight Of Total Mix. %	Precent Rubber To Percent Asphalt By Weight Of Binder %/%	Bulk Unit Weight g/cc			Marshall Stability Pounds			Marshall Flow 0.01 inch		
		Spe*1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3
4.5 %	0.0/100	2.227	2.213	2.205	3081	3032	2953	8	8.5	10.5
	5/95	2.230	2.238	2.228	3898	3931	3874	8.5	8	9.6
	10/90	2.201	2.218	2.226	3461	3512	3536	9	8.5	8
	15/85	2.188	2.201	2.181	3387	3421	3398	8	7.5	8.5
	20/80	2.177	2.152	2.169	3376	3332	3345	7	8	7.5
5 %	0.0/100	2.229	2.252	2.239	3767	3831	3811	10	9.3	9.5
	5/95	2.252	2.259	2.257	3980	4015	4011	10	9	9.2
	10/90	2.221	2.219	2.220	3558	3545	3550	8.5	9	8.6
	15/85	2.211	2.215	2.210	3416	3431	3419	8.5	8	8.1
	20/80	2.202	2.208	2.217	3389	3398	3416	8	7.5	7.3
5.5%	0.0/100	2.259	2.262	2.262	3442	3451	3457	11	10.5	10.3
	5/95	2.277	2.269	2.273	4065	4045	4046	10.6	10	10
	10/90	2.229	2.227	2.231	3550	3538	3565	9.1	9.5	9
	15/85	2.218	2.215	2.218	3458	3445	3456	8	9.5	8
	20/80	2.210	2.218	2.214	3343	3364	3349	8	7	8.1
6 %	0.0/100	2.278	2.273	2.289	3451	3442	3463	11.5	11.9	10.8
	5/95	2.287	2.292	2.288	3839	3871	3843	11	10.5	10.6
	10/90	2.238	2.231	2.236	3365	3334	3360	9	10.5	9
	15/85	2.218	2.225	2.223	3229	3275	3246	9	8	8.8
	20/80	2.219	2.217	2.224	3186	3289	3231	8	8	7.4
6.5%	0.0/100	2.264	2.259	2.260	2974	2922	2957	12	14	13
	5/95	2.271	2.284	2.279	3319	3381	3359	13	11	12
	10/90	2.238	2.229	2.232	2592	2531	2533	9.5	11	11
	15/85	2.226	2.218	2.216	2432	2393	2378	11	8.5	9
	20/80	2.219	2.212	2.214	2386	2335	2365	7.5	9	8.4

Note*: Specimen.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.4 INDIVIDUAL TEST RESULTS OF MECHANICAL PROPERTIES OF RUBBER ASPHALT CONCRETE MIXTURES. mARSHALL SPECIMENS WERE TESTED ACTER HAVINC BEEN SOAKED IN WATER FOR 24 HOUR AT 60

Percent Binder Content By Weight Of Total Mix. %	Precent Rubber To Percent Asphalt By Weight Of Binder %/%	Bulk Unit Weight g/cc			Marshall Stability Pounds			Marshall Flow 0.01 inch		
		Spe*1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3
4.5 %	0.0/100	2.211	2.202	2.223	2553	2486	2572	12	12.5	11.2
	5/95	2.225	2.231	2.234	3270	3323	3352	9	8	7
	10/90	2.219	2.220	2.209	2705	2732	2648	8	8.1	8.5
	15/85	2.182	2.195	2.199	2363	2385	2392	9	8.7	7.5
	20/80	2.176	2.161	2.152	2123	2085	2023	7	7.9	8.5
5 %	0.0/100	2.245	2.237	2.244	2981	2935	2976	8.1	9.5	8.5
	5/95	2.249	2.254	2.256	3241	3298	3301	9.5	8.3	8
	10/90	2.225	2.216	2.222	2753	2704	2745	8.1	8.5	8
	15/85	2.203	2.217	2.213	2449	2523	2519	8.5	8	8.4
	20/80	2.216	2.223	2.191	2278	2332	2326	8.5	7.5	7.7
5.5%	0.0/100	2.257	2.262	2.264	2579	2589	2596	10	9.5	9
	5/95	2.276	2.268	2.278	3140	3162	3175	9.5	9	9.4
	10/90	2.233	2.229	2.231	2768	2675	2759	8	9	8.5
	15/85	2.215	2.212	2.221	2551	2539	2569	8.5	9	7.7
	20/80	2.216	2.209	2.217	2423	2384	2429	8	7.1	8
6 %	0.0/100	2.278	2.283	2.285	2448	2498	2506	10.5	10.4	10
	5/95	2.281	2.289	2.291	2865	2897	2902	10.5	10	8.9
	10/90	2.235	2.234	2.239	2625	2582	2632	8.6	9	8.5
	15/85	2.221	2.225	2.223	2633	2689	2673	8.5	8	8.1
	20/80	2.224	2.216	2.223	2742	2683	2735	7.5	7	8
6.5%	0.0/100	2.259	2.263	2.258	1995	2035	1988	11.5	13	11.5
	5/95	2.275	2.278	2.278	2457	2491	2489	11.5	10.5	11.3
	10/90	2.236	2.231	2.235	2036	1978	2031	9.1	10.5	9.5
	15/85	2.223	2.219	2.218	2045	2009	1994	8.4	9	9
	20/80	2.216	2.211	2.215	2092	2049	2090	7.3	8	7.5

Note*: Specimen.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.5 INDIVIDUAL TEST RESULTS OF MECHANICAL PROPERTIES OF RUBBER ASPHALT CONCRETE MIXTURES. MARSHALL SPECIMENS WERE TESTED AFTER HAVING BEEN SOKED IN WATER FOR 1/2 HOUR AT 100 C

Percent Binder Content By Weight Of Total Mix. %	Precent Rubber To Percent Asphalt By Weight Of Binder %/%	Bulk Unit Weight g/cc			Marshall Stability Pounds			Marshall Flow 0.01 inch		
		Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3
4.5 %	0.0/100	2.204	2.215	2.220	2085	2104	2153	10	10	9.4
	5/95	2.225	2.238	2.227	2899	2961	2915	10	9	9.5
	10/90	2.218	2.204	2.214	2343	2259	2328	9.5	10.5	9.7
	15/85	2.207	2.188	2.178	1969	1930	1915	8.8	9	9.5
	20/80	2.159	2.173	2.169	1722	1761	1743	8.5	7.5	8.3
5 %	0.0/100	2.245	2.242	2.236	2605	2598	2549	10	10.5	11
	5/95	2.256	2.259	2.256	2872	2899	2869	10	9.8	10.5
	10/90	2.219	2.223	2.221	2366	2389	2382	11	9	10
	15/85	2.209	2.212	2.218	2017	2067	2072	10	9	8
	20/80	2.209	2.213	2.208	1872	1886	1852	7.4	7	9
5.5%	0.0/100	2.261	2.259	2.269	2283	2247	2301	11.6	12	11.5
	5/95	2.275	2.279	2.280	2864	2879	2885	11.5	11	10.8
	10/90	2.231	2.229	2.239	2427	2381	2434	11	10	10.8
	15/85	2.219	2.215	2.220	2148	2117	2152	9	10	8.9
	20/80	2.208	2.214	2.217	1967	1978	1986	8.5	8	7.8
6 %	0.0/100	2.279	2.284	2.280	2202	2269	2258	13	12.5	12.6
	5/95	2.283	2.288	2.290	2543	2592	2605	13	12	11
	10/90	2.237	2.232	2.233	2289	2263	2282	10	11.2	10
	15/85	2.223	2.219	2.221	2235	2166	2229	8.3	10	9
	20/80	2.221	2.227	2.218	2219	2228	2177	8	7.9	9
6.5%	0.0/100	2.259	2.257	2.264	1762	1750	1798	14.2	14	15
	5/95	2.273	2.278	2.277	2153	2192	2189	14	13	13.2
	10/90	2.236	2.238	2.231	1772	1788	1720	11.5	11	12
	15/85	2.220	2.225	2.218	1725	1751	1708	10.5	10	11
	20/80	2.211	2.216	2.215	1744	1785	1781	9.5	8.2	9

Note*: Specimen.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.6 INDIVIDUAL TEST RESULTS OF MAXIMUM THEORETICAL SPECIFIC GRAVITY OF RUBBER-ASPHALT CONCRETE MIXTURES CONTAINING 6.5% BINDER CONTENT (RUBBER-BITUMEN BLEND) BY WEIGHT OF TOTAL MIX

Percent Rubber To Percent Bitumen By Weight Of Binder Content %/%	Maximum Theoretical Specific Gravity	
	Specimen 1	Specimen 2
0.0/100	2.349	2.355
5/95	2.358	2.350
10/90	2.353	2.359
15/85	2.362	2.354
20/80	2.359	2.361

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.7 INDIVIDUAL TEST RESULTS OF WHEEL TRACK TEST

CONDUCTED ON RUBBER-BITUMEN CONCRETE MIX SPECIMENS HAVING TYPE 1

GRADATION SHOWN IN FIGURE 3.1 AND 6% BINDER CONTENT

Percent Rubber To Percent Bitumen By Weight Of Rubber-Bitumen Blend (Binder) %/% -->	0.0/100			5/95			10/90			15/85			20/80		
Time	Penetration (MM)														
(Hours)	Sp*1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3
0.5	2	1.8	2.2	1.0	0.8	1.2	0.7	0.9	0.65	1.25	0.75	1.0	1.0	1.2	1.4
1	2.2	2.8	2.5	1.25	1.2	1.30	1.0	1.1	0.9	1.35	1.15	1.25	1.4	1.5	1.6
1.5	2.25	3.4	2.6	1.35	1.30	1.40	1.15	1.2	1.1	1.35	1.15	1.25	1.4	1.5	1.6
2	2.4	3.5	2.8	1.5	1.5	1.5	1.25	1.35	1.15	1.35	1.15	1.25	1.4	1.5	1.6
2.5	2.5	3.5	3	1.6	1.6	1.75	1.35	1.5	1.2	1.5	1.2	1.35	1.4	1.5	1.6
3	2.5	3.5	3	1.8	1.6	1.85	1.4	1.6	1.5	1.75	1.25	1.5	1.4	1.5	1.6
4	2.5	3.5	3	2.2	1.8	2.0	1.4	1.6	1.5	1.75	1.25	1.5	1.4	1.5	1.6
5	2.5	3.5	3	2.5	2.0	2.25	1.4	1.6	1.5	2	1.5	1.75	1.4	1.5	1.6
6	2.5	3.5	3	2.5	2.0	2.25	1.4	1.6	1.5	2	1.5	1.75	1.7	1.7	1.85
7	2.5	3.5	3	2.5	2.0	2.25	1.7	1.8	1.75	2	1.5	1.75	1.7	1.7	1.85
8	2.5	3.5	3	2.5	2.0	2.25	1.7	1.8	1.75	2.25	1.75	2	1.7	1.7	1.85
9	2.5	3.5	3	2.5	2.0	2.25	1.8	2.1	2.1	2.25	1.75	2	2.0	1.8	2.2
10	2.5	3.5	3	2.5	2.0	2.25	1.8	2.1	2.1	2.5	2.0	2.25	2.0	1.8	2.2
11	2.5	3.5	3	2.5	2.0	2.25	2.0	2.5	2.25	2.5	2.0	2.25	2.25	2.0	2.5
12	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.5	2.0	2.25	2.25	2.0	2.5
13	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	2.5	2.25	2.75
14	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	2.5	2.25	2.75
15	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	2.6	2.75	2.9
16	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	2.75	3.0	3.25
17	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	3.0	3.25	3.5
18	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	3.0	3.25	3.5
19	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	3.25	3.5	3.75
72	2.5	3.5	3	2.5	2.0	2.25	2.25	2.75	2.5	2.75	2.25	2.5	3.25	3.5	3.75

Note*: Specimen.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.8 INCIVIDUAL TEST RESULTS OF WHEEL TRACK TEST

CONDUCTED ON RUBBER-BITUMEN CONCRETE MIX SPECIMENS HAVING TYPE 2 GRADATION SHOWN IN FIGURE 3.2 AND 4.5% BINDER CONTENT

Percent Rubber To Percent Bitumen By Weight Of Rubber-Bitumen Blend (Binder) %/% -->	0.0/100			5/95			10/90			15/85			20/80		
Time	Penetration (MM)														
(Hours)	Sp*1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3	Sp.1	Sp.2	Sp.3
1	1	1.5	0.5	0.4	0.2	0.3	2.5	3.0	2.0	1.9	1.4	1.2	0.5	1	1.5
2	1	1.5	0.5	0.7	.5	0.6	3.0	3.5	2.5	3.2	1.8	1.6	0.6	1.4	2.5
3	1.0	1.5	0.5	1.1	0.9	1.0	3.5	4.0	3.0	6	1.9	1.7	0.9	1.9	3.2
4	1.5	2	1	1.1	0.9	1.0	3.8	4.2	3.4	6.0	1.9	1.7	1.3	2.1	3.5
5	1.8	2.2	2	1.1	0.9	1.0	4	4.5	3.5	6.1	1.9	1.9	1.7	2.2	3.9
6	1.8	2.2	2	1.1	0.9	1.0	4.1	4.6	3.6	6.2	1.9	2.1	2.1	2.3	4.0
7	1.9	2.2	2	1.1	0.9	1.0	4.2	4.7	3.7	6.3	2.0	2.2	2.6	2.5	4.2
8	2.0	2.4	2.2	1.1	0.9	1.0	4.3	4.8	3.8	6.4	2.1	2.6	3.0	2.8	4.4
9	2.4	2.8	2.6	1.1	0.9	1.0	4.4	4.9	3.9	6.5	2.2	2.7	3.2	3.0	4.6
10	2.9	3.1	3	1.1	0.9	1.0	4.5	5.0	4.0	6.6	2.3	3.1	3.9	3.2	4.9
11	3.2	3.4	3.3	1.1	0.9	1.0	4.5	5.0	4.0	6.7	2.4	3.2	4	3.3	5.0
12	3.2	3.4	3.3	1.1	0.9	1.0	4.7	5.2	4.2	6.8	2.5	3.3	5	4.5	5.5
13	3.2	3.4	3.3	1.1	0.9	1.0	4.8	5.3	4.3	6.9	2.6	3.4	6.5	6	7
14	3.2	3.4	3.3	1.1	0.9	1.0	4.9	5.4	4.4	7.0	2.7	3.5	8	7.5	8.5
15	3.2	3.4	3.3	1.1	0.9	1.0	5.0	5.5	4.5	7.1	2.8	3.9	28d	28e	28f
16	3.2	3.4	3.3	1.1	0.9	1.0	5.2	5.7	4.7	7.1	2.8	3.9			
17	3.2	3.4	3.3	1.1	0.9	1.0	5.3	5.8	4.8	7.2	2.9	4.3			
18	3.2	3.4	3.3	1.1	0.90	1.0	5.4	5.9	4.9	7.3	3.0	4.4			
19	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.4	3.1	4.5			
20	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.4	3.1	4.5			
21	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.4	3.1	4.5			
22	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.4	3.1	4.5			
23	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.5	3.2	4.6			
24	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.5	3.2	4.6			
25	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.5	3.2	4.6			
26	3.2	3.4	3.3	1.2	1.0	1.1	5.5	6	5	7.5	3.2	4.6			
27	3.2	3.4	3.3	1.25	1.15	1.2	5.5	6	5	7.6	3.3	4.7			
28	3.2	3.4	3.3	1.25	1.15	1.2	5.5	6	5	7.8	3.4	4.7			
29	3.4	3.6	3.5	1.25	1.15	1.2	5.5	6	5	7.9	3.5	4.8			
30	3.5	3.9	3.7	1.25	1.15	1.2	5.5	6	5	8.0	3.6	4.9			
31	3.6	4	3.8	1.25	1.15	1.2	5.5	6	5	8.2	4.0	5.2			

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

Continue

32	3.7	4.1	4.2	1.25	1.15	1.2	5.5	6	5	8.5	4.5	6.5			
33	3.7	4.1	4.2	1.25	1.15	1.2	5.5	6	5	9	5	7			
34	3.7	4.1	4.2	1.25	1.15	1.2	5.5	6	5	10	6	9.2			
35	3.8	4.6	4.2	1.25	1.15	1.2	5.5	6	5	14	10	12			
36	3.9	4.7	4.3	1.25	1.15	1.2	5.5	6	5	28a	28b	28c			
37	4	4.8	4.4	1.25	1.15	1.2	5.5	6	5						
38	4	5.0	4.5	1.25	1.15	1.2	5.5	6	5						
39	4	5.0	4.5	1.25	1.25	1.24	5.5	6	5						
40	4	5.0	4.5	1.25	1.25	1.24	5.5	6	5						
41	4	5.0	4.5	1.3	1.25	1.35	5.5	6	5						
42	4	5.0	4.5	1.3	1.25	1.35	5.5	6	5						
43	4	5.0	4.5	1.3	1.25	1.35	5.5	6	5						
44	4	5.0	4.5	1.3	1.25	1.35	5.5	6	5						
45	4	5.0	4.5	1.3	1.25	1.36	5.5	6	5						
46	4	5.0	4.5	1.3	1.25	1.36	5.5	6	5						
47	4	5.0	4.5	1.4	1.3	1.5	5.5	6	5						
48	4	5.0	4.5	1.4	1.3	1.5	5.5	6	5						
49	4	5.0	4.5	1.4	1.3	1.5	5.5	6	5						
50	4	5.0	4.5	1.4	1.3	1.5	5.5	6.0	5.0						
72	5	5.5	4.5	1.5	1.4	1.6	6	6.5	5.5						

Note*: Specimen.

Note a : Failure Occurred After 35.75 Hours.

Note b : Failure Occurred After 36.20 Hours.

Note c : Failure Occurred After 36.05 Hours.

Note d : Failure Occurred After 14.55 Hours.

Note e : Failure Occurred After 14.70 Hours.

Note f : Failure Occurred After 14.25 Hours.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

TABLE D.9 INDIVIDUAL TEST RESULTS OF SKID RESISTANCE (BPN) OF RUBBER-BITUMEN CONCRETE MIX SPECIMENS HAVING TYPE 1 GRADATION SHOWN IN FIGURE 3.1 AND 6% BINDER CONTEN. THE SPECIMENS WERE TESTED BEFORE AND AFTER THE WHEEL TRACKING TEST.

Percent Rubber To Percent Bitumen By Weight Of Rubber-Bitumen Blend (Binder) %/%	Skid Resistance Number (BPN) Before The Wheel Tracking Test			Skid Resistance Number (BPN) After The Wheel Tracking Test		
	Spe*1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3
0.0/100	91.8	89.5	92.3	64.1	63.2	63.5
5/95	87.3	86.8	85.7	61.2	61.6	59.6
10/90	80.2	79.8	81.8	58.1	57.2	57.8
15/85	82.5	83.1	85.2	58.1	57.9	60.1
20/80	91.4	90.1	90.3	62.2	61.8	62.9

Note*: Specimen.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

ملخص

الهدف من هذا البحث هو استكشاف امكانية تحسين أداء الخلطات الاسفلتية والمستعملة في طبقة السطح باضافة المطاط المفلكن المطحون الى هذه الخلطات لتتناسب والحمولات العالية وتخدم لسنوات أطول وكذلك فان استعمال المطاط كبديل لجزء من الاسفلت سيوفر في التكاليف وخاصة وأن الاف العجلات العادمة يمكن استعمالها وبهذا نحل مشكلة بيئية مهمة.

المواد المستعملة في هذا البحث هي: المطاط المفلكن المطحون المار من منخل ٢٠ وتم احضاره من مصنع للاطارات قرب عمان، اسفلت ذو غرز ٦٠/٧٠ وتم احضاره من شركة مصفاة البترول الأردنية وحصمة جيرية تم احضارها من كسارات في منطقة عمان.

تم اجراء الاختبارات المتعلقة بتحديد الخواص الفيزيائية لخليط المطاط والاسفلت وهذه الفحوصات هي: المطالية، النعومة، درجة الوميض، درجة الحريق، درجة الغرز، الوزن النوعي والتسليخ.

تم اجراء الاختبارات المتعلقة بتحديد الخواص الميكانيكية للخلطات الخرسانية الاسفلتية المطاطية وهذه الاختبارات هي: اختبار مارشال، اختبار آلة تتابع العجلات واختبار مقاومة الانزلاق باستعمال البندول البريطاني.

تم تقسيم عينات مارشال الى ٣ مجموعات، وتم نقع المجموعة الأولى بالماء قبل فحصها لمدة ٢/١ ساعة وتحت درجة ٦٠ والمجموعة الثانية لمدة ٢٤ ساعة تحت درجة حرارة ٦٠ والمجموعة الثالثة لمدة ٢/١ ساعة تحت حرارة ١٠٠ درجة مئوية. تم استعمال خمسة نسب من خليط المطاط والاسفلت منسوبة الى وزن الخلطة الخرسانية الاسفلتية المطاطية الكلي وهي كالتالي: ٤,٥%، ٥%، ٥,٥%، ٦% و ٦,٥% وكذلك تم استعمال خمسة نسب من المطاط منسوبة الى وزن خليط المطاط والاسفلت وهي كالتالي: صفر %، ٥%، ١٠%، ١٥%، ٢٠%.

399019

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit

بالنسبة للخواص الفيزيائية لخليط الاسفلت والمطاط فبزيادة

• المطاط نقصت المطالية ودرجة الغرز ودرجة الوميض ودرجة الاحتراق بينما زادت النعومة والوزن النوعي ولكن لم يحصل أي نقص يذكر على تسليخ الاسفلت عن الحصمة.

بالنسبة للخواص الميكانيكية للخلطة الخرسانية الاسفلتية المطاطية فقد تم الاستنتاج بان استعمال خلطات خرسانية اسفلتية مطاطية تحتوي على خليط من الاسفلت والمطاط يتراوح بين ٤,٥% الى ٥,٨% من وزن خلطة الاسفلت المطاطية الكلي حيث يشمل هذا الخليط على مطاط من ٧% الى ١٠% من وزن نفس الخليط فان الخواص الميكانيكية للخلطات الخرسانية الاسفلتية المطاطية تظل مقبولة لمتطلبات مواصفات وزارة الاشغال العامة والاسكان وهذه الخواص هي: نسبة الفراغات الهوائية، نسبة الفراغات المعدنية، الثبات، الزحف، القساوة، المتبقي من الثبات والمتبقي من القساوة. وكذلك فان استعمال النسب السابقة لخليط الاسفلت والمطاط ونسب المطاط الى الخليط يقلل من حساسية الخلطة الخرسانية الاسفلتية المطاطية للماء والحرارة.

تم التوصية باضافة نسبة ٧% - ١٠% مطاط الى خليط الاسفلت والمطاط حيث نحصل على فائدة اضافية للخلطة من ذلك وكذلك تم التوصية بتثبيت نسة اللزوجة لجميع نسب خليط الاسفلت والمطاط عند اجراء الفحوصات المخبرية واجراء اختبارات أخرى على الخلطات الخرسانية الاسفلتية المطاطية كاختبار الشد غير المباشر واختبار تكساس للتجمد والذوبان وكذلك اجراء فحوصات كيماوية على المطاط. كذلك تم التوصيه باجراء التجارب على أنواع أخرى من المطاط والحصمة والاسفلت والخلطات الخرسانية الاسفلتية المطاطية وانشاء مقاطع تجريبية على الطرق لفحصها واستكشاف امكانية استعمال خليط الاسفلت والمطاط في الوجه الختامي للطرق.

All Rights Reserved - Library of University of Jordan - Center of Thesis Deposit